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Modelling Temporal and Spatial Changes in Landscape Configuration and Land-Management in Montado System: Impact on Diversity of Land Cover and Biodiversity Patterns

Tilahun Mulatu

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Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia, realizada sob a orientação científica do Professor Doutor José Paulo Sousa (Universidade de Coimbra) e do Professor Doutor João Cabral (Universidade de Trás-os-Montes e Alto Douro)

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Index of Figures Pages

Index of Tables Pages

Index of Appendixes Pages

Contents

Abstract : *Montado, a human shaped agro-silvopastoral system in Portugal, has been experiencing series of changes following the transformation of agricultural policies. Such changes are responsible for altering the structure and composition of montado landscape and hence the biodiversity of the system. Management practices in montado system usually focus on a single and common land use (agroforestry) that represent only part of montado landscape. A recently developed StDM (Stochastic Dynamic Modelling) was applied to model the spatial and temporal patterns in the system and predict changes in biodiversity patterns of passeriform species considering both with and without agroforestry management. Model outputs showed the land use dynamics favoring the expansion of areas with intense and intermediate canopy at the expense of open areas. This resulted in a declining temporal and spatial trend for species richness, with the higher declining rate observed for open area species. Contrary to our expectation, the species richness is even more reduced with the management of agroforestry. Therefore, a detailed understanding on the complexity and balance among different land uses in the system followed by augmentation of management efforts to other biodiversity enhancing land use types will improve the biodiversity of the system than focusing only on a single or few land use types.*

Key Words: *Montado, Land use Dynamics, Passeriform functional traits, Stochastic Dynamic Model.*

1 Introduction

1.1 History of Land-use Dynamics and Management in Montado System

The Common Agriculture Policy (CAP) is changing the traditional agricultural pattern and landscape in countries of the European Union (EU). Although Southern Europe has evolved over thousands of years with a gradual increasing role played by human activity (Jones et al., 2011), the advent of the agricultural intensification quickly induced profound changes in landscape structure. In this context, a significant change in Portuguese land use patterns has been reported by different authors (Jones etal., 2011; Fidalgo, 2007; Coelho etal., 2004). The CAP promotes the intensive agriculture instead of the traditional land uses, which were almost abandoned (Jones etal., 2011). Montado system in Portugal is not an exception passing through a series of changes that resulted in altering the typical nature of these traditional systems. In fact, the montado ecosystem was highly exploited for intensive agricultural production of cereals between the year 1900 and 1986, whereas this trend slowed down after 1963 following the scarcity of arable lands (Jones et al., 2011). The period after the year 1986 involves the execution of agricultural policies encouraging meat/milk industry and afforestation (Cabanillas etal., 2012; Blondel, 2006; Jones et al., 2011). This change in policy was responsible for increasing the rate of land abandonment to date.

Montado system (landscape) represents a huge area in Portugal characterized by a mosaic of different land use types that ensure the multi-functionality of the typical agricultural practices. This system is mainly dominated by species of oak forest (*Quercus suber* and *Quercus ilex*) and recognized as a single and generic land use type of traditional agro-forestry in Portugal (agro-silvopastoral system). Agro-forestry is characterized by low tree density (40 to 80 trees/ha), with trees exploited for cork and the understorey cleared of shrubs for grazing, crops (mainly wheat, barley and oats) or both (Acacio, 2009). Since the montado system is a landscape comprising diverse land use types, including purely agriculture and forest covers, each playing different ecological roles that contribute to maintain the typical biodiversity as a whole (Beaufoy, 2013). Therefore, the idea of representing the montado system as a single land use type (agro-forestry) will underestimate the real complexity of the system (Pinto-Correia and Godinho, 2013). However, since agro-forestry comprises significant portion of montado landscape and exhibits both the nature of closed and open systems with intermediate disturbance, it is still a very crucial land use for maintaining the biodiversity of the whole system.

Changes in montado landscape reflect changes in environmental conditions that affect the fauna and flora in the respective mosaic of land use types. In most cases, this will lead to reduced biodiversity. Montado has been experiencing changes in landscape patterns for the last three decades (Pinto-Correia and Mascarenhas, 1999; Joffre, 1999; Nunez etal., 2005) mostly by reducing the traditional management of the system. The gradual abandonment allows the excessive expansion of the shrub communities that becomes dense shrub lands and woods, replacing the typical mosaic of the montado system. Although this mosaic is crucial for provision of cork and livestock production (Pinto-Correia and Mascarenhas, 1999), the recent change in landscape patterns is responsible for modifying the very particular biodiversity of these systems (Blondel, 2006; Pinto-Correia etal., 2011; Mendes etal., 2011; Azul etal.,2011). Major concerns resulting from altered biodiversity include constrained provision of characteristic ecological services (Bugalho etal., 2011) and decreasing the conservationist and socio-ecological value of the system (Fidalgo etal., 2007).

According to Correia and Mascarenhas (1999), the main agricultural changes are either: (1) the abandonment of farms or (2) the agricultural intensification, resulting in gaps in the system structure. The agricultural abandonment is responsible for the expansion of shrub communities on non fertile and dry lands, increasing the area of woodland forests on fertile and humid areas (Acacio, 2009). Conversely, the agricultural intensification that involves over exploitation of oak forest for cork, charcoal and livestock production is also responsible for compromising the health and productivity of oak forest and for reducing heterogeneity in the system (Correia and Mascarenhas, 1999).

Traditional management practices in a montado system involve livestock grazing and manual clearance of shrubs (Mendes etal., 2011). This is responsible for maintaining the habitat diversity and hence the typical biodiversity of these humanized systems. When these management practices (livestock production and shrub clearance) became too strong to affect the regeneration of oak forest, then the system became over exploited (intensive agriculture). While on the other extreme, if the management practices became too weak to allow enough time for the shrub community to expand in dry and non-fertile areas and oak forest in fertile and humid areas, then the system became less managed (extensive agriculture). The conservation measures suggested to date are focused on avoiding the two extremes (intensification and extensification) while maintaining optimal management practices to protect the threatened montado ecosystem and the biodiversity contained in it (Correia and Mascarenhas, 1999).

1.2 The BioAssess Project

The BioAssess project, the acronym of the "Biodiversity Assessment Tool", was a pan European project that aimed to assess biodiversity changes resulting from different land use management systems in different European countries (Silva, 2012). The project involved eight European countries including Portugal and its aim was to select, from each country, a set of representative land use units that can represent the diversity of the landscape types and ecological attributes in those countries. The land use units were selected in a way to show the gradient of land use intensity ranging from forest dominated land uses to agricultural patches (Sousa etal., 2004; Silva, 2012). Diverse indicators were used for the project including Collembola, Coleoptera and Ave taxon (Silva, 2012). For the current study, bird species richness originally taken from the same project was used as indicators for assessing the biodiversity and ecological status of the montado landscape.

1.3 Ecological Indicators

The use of ecological indicators is crucial for investigating changes taking place in a given environment (Niemi and McDonald, 2004; Dale and Beyeler, 2001; Lindenmayer, 1999; Landres etal, 1988; Villard and Carignan, 2001). Although the relations between birds and agricultural changes are complex and the use of ecological indicators is criticized for relaying on a single or few species that barely reflect the holistic nature of a system (Fleming and Alexander, 2003), inability of selecting indicator species that fit the demand of management goals and lack of scientific rigor when selecting appropriate indicator species (Dale and Beyeler, 2001), some studies have been produced using birds as ecological integrity indicators in agro-ecosystems (e.g., Suarez-Seoane etal., 2001; Santos and Cabral, 2004; Cabral et al., 2007; Sirami et al, 2008). In a previous overview of this problematic in Mediterranean agro-ecosystems, Santos and Cabral (2004) suggested that passerine communities present several characteristics that have justified their relevance as ecological indicators: (1) they usually occur in high densities in the studied habitats, (2) they are functionally placed at an intermediate position in the food webs (Moreby and Stoate, 2001), (3) they provide cheap and easy measurements (due to their conspicuous nature) if standard methodologies are applied (Bibby et al., 1992; Ralph et al., 1993), (4) they are sensitive to landscape and agricultural changes from microhabitat to landscape level (Saap, 1998; Villard and Carignan, 2001), (5) for many species, demography, behaviour, distribution and phenology are connected with seasonal and spatial changes in farming practices (Omerod and Watkinson, 2000), and (6) they have the capacity for population recovery in response to good management procedures in previously disturbed ecosystems (Schulz etal., 2004; Kati etal., 2002). In fact, birds have been widely used as ecological indicators in different types of habitats including riparian areas (Croonquist and Brooks, 1991), forest (Canterbury et al., 2000), wetland (Adamus and Brandt,1990), rangelands (Bradford et al., 1998), lakes (Moors, 1993) and agricultural systems (Suarez-Seoane etal., 2001; Sirami etal, 2008). The use of multiple species as ecological indicators is very crucial for understanding the global response of species to disturbance (Schulz etal., 2004; Kati etal., 2002), however grouping these species into guilds is even more efficient in reflecting the land use gradients (Santos and Cabral, 2003; Robert etal., 2003; Croonquist and Brooks, 1991). Various indices have been developed for measuring the response of indicator species to environmental disturbances. Measuring species richness is a basic objective of many field studies carried out in community ecology and is also of crucial concern when dealing with the conservation and management of biodiversity (Boulinier etal., 1998). Richness index, that has been used as a robust measure for response variables has been frequently applied in bird studies (Gil-Tena etal., 2010; Boulinier etal., 1998; Nally and Fleishman, 2012; Cam etal., 2000; John and Kabigumila, 2011). In addition to this, since species richness can easily be measured from ground observation, it can also serve to calibrate model projections with empirical observations.

1.4 Ecological Modelling

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 (Andreasen et al., 2001). The most popular tools to date have been biological indices, which reduce the dimensionality of complex ecological data sets to a single univariate statistic, and ordination methods, which summarize the multi-dimensionality of ecological data sets in a 2-D or 3-D plots (Cabral et al., 2007). Nevertheless, when a time factor is present within the data, they are unable to estimate, in a comprehensible way, the structural changes when the habitat conditions are substantially changing (Jørgensen and Bernardi, 1997). Therefore, ecological integrity studies have been improved by creating spatially explicit dynamic models that simultaneously attempt to capture the structure and the composition in systems affected by long-term environmental disturbances (e.g., Bastos et al., 2012). These are, for instance, the impacts resulting from the development of new types of agricultural practices (Santos and Cabral, 2004). Spatially explicit dynamic modelling is very efficient since it can capture both the changes in space (static model) and time (dynamic model) simultaneously.

Since many of the ecosystem phenomenological aspects are holistic, whole-system properties, the main vocation of the Stochastic Dynamic Methodology (StDM) is a mechanistic understanding of the holistic ecological processes, based on statistical parameter estimation methods (Santos et al., 2013). This recent research is based on the premise that the general statistical patterns of ecological phenomena are emergent indicia of complex ecological processes that do indeed reflect the operation of universal law-like mechanisms. StDM was used for modeling ecological indicators in response to changes in land use (Bastos et al., 2012; Cabral et al., 2007; Santos and Cabral, 2004), climate and hydrological changes (Hughes etal., 2012; Carvalho etal., 2013), estuarine eutrophication (Silva-Santos etal., 2006), wind farm installation (Santos etal., 2010), and fire occurrence (Silva-Santos etal., 2010).

The spatially explicit StDM proposed here includes three steps to produce simulation models that permit the creation of multi-habitat patterns from changes in farming systems, whose patterns are the basis of spatially explicit ecological models. The primary step involves a multiple regression procedure that helps to understand the global influence of explanatory variables on response variables. Nevertheless, since this statistical test output is static, one of the central requirements of StDM is that the data set recorded includes pertinent gradients of changes. In this way, the factors of time and space were implicit in the respective treatment. Such a procedure allows more realism, as the respective parameters are being considered with regard to their embedding in time and space. This is of particular importance when it comes to the comprehension of the indicator's response. The second step involves the construction of a dynamic model based on the relationship between response (bird species richness) and explanatory (land uses) variables extracted from the previous step, including stochastic principles, which take into consideration the random behaviour of some environmental variables with influence on the ecological indicators selected. The limit values for the stochastic environmental variables were determined in accordance with their realistic ranges. The final step involves the integration of the dynamic model with GIS to produce maps that can show the changes in space and time.

1.5 Main Objectives

The main objective of the current study is to understand the dynamics of the montado system along time, with and without traditional management, and the ecological consequences of such changes in the typical passerine traits as ecological indicators of the montado system integrity. The hypotheses to be tested include: (1) that the measures selected are representative of the local passerine community, and (2) that the montado integrity can be partly assessed by these potential ecological indicators. These hypotheses were tested by applications of a spatially explicit stochastic dynamic framework in order to capture the complexity of some ecological consequences resulting from the gradients of changes expected in the studied montado ecosystems. The information obtained from this study will contribute for a better understanding and conservation of the most said and threatened montado system and the biodiversity comprised in it.

2 Methodology

2.1 Study Area

The study area encompasses one administrative region in central Portugal, the Samora Correia County (Figure 1). The study area, which is 30, 578 ha wide, is located between 38°57 " N 8°56" W and 38°45"N 8°42" W. The area is characterized by typical Mediterranean climate with 669 mm of annual rainfall and 16.8°C mean annual temperature (Climate-data.org, 2014). The altitude of the study area ranges from 8 - 46m (Portugal Elevation Map, 2014). The western and northern part of the study area is dominated by areas that are under significant human influence like built-up areas and agricultural fields. While the southern part of the study area, which has reduced human influence, is dominantly covered by oak forest that frequently is interspersed by pastures, arable lands, agricultural lands, eucalyptus and coniferous forests forming a mosaic of land uses. The part of Samora Correia that involves the estuarine features of Tagus river like sand dunes, marshes, and intertidal zones are excluded from our study area since the current study focus only on terrestrial ecosystem.

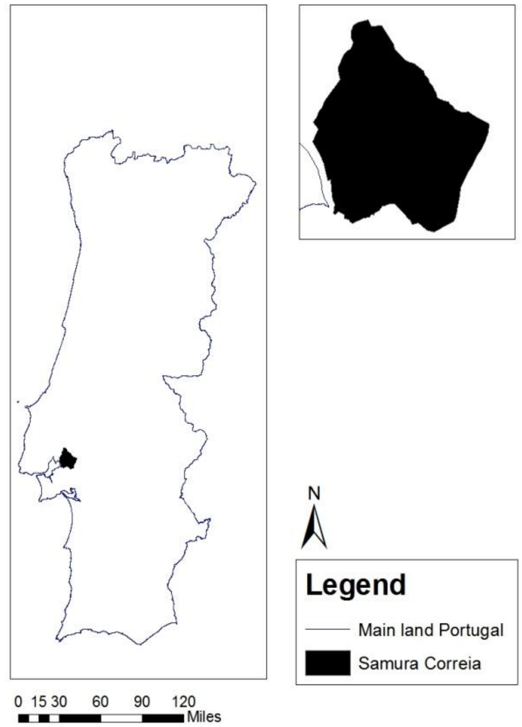

Figure 1. Location of the study area in Portugal, the Samura Correia County (dark area).

2.2 Bird Species Survey

The species data for the current study was taken from bird counts made for the BioAssess project. The count data was made in selected points within the study area for the year 2001 and 2002. Sampling sites within the study area are located in alluvial plain of Tagus river (left bank), 20km east of Lisbon (Sousa, 2003). Stratified sampling was used for locating sampling sites in the study area. Sampling site one is located in thick oak forest, sampling site two is inside Eucalyptus forest, sampling site three up to five are located in oak forests with an increasing degree of fragmentation, and sampling site six is in agricultural area. A total of eighty nine sampling points from the six different sites were used for collecting species data. These eighty nine sampling points are placed 200m apart from each other in each sampling site.

2.3 Passerine Trait Based Indicators

The trend we observe when using total species richness is a cumulative responses of whole species in the study area. This usually masks the individual responses of small groups of species that are functionally related. Besides, studies on other indicator taxa also show that using total species richness as a predictor for the gradient of land use often leads to a result that contradicts Intermediate Disturbance Hypothesis (Silva etal., 2007, Ponge, 2003) and Species Area Hypothesis (Purtauf etal., 2004). However, this contradiction can be avoided by using trait based indicators for different taxa (Silva etal., 2007, Purtauf etal., 2004, Barbaro and Halder, 2009, Ponge, 2006, Woodcock etal., 2010).

Trait development is necessary for revealing hidden responses by these functionally related groups of species. Since our aim for the current study is to understand land use dynamics that mainly involves closed areas (forests), open areas (grasslands, agricultural lands, pastures) and areas with intermediate canopy (scrublands), the traits selected here are specifically related with one or few of the above land uses. Therefore, these traits seem to be more efficient in responding to small changes in one or few of the above land use types.

Bird species observed in the study area were categorized into different functional groups (guilds) based on their feeding, nestling and foraging habits. A wide range of studies were consulted to classify the species into trait groups (Cramp etal., 1977 - 1994; Daniel etal., 2007; Sorensen, 1981; Tryjanowski and Lorek, 2000; Park etal., 2008; Favaron etal., 2009, Surmacki, 2005; Alonso etal., 2009, Antczak etal., 2004, Telleria and Santos, 1997; Isenmann and Fradet, 1998; Milwright, 2010).

A total of 39 passeriform species were used for developing the traits (appendix I). We excluded other non-passeriform species due to their non uniform responses. For feeding traits, insectivorous, granivours and mixed feeding groups were considered. For nestling traits, ground and arboreal nestling groups were considered. For foraging traits, woodland, grassland and generalist groups were considered. The Foraging behavior of birds is important since there is a distinct response of birds to changes in grassland and woodland ecosystems (Preiss etal., 1997) and such difference between the species will help to understand the gradient of land use changes in the system. Similarly, for the nestling behavior, there is a distinct responses of bird species that can directly respond to changes in woodland and grassland ecosystems (Surmacki, 2005). However, for feeding groups, the bird traits directly respond to the availability of insects as closed systems will have higher insect abundance due high humidity than open systems (Pedro, 2010; Telleria and Santos, 1997). Likewise insect eating birds will be dominant in closed systems than opens systems and the reverse is true for grain eating birds.

2.4 Land Cover Characterization of Sampling Points

A radius of 500m around each sampling point was used for collecting Corine layer data (Hiekkinen, 2004) for the year 2000 (CLC2000). A total of fourteen Corine land use categories were associated with our sampling points (Table 1).

Table 1. The different Corine land use types and their CLC codes and description as it was explained in CLC2000 layer.

CLC Code	General Category	Description
121	Artificial surfaces	Industrial or commercial units
142	Artificial surfaces	Sport and leisure facilities
211	Agricultural areas	Non-irrigated arable land
212	Agricultural areas	Permanently irrigated land
213	Agricultural areas	Rice fields
243	Agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation
244	Agricultural areas	Agro-forestry areas
311	Forest and semi natural areas	Broad-leaved forest
312	Forest and semi natural areas	Coniferous forest
313	Forest and semi natural areas	Mixed forest
321	Forest and semi natural areas	Natural grasslands
322	Forest and semi natural areas	Moors and heathland
324	Forest and semi natural areas	Transitional woodland-shrub
512	Water bodies	Water bodies

One of the land cover types identified by the Corine layer, "land principally occupied by agriculture, with significant areas of natural vegetation" (Table 1), is renamed here as agri-natural vegetation and the same term will be used for the remaining part of this thesis manuscript.

Permanently irrigated arable lands and rice fields are considered as agricultural areas. Transitional woodland shrub will be considered as shrub land. Industrial or commercial units, sport and leisure facilities are merged as built- up areas.

Since Corine layer does not differentiate between oak and eucalyptus forests (both regarded as broad-leaved forest as shown in Table 1), additional data from Cos 90 layer (IGEO, 2014) was used for identifying the fifteenth land use type (eucalyptus forest) within the known distribution of broad-leaved forest in the study area. Oak forest comprises the largest area in the study area (nearly 9900 ha) followed by agricultural area (7000 ha) and agro-forestry (3200 ha) as shown in Figure2.

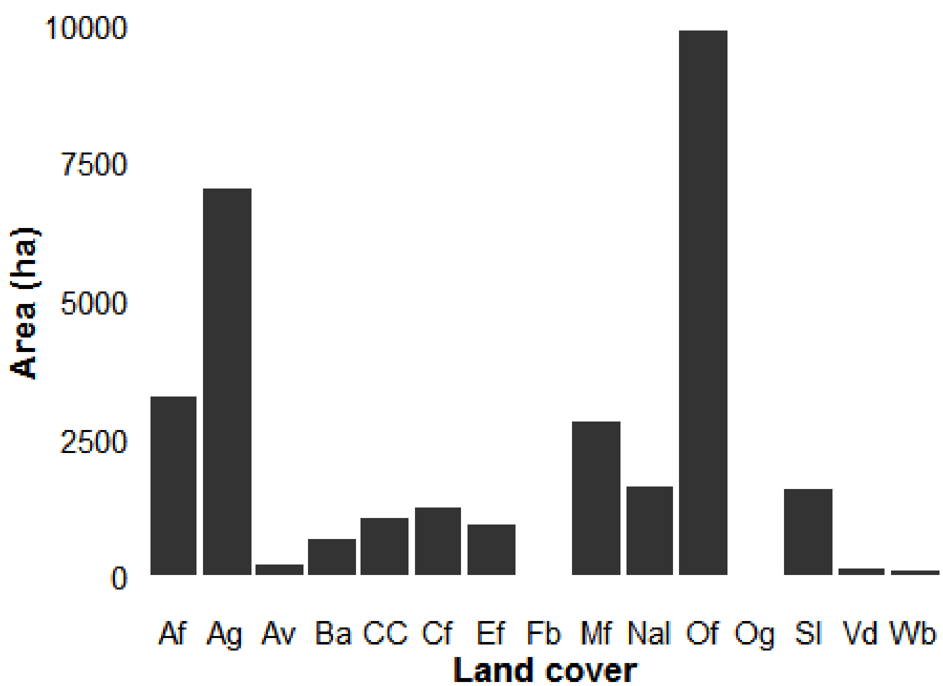

Figure 2. The area comprised by each land cover type in Samora Correia County. Af: Agro-forestry, Of: Oak forest, Sl: Shrub land, Ag: Agriculture, Cf: Coniferous forest, Ef: Eucalyptus forest, Mf: Mixed forest, Nal: Non-irrigated arable land, Av: Agri-natural vegetation.

The dominant oak forest is well distributed in southwestern, central and western part of Samora Correia (Figure 3). While the other dominant land cover (agricultural area) is mainly distributed to the eastern part of Samora Correia though there are also small areas along the northern and western margin of the study area. Agro-forestry has a sandwich distribution between oak forest and agricultural area. From this, one can understand that the intensity of land use increases as we go from the southwestern to northeastern part of the Samora Correia and agro-forestry being distributed between the two extreme land covers can serve as a buffer with intermediate human influence. The other important land cover (shrub land) is distributed very close to other land covers including oak, eucalyptus, coniferous and mixed forest. The Corine information for other land covers including complex cultivation patterns, permanent crops (fruit trees and berry plantation, olive groves, vineyards), and water bodies was not extracted by the buffers around each sampling point. Therefore, these land covers (grouped here as unclassified land covers in Figure 3) and builtup area will remain constant in our dynamic model without causing any effect on our response variables.

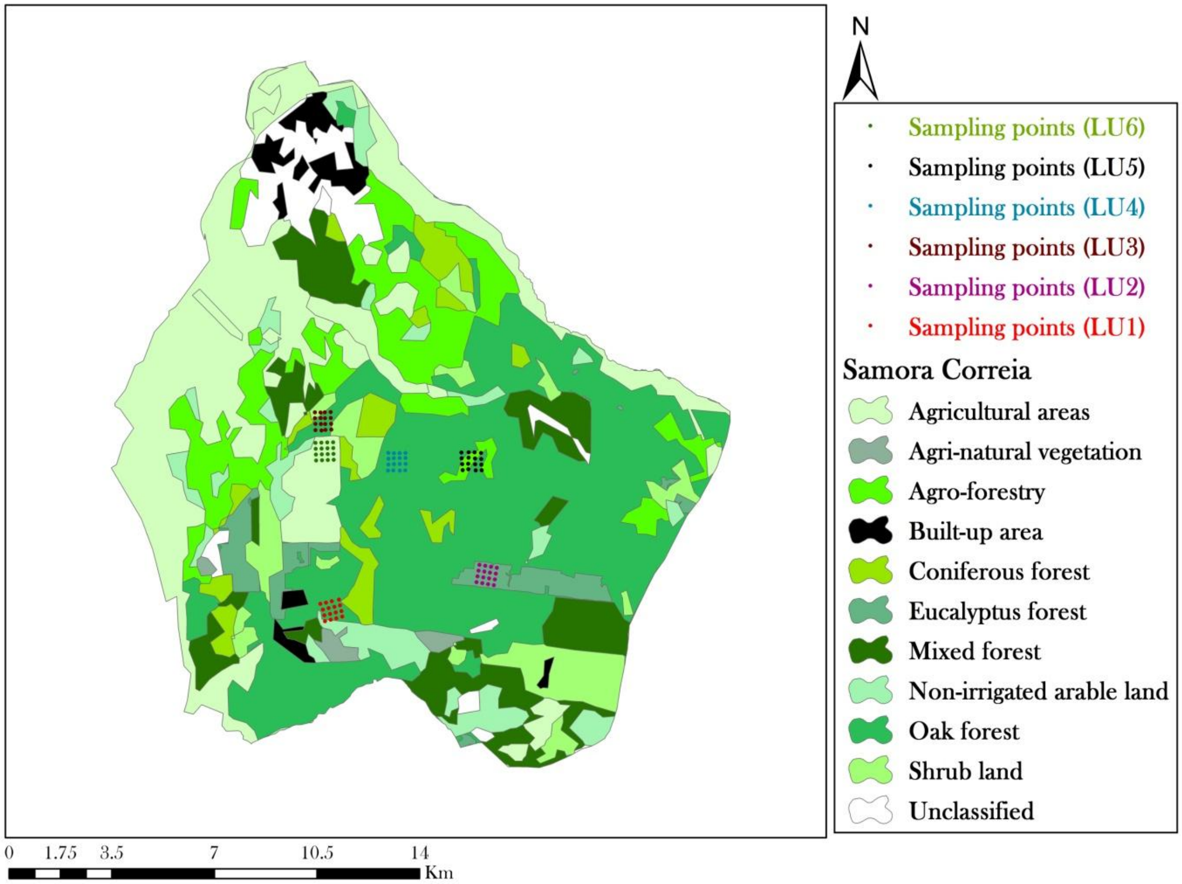

Figure 3. The distribution of bird sampling points and land cover types in Samora Correia.

Fragstat, a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns (McGarigal and Marks, 1994), was used to characterize each of the eighty nine points with Corine data. The various indices in fragstat can be grouped into landscape composition and landscape configuration indices. Landscape composition indices like total area and percentage of land uses are proven to be highly relevant to bird studies (Uuemaa etal., 2009). Since majority of the variables extracted from fragstat indices are correlating each other, only ten variables (see Table 2) were selected for multiple regression analysis.

Table 2. The lists of selected land use variables and their respective codes used in multiple regression analysis.

Selected Variables

Level	Variable code	Description
Patch	F _ AREA	Patch area of cork oak forest
Class	F_PLAND	Percentage of cork oak forest
Class	A_PLAND	Percentage of non-irrigated arable land
Class	AF_PLAND	Percentage of agro-forestry
Class	G_PLAND	Percentage of coniferous forest
Class	B_PLAND	Percentage of agricultural areas
Class	D_PLAND	Percentage of agri-natural vegetation
Class	J_PLAND	Percentage of shrub land
Class	F_PARA_MN	Parameter to area ratio for cork oak forest
Landscape	PR	Patch richness

2.5 Stochastic-Dyanmic Model (StDM) Framework

The StDM framework developed here mainly involves three main steps which include multiple regression analysis, dynamic model construction and the final integration of the outputs from dynamic model with GIS. Figure 4 shows how the different steps (including preliminary land use characterization of sampling points) are related to one another graphically, which is considered here as a spatially explicit dynamic framework for the whole procedures in StDM. Here after, each of these steps will be described separately.

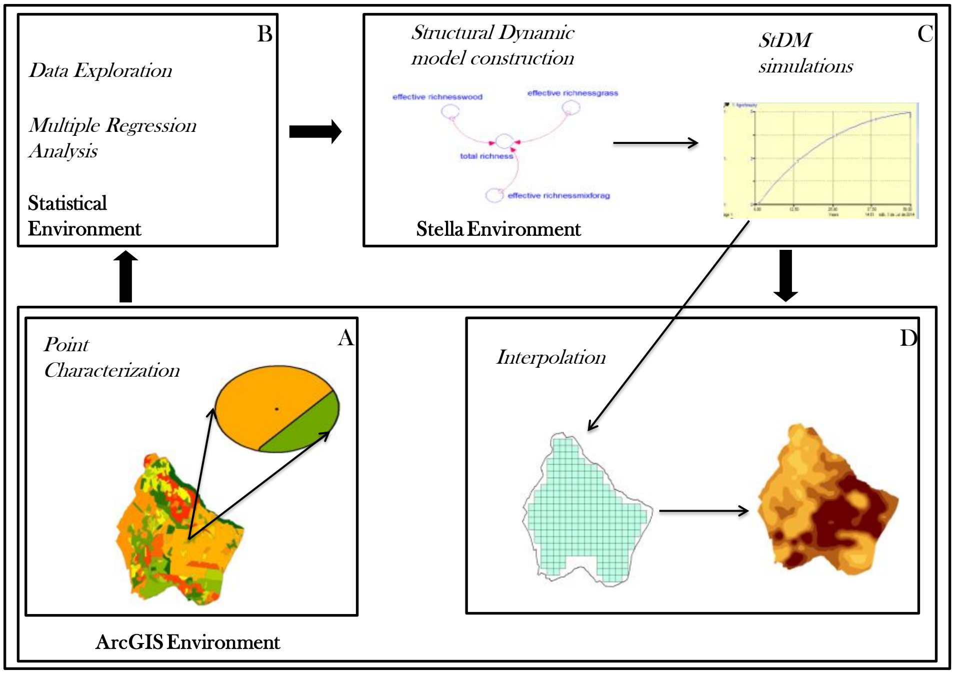

Figure 4. The general framework of the spatially explicit StDM and the steps involved in it; Land use characterization of sampling points (A), Statistical multivariate analysis and Multiple regression analysis (B), Construction of dynamic model followed by simulations (C), Integration of simulation outputs with GIS (D).

2.5.1 Multiple regression analysis

The StDM model construction was preceded by a statistical procedure, for parameter estimation, to test for relationships between dependent and independent variables (Santos and Cabral, 2004). The dependent variable corresponds to the passerine species richness of each trait considered. The independent variables are expressed in the percentage of area occupied by each land use class or landscape metric (Table 2). In order to avoid multi-collinearity, the selected ten predictors for the passerine traits were tested for pair-wise correlation using Spearman's rho correlation coefficient and only predictors with correlation lower than 0.7 (Wisz and Guisan, 2009) and Generalized Variance Inflation Factor lower than 5 were considered (Neter et al., 1996) using data dredge statistics (SAM 4.0®) and then to run multiple regression analysis in Genstat software (version 13.0, VSN International). Those variables that were found to be non correlated and normally distributed were chosen for multiple regression analysis. All response variables were fitted with the poison distribution. The multivariate regression was performed to select models that have the smallest Akaike and highest R_{aj}^{2} value. The Akaike information is important since it can help us choose the model with the lowest information loss (Akaike, 1974). R_{aj}^2 value is also used to check if the distribution of our response variables fits the poison distribution (Cameron, 1995).

2.5.2 Conceptualization of the Stochastic-Dynamic Model

The diagram for the dynamic model presented in Figure 7 is based on the relationships detected in the previous statistical procedures, supported by datasets that include the whole regional gradients of the main studied habitat changes. Therefore, in a holistic perspective, the partial regression coefficients represent the global influence of the selected habitat variables that are representative of several complex ecological processes in each study unit. Yet, they were not included explicitly in the model, but were related to the passerine traits occurrence. These led the interface between the dynamic model construction and the StDM outputs (Figure 11). For parameterization of the dynamic model, the history of land use dynamics in montado system was studied. According to Acacio and Holmgren (2014), the main dynamics of land use occurs between cork oak forest, cork oak savanna (agro-forestry), and shrub community (Figure 5). The cork oak savanna (agro-forestry) stands for the typical montado system with understorey management (Bossard etal., 2000). Acacio and Holmgren (2014) indicated that the shrub community that covers a significant amount of area in the montado system is not a transitional stage that has a potential to develop into mature oak forest. In fact, they consider the shrub community as a stabilized community in the region. This is because oak forest has very slow regeneration rate and previously forest occupied areas in the system are becoming very dry giving a competitive advantage for the shrub offshoots than oak seedlings. From their analysis, it can be understood that cork oak savannas are the origin for both the shrub and oak forest community and if at all we observe any direct changes from oak forest to shrub land, this must be as a result of forest fire or drought in the region. The reverse is true only if there is a strict restoration of oak forest in the region.

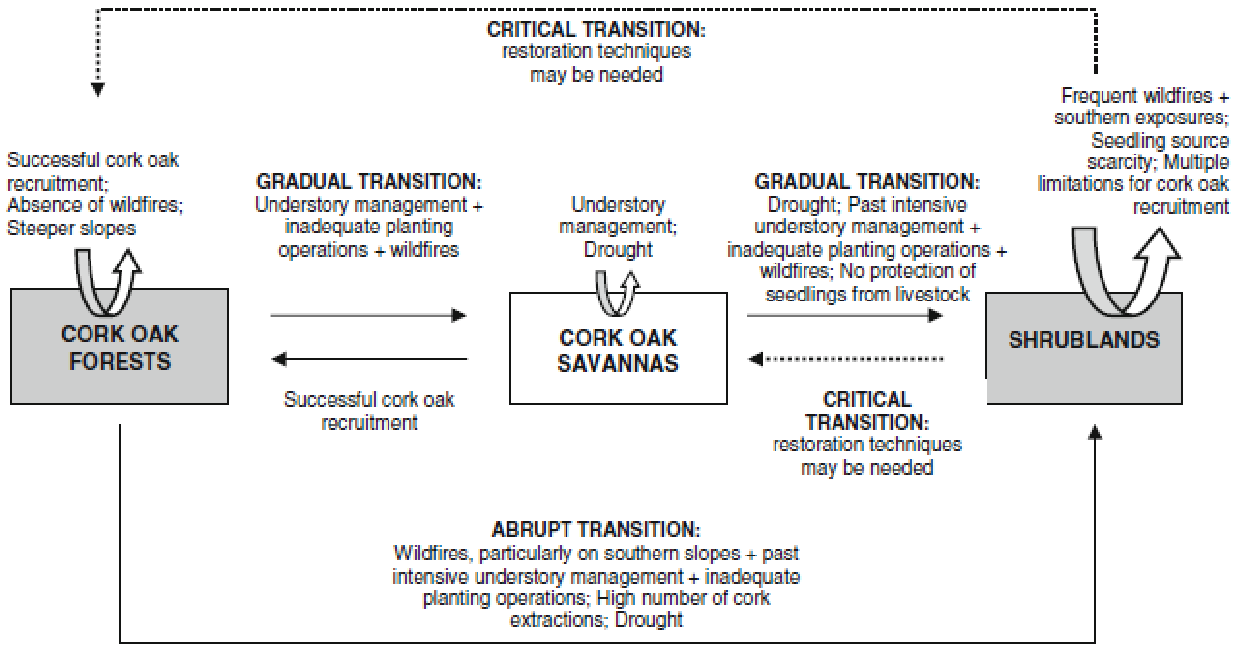

Figure 5. The main land use dynamics in montado system between the three land use types (Cork oak forest, Cork oak savannas (Agro-forestry) and Shrub land). Adapted from Acacio and Holmgren (2014).

The rates for the changes between these land covers were also taken from Acacio and Holmgren (2014). Figure 6 shows the amount of changes between the land covers discussed above.

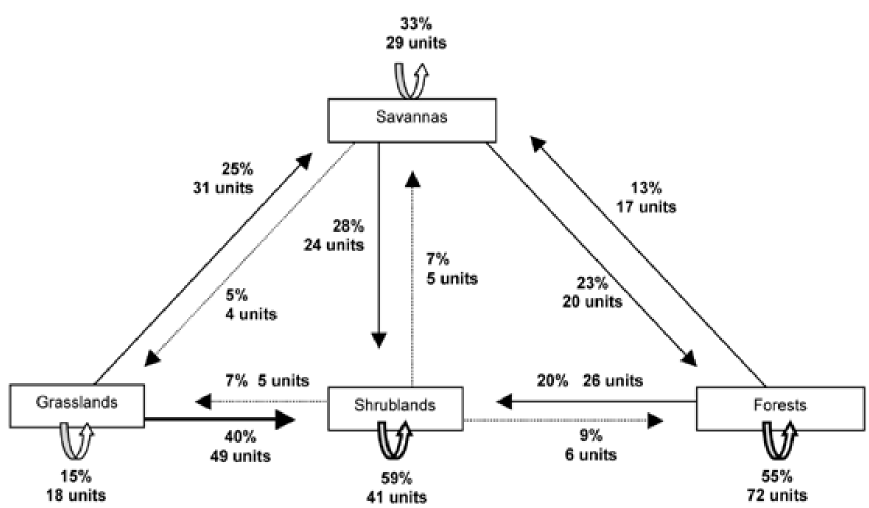

Figure 6. The amount of changes between the different land use types in montado system for 45 years. Dark arrows represent big changes (>10%), light arrows represent small changes (<10%) and curved arrows represent the amount of area that remains within each land use type. Adapted from Acacio and Holmgren (2014).

The dynamics of land uses among all land cover types in montado system including agricultural lands, eucalyptus, coniferous and mixed forests were also studied by Silva etal. (2011). Accordingly the rates of changes for the rest of land cover types, that were not included in the previous study, were obtained from Silva et al. (2011). Table 3 shows the calculated rates of change per year for the different land cover types used in the current model. Each rate is calculated from the 45 years of changes obtained from Acacio and Holmgren (2014) and 15 years of changes obtained from Silva et al. (2011). To calculate these annual rates (AR) the following formula was used (Chaves et al., 2000):

$$AR = [(1+ATR) \exp(1/TIY)]-1$$

where, ATR is the actual total rate, given by the current extent at the study area divided by their potential spread area (Silva et al., 2011; Acacio and Holmgren, 2014), and TIY is the time interval in years, given by the number of years counted from the beginning of the firstly changes reported in the Acacio and Holmgren (2014) and Silva et al. (2011) works.

Table 3. The calculated annual rates for land use changes in montado system

Original Land Cover \ Changed Land Cover	Agro-forestry	Oak Forest	Shrub Land	Eucalyptus Forest	Coniferous Forest	Mixed Forest	Agriculture	Non-Irrigable Arable Land	Agri-natural Vegetation
Agro-forestry		0.0046	0.0073	-	-	0.0073	0.0012	-	0.0012
Oak Forest	0.0027		-	-	-	0.0025	-	-	-
Shrub Land	-	-		0.0046	-	-	-	-	-
Eucalyptus Forest	-	-	-		-	-	-	-	-
Coniferous Forest	-	-	-	-		-	-	-	-
Mixed Forest	-	-	-	-	-		-	-	-
Agriculture	0.0049	-	0.0075	-	-	-		-	-
Non-Irrigable Arable Land	0.0049	0.0049	0.0075	-	-	-	0.0049		-
Agri-natural Vegetation	0.0049	-	0.0075	-	-	-	-	-	

After understanding the possible interchange between the land covers and their corresponding rates, we use the same information as a guide to construct and parameterize the conceptual diagram of the dynamic model (Figure 7 to 11). For the development of the structural dynamic and StDM models, the software STELLA 9.0.3 ® was used. All the parameters and equations used in the model construction are available in the Appendix III - VI.

In the dynamic model constructed, the land uses are represented by state variables and the responses are represented by converters. The entire model is divided into five sub-models. Sub-model one comprises the main dynamics that occurs between agro-forestry, cork oak forest and shrub land covers (Figure 7). Sub-model two comprises the dynamics in open systems including agri-natural vegetation, agricultural and non-irrigated arable lands (Figure 8). Sub-model three comprises the dynamics in closed (forested) systems except cork oak forest which is included in sub-model one. This sub-model includes mixed, eucalyptus and coniferous forests (Figure 9). Sub-model four comprises the dynamics in forest fire and patch richness. However, the same sub-model also comprises the constant land covers like permanent crops, complex cultivation patterns, built-up areas and water bodies (Figure 10). The final sub-model comprises the dynamics in our StDM response variables (both total and trait richness). Although the model is divided into five sub-models, each of these sub-models are connected to each other. For instance, sub-model one, two and three are connected each other through different flows (Appendix V) and sub-model five is connected with sub-model one, two and three through connectors like patch richness (PR), and percentage of land cover (PLand) and the state variables themselves (Appendix III). Sub-model four (excluding the constant land covers) which comprises patch richness, fire intensity and occurrence connects all the sub-models.

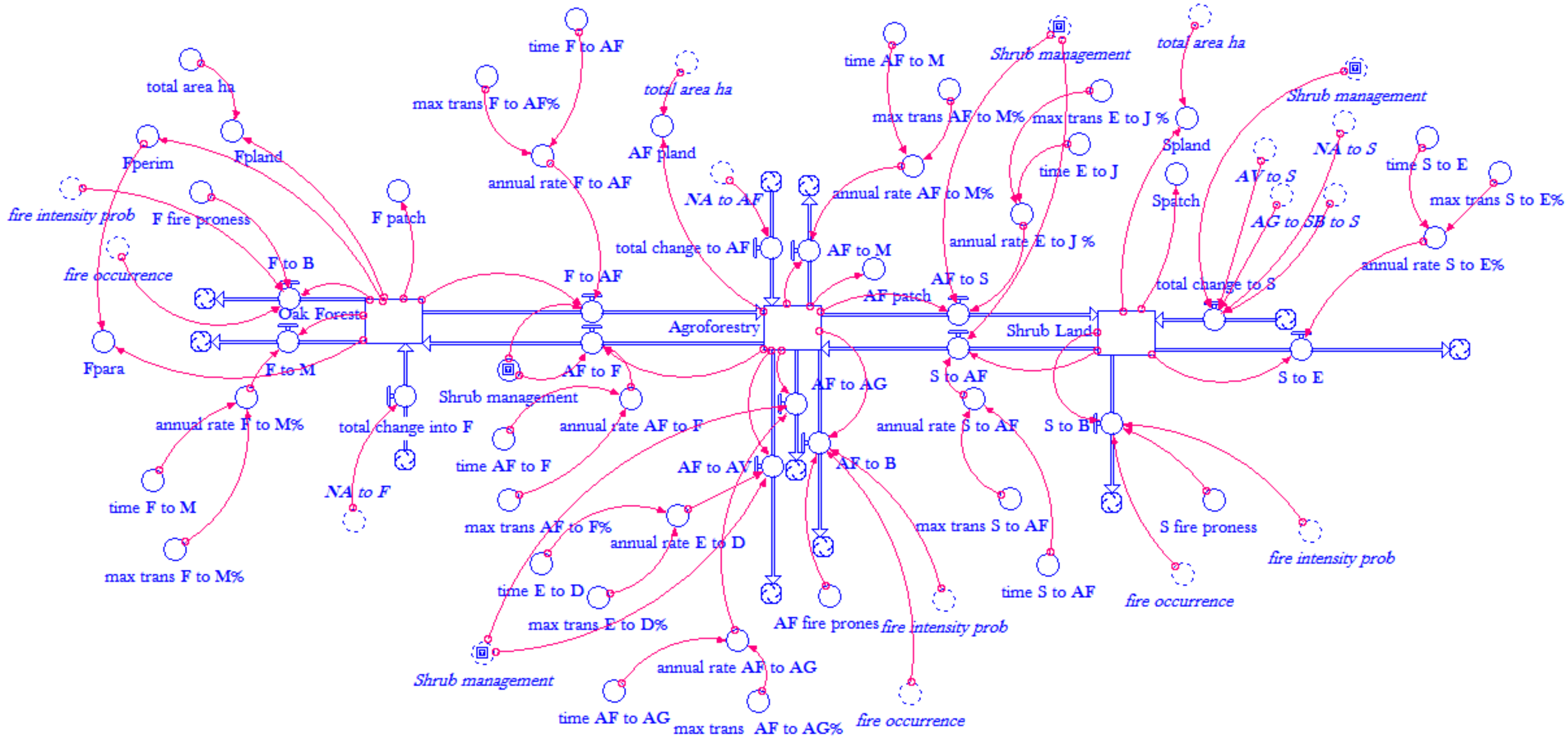

Figure 7. Sub-model 1; The main land use dynamics between cork oak forest, agro-forestry and shrub land.

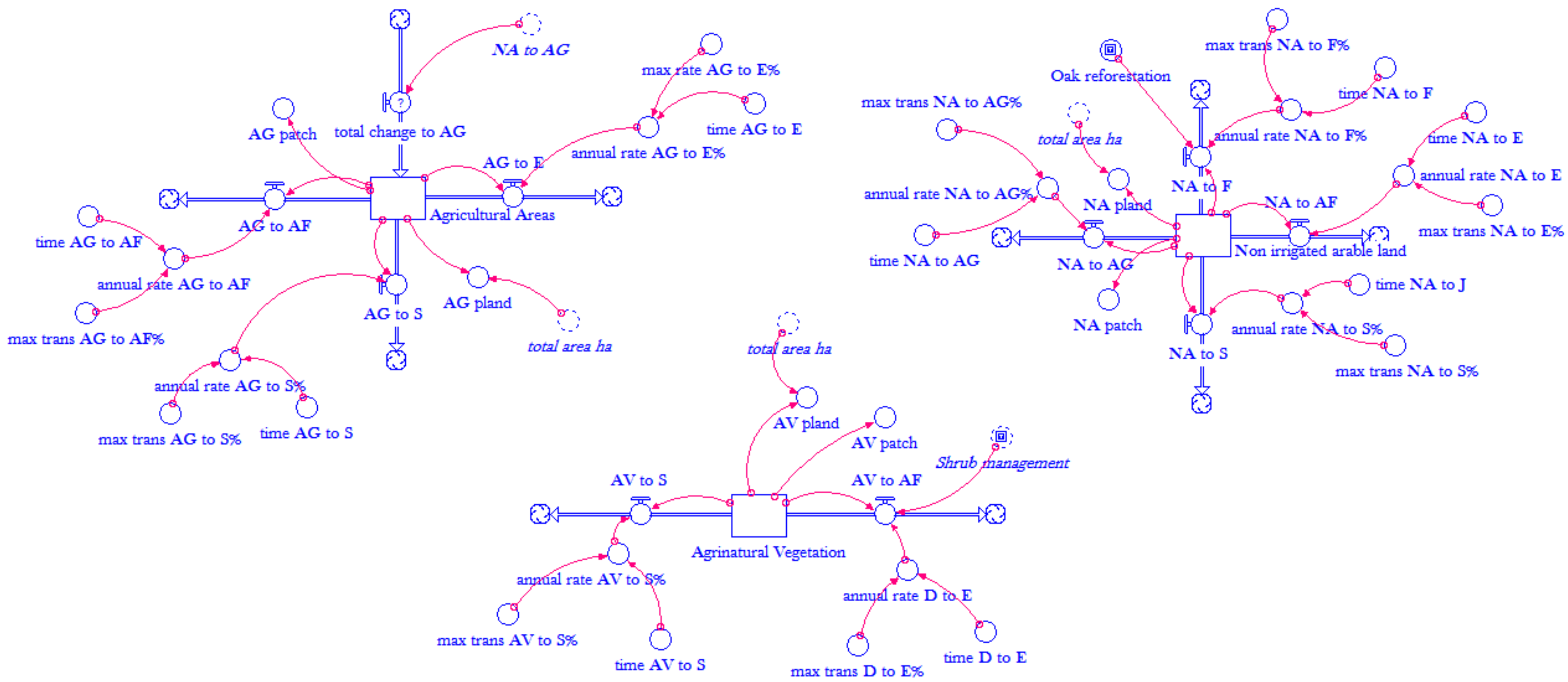

Figure 8. Sub-model 2; The land use dynamics involving open systems including agricultural areas, non-irrigated arable lands and agri-natural vegetation.

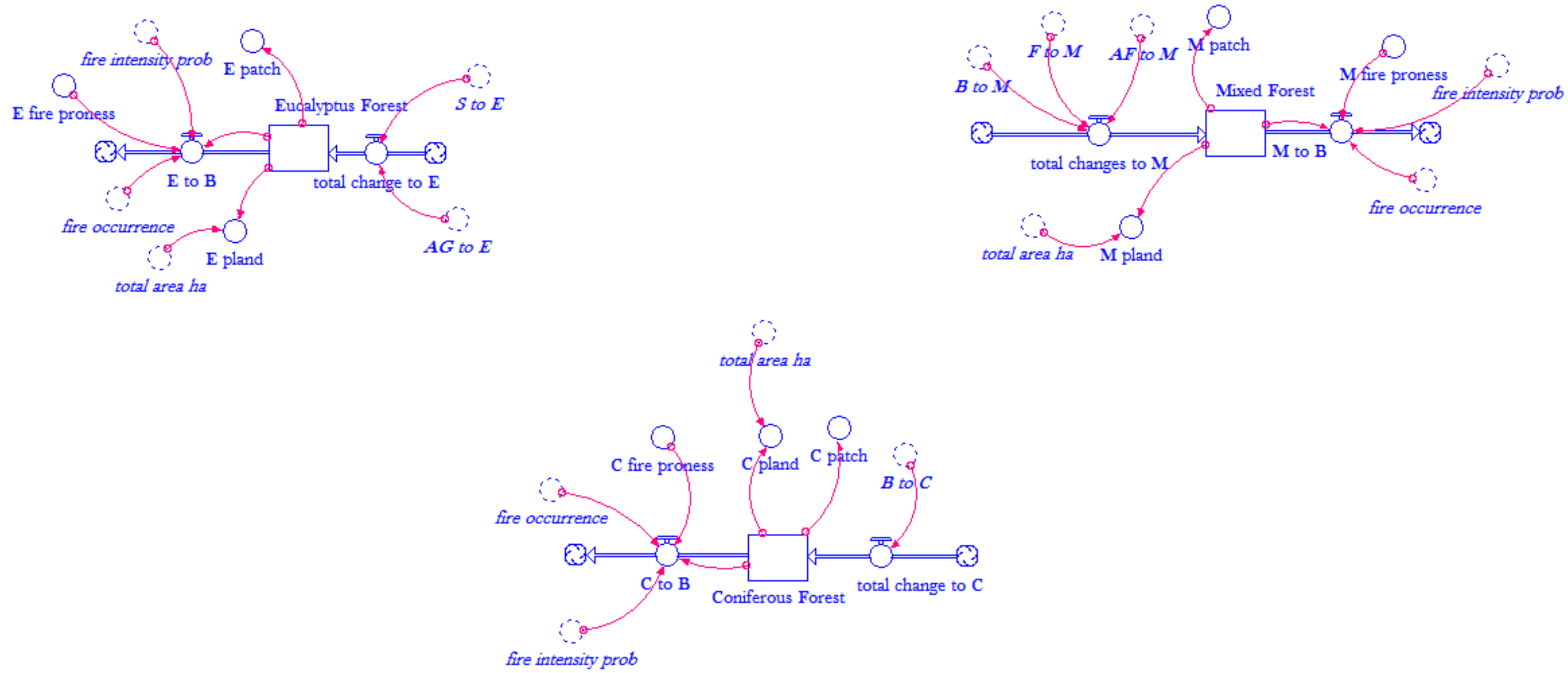

Figure 9. Sub-model 3. The land use dynamics in closed systems including mixed, coniferous and eucalyptus forest.

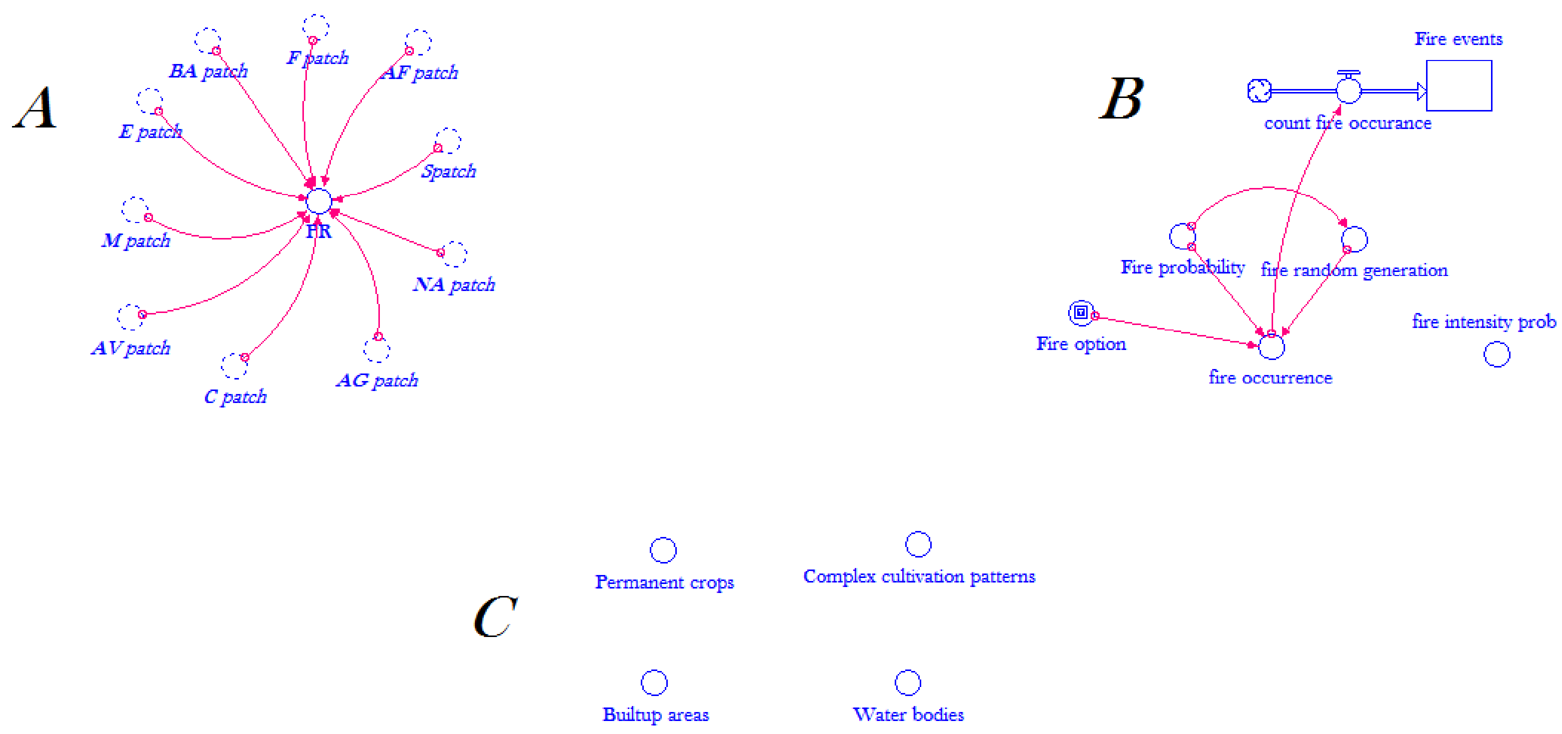

Figure 10. Sub-model 4: Dynamics in fire probability (B) and patch richness (A) and constant land uses (C)

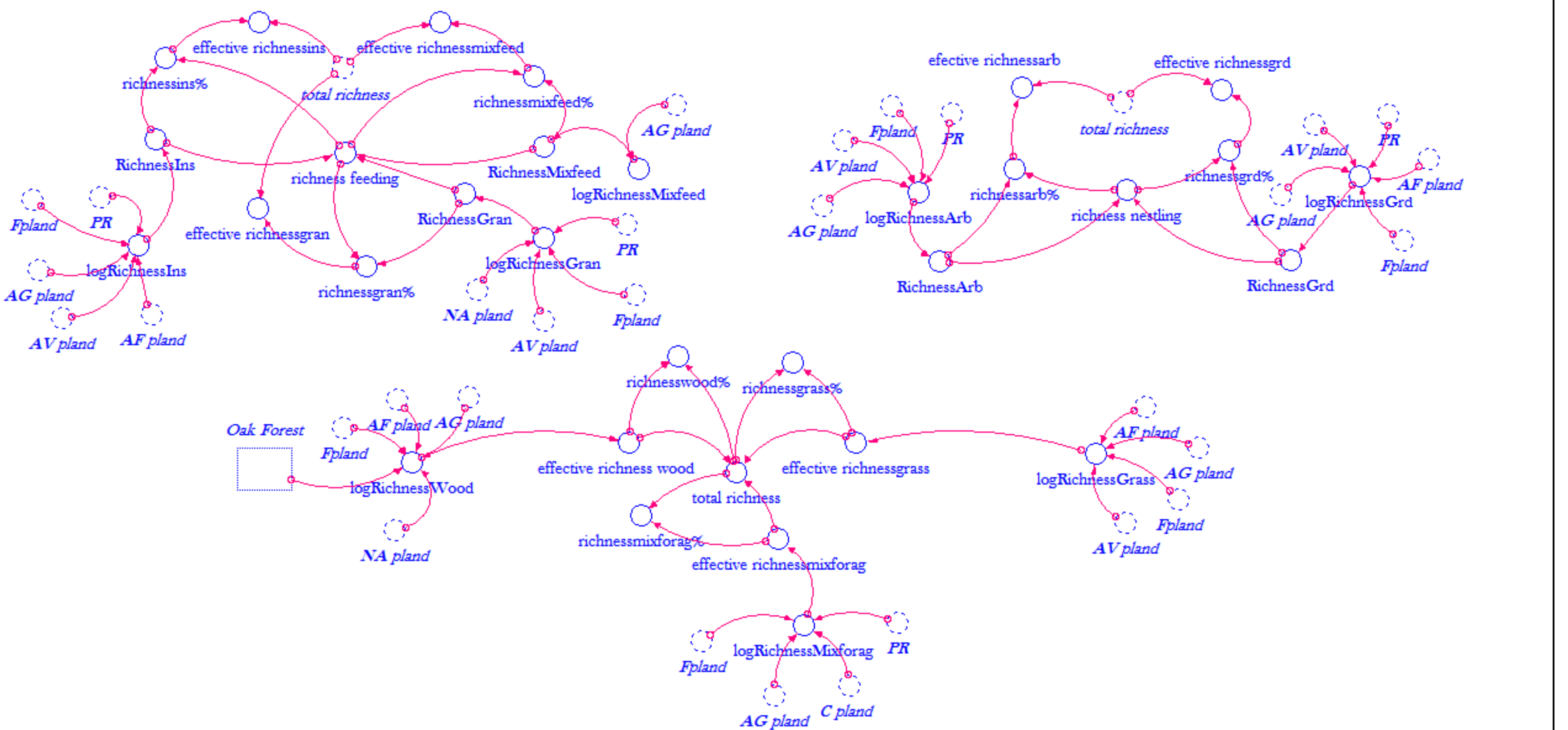

Figure 11. Sub-model 5: dynamics in StDM response variables

2.5.2.1 Stochastic Events

A stochastic forest fire event was incorporated into the model (Figure 10B) to understand the effect of fire occurrence on land use dynamics. We used the information on forest fire inventory in the study area (ICNF, 2014) to determine the probability of fire occurrence in the region. Accordingly, a random fire occurrence once in 65 years was used for the current model. The impact of the fire (fire intensity) also made to vary randomly between zero (no effect) to one (total removal of a particular land use). Different extent of fire proneness for different land use types were also considered since different land covers have different resistance to fire (Silva etal., 2009). The relative fire proneness for the different land cover in the model was taken from Silva etal. (2009).

2.5.2.2 Model Simulation and Scenarios

After completing the dynamic model, 252 fishnet grids (each cell with 1 x 1 km) were made for the whole region of Samora Correia to extract the area of each Corine land use type contained in each grid cell. The calculated area will then be used as initial values for the thirty years projection. The dynamic model constructed made to run for thirty year in Stella for each of 252 grids cells. The calculated initial values from each grid cell were imported to Stella at the beginning of every run. An average of 100 simulations per every grid, each running up to thirty years, were compiled for the next step in ArcGIS.

Based on the history of land use dynamics and management in montado system discussed above (see chapter 1.1), management option for conserving the typical nature of the system should involve the exclusion of either agricultural extensification (land abandonment) or intensification in the system. The specific land use type, according to Corine layer classification, that represents the typical montado system is agro-forestry (Bossard etal., 2000; Pinto-Correia and Godinho, 2013). Therefore, for understanding the effect of management activities on the biodiversity of the system, we incorporated into our dynamic model a management scenario that prevents any change from agro-forestry to other kind of land use types while the same scenario allows changes from any land use type to agro-forestry. By doing so, the changes from the typical montado system (agro-forestry) to deep woodland (oak forest) or shrub land as a result of land abandonment will be avoided under this management scenario.

2.5.3 Spatially Explicit Dynamic Projections

At this specific stage of StDM, the outputs from the dynamic model are incorporated into ArcGIS to produce visual maps that show the dynamics spatially. The grid projected values for the response variable are now imported to ArcGIS for interpolation between grid points. Although the selected spatial units capture the main combinations of the principal habitats that characterize the study area, each output only represents a preliminary independent contribution for the global pattern of the passerine traits spatial occurrence. Since the dynamic projections neglect spatial relationships among individual study units, a kriging GIS interpolation method (Sherman, 2010) was applied to project and integrate those trait attributes for the overall study area (regional scale), by incorporating spatial autocorrelation among abundances per study unit (Zhang and Murayama, 2011). The interpolation produce visual maps that shows the spatial gradients for the response variables, creating an integrative picture, in space and time, of the passerine species richness responses to the gradients of habitat changes.

3 Results

3.1 Effects of Land use Patterns on Bird Species Richness

Multiple regression analysis applied to our data resulted in different models (for each response variable). Table 4 shows the coefficients of explanatory variables for each foraging trait groups. The same result for nestling and feeding trait groups is provided in Appendix II.

Each model shows the importance of each explanatory variable in explaining the variability in each response variables. Woodland species showed a positive relation with forest related variables (F_PLAND and AF_PLNAD) and they showed a negative relation with agricultural areas (AG_PLAND). However, woodland species also show positive relation to non-forest related land uses like non-irrigated arable land (NA_PLAND) and negative relation with patch area of oak forest (Oak_Forest). Grassland species show positive relation with both forest and non-forest related variables, however agri-natural vegetation (AV_PLAND) has the highest effect on grassland species. Generalist species showed a positive relation with forest related variables and negatively related with non-forest related variables. Unlike woodland and grassland species, generalist species also show a positive relation with percentage of coniferous forests (C_PLAND) and patch richness (PR).

Arboreal nestling species showed a positive relation with forest related variables and patch richness while showing a negative relation with percentage of agricultural lands. Ground nestling species were positively related with percentage of agricultural lands while maintaining the same positive relation with forest related variables (Appendix II).

Insectivorous species showed a positive relation with forest related variables and patch richness. The same indicator also shows a negative relation with percentage of agricultural lands. Granivorous species showed a positive relation with forest related variables and patch richness and they are also negatively related with non-forest related variables like percentage of non-irrigated arable land. Since the multiple linear regression obtained for mixed feeding species is not significant (Appendix II), the mixed feeding trait group is excluded from the rest of data analysis.

Table 4. The regression equations, degrees of freedom (DF), the coefficient of determination (R_{aj}^2), F-values and their significance level for all combinations reported, as selected by multiple regression analysis for foraging trait groups. The specification of all variables is expressed in Tables 2.

Equation	DF	R_{aj}^2	F	P
Richness woodland species (Rwood)				
log (Rwood) = 1.29 + 0.0109 (NA_PLAND) - 0.02138 (AG_PLAND) + 0.00414 (AF_PLAND) - 0.0000896 (Oak_Forest) + 0.00759 (F_PLAND)	5	73.55	28.14	<0.001
Richness grassland species (Rgrass)				
log(Rgrass) = 0.776 + 0.01187 (AG_PLAND) + 0.0712 (AV_PLAND) + 0.01074 (AF_PLAND) + 0.00869 (F_PLAND)	4	57.18	9.41	<0.001
Richness generalist species (Rgen)				
log(Rgen) = 1.120 - 0.00987 (AG_PLAND) + 0.00469 (F_PLAND) + 0.0107 (C_PLAND) +0.0599 (PR)	4	61.76	10.33	<0.001
Total richness (TR)				
TR = Richness woodland species + Richness grassland species + Richness generalist species				

3.2 Temporal Variability in Landscape Composition with/without Management

For the scenario without montado management (land abandonment), the entire thirty year period of prediction showed a declining trend for oak forest, agro-forestry, agricultural and non-irrigated arable land while shrub land, burned areas, agri-natural vegetation, mixed and eucalyptus forest showed an increasing trend (Figure 12). However, the coniferous forest remains stable for the whole period.

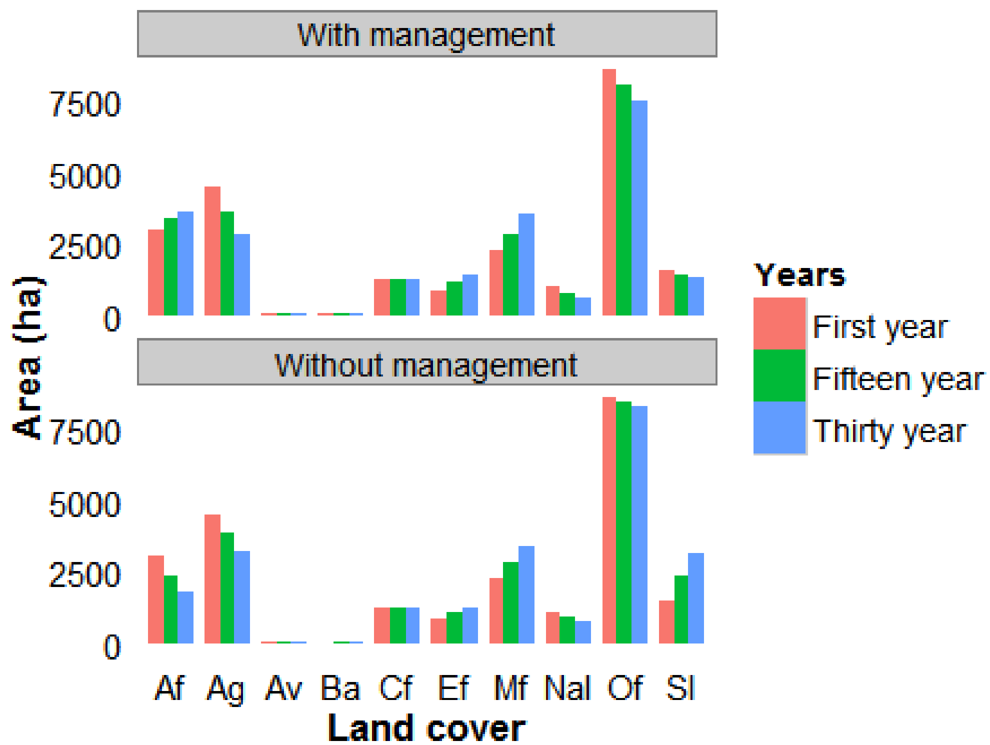

Figure 12. The global trend for the different land uses along the three periods (first, fifteen and thirty years) both with and without management scenario. Af: Agro-forestry, Of: Oak forest, Sl: Shrub land, Ag: Agriculture, Cf: Coniferous forest, Ef: Eucalyptus forest, Mf: Mixed forest, Nal: Non-irrigated arable land, Av: Agri-natural vegetation, Ba: Burnt area.

For the scenario with montado (agro-forestry) management together with oak reforestation in areas that are suitable for survival and growth of oak seedlings, land covers like agri-natural vegetation, oak forest, agricultural and non-irrigated arable land showed a declining pattern. The same pattern for the latter three land covers was also seen under without management scenario except the decline here is greater than the one observed under without management scenario (Figure 12). Agro-forestry, unlike the one obtained under without management scenario, showed an increment along time together with burnt areas, mixed and eucalyptus forest. On the other hand, shrub land that has an increasing pattern under without management scenario, now obtains a declining pattern along time. Coniferous forest remain stable similar to what was observed under without management scenario.

3.3 Spatio-Temporal Variability in Passerine Richness with and without Management Scenario

3.3.1 Trends in Total Species Richness

The average for total species richness obtained from each 252 grid cells in whole study area showed no significant variability along time. An average of 15 species was obtained in the first, fifteen and thirty years of the model projections for both with and without management scenarios.

For both scenarios, spatial variability among different locations in the study area was higher with maximum of 25 species and a minimum of 7 species. The spatial trend under without management scenario shows the increasing number of species richness in core areas till fifteen years but this was later followed by a declining trend between fifteen and thirty years (Figure 13). However, under management scenario, there is a larger and continuous reduction in species rich areas along the thirty years period.

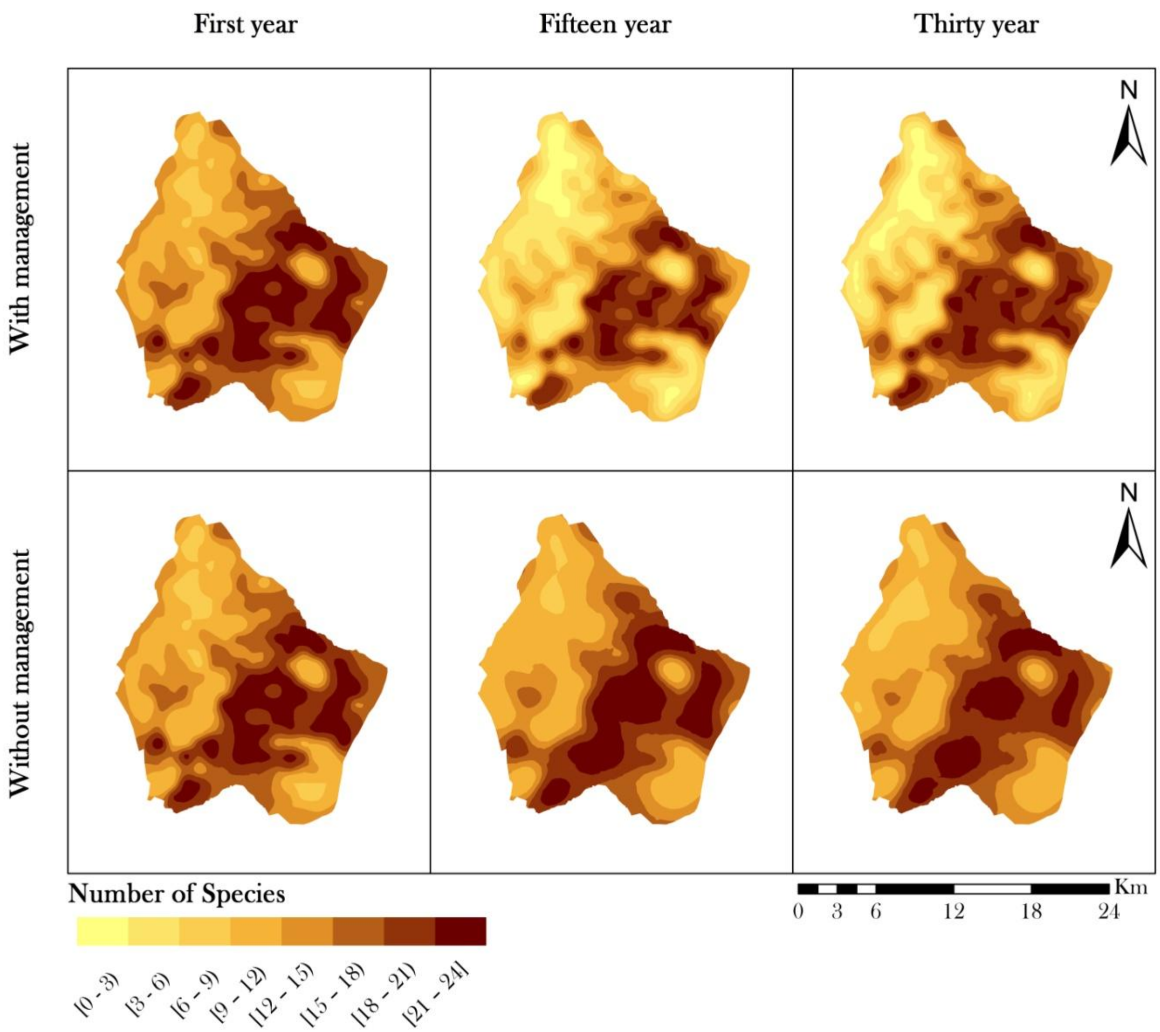

Figure 13. Spatial-temporal patterns for passerine total species richness in the study area considering both with and without management scenarios.

A separate analysis of the land use composition only for the areas with higher values of species richness (upper class regions), represented by very dark regions under without management scenario in Figure 13, was done for identifying the specific land use composition that is responsible for higher species richness in these regions. Accordingly, oak forest was found to be prevalent in all the areas where there are higher values of total species richness (Figure 14).

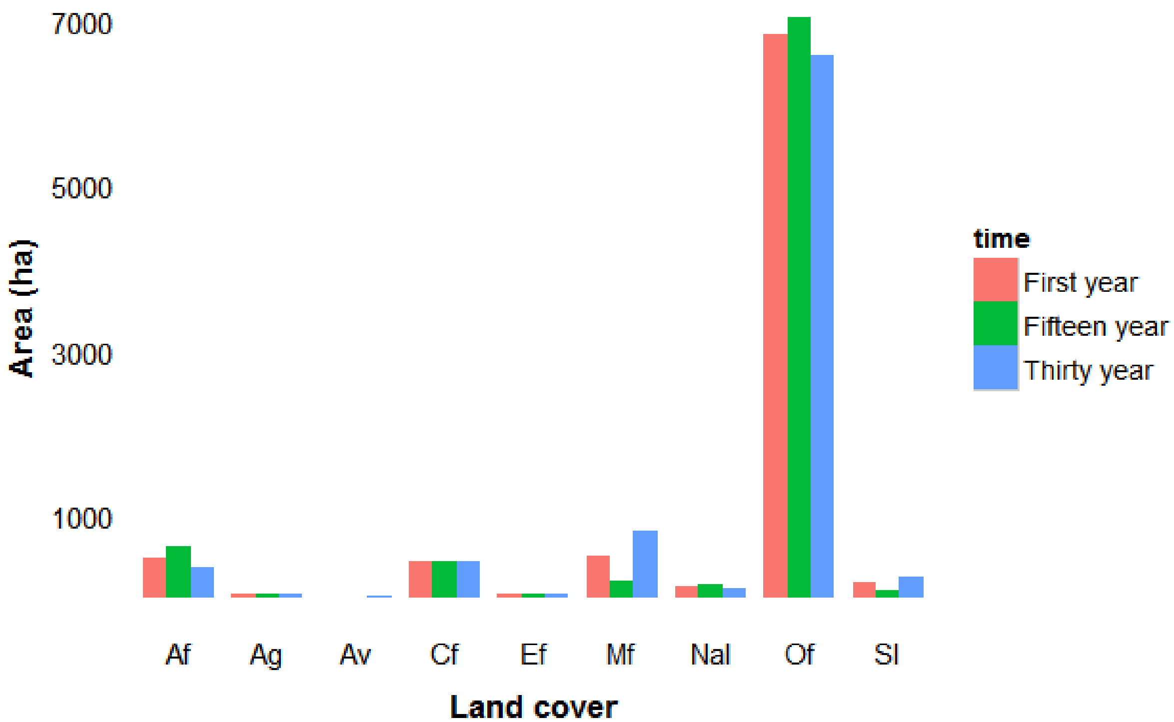

Figure 14. Land use composition for selected areas with passerine total species richness greater than 21 species (upper class regions), considering a scenario without management and/or agricultural abandonment. Af: Agro-forestry, Of: Oak forest, Sl: Shrub land, Ag: Agriculture, Cf: Coniferous forest, Ef: Eucalyptus forest, Mf: Mixed forest, Nal: Non-irrigated arable land, Av: Agri-natural vegetation.

3.3.2 Trends in Trait Based Indicators

3.3.2.1 Foraging Traits

For the scenario without montado management, the average richness of the whole study area (i.e. the average of the 252 grid cells) for grassland species shows a decline from six to five species along the thirty years period. However, generalist (mixed foraging) species increases from four to five species and woodland species remain five species for the entire period of projection.

Similar to without management scenario, reduced temporal variability in average trait richness was also observed under management scenario with grassland species declining and generalist species increasing by single species and woodland species remaining five species for the entire thirty years period. Despite the reduced temporal variability in average foraging trait richness above, there is high spatial trait variability among different location within the study area for both management scenarios. For instance, the most species rich areas for grassland species were found in the eastern margin of the study area while for woodland species the distribution is mainly to the central and western part of the study area (Figure 15 and 17).

3.3.2.1.1 Grassland Species

For both management scenarios, the projected map for grassland species shows a decline in species rich areas (greater than eight species) along time see Figure 15. These species rich areas, that were originally concentrated in eastern margin of the study area, declined both at fifteen and thirty years projection leaving small areas with no more than seven species. Under management scenario, the same declining pattern in species rich areas was observed except the decline here is lower than the one observed under without management scenario.

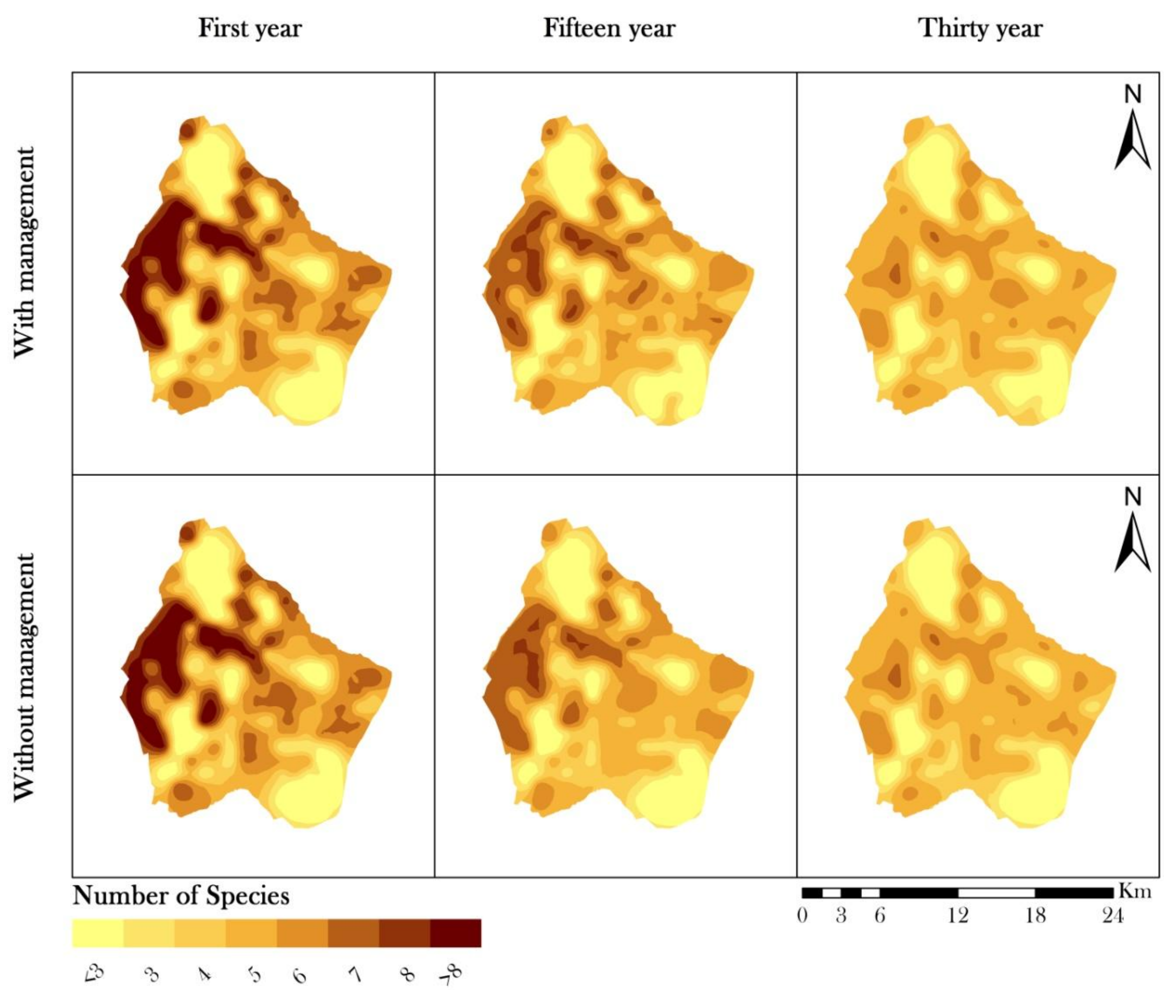

Figure 15. Spatial-temporal patterns for grassland species richness in the study area considering both with and without management scenarios.

3.3.2.1.2 Woodland Species

For both management scenarios, the projected maps for species rich areas of woodland species show a declining pattern along time (Figure 16). The species rich areas, which were originally distributed in the central and western part of the study area, become more fragmented during the last periods of projection. However, the changes seen for grassland species are more pronounced than the one observed for woodland species. Unlike to grassland species, under management scenario, a greater decline in species rich areas for woodland species were observed along time.

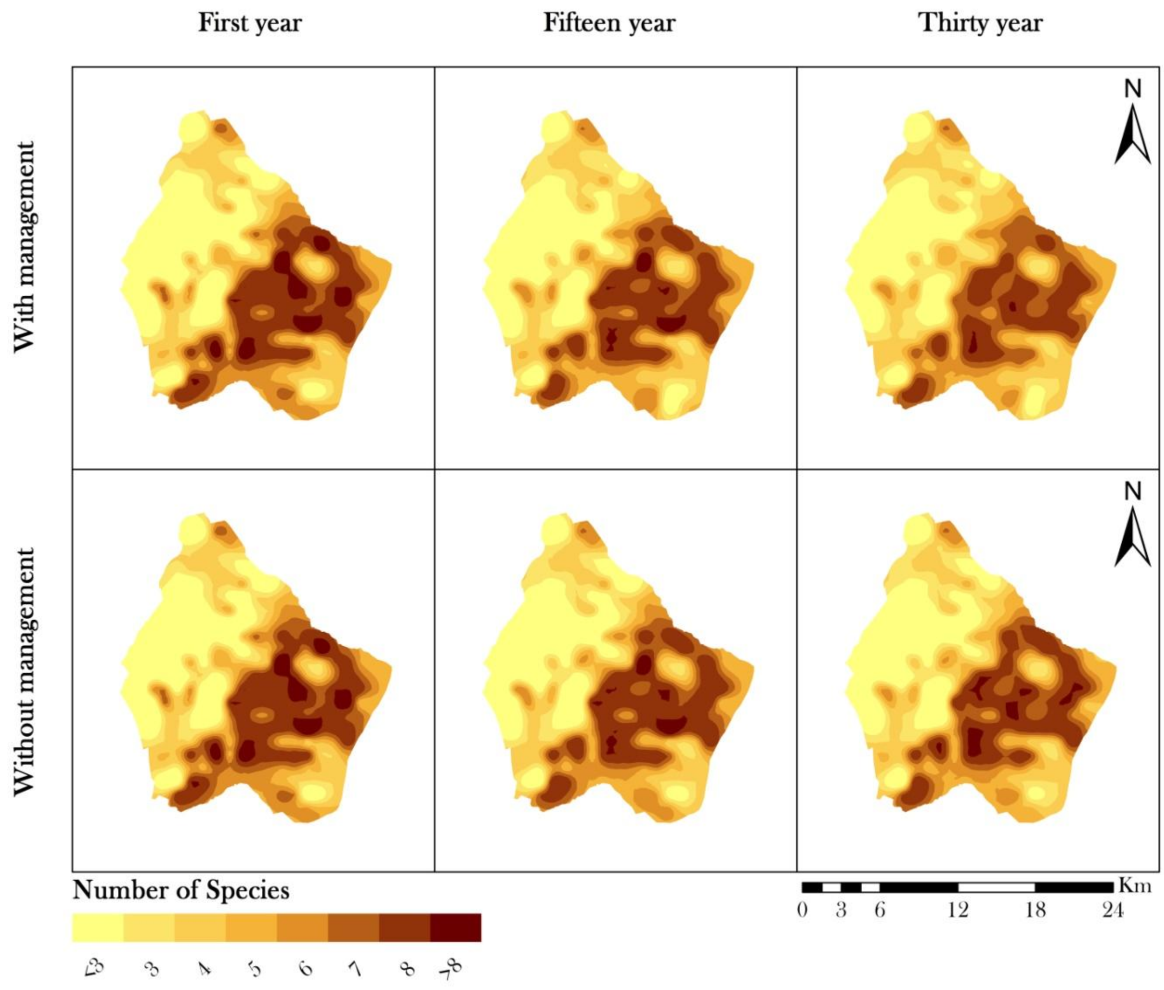

Figure 16. Spatial-temporal patterns for woodland species richness in the study area considering both with and without management scenarios.

3.3.2.1.3 Generalist species

For both management scenarios, the projected map for species rich areas of generalist species shows an increasing pattern along time except that larger decline is observed under management scenario (Figure 17). From the three projected map, it can be understood that the generalist species richness was very poor in areas where there is high species richness for grassland species and is higher where there high species richness for woodland species.

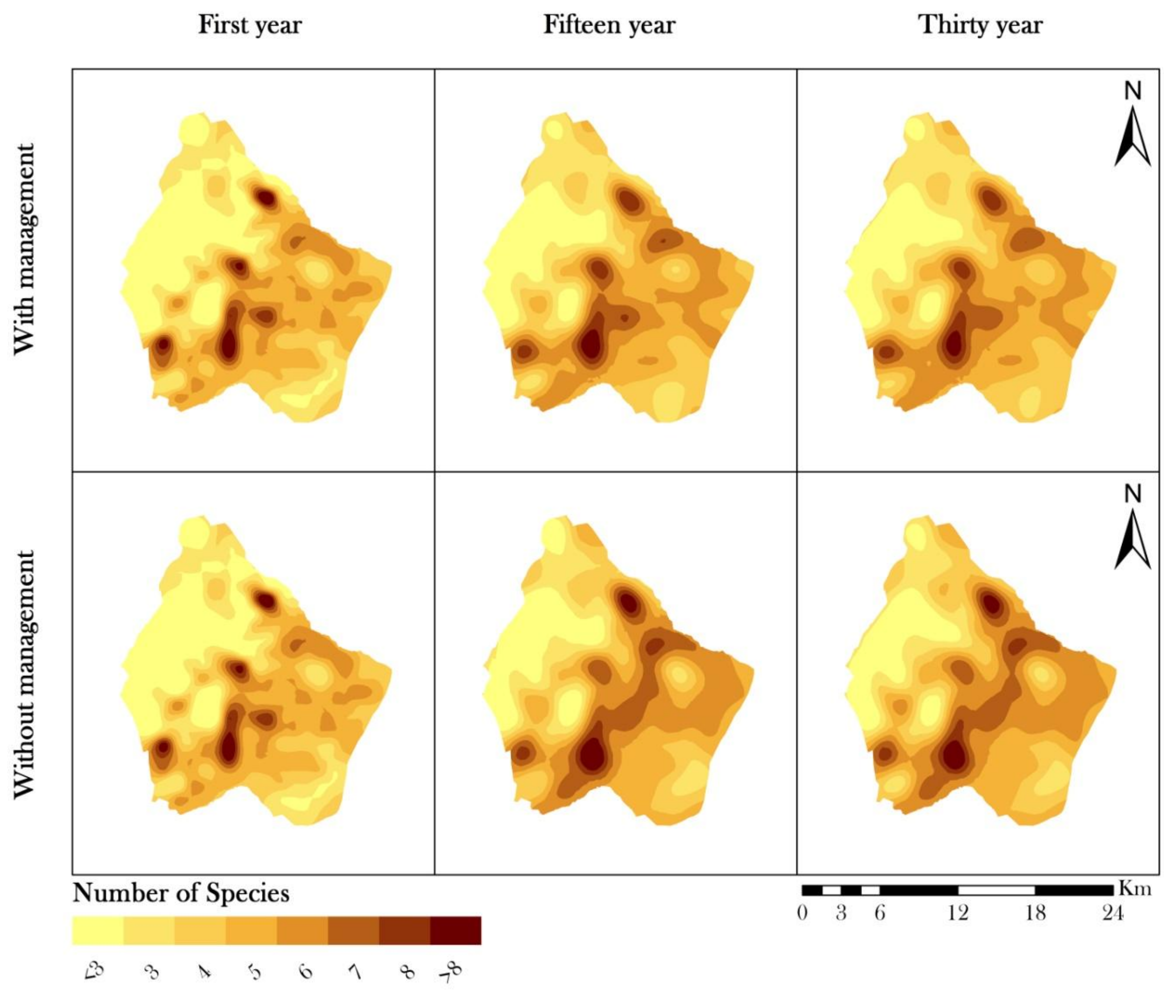

Figure 17. Spatial-temporal patterns for generalist (mixed foraging) species richness in the study area considering both with and without management scenarios.

A separate analysis of land use composition at species rich areas (greater than eight species), that are represented by very dark regions in all the projected maps for all foraging trait groups under without management scenario, indicates that grassland species are more related with agro-forestry and agricultural lands while woodland are more related with oak forest. However, in those areas where there high species richness for generalist species, a slight dominance by oak forest is observed while the remaining land covers are represented almost evenly.

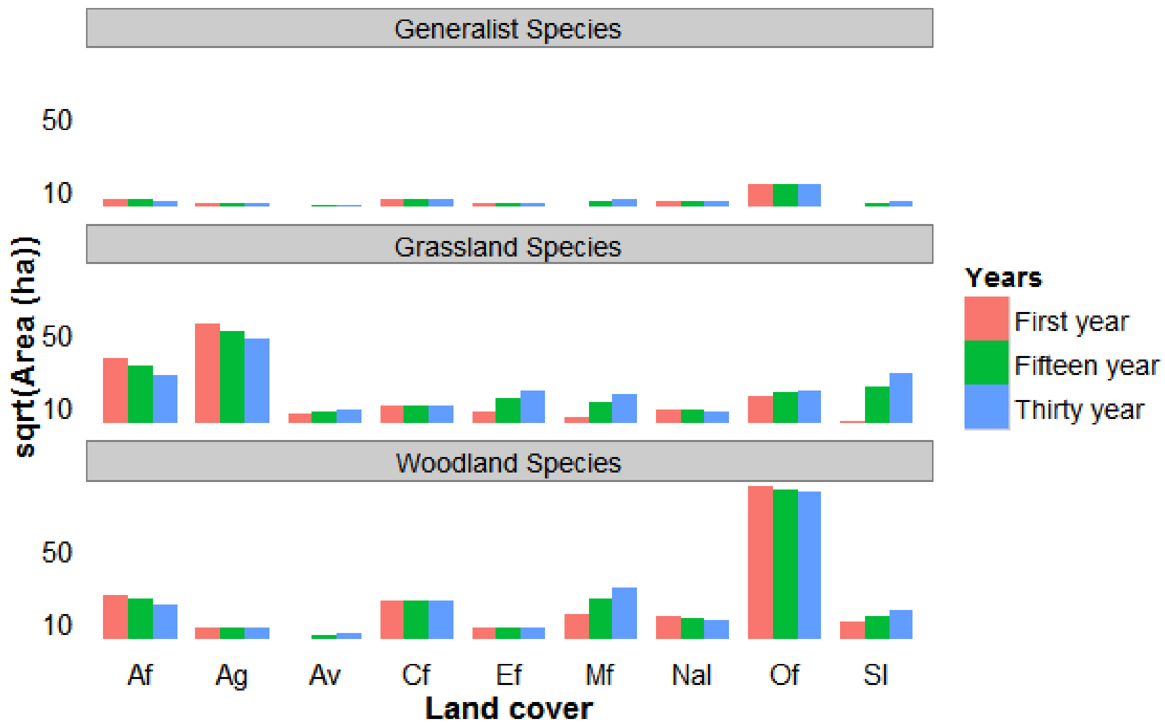

Figure 18. Land use composition for selected areas with foraging trait species richness greater than 8 species, considering a scenario without management and/or agricultural abandonment. Af: Agro-forestry, Of: Oak forest, Sl: Shrub land, Ag: Agriculture, Cf: Coniferous forest, Ef: Eucalyptus forest, Mf: Mixed forest, Nal: Non-irrigated arable land, Av: Agri-natural vegetation. The area is square root transformed due to huge difference between the land covers.

3.3.2.2 Nestling Traits

Similar to foraging traits, the average richness of the whole study area for nestling trait groups has a reduced temporal variability under both with and without management scenarios. The average species richness for arboreal and ground breeding species remain nine and six species respectively along the thirty years period. However, there is high spatial variability between different locations within the study area in terms of nestling trait richness under both management scenarios.

The projected map for arboreal breeding species encompasses a wider species rich areas nearly equivalent to the one obtained for total species richness explained above (Figure 13). These species rich areas also comprise more areas with higher species richness (greater than twelve species) when compared with all trait groups used in the current study. Ground breeding species, unlike arboreal breeding species, do not have a wide areas characterized by high species richness (most species rich areas comprise only seven species). However, still they have wide distribution of species rich areas in the study area since they are distributed to the eastern, central and western part of the study area (a pattern not seen in any other trait group) (Figure 19).

3.3.2.2.1 Ground Breeding Species

Under both management scenarios, the species rich areas for ground breeding species shows a declining pattern along time (Figure 19). However, the reduction in species rich areas is larger under with management scenario than the one observed under without management scenario.

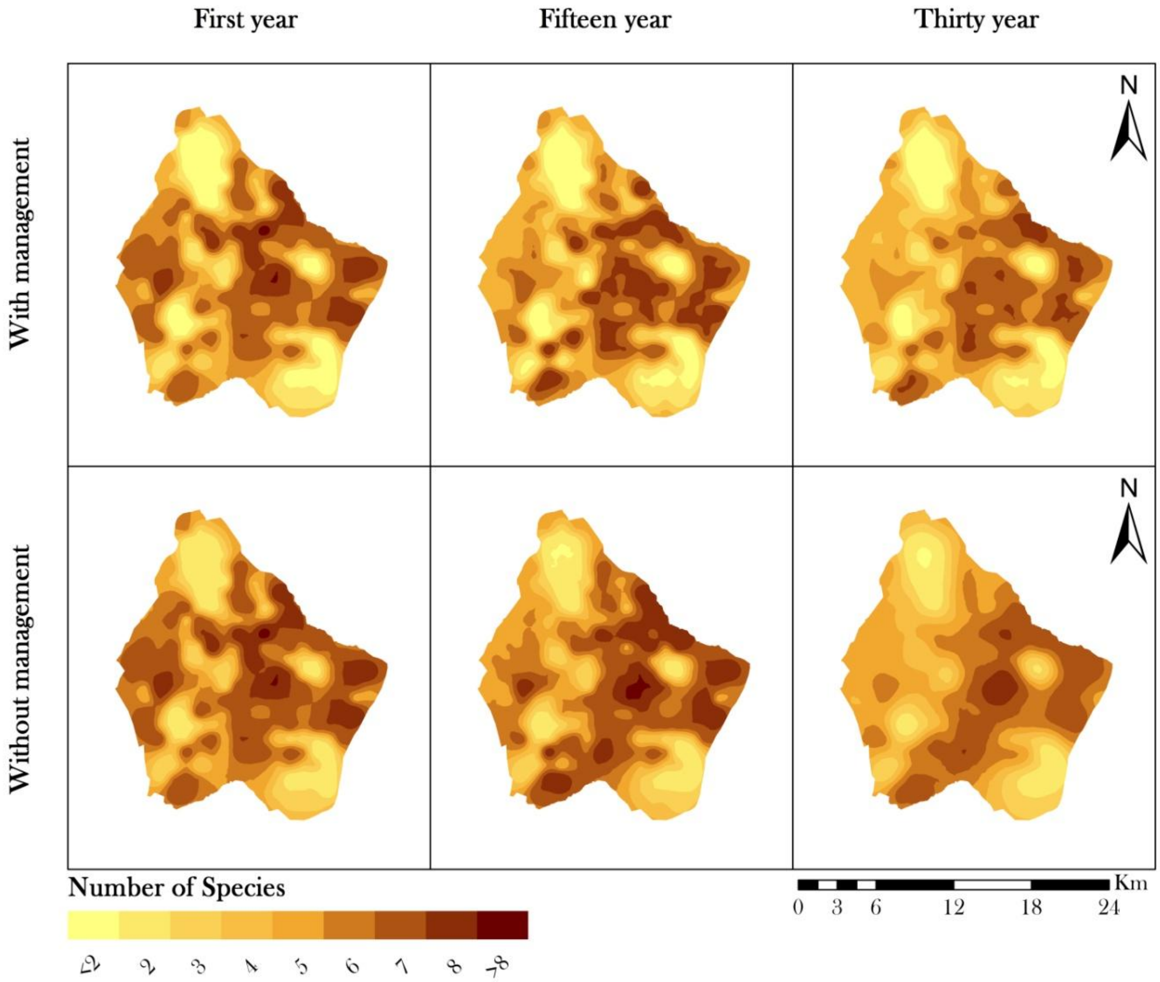

Figure 19. Spatial-temporal patterns for ground breeding species richness in the study area considering both with and without management scenarios.

3.3.2.2.2 Arboreal Breeding Species

Similar to ground breeding species, the species rich areas for arboreal breeding species showed a declining trend along the thirty years period for both management scenarios (Figure 20) and the decline under with management scenario was larger than the one observed under without management scenario.

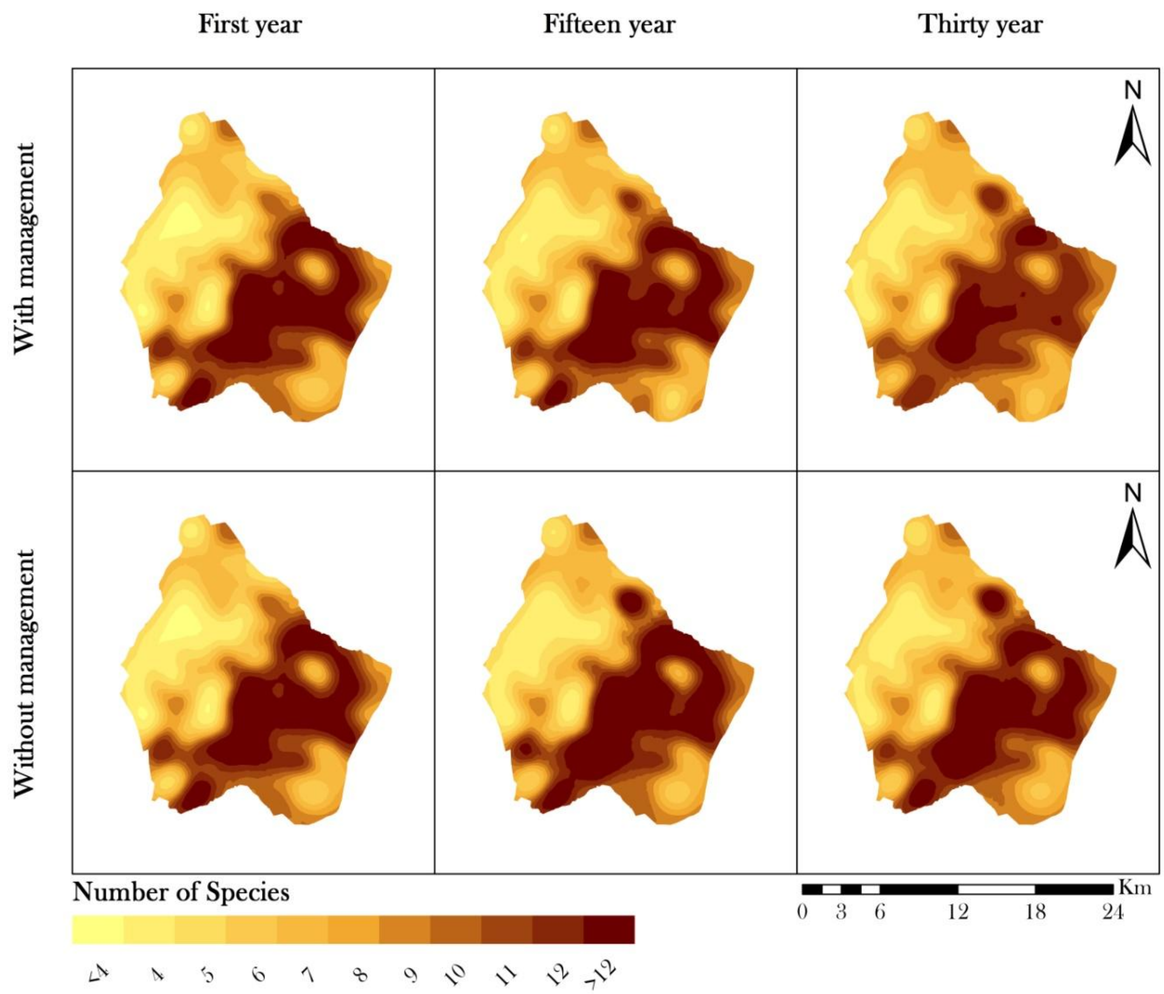

Figure 20. Spatial-temporal patterns for arboreal breeding species richness in the study area considering both with and without management scenarios.

A separate analysis of land use composition in species rich areas (upper class regions) that are represented by very dark regions in the projected map for all nestling trait groups showed that higher number of arboreal breeding species are found in areas where oak forest is more prevalent (Figure 21). However, areas with high number of ground breeding species were slightly dominated by agro-forestry, oak forest, mixed forest and shrub land.

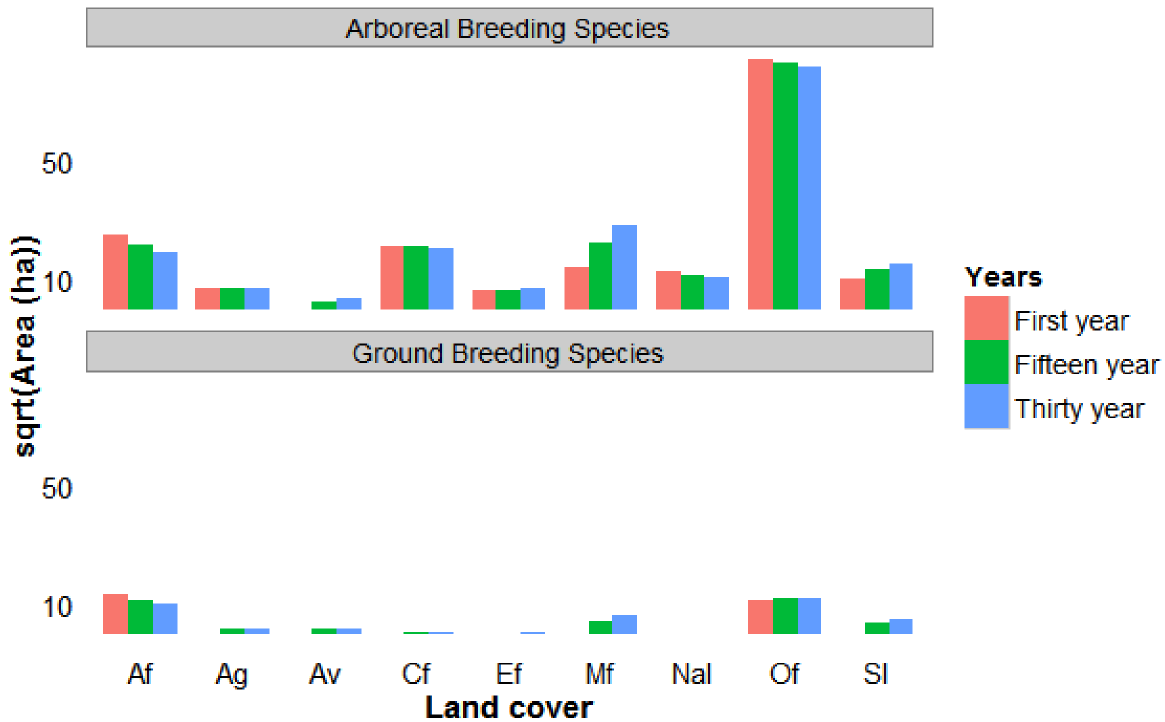

Figure 21. Land use composition for selected areas with arboreal and ground breeding species richness greater than 8 species (upper class region), considering a scenario without management and/or agricultural abandonment. Af: Agro-forestry, Of: Oak forest, Sl: Shrub land, Ag: Agriculture, Cf: Coniferous forest, Ef: Eucalyptus forest, Mf: Mixed forest, Nal: Non-irrigated arable land, Av: Agri-natural vegetation. The area is square root transformed due to huge difference between the land covers.

3.3.2.3 Feeding Traits

Similar to other trait groups, the average species richness of the whole study area for feeding trait groups showed reduced temporal variability. Under without management scenario, granivorous species increases from three to four species and insectivorous species maintain the same ten species for the entire thirty years period. While under with management scenario, both granivorous and insectivorous species maintain three and ten species respectively for the entire thirty years period.

However, there is high spatial variability between different locations in the study area in terms of feeding trait richness for both management scenarios. Insectivorous species have wider species rich areas that go from southwestern to northeastern part of the study area (Figure 23).

3.3.2.3.1 Granivorous Species

Unlike the other trait groups, the projected map for granivorous species shows a tendency increasing pattern along the thirty years period under without management scenario (Figure 22). There is a slight tendency of declining pattern under with management scenario. However, the general spatial-temporal pattern of granivorous species is not very efficient since it does not show the clear changes along time.

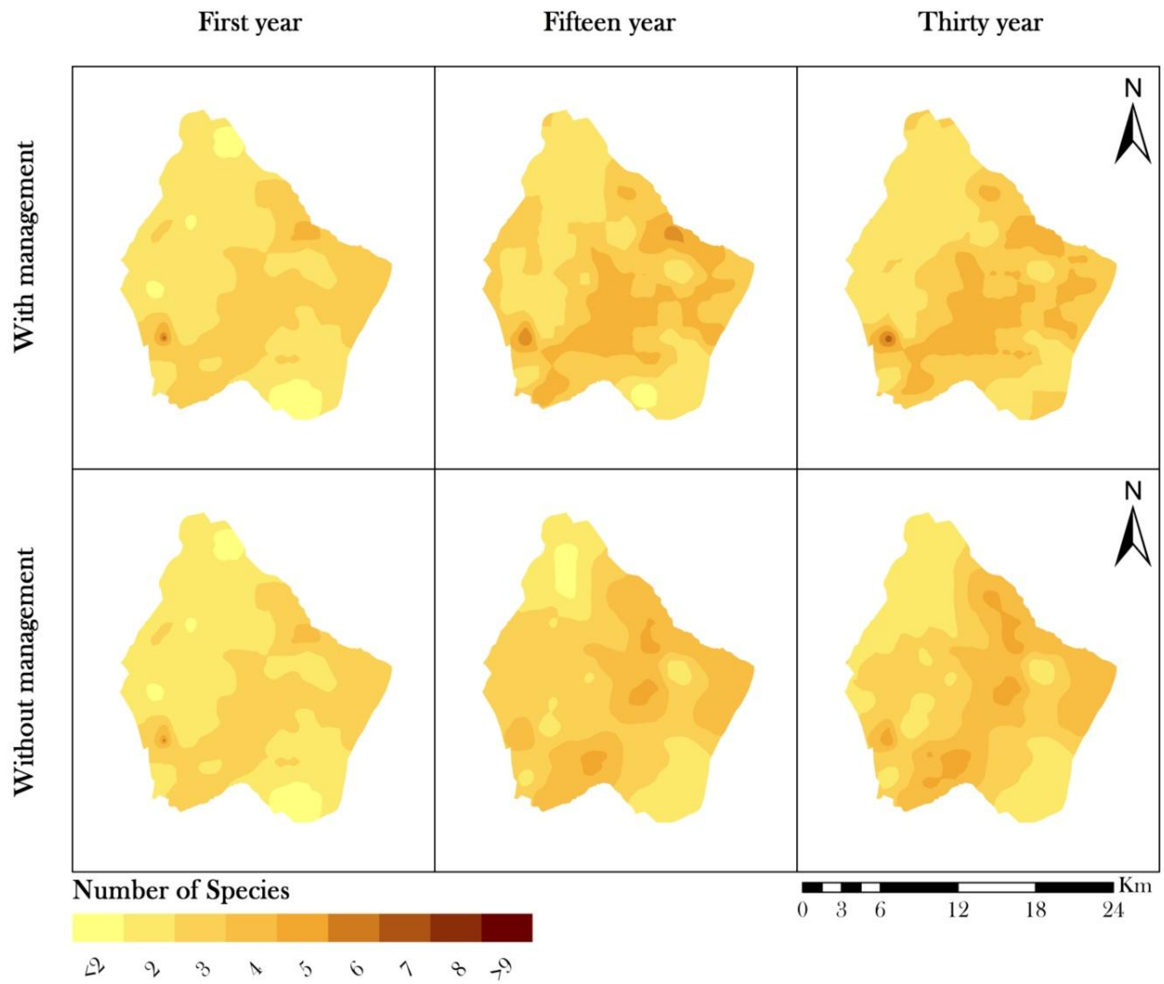

Figure 22. Spatial-temporal patterns for granivorous species richness in the study area considering both with and without management scenarios.

3.3.2.3.2 Insectivorous Species

The projected map for insectivorous species shows very small changes along the thirty years period under both with and without management scenario (Figure 23). Similar to all the traits above, the decline in species rich areas under without management scenario is smaller than the one observed under with management scenario.

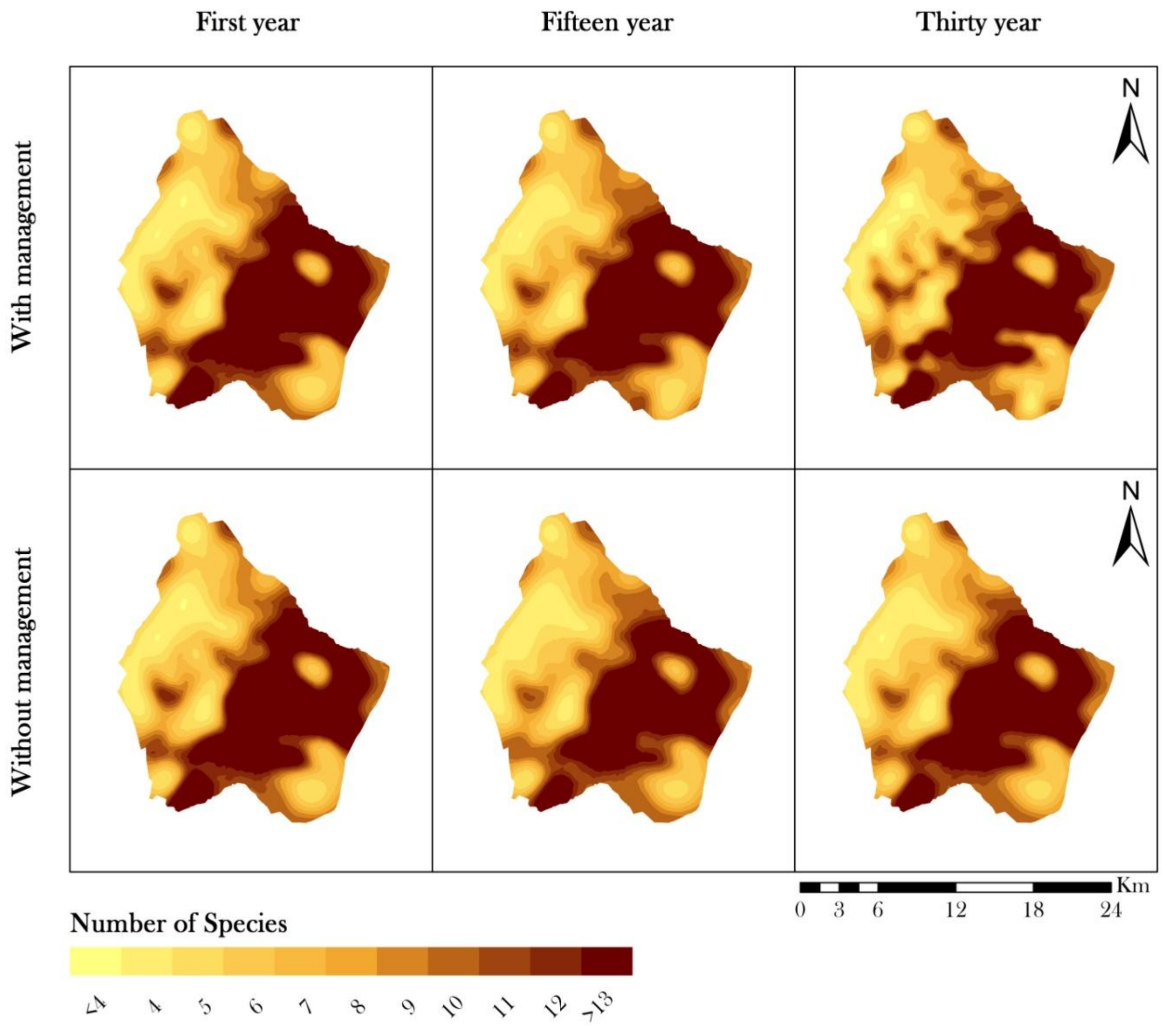

Figure 23. Spatial-temporal patterns for insectivorous species richness in the study area considering both with and without management scenarios.

A separate analysis to determine the land use composition in species rich areas indicates that oak forest is more prevalent in areas where there is higher number of insectivorous species (Figure 24). However, in areas where there is high number of granivorous species, oak forest and coniferous forest are slightly dominant while the other land covers are almost uniform.

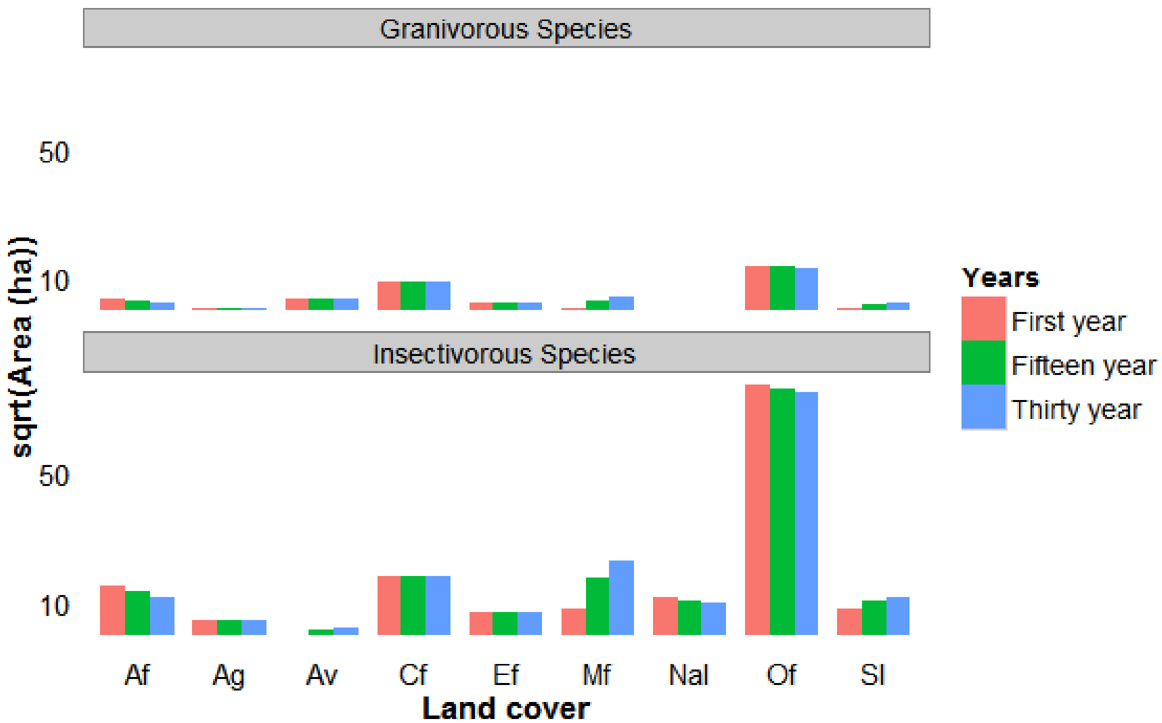

Figure 24. Land use composition for selected areas with granivorous and insectivorous species richness greater than 8 and 13 species respectively (upper class region), considering a scenario without management and/or agricultural abandonment. Af: Agro-forestry, Of: Oak forest, Sl: Shrub land, Ag: Agriculture, Cf: Coniferous forest, Ef: Eucalyptus forest, Mf: Mixed forest, Nal: Non-irrigated arable land, Av: Agri-natural vegetation. The area is square root transformed due to huge difference between the land covers.

4 Discussion

4.1 Effect of land use patterns on Species Diversity

The simulation results show that the indicators selected were not indifferent to the structural changes expected to occur in the studied montado agro-ecosystems. The response of the passerine traits associated with species occurrence, habitat/food resources and breeding conditions, is variable and sensitive to those structural changes. The overall response of species to the different land uses indicates that oak forest and agricultural areas influence majority of the trait groups. Traits associated with forest cover like woodland, arboreal breeding and insectivorous species were positively related with the area of cork oak forest, agro-forestry and agri-natural vegetation while showing negative relation with agricultural areas. This is because most forest adapted passeriformes are specialist to live in closed systems, and their activity in open systems is very minimal. Since most forest passeriformes in Mediterranean region, that have origins from western Europe, are forest specialists (Suarez etal., 2002, Sirami etal., 2008: Preiss etal., 1997: Tena etal., 2007), it is not a surprise to see them having negative relation with agricultural areas. In addition to this, the reason for the same trait to have a positive relation with non-irrigated arable land (a type of open system) could be due to the close proximity of non-irrigated arable lands to oak forest distribution in the study area.

On the contrary, the traits associated with open systems like grassland, ground breeding and granivorous species were having positive relation both with area of cork oak and agricultural lands. This could happen because passerine species that have origin in Mediterranean region are mainly adapted to open systems including agricultural areas (Suarez etal., 2002). However, the same study and Telleria (2001) also asserts that these species have comparable distribution in forest systems since grassland species in the region are edge and open area bird species. Traits for generalist species also showed positive relation with cork oak forest and a negative relation with agricultural areas similar to woodland species. This indicates that the generalist species used in the current study could be dominated by woodland generalist species. Generalist species are also positively related with coniferous forest and total patch richness. This indicates that generalist species, though they show preference for forested systems, also are strongly related with increasing number of patches (mixed land cover types) that enables them to take advantage of the diverse land cover types. The fact that they are also positively affected by coniferous forest (just like they are affected by cork oak forest) indicate that generalist species do not specifically respond to forest cover types as it also indicated by Tena etal. (2007).

4.2 Land use Dynamics With and Without Management Scenarios

The large increment in shrub land and mixed forest under without management scenario occurs because significant portion of other land cover types like agro-forestry, agricultural and non-irrigated arable land is changing into the former land cover types. However, under management scenario, the large increment observed was for agro-forestry and mixed forest. This happens because the large amount of area that was being converted into shrub land under without management scenario is not being maintained as agro-forestry area as a result of montado management. Despite, the increasing trend observed for agro-forestry under with management scenario, we also observe a higher rate of decline for cork oak forest. This is because, the increasing pattern for agro-forestry is not just at the expense of shrub land area but also some area from the cork oak forest is being converted to agro-forestry as a result of montado management. Other land cover types including eucalyptus forest showed increasing pattern in both scenarios due to the increasing trend of converting unproductive agricultural areas into eucalyptus plantations (Kardall etal., 1986: Jones etal., 2011). Coniferous forest remains nearly constant since the dynamics in this forest is highly dependent on forest fire occurrence which is very rare in our study area (Silva etal., 2011).

In general, the land use dynamics in Samora Correia is facilitating the expansion of areas with intense and intermediate canopy while reducing the proportion of open areas. Moreover, such increment in canopy cover is even more pronounced when montado management through avoiding land abandonment and oak reforestation is implemented.

4.3 Dynamics in Species Diversity With and without Management Scenario

The average for the total and trait richness of the study area (both with and without management scenario) showed reduced variability along time. The average values will strongly vary only if we have huge change in our system, like a forest land cover in the initial year is completely replaced by agricultural area at the end of thirty year. Because we have no such big changes in the study area, the average values both for total and trait richness showed reduced or no changes for the whole thirty years period of simulation.

The projected map for trait richness showed high variability between the three periods (first, fifteen and thirty) than the total richness. This is because the total species richness is the cumulative response of all trait groups and this usually has small variability along time. However, the traits richness includes the richness of few functionally related species that respond to changes in specific land cover types. This is responsible for higher variability in trait richness along time.

The distribution of areas with high total species richness declined till the last year of projection when no management practices were taking place in the system. The decline for grassland species was found to higher than the other trait groups since we have high rate of reduction in open areas. Grassland species in Mediterranean region are highly adapted to human shaped systems like montado besides they are resident species of the region (Telleria, 2001). The huge reduction in open areas, specially agricultural areas, is responsible for the total exclusion of these species from their natural habitats, which again leads to extinction of these species.

Contrary to our expectation, the species rich areas for both total and trait richness except grassland species, strongly declined under management scenario. However, montado management slightly improves the species richness of grassland species, still it is responsible for reducing the species richness of other trait groups. Hence, expanding agro-forestry area at the expense of other important land covers like oak forest and agricultural areas does not result in increasing the total bird species richness of the study area.

Land-use management is often focused on few species and local processes, but in dynamic, agricultural landscapes, only a diversity of insurance species may guarantee resilience (the capacity to reorganize after disturbance) (Tscharntke etal., 2005). Montado system is a combination of different land uses that emanates from purely agricultural areas to mature forest. Conserving a single land cover type, here agro-forestry, may not improve the bird species richness in a system like montado where we have a mosaic of land uses. Rather, bird species could be improved by preserving the multi-functionality of the system. This can be achieved, first through understanding the mosaic nature of the system and then recognizing the specific contribution from the diverse land uses in the system for maintaining biodiversity. There are still uncertainties in defining what a montado system is and what it comprises (Beaufoy, 2013). A clear definition of montado is still necessarily to understand the complexity of the system. Second, through managing the balance between the diverse land uses in the system according to their relevance for biodiversity, it will be possible to maintain the multi-functionality of the system while conserving the biodiversity contained in it.

5 Conclusions

The land use dynamics that has been taking place in montado system is responsible for constantly altering the land use composition of the system. Such change in land use composition is reducing species diversity of the system. Passeriform species, which has been often used as suitable indicators for understanding the gradient of land uses, responded very well to the changes in land use composition. Agro-forestry, a typical montado system with savanna like physiognomy, has been considered as a montado system that plays a major role in maintaining the biodiversity in montado landscape. However, there are still arguments if what is called agro-forestry represents the whole montado system (landscape). Similarly, our results also show that managing a single local land cover type (agro-forestry) cannot guarantee the recovery of biodiversity in the system at regional level. Rather managing the land use diversity and hence the multi-functionality of the system through extending the conservation efforts to other land cover types is very crucial for managing the biodiversity of the whole montado system.

Despite the limitations inherent to an academic demonstration, the simulation results reflect well the shift of the montado agro-ecosystem towards new expected conditions and the indicators proposed are capable of responding with credibility to key changes. Therefore, considering that almost all northern Mediterranean countries are, or will be, regulated by CAP policies, encouraging the intensification of production processes, the study region will probably lose many of its traditional characteristics and the respective ecological integrity will decline.

Overall, the spatially explicit StDM framework, applied in this study, seems to represent a useful contribution to predict key changes in the passerine species richness trends, namely by quantifying its main distribution area under different possible management scenarios. Moreover, the proposed framework allows not only the direct interpretation of the local dynamic trends of indicator response, but also the visualization of their emergent spatial distribution at a regional scale. The obtained simulation results are encouraging since they seem to demonstrate the reliability of the approach in capturing the dynamics of ecological systems by predicting the behavioural pattern for their key components selected under complex and variable environmental spatial scenarios. Therefore, since habitats are characterized by a high degree of heterogeneity in space and time, influenced by many interacting factors and feedback mechanisms, this multi-scale approach is particularly helpful to capture these influences under relevant management scenarios.

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Appendix I. The list of passeriform species, their common name, feeding, nestling and foraging traits. I: Insectivorous, G: Granivorous , M: Mixed Feeders (Feeding), A: Arboreal breeding, G: Ground breeding (Nestling), W: Woodland, G: Grassland and I: Mixed Foraging (Foraging).

NO.	Species	Common name	Feeding	Nestling	Foraging
1	*Aegithalos caudatus*	Long-tailed Tit	I	A	W
2	*Anthus pratensis*	Meadow Pipit	I	G	G
3	*Calandrella brachydactyla*	Short-toed Lark	M	G	G
4	*Carduelis carduelis*	Goldfinch	G	A	I
5	*Carduelis chloris*	Greenfinch	G	A	I
6	*Certhia brachydactyla*	Short-toed Treecreeper	I	A	W
7	*Cisticola juncidis*	Fan-tailed Warbler	I	G	G
8	*Corvus corone*	Carrion Crow	M	A	G
9	Cyanopica cyanus	Azure-Winged Magpie	M	A	I
10	*Erithacus rubecula*	Robin	I	G	W
11	*Fringilla coelebs*	Chaffinch	M	A	I
12	*Galerida cristata*	Crested Lark	M	G	G
13	*Garrulus glandarius*	Jay	M	A	W
14	*Hippolais polyglotta*	Melodious Warbler	I	A	I
15	*Lanius excubitor/meridionalis*	Great Grey Shrike	I	A	G
16	*Lanius senator*	Woodchat Shrike	I	A	G
17	*Lullula arborea*	Woodlark	I	G	G
18	*Luscinia megarhynchos*	Nightingale	I	G	W
19	*Miliaria calandra*	Corn Bunting	G	G	G
20	*Oriolus oriolus*	Golden Oriole	I	A	W
21	*Parus caeruleus*	Eurasian Bluetit	I	A	W
22	*Parus cristatus*	eurasian Crestedtit	I	A	W
23	*Parus major*	Great Tit	I	A	W
24	*Passer domesticus*	House Sparrow	G	A	G
25	*Passer montanus*	Tree Sparrow	G	A	I
26	*Petronia petronia*	Rock Sparrow	G	A	G
27	*Phoenicurus ochruros*	Black Redstart	I	G	G
28	*Phoenicurus phoenicurus*	Redstart	I	G	W
29	*Phylloscopus bonelli/orientalis*	Bonelli's Warbler	I	G	W

30	*Phylloscopus brehmii*	Chiffchaff	I	G	W
31	*Saxicola torquata*	Stonechat	I	G	G
32	*Serinus serinus*	Serin	G	A	G
33	*Sitta europaea*	Eurasian Nuthatch	I	A	W
34	*Sturnus unicolor*	Spotless Starling	I	A	I
35	*Sylvia atricapilla*	Blackcap	I	A	W
36	*Sylvia melanocephala*	Sardinian Warbler	I	G	I
37	*Troglodytes troglodytes*	Wren	I	A	W
38	*Turdus merula*	Blacbird	I	A	I
39	*Turdus philomelos*	Song Thrush	I	A	I

Appendix II. **The regression equations, degrees of freedom (DF), the coefficient of determination (R_{aj}^2), F-values and their significance level for all combinations reported, as selected by multiple regression analysis for feeding and nestling trait groups. The specification of all variables is expressed in Tables 2.**

Equation	DF	R_{aj}^2	F	P
Richness Insectivore Species (Rins)				
log(Rins) = 1.726 - 0.00656(AG_PLAND) + 0.0296(AV_PLAND) + 0.00435(AF_PLAND) + 0.00785(F_PLAND) + 0.0675(PR)	5	75.44	27.08	<0.001
Richness Granivorous Species (Rgran)				
log(Rgran) = 0.335 - 0.0145(NA-PLAND) + 0.0581(AV_PLAND) + 0.0056(F_PLAND) + 0.153(PR)	4	27.11	3.11	0.014
Richness Mixed Feeding Species (R mixfeed)				
log(Rmixfeed)= 0.5074 + 0.00328(AG_PLAND)	1	5.37	1.72	0.189
Richness Arboreal Species (Rarb)				
log(Rarb)= 1.898 - 0.00823(AG_PLAND) + 0.0236(AV_PLAND) + 0.00543(F_PLAND) + 0.0486(PR)	4	57.43	24.24	<0.001
Richness Ground Species (Rgrd)				
log(Rgrd)= 0.668 + 0.00711(AG_PLAND) + 0.0457(AV_PLAND) + 0.01072(AF_PLAND) + 0.01039(F_PLAND) + 0.0696(PR)	5	91.74	9.09	<0.001

Appendix III. Equations for explanatory (land use) variables

Agricultural areas

*Agricultural areas(t) = Agricultural areas(t - dt) + (AF to AG + total change to AG + AG to AF - AG to S - AG to E) * dt*

INIT Agricultural areas = 0

INFLOWS:

*AF to AG = if shrub management=0 then annual rate AF to AG *Agroforestry else 0*

total change to AG = NA to AG

OUTFLOWS:

*AG to AF = if shrub management=1 then Agricultural areas *annual rate AG to AF else 0*

*AG to S = Agricultural areas *annual rate AG to S%*

*AG to E = Agricultural areas *annual rate AG to E%*

Agro-forestry

*Agroforestry(t) = Agroforestry(t - dt) + (S to AF + AV to AF + F to AF + AG to AF + total change to AF - AF to S - AF to AV - AF to F - AF to B - AF to AG - AF to M) * dt*

INIT Agroforestry = 0

INFLOWS:

*S to AF = if shrub management = 1 then Shrub land *annual rate S to AF else 0*

*AV to AF = if shrub management =1 then annual rate D to E *Agri-natural vegetation else 0*

*F to AF = if shrub management=1 then Oak Forest *annual rate F to AF else 0*

*AG to AF = if shrub management=1 then Agricultural areas *annual rate AG to AF else 0*

total change to AF = NA to AF

OUTFLOWS:

*AF to S = if shrub management=0 then Agroforestry *annual rate E to S % else 0*

*AF to AV = if shrub management = 0 then Agroforestry *annual rate E to D else 0*

*AF to F = if shrub management = 0 then Agroforestry *annual rate AF to F else 0*

*AF to B = if fire occurrence=1 then fire intensity prob*Agroforestry*AF fire proness ELSE 0*

*AF to AG = if shrub management=0 then annual rate AF to AG*Agroforestry else 0*

*AF to M = Agroforestry*annual rate AF to M%*

Burnt area

*Burnt area(t) = Burnt area(t - dt) + (M to B + total changes to B - B to S - B to M - B to C) * dt*

INIT Burnt area = 0

INFLOWS:

*M to B = if fire occurrence=1 then fire intensity prob*Mixed Forest*M fire proness else 0*

total changes to B = F to B+S to B+AF to B+C to B+E to B

OUTFLOWS:

*B to S = annual rate B to S*Burnt area*

*B to M = Burnt area*annual rate burn to M%*

*B to C = annual rate burn to C%*Burnt area*

Coniferous forest

*Coniferous Forest(t) = Coniferous Forest(t - dt) + (total change to C + C inflow - C to B) * dt*

INIT Coniferous Forest = 0

INFLOWS:

total change to C = else B to C

OUTFLOWS:

*C to B = if fire occurrence=1 and fire intensity prob=1 then Coniferous Forest else fire intensity prob*C fire proness*Coniferous Forest*fire occurrence*

Eucalyptus forest

Eucalyptus *Forest(t) =* Eucalyptus *Forest(t - dt) + (total change to E - E to B) * dt*

INIT Eucalyptus *Forest = 0*

INFLOWS:

total change to E = S to E+AG to E

OUTFLOWS:

E to B = if fire occurrence=1 and fire intensity prob=1 then Eucalyptus *Forest else fire intensity prob *E fire proness **Eucalyptus *Forest *fire occurrence*

Fire events

*Fire events(t) = Fire events(t - dt) + (count fire occurance) * dt*

INIT Fire events = 0

INFLOWS:

count fire occurance = fire occurrence

OUTFLOWS:

Agri-natural vegetation

*Agri-natural vegetation(t) = Agri-natural vegetation(t - dt) + (AF to AV - AV to AF - AV to S) * dt*

INIT Agri-natural vegetation = 0

INFLOWS:

*AF to AV = if shrub management = 0 then Agroforestry *annual rate E to D else 0*

OUTFLOWS:

*AV to AF = if shrub management =1 then annual rate D to E *Agri-natural vegetation else 0*

*AV to S = Agri-natural vegetation *annual rate AV to S%*

Mixed forest

*Mixed Forest(t) = Mixed Forest(t - dt) + (B to M + total changes to M - M to B) * dt*

INIT Mixed Forest = 0

INFLOWS:

*B to M = Burnt area *annual rate burn to M%*

total changes to M = F to M+AF to M

OUTFLOWS:

*M to B = if fire occurrence=1 and and fire intensity prob=1 then Mixed Forest else then fire intensity prob*Mixed Forest*M fire proness else 0*

Non-irrigated arable land

*Non irrigated arable land(t) = Non irrigated arable land(t - dt) + (NA to AF - NA to S - NA to AG - NA to F) * dt*

INIT Non irrigated arable land = 0

OUTFLOWS:

*NA to AF = Non irrigated arable land*annual rate NA to E*

*NA to S = Non irrigated arable land*annual rate NA to S%*

*NA to AG = Non irrigated arable land*annual rate NA to AG%*

*NA to F = if Oak reforestation=1 then Non irrigated arable land*annual rate NA to F% else 0*

Oak forest

*Oak Forest(t) = Oak Forest(t - dt) + (AF to F + total change into F - F to AF - F to B - F to M) * dt*

INIT Oak Forest = 0

INFLOWS:

*AF to F = if shrub management = 0 then Agroforestry*annual rate AF to F else 0*

total change into F = NA to F

OUTFLOWS:

*F to AF = if shrub management=1 then Oak Forest*annual rate F to AF else 0*

*F to B = if fire occurrence=1 and fire intensity prob=1 then Oak Forest else then fire intensity prob*Oak Forest*F fire proness else 0*

*F to M = annual rate F to M%*Oak Forest*

Shrub land

*Shrub land(t) = Shrub land(t - dt) + (AF to S + B to S + total change to S - S to AF - S to B - S to E) * dt*

INIT Shrub land = 0

INFLOWS:

*AF to S = if shrub management=0 then Agroforestry*annual rate E to S % else 0*

*B to S = annual rate B to S*Burnt area*

total change to S = if shrub management=0 then NA to S+AV to S+AG to S else 0

OUTFLOWS:

*S to AF = if shrub management = 1 then Shrub land*annual rate S to AF else 0*

*S to B = if fire occurrence=1 and fire intensity prob=1 then Shrub land else fire intensity prob*S fire proness*Shrub land*fire occurrence*

S to E = if Eucalyptus *plantation=1 then annual rate S to E%*Shrub land else 0*

Water bodies

Water bodies= 0

Built-Up areas

Builtup Area= 0

Complex cultivation patterns

Complex Cultivation Patterns = 0

Permanent crops

Permanent Crops = 0

AF patch = if Agroforestry>0 then 1 else 0

AG patch = if Agricultural areas>0 then 1 else 0

AV patch = if Agri-natural vegetation>0 then 1 else 0

BA patch = if Builtup Area>0 then 1 else 0

C patch = if Coniferous Forest>0 then 1 else 0

E patch = if Eucalyptus *Forest>0 then 1 else 0*

F patch = if Oak Forest>0 then 1 else 0

M patch = if Mixed Forest>0 then 1 else 0

Spatch = if Shrub land>0 then 1 else 0

NA patch = if Non irrigated arable land>0 then 1 else 0

PR = F patch+NA patch+AG patch+C patch+AV patch+AF patch+Spatch+M patch+E patch+BA patch

total area ha = 100

F para = if Oak Forest>0 then Fperim/Oak Forest else 0

F perim = 2(3.14*Oak Forest)^0.5*

*F pland = (Oak Forest/total area ha)*100*

*M pland = Mixed Forest/total area ha*100*

*NA pland = (Non irrigated arable land/total area ha)*100*

*S pland = (Shrub land/total area ha)*100*

*AF pland = (Agroforestry/total area ha)*100*

*AG pland = (Agricultural areas/total area ha)*100*

*AV pland = (Agri-natural vegetation/total area ha)*100*

BA pland = Builtup Area/total area ha

*C pland = (Coniferous Forest/total area ha)*100*

E pland = Eucalyptus *Forest/total area ha*

Appendix IV. Equations for response variables (bird species richness)

*efective richnessarb = richnessarb%*total richness*

*effective richnessgran = richnessgran%*total richness*

effective richnessgrass = 2.7182^logRichnessGrass

*effective richnessgrd = richnessgrd%*total richness*

*effective richnessins = richnessins%*total richness*

*effective richnessmixfeed = richnessmixfeed%*total richness*

effective richnessmixforag = 2.7182^logRichnessMixforag

effective richnesswood = 2.7182^logRichnessWood

*logRichnessArb = 1.898 -0.00823*AG pland+0.0236*AV pland+0.00543*Fpland+0.0486*PR*

*logRichnessGran = 0.335-0.0145*NA pland+0.0581*AV pland+0.00560*Fpland+0.1530*PR*

*logRichnessGrass = 0.776+0.01187*AG pland+0.0712*AV pland+ 0.01074*AF pland+ 0.00869*Fpland*

*logRichnessGrd = 0.668+0.00711*AG pland+0.0457*AV pland+ 0.01072*AF pland+0.01031*Fpland+0.0696*PR*

*logRichnessIns = 1.726-0.00656*AG pland+0.0296*AV pland+0.00435*AF pland+0.00785*Fpland+0.0675*PR*

*logRichnessMixfeed = 0.5074+0.00328*AG pland*

*logRichnessMixforag = 1.120-0.00978*AG pland+ 0.00469*Fpland+ 0.0107*C pland+0.0599*PR*

*logRichnessWood = 1.29+0.01090*NA pland-0.02138*AG pland+0.00414*AF pland-0.0000896*Oak Forest+ 0.00759*Fpland*

RichnessArb = 2.7182^logRichnessArb

richnessarb% = RichnessArb/richness nestling

RichnessGran = 2.7182^logRichnessGran

richnessgran% = RichnessGran/richness feeding

richnessgrass% = effective richnessgrass/total richness

RichnessGrd = 2.7182^logRichnessGrd

richnessgrd% = RichnessGrd/richness nestling

RichnessIns = 2.7182^logRichnessIns

richnessins% = RichnessIns/richness feeding

RichnessMixfeed = 2.7182^logRichnessMixfeed

richnessmixfeed% = RichnessMixfeed/richness feeding

richnessmixforag% = effective richnessmixforag/total richness

richnesswood% = effective richnesswood/total richness

richness feeding = RichnessIns+RichnessMixfeed+RichnessGran

richness nestling = RichnessArb+RichnessGrd

total richness = effective richnessgrass+effective richnesswood+effective richnessmixforag

Appendix V. Equations for flows between land uses.

annual rate AF to AG = ((1+max trans AF to AG%)^(1/time AF to AG))-1

annual rate AF to F = ((1+max trans AF to F%)^(1/time AF to F))-1

annual rate AF to M% = ((1+max trans AF to M%)^(1/time AF to M))-1

annual rate AG to AF = ((1+max trans AG to AF%)^(1/time AG to AF))-1

annual rate AG to E% = ((1+max rate AG to E%)^(1/time AG to E))-1

annual rate AG to S% = ((1+max trans AG to S%)^(1/time AG to S))-1

annual rate AV to S% = ((1+max trans AV to S%)^(1/time AV to S))-1

annual rate burn to C% = ((1+max trans burn to C%)^(1/time burn to C))-1

annual rate burn to M% = ((1+max trans burn to M%)^(1/time burn to M))-1

annual rate B to S = ((1+max trans burn to S%)^(1/time B to S))-1

annual rate D to E = ((1+max trans D to E%)^(1/time D to E))-1

annual rate E to D = ((1+max trans E to D%)^(1/time E to D))-1

annual rate E to S % = ((1+max trans E to J %)^(1/time E to J))-1

annual rate F to AF = ((1+max trans F to AF%)^(1/time F to AF))-1

annual rate F to M% = ((1+max trans F to M%)^(1/time F to M))-1

annual rate NA to AG% = ((1+max trans NA to AG%)^(1/time NA to AG))-1

annual rate NA to E = ((1+max trans NA to E%)^(1/time NA to E))-1

annual rate NA to F% = ((1+max trans NA to F%)^(1/time NA to F))-1

annual rate NA to S% = ((1+max trans NA to S%)^(1/time NA to J))-1

annual rate S to AF = ((1+max trans S to AF)^(1/time S to AF))-1

annual rate S to E% = ((1+max trans S to E%)^(1/time S to E))-1

Appendix VI. Equations for fire probability, fire proneness, maximum rate of transformation, time for transformation and management options

Fire probability

fire intensity prob = RANDOM(0.1)

fire occurrence = IF fire option =1 and fire random generation=fire probability THEN 1 ELSE 0

Fire option = 0/1

Fire probability = 62

fire random generation = ROUND(RANDOM(1, fire probability))

Fire proneness constant

AF fire proness = 0.027

C fire proness = 0.096

E fire proness = 0.07

F fire proness = 0.027

M fire proness = 0.065

S fire proness = 1

max rate AG to E% = 0.2

max trans AF to F% = 0.23

max trans AF to M% = 0.39

max trans AG to AF% = 0.25

max trans AG to S% = 0.4

max trans AV to S% = 0.4

max trans burn to C% = 0.11

max trans burn to M% = 0.18

max trans burn to S% = 1

max trans D to E% = 0.25

max trans E to D% = 0.05

*max trans **E** to **J** % = 0.28*

*max trans **F** to **AF**% = 0.13*

*max trans **F** to **M**% = 0.12*

*max trans **NA** to **AG**% = 0.25*

*max trans **NA** to **E**% = 0.25*

*max trans **NA** to **F**% = 0.25*

*max trans **NA** to **S**% = 0.4*

*max trans **S** to **AF** = 0.07*

*max trans **S** to **E**% = 0.23*

*max trans **AF** to **AG**% = 0.05*

*time **AF** to **AG** = 45*

*time **AF** to **F** = 45*

*time **AF** to **M** = 45*

*time **AG** to **AF** = 45*

*time **AG** to **E** = 45*

*time **AG** to **S** = 45*

*time **AV** to **S** = 45*

*time burn to **C** = 15*

*time burn to **M** = 15*

*time **B** to **S** = 3*

*time **D** to **E** = 45*

*time **E** to **D** = 45*

*time **E** to **J** = 45*

*time **F** to **AF** = 45*

*time **F** to **M** = 45*

time NA to AG = 45

time NA to E = 45

time NA to F = 45

time NA to J = 45

time S to AF = 45

time S to E = 45

Management options

Oak reforestation = 0/1

Shrub management = 0/1