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Is biodiversity linked with farm management options in vineyard landscapes? A case study combining ecological indicators within a hybrid modelling framework

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ABSTRACT

Sustainable management of biodiversity in agricultural landscapes is a European Union objective supported on multifunctional agri-environment measures. The effectiveness of specific practices implemented to reverse declines in farmland biodiversity should be monitored using straightforward methodologies and indicators. This work outlines an innovative hybrid framework to predict the response of biodiversity indicators to farm management options. We exemplify the framework application, integrating monitoring, statistics and spatio-temporal modelling procedures with a case study using flying vertebrates' patterns for indicating biodiversity trends. The indicators considered depict significant divergences within contrasting on-farm implemented environmental management options. In fact, while birds' abundance was expected to increase within environmentally friendly options, bats passes showed fluctuating patterns. Overall, the framework and indicators selected were considered relevant for biodiversity assessments in vineyard landscapes. This approach also provides a promising baseline to support sustainable management practices and options for other agroecosystems, derived from ecological models with increased predictive power and intuitiveness to decision makers and environmental managers.

1. Introduction

In the European Union (EU) agricultural landscapes cover almost half of its total surface (European Union, 2018). Several species of wildlife have adapted themselves to traditional agricultural landscapes, performing significant ecosystem services and nature's contributions to people (ESNCP) such as pest outbreak control, pollination, nutrient cycling and resilience to environmental stressors (Whelan et al., 2008; Garfinkel and Johnson, 2015; Milligan et al., 2016; Williams et al., 2017). From the middle of the 20th century, agricultural practices and techniques became more intensive, changing the traditional management paradigms and spawning environmental problems such as soil and water pollution, natural resources depletion and creating a widespread decline in biodiversity (Benton et al., 2003; Kontsiotis et al., 2017). One of the main threats to biodiversity in the EU, especially in the Mediterranean areas, is the current replacement of traditional and low intensity agriculture by intensive agriculture and forestation or, via abandonment, by fire-prone shrublands and degraded forests (Donald, 2004; Donald et al., 2006; Schulp et al., 2016).

Vineyards account for a significant land use within EU agriculture, 3,481,000 ha in 2013 (GAIN, 2015). Vineyards are associated with one of the most important EU agroindustry, wine production and have

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noteworthy implications in socio-cultural practices, traditions and economy (European Union, 2018). In fact, wine production has a history of thousands of years in the region (UNESCO, 2001; Lourenço-Gomes et al., 2015; Rebelo et al., 2015) and traditional plantations, often mixed with other crops have high aesthetic and natural value (Altieri and Nicholls, 2002; Barbera and Cullotta, 2016).

Several works highlight that current vineyard management (but also winemaking) is linked with numerous environmental impacts and threats to biodiversity (Costa et al., 2016; Hillis et al., 2018), namely by the homogenization of landscapes and destruction of natural habitats, intensive use of agrochemicals, high demand of water for irrigation in dry areas, among other (e.g. Christ and Burritt, 2013; Assandri et al., 2016). Presently viticulture faces pivotal challenges namely to increase quality standards and production within climate change while implementing sustainable agricultural practices able to decrease environmental impacts and promote ecosystem and biodiversity conservation (Fraga et al., 2012; Caprio et al., 2015; Rusch et al., 2015; Salomé et al., 2016).

Biodiversity in agroecosystems is considered critical for several ESNCP (Jedlicka et al., 2011; Thiéry, 2018; Katayama et al., 2019), especially by supporting and being linked with more sustainable agricultural productions (ELN-FAB, 2012; Wood et al., 2015). In this scope, quantitative assessments of biodiversity should be gauged using indicators, species acting as surrogates of others with similar functioning, ecological roles and parallel responses to environmental conditions but that are straightforwardly monitored using standard methodologies (Díaz and Cabido, 2001; Clergue et al., 2009; Faulwetter et al., 2014; Wood et al., 2015). Biodiversity indicators could be core in agroecosystem management due to the ability to integrate production, sustainability, biodiversity and associated ESNCP (Brussaard et al., 2010; Kremen and Miles, 2012; Wood et al., 2015). As more and more farmers recognize the importance of biodiversity (Altieri, 1999; Montoya et al., 2020), an increasing number of wine producers and agronomists urge for information to select win-win management practices, i.e. effective "environmental-friendly" measures compatible with agricultural practices (Bennett et al., 2006; Christ and Burritt, 2013; Szolnoki, 2013; Alignier and Baudry, 2015; Millan et al., 2015; Montoya et al., 2020).

Win-win management practices would benefit from the knowledge of the multivariate factors shaping biodiversity in viticulture, reducing the time and expense required for adjusting conservation techniques within farms (Bianchi et al., 2013). This might also contribute to involve all actors of the wine sector (from producers to consumers), i.e. indicators showing adjusted management practices satisfying both biodiversity conservation and sustainable wine production might increase customers' engagement (Green et al., 2005; Osawa et al., 2016).

As bird and bat species respond to multidimensional characteristics of ecosystems and landscapes (Morelli et al., 2014; Jeliazkov et al., 2016), individual species and/or guilds have been used as biodiversity indicators of agroecosystems (Santos et al., 2013, 2018; Assandri et al., 2016; Froidevaux et al., 2017; Silva et al., 2017). Birds and bats provide significant supporting and regulating services, ranging from pest control to seed dispersal, are taxonomically stable and are highly reactive to environmental stressors and changes (Whelan et al., 2008; Sekercioglu, 2012; Park, 2015). Additionally they act as mobile links that transfer energy both within and among ecosystems, thus contributing to landscape functioning and resilience (Jones et al., 2009; Wenny et al., 2011; Whelan et al., 2015).

Ecological modelling requires knowledge on ecosystem functioning and on the main environmental issues influencing trends (Jørgensen and Bendoricchio, 2001; Santos et al., 2016a), necessary for developing spatio-temporal tools able to predict the outcome of alternative scenarios (Santos and Cabral, 2004; Santos et al., 2010, 2013, 2016b, 2018; Bastos et al., 2012). The Stochastic Dynamic Methodology (StDM) is a hybrid modelling protocol designed to recreate ecological cause-effect networks by combining robust information-theoretic methods within dynamic simulations (Santos et al., 2011, 2013, 2016b). Compared with traditional spatial and temporal approaches, StDM models have the advantage of taking into account dynamic interactions and random effects with influence on ecological responses (Van Der Meer et al., 1996; Santos and Cabral, 2004; Morinha et al., 2017). Even though with outputs emerging from complex processes characterizing real systems, the StDM framework simplifies several modelling processes such as parameterization, complexity and variable selection (Bastos et al., 2012; Santos et al., 2013, 2018) in practice the extraction of pertinent holistic relationships between response and explanatory variables is completed using multivariate statistical techniques (e.g. Generalized linear models – GLzM).

In this work we present a hybrid modelling framework, based on the StDM principles, to predict ecological indicators response - bird and bat metrics – to management practices in viticulture. Farm was considered the correct scale from which to understand and evaluate leading management options for biodiversity and ecosystem functioning. Using a case study, we demonstrate

(1) how to establish the main cause-effect relationships between prevailing environmental variables and patterns of biodiversity in wine farms, (2) the steps to develop the framework, used to predict biodiversity indicators' response to different management paradigms and environmental conditions and (3) the applicability of this approach to support biodiversity enhancement and conservation efforts in agroecosystems.

2. Materials and methods

2.1. Study area

The present study was carried out in the Douro Demarcated Region, Portugal (Fig. 1). This region, the oldest demarcated winemaking region in the world, is considered a UNESCO World Heritage due to its cultural landscape of outstanding beauty (Andresen et al., 2004) and unique wine, the Port wine (http://whc.unesco.org/en/list/1046/). The climate in Douro Demarcated Region is chiefly Mediterranean, with rainfall ranging from 400 to 1000 mm per annum, mostly concentrated in the coldest period of the year. The geomorphology consists of steep hills and box valleys that flatten out into plateaus above 400 m (UNESCO, 2001). Vines are the predominant crop in western areas while almond and olive groves tend to increase in importance in the dry eastern areas. The landscape is a monumental sculpture of wired terraces, where vineyards prevail next to olive and almond groves, including significant areas of natural and seminatural Mediterranean vegetation.

Six farms ("Quintas"), whose major activity is grapes and wine production, "Quinta da Granja", "Quinta de Arnozelo", "Quinta de São Luiz", "Quinta do Cidrô", "Quinta dos Aciprestes" and "Quinta das Carvalhas" were selected to implement our monitoring protocol associated with the StDM framework (Fig. 1).

2.2. General overview of the StDM framework

The StDM hybrid framework consists of step-by-step framework (Fig. 2) integrating monitoring and modelling techniques habitat characterization, farm management information and indicators monitoring (Fig. 2a) compilation of a unified database containing the sets of information for the biodiversity indicators (Fig. 2b) multivariate statistical techniques to detect the holistic relationships with ecological significance between the biodiversity indicators, habitats and farm management (Fig. 2c) development of a dynamic model integrating ecological derived information with the previous holistic relationships detected (Fig. 2d) spatio-temporal simulation of the indicators response to the selected scenarios (Fig. 2e).

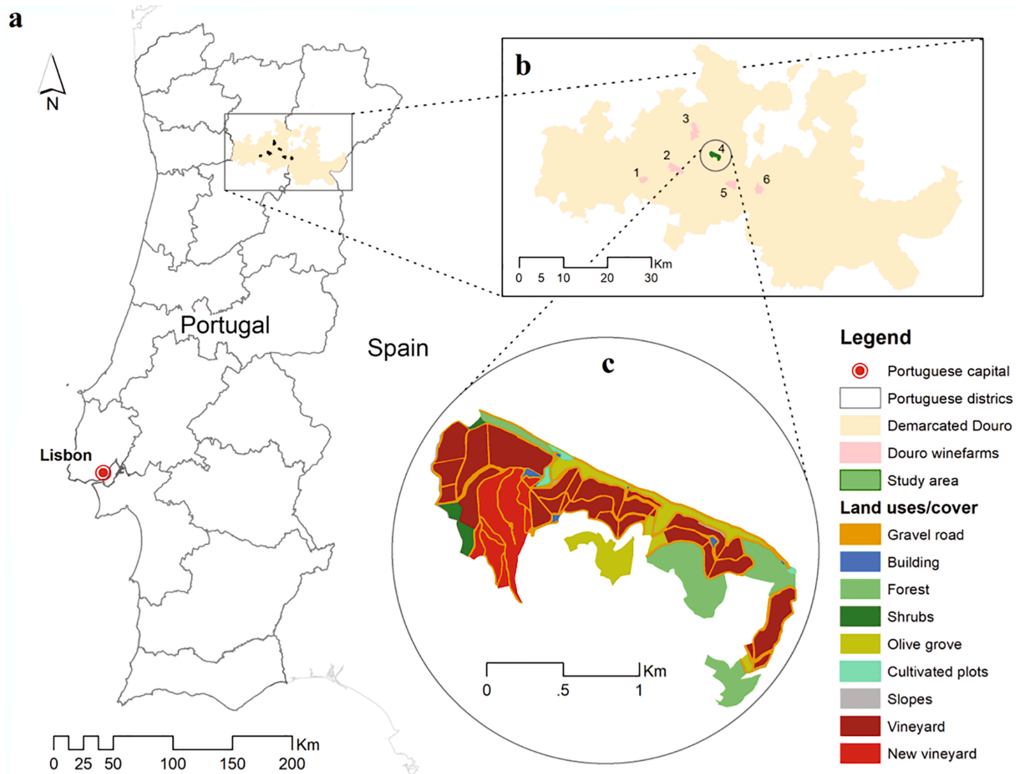

Fig. 1. Location of the Demarcated Douro Region (a) in Portugal, (b) the farms in the Demarcated Douro Region - 1, "Quinta de São Luis"; 2, "Quinta das Carvalhas"; 3, "Quinta da Granja"; 4, "Quinta dos Aciprestes"; 5, "Quinta do Cidrô"; 6, "Quinta de Arnozelo" - (c) land use / land cover of the farm highlighted in the work, "Quinta dos Aciprestes".

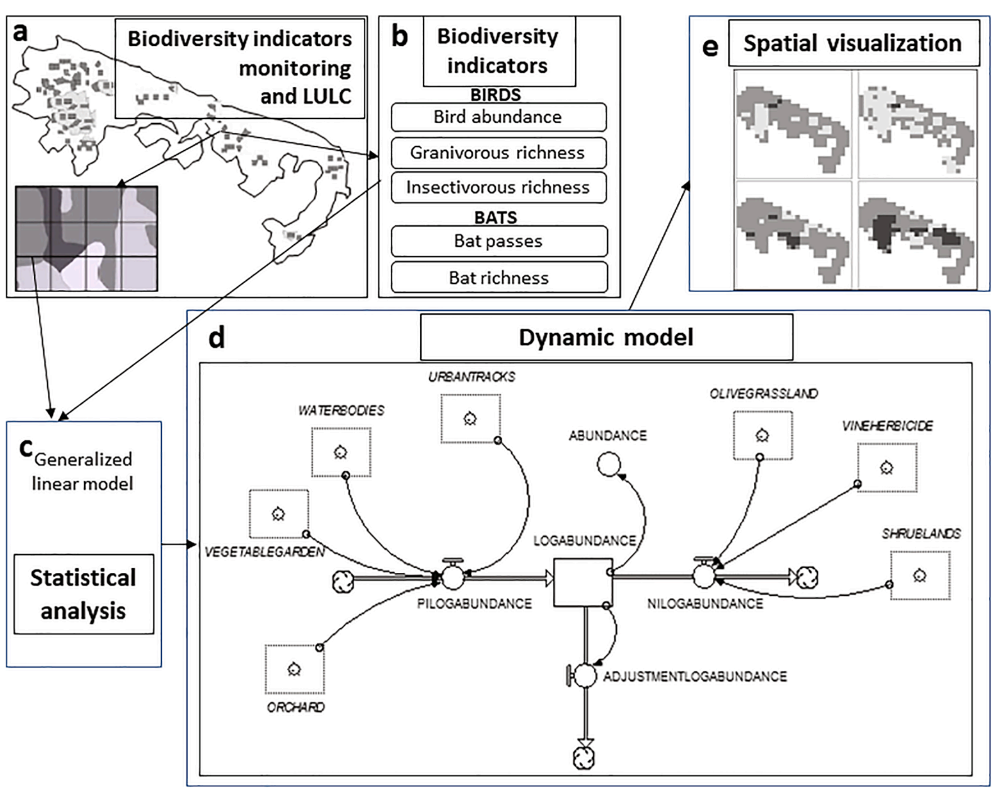

Fig. 2. The StDM conceptual framework for predicting the response of the biodiversity indicators selected (birds and bats) as a response to land use cover changes (LUCC) and management practices: (a) ecological characterization and monitoring; (b) database compilation; (c) multivariate statistical analysis; (d) dynamic model framework; (e) spatio-temporal overview.

2.3. Indicators monitoring

2.3.1. Biodiversity indicators

Forty-nine locations were selected in 2012 and 2013 for performing bird counts and bat passes counts (7 in São Luiz and Carvalhas, 8 in Aciprestes and Cidrô, 9 in Granja, and 10 in Arnozelo) (Fig. 2a), carefully chosen in accordance with the importance of habitats present within each farm. Bird counts and bat passages were carried out in the centre of each habitat, during spring and early summer, when both taxa assemblages attain higher diversities and activity in this region (Santos and Cabral, 2004; Charbonnier et al., 2016). Data on ambient temperature, wind speed and relative humidity were recorded at all sampling locations using a portable weather station (Kestrel 4500 Pocket Weather Tracker). Sampling survey period and intensity, although inadequate for a definitive inventory, served the purpose of comparing general sensitivity to the management options, in the scope of their application as biodiversity indicators (Dale and Beyeler, 2001; Cajaiba et al., 2018).

2.3.1.1. Bird counts. Birds were monitored by a professional ornithologist through a 10 min point count until 3 h after sunrise, a period when most species are active (Ralph et al., 1993). As point counts allow an immediate collection of habitat and management information they were preferred to transects and mapping methods (Bibby et al., 1992). Bird species were posteriorly divided in guilds, insectivorous and granivorous, using reference bibliography (Söderström and Pärt, 2000; Santos and Cabral, 2004; Wilman et al., 2014; Morgado et al., 2020).

2.3.1.2. Bat monitoring. Bat activity was recorded at ground level through 10 min point counts, using the ultrasound detector D240X (Pettersson Elektronik AB), in periods coincident with the main peak of activity (Erkert, 1982). Bat passes are defined as a sequence of >2 echolocation pulses of search-phase (Broders, 2003; Kunz et al., 2007; Boughey et al., 2011), which can be described as an increase in amplitude of bat sound followed by a sudden decrease (Silva et al., 2017). All recordings were analysed manually with BatSound 3.31®software (Pettersson Elektronik AB, Uppsala) using a sampling frequency of 44.1 kHz, with 16 bits/sample, and a 1024-point FFTs with a Hanning window for analysis (Kalda et al., 2015). The species identification, whenever possible, was supported by the analysis of pulse variables such as pulse structure, minimum frequency, maximum frequency, pulse duration, interval between pulses and frequency of maximum energy (Kalda et al., 2015). All bat species were grouped with the insectivorous guild (Denzinger and Schnitzler, 2013; Mancini et al., 2019).

2.3.2. Habitat characterization

Land use/land cover (LULC) and management options by farm were accessed using a GIS database associated with the ECOVITIS project (http://www.advid.pt/ECOVITIS and Corine Land Cover 2006) (EEA, 2012), combined with detailed field works and complementary information (Table 1). The spatial analyses were carried out using ArcGIS® 10.1 Geographic Information System software (ESRI, 2013a).

2.4. Determining the influence of LULC on the biodiversity indicators

LULC and management categories were considered explanatory variables while bird abundance and bat passes response variables – our biodiversity indicators (granivorous' richness, insectivorous' richness, and bat richness were also gauged) in the Generalized linear models (GLzM). GLzM were preferred to Generalized linear mixed models (GLzMM) due to the small number of random levels (six farms) that could lead to very small and/or imprecise estimates of random effects, such as lack of convergence, zero variance estimates among other problems (Bolker et al., 2009; Stroup, 2013) (additional information in Appendix A). Additionally, as within our StDM hybrid framework simulations, farm characteristics (LULC and management variables) change (accordingly with the scenarios) the interpretation of the influence of farm random effects on the results obtained could be difficult to tackle (Santos et al., 2013).

The explanatory variables were tested for pairwise correlation (Spearman's rho correlation coefficient correlation <0.7 and generalized variance inflation factor <5 (Wisz and Guisan, 2009). A set of competing models was fitted on retained explanatory variables (Poisson/Quasi-poisson) and the "best model" supported by the data was selected (lower AICc/Quasi AICc and higher adjusted R^2) (Akaike, 1974; Hurvich and Tsai, 1989; Anderson et al., 2000; O'Hara and Kotze, 2010; Bastos et al., 2012; Santos et al., 2016a; Gupta et al., 2020), i.e. we have only considered equations with the lowest AICc/Quasi-AICc (parsimonious models) for standardizing the criteria and minimizing subjectivity in the model selection (Santos et al., 2011, 2016a). All statistical analysis were carried out using the R software (R-Core-Team, 2017), using the packages MuMln (Bartón, 2020) and R commander (Fox and Bouchet-Valat, 2020).

Table 1
Land use / land cover (LULC) and management variables description and their model codes.

Land use/ land cover management code	Description
Vineherbicide	Vineyard with herbicide application
Vineherbicideline	Vineyard with application herbicide only in the rows
Vinegrass	Vineyard with ground cover vegetation both in the rows and between the rows, no herbicide
Urbantracks	Urban elements, like buildings, roads, tracks
Forest	Natural and semi-natural forest
Abandonedorchards	Abandoned or extensively managed orange orchards, almond orchards and olive groves
Shrublands	Shrublands dominated by Ericaceae, Leguminosae and Labiatae shrubs, mostly Arbutus, Erica, Halimium, Cytisus, Ulex and Lavandula
Oliveherbicide	Olive groves with herbicide application
Olivegrassland	Olive groves with ground cover vegetation, no herbicide
Vegetablegarden	Vegetables garden
Orchards	Fruit orchards, mostly intensively managed orange orchards
Waterbodies	Ponds, small brooks

2.5. Conceptualization of the dynamic model

The hybrid StDM framework is a sequential modelling protocol for predicting the influence of environmental changes in the structure and functioning of agroecosystems (please see details regarding the StDM framework in Appendix B). The spatial dynamic projections for each site were produced by combining the information-theoretic models (see please 2.4.) within a system dynamics software for modelling environmental interactions, namely the influence of management options on the biodiversity indicators' dynamics (e.g. Santos et al., 2013). Realistic patterns of farm changes and management options were simulated, parameterized using relevant information (http://www.eea.europa.eu/soer/countries/pt/land-use-state-and-impacts-portugal). In brief, the system dynamics environment enabled the implementation of realistic LULC and management scenarios while the output from the best models provided information on the ecological responses, i.e. biodiversity indicator trends. A period of 20 years was considered for simulating farm changes and estimate of the biodiversity indicators' responses (the time unit considered was the year). The StDM model, developed using STELLA 9.0.3.1® software (www.iseesystems.com), is able to encompass stochastic and deterministic processes, taking into consideration the level of uncertainty of the environmental variables tested (Santos et al., 2018, 2019).

2.5.1. Testing three management scenarios for the "Quinta dos Aciprestes" farm

In order to test the significance of the management scenarios, "Quinta dos Aciprestes" farm (Fig. 1) was chosen, for demonstrative purposes, to perform the simulations. Three realistic scenarios were considered to predict the biodiversity indicators' responses to different Land use Cover changes (LUCC) and management practices according to environmental targets (Appendix C):

a) Scenario 1 (intensification scenario) simulates the intensification of all agricultural activities in the farms, increasing the areas of intensive vineyards, intensive orchards and intensive olive groves, at the expense of other LULC.
b) Scenario 2 (equilibrium scenario) maintains a balance between production and biodiversity conservation – simulates the application of herbicides only in the vine lines and tree lines in the orchards and the installation of green infrastructures such as shrublands/hedgerows and forests in marginal areas.
c) Scenario 3 (eco-friendly scenario) was designed in order to adopt a conservation management strategy, increasing the habitats diversity, "extensifying" production and replacing intensive viticulture by sustainable viticulture. This scenario simulates ecological management of vineyards and olive groves, the installation of green (natural vegetation) and blue (waterbodies) infrastructures such as shrublands/hedgerows and ponds and even the substitution of intensive orchards in less productivity locations by shrublands and/or forests.

All scenarios also include the assumption that the interactions between LULC and management involve changes imposed by the farmers' options, such as abandonment (the natural transition of abandoned orchards invaded by shrubs which can eventually lead to a forested state) (Navarro and Pereira, 2012; Levers et al., 2018) or from intensive viticulture to more "environmentally friendly" management practices (Santos et al., 2013; Costa et al., 2016; Hillis et al., 2018; Morgado et al., 2020). Please see details regarding the initial percentage of LULC in the Appendix D.

Data regarding the coordinates of each location in the farm, LULC and responses of indicators by ha were introduced in ArcView GIS 10.1® software (ESRI, 2013b) in order to create a spatial illustration of the responses. Possible differences between scenarios for bird abundance and bat passes results were tested with a Wilcoxon signed-rank test with continuity correction (Wilcoxon, 1945), using R commander (Fox and Bouchet-Valat, 2020).

2.5.2. Testing the application of ecological infrastructures in the farms

For testing the response of the biodiversity indicators to the overall installation of ecological infrastructures in specific locations in the "Quinta dos Aciprestes" farm, ecological corridors were considered. Ecological corridors defined as "linear two-dimensional landscape elements that connects two or more patches of wildlife habitat" (Soule and Gilpin, 1991; Ottomano Palmisano et al., 2016), are expected to facilitate the exchange of individuals between isolated subpopulations (Hilty and Merenlender, 2004; Jalkanen et al., 2020). In our study two types of ecological corridors were designed as a) 100% occupied by shrublands/hedgerows (CS) and b) 50% shrublands/hedgerows and 50% water bodies (CSW) such as ponds. In fact, several species of birds and bats prefer to fly along linear landscape elements and riparian habitats due to the diversity of food in edges, guideposts for flight routes, and wind and predator shelter (Wickramasinghe et al., 2003; Rainho, 2009; Kontsiotis et al., 2017). The visualisation of results and comparison of the efficacy of the ecological corridors installation was assessed using a similar method to 2.5.1.

3. Results

3.1. General results

We counted 2019 birds that were distributed within 62 species, 28 families and 4 guilds (Appendix E, Table E.1). Regarding bats, 543 passes were recorded distributed by 13 species (Appendix E, Table E.2) and a guild (insectivorous).

3.2. Estimating the response of the biodiversity indicators to the LULC and management variables

3.2.1. Habitats and management options' influence on birds

Bird abundance was positively related with the area occupied by orchards, urban elements, vegetable gardens and water bodies, and negatively related with the areas occupied by olive groves, vineyards with herbicide sprayed and shrublands (Table 2).

Urban elements, like buildings, roads, tracks seemed to be the most positive influencing factors on the granivorous richness, while forests were associated with a reduction (Table 3).

Insectivorous richness was positively correlated with the areas occupied by abandoned orchards, forest, areas with olive groves with herbicide sprayed and water bodies (Table 4).

For the Overall richness and complementary indicators tested (Carnivorous richness and Generalists richness), no model that emerged from the relation with LULC and management was considered to fit the data.

3.2.2. Habitats and management options' influence on bats

The number of bat passes was positively related with complexity of the landscape, namely vineyards managed without herbicide sprayed and water bodies, vegetable gardens and orchards and negatively related with forests and vineyards with herbicide sprayed between the vine rows (Table 5).

On the other hand, main positive influencing factors on bat richness were related with vegetable gardens and orchards (Table 6).

3.3. Spatially explicit dynamic scenarios

For demonstrating purposes and considering their simplicity and widespread use as farmland biodiversity indicators, bird abundance and bat passes (e.g. Doxa et al., 2010; Kleijn et al., 2011; Kalda et al., 2015) were spatially presented using the StDM framework (details concerning the model and equations are associated with Appendix F and Appendix G).

3.3.1. LULC and management scenarios

3.3.1.1. Birds. Using the three scenarios, the model simulations show significant changes in bird abundance (Fig. 3). Scenario 1

Table 2
Coefficients for all the independent variables selected by the Generalized linear model (GLzM) to predict Bird Abundance: variables estimate (Estimates), standard error (SE), z value (Z), probability of z (Pr(>|z|)). Model description: Degrees of Freedom: 48 (i.e. Null), 41 Residual, Null deviance: 413.49, Residual deviance: 267.71, Akaike AICc: 511.36. Variables explanation in Table 1.

Coefficients	Estimates	SE	Z	Pr(>|z|)
Intercept	2.8566	0.0512	55.789	< 2e-16
Olivegrassland	−0.4059	0.1906	−2.129	0.033260
Orchards	1.2687	0.5254	2.415	0.015741
Shrublands	−0.3647	0.1810	−2.015	0.043930
Urbantracks	0.6051	0.1796	3.369	0.000754
Vegetablegarden	1.5923	0.7031	2.265	0.023535
Vineherbicide	−0.2370	0.1673	−1.416	0.156737
Waterbodies	5.9609	0.5217	11.426	< 2e-16

Table 3
Coefficients for all the independent variables selected by the Generalized linear model (GLzM) to predict Granivorous Richness: variables estimate (Estimates), standard error (SE), t value (T), probability of t (Pr(>|t|)). Model description: Degrees of Freedom: 48 (i.e. Null), 46 Residual, Null deviance: 18.937, Residual deviance: 11.744,Quasi-AICc: 168.57. Variables explanation in Table 1.

Coefficients	Estimates	SE	T	Pr(>|t|)
Intercept	1.1717	0.0528	22.194	<2e-16
Forest	−0.6352	0.1992	−3.188	0.0026
Urbantracks	0.6735	0.2759	3.287	0.0004

Table 4
Coefficients for all the independent variables selected by the Generalized linear model (GLzM) to predict Insectivorous Richness: variables estimate (Estimates), standard error (SE), t value (T), probability of t(Pr(>|t|)). Model description: Degrees of Freedom: 48 (i.e. Null), 44 Residual, Null deviance: 33.066, Residual deviance: 21.803,Quasi-AICc: 190.61. Variables explanation in Table 1.

Coefficients	Estimates	SE	T	Pr(>|t|)
Intercept	1.30056	0.05915	21.988	<2e−16
Abandonedorchards	0.60184	0.20194	2.980	0.0047
Forest	0.45052	0.17277	2.608	0.0124
Oliveherbicide	0.67155	0.23569	2.849	0.0067
Waterbodies	2.93985	1.01109	2.908	0.0057

Table 5
Coefficients for all the independent variables selected by the Generalized linear model (GLzM) to predict Bat passes: variables estimate (Estimates), standard error (SE), z value (Z), probability of z (Pr(>|z|)). Model descriptors: Degrees of Freedom: 48 Total (i.e. Null), 42 Residual, Null Deviance: 229.2, Residual Deviance: 99.81, AICc: 203.1. Variables explanation in Table 1.

Coefficients	Estimates	SE	Z	Pr(>|z|)
Intercept	0.6580	0.1764	3.730	0.000191
Forest	−1.6681	0.8135	−2.050	0.040331
Orchards	4.0727	1.2076	3.372	0.000745
Vegetablegarden	6.2476	1.4265	4.380	1.19e−05
Vinegrass	6.9343	0.8625	8.040	9.00e−16
Vineherbicideline	−0.8293	0.3278	−2.530	0.011403
Waterbodies	9.7177	1.2081	8.044	8.73e−16

Table 6
Coefficients for all the independent variables selected by the Generalized linear model (GLzM) to predict Bat Richness: variables estimate (Estimates), standard error (SE), tvalue (T), probability of t (Pr(>|t|)). Model descriptors: Degrees of Freedom: 48 Total (i.e. Null), 46 Residual, Null Deviance: 42.06, Residual Deviance: 36.22, Quasi-AICc: 114.5. Variables explanation in Table 1.

Coefficients	Estimate	SE	T	Pr(>|t|)
Intercept	−0.2381	0.1321	−1.802	0.0781
Orchards	3.3246	1.5019	2.214	0.0319
Vegetablegarden	5.0966	1.7801	2.863	0.0063

(intensification scenario) projected a considerable decrease in bird abundance, considering the implemented land use cover changes (LUCC) and management options (Fig. 3b), when comparing with the actual bird abundance (considering the current LULC and management options, Fig. 3a). On the other hand, for scenario 2 (equilibrium scenario) an increase in abundance was predicted (Fig. 3c). This trend is accentuated in scenario 3 (eco-friendly scenario) (Fig. 3d). The Wilcoxon test confirmed the significant differences depicted (Appendix H, Table H.1).

3.3.1.2. Bats. When applying the three scenarios, relevant changes occurred in the bat passes indicator (Fig. 4). Bat passes, considering the actual LULC and management options are depicted in Fig. 4a. Scenario 1

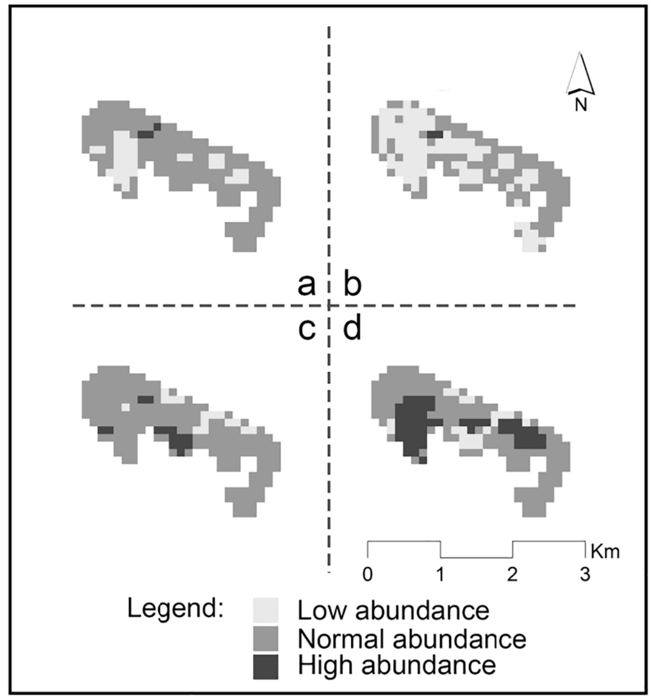

Fig. 3. Predicted changes in bird abundance for (a) the actual LULC and management in the Acipreste farm and for 20 years after the implementation of the following scenarios: (b) scenario1 (intensification scenario); (c) scenario 2 (equilibrium scenario); (d) scenario 3 (eco-friendly scenario). Low abundance is considered for values below first quartile of monitored data (16), normal abundance is considered for values simulated between the first and the third quantile of the monitored data (16-24) and high abundance is considered for values above the third quantile (24).

(intensification scenario) anticipated a considerable increase in the bat passes compared with their activity observed for the actual LULC, considering the implemented LUCC and management options (Fig. 4b). On the other hand, for scenario 2 (equilibrium scenario) a decrease in bat passes was predicted (Fig. 4c) while a positive trend of bat passes was predicted in scenario 3 (eco-friendly scenario) (Fig. 4d). The Wilcoxon test confirmed the significant differences depicted (Appendix H, Table H.1).

3.3.2. Installation of ecological corridors

3.3.2.1. Bird abundance. Using the two types of ecological corridors, relevant changes in bird abundance were simulated (Fig. 5). Ecological corridors dominated by shrublands/hedgerows (CS) seem to decrease bird abundance (Fig. 5c). On the other hand, ecological corridors containing 50% of shrublands/hedgerows and 50% of waterbodies (CSW) depicted a significant increase in bird abundance (Fig. 5d). The Wilcoxon test confirmed the significant differences depicted (Appendix H, Table H.2).

3.3.2.2. Bat passes. Using the both types of ecological corridors, relevant changes in bat activity were simulated (Fig. 6). Ecological corridors dominated by shrublands (CS) are predicted to increase bat passes (Fig. 6c). This trend was augmented when ecological corridors containing 50% of shrublands and 50% of waterbodies (CSW) were modelled (Fig. 6d). The Wilcoxon test confirmed the significant differences depicted (Appendix H, Table H.2).

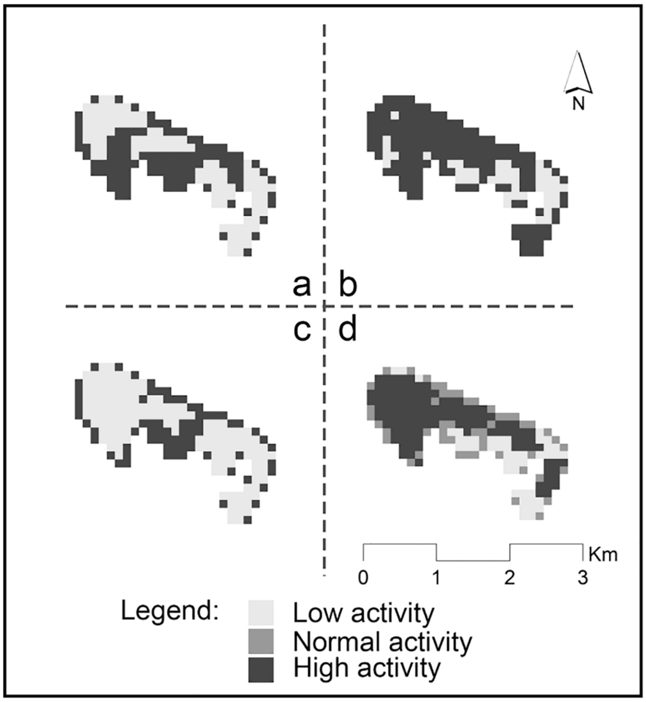

Fig. 4. Predicted changes in bat activity for (a) the actual LULC and management in the Aciprestes farm and for 20 years after the implementation of the following scenarios: (b) scenario1 (intensification scenario); (c) scenario 2 (equilibrium scenario); (d) scenario 3 (eco-friendly scenario). Low activity is considered for values below first quartile of monitored data (1), normal activity is considered for values between the first and the third quantile of monitored data (1-3) and high abundance is considered for values above the third quantile (3).

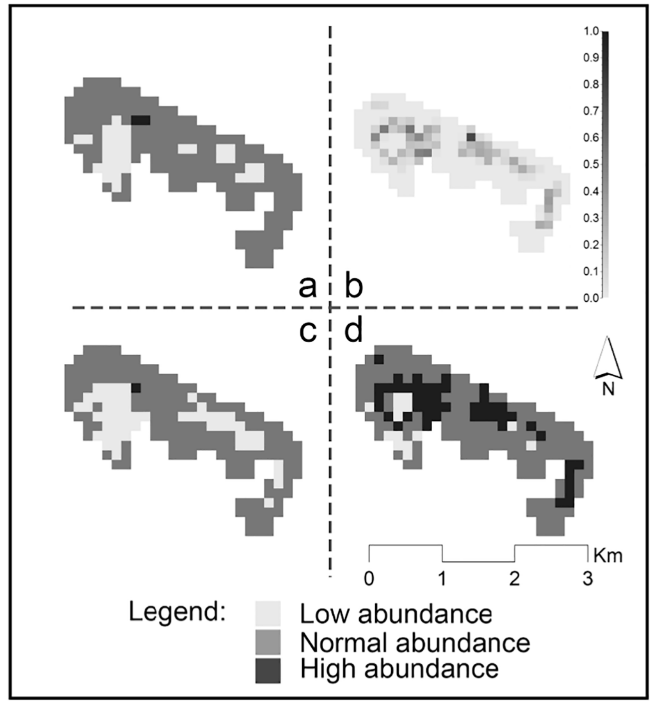

Fig. 5. Predicted changes in bird abundance for the Aciprestes farm: (a) bird abundance for the actual LULC and management; (b) areas selected for the creation of the ecological corridors (with LULC of the ecological corridors on a scale from 0 to 1 ha for each ha of the farm; (c) birds' abundance in response to shrubland corridors (CS); (d) bird abundance in response to shrubland/hedgerows and waterbodies corridors (CSW). Low abundance is considered for values below first quartile of monitored data (16), normal abundance is considered for values simulated between the first and the third quantile of the monitored data (16-24) and high abundance is considered for values above the third quantile (24).

4. Discussion

4.1. Management options, ecological corridors and biodiversity indicators

The obtained results show that the indicators selected were sensitive and strongly related with the management options and LUCC, which agrees with several published works in this scope (Boughey et al., 2011; Phalan et al., 2011; Assandri et al., 2016). "Blue infrastructures" (waterbodies) are determinant factors in Mediterranean agroecosystems, especially in the summer, and ponds have been shown to increase bird abundance (Al-Shehabi et al., 2014; Bock, 2015) and bat activity, namely due to the bounty of food resources (Toffoli and Rughetti, 2017). Other habitats that have positive effects on the birds and bats are "green infrastructures" in the vineyards (such as orchards, flower beds and vegetable gardens) that increase the complexity of the vineyard landscape (Katayama et al., 2019). These elements are used by birds and bats for foraging, roosting and breeding (Brambilla et al., 2015; Brown et al., 2015), that benefit from additional protection to weather extremes and predators (Kelly et al., 2016). On the other hand, bat activity in the studied vineyard landscape seems negatively associated with forest landscapes, probably because most community is associated with common open space species (e.g. Pipistrellus sp.), dominant within agricultural landscapes (Blakey et al., 2017). Anyway forests are fundamental for roosting and even foraging by more cryptic species that might not have been detected by our sampling protocol (Wickramasinghe et al., 2003; Denzinger and Schnitzler, 2013; Ferreira et al., 2015; Azam et al., 2016). Also, detectability decreases in complex habitats (Kaiser and O'Keefe, 2015).

In accordance with previous studies (Hanspach et al., 2011; Jeliazkov et al., 2016; Kirk and Lindsay, 2017; Wilson et al., 2017), rural landscape homogenization and chemical intensification (illustrated in our study by the intensification scenario) are relevant factors in explaining bird decline in agroecosystems, probably due to the depletion of trophic resources and nesting opportunities. An unexpected result from this scenario was the increase in bat passes under the intensified agricultural practices (e.g. reduction in natural and semi-natural areas and an increase in agrochemical use). Some authors have justified this trend on the increasing number of movements among roosting and the more distant suitable foraging sites (Toffoli and Rughetti, 2017). This result might show increasing energy spent when feeding and a selection of species known to fly longer distances and with large home ranges (Wickramasinghe et al., 2003; Denzinger and Schnitzler, 2013; Mendes et al., 2014; Azam et al., 2016).

A small increase in bird abundance was noticed when the use of herbicide was simulated to be restricted to the vine rows (in the equilibrium scenario). Schaub et al. (2010), Arlettaz et al. (2012) and Paiola et al. (2020) provided evidence that patches of grassy habitats are important for the birds that feed on seeds and soil invertebrates and even for some bat species (Wickramasinghe et al., 2003; Shapiro et al., 2020). The simulation of "sustainable management" (eco-friendly scenario) substantially increased bird abundance, possibly mimicking the associated resources to more diverse and complex LULC (Morelli et al., 2012; Kirk and Lindsay, 2017; Steel et al., 2017). Again, the results of our simulation including eco-friendly management practices suggest that green infrastructures and blue infrastructures increase bird abundance and bat activity, consistent with other studies in this scope (Smart et al., 2006; Rainho and Palmeirim, 2011; Froidevaux et al., 2017; Jóhannesdóttir et al., 2017).

Ecological corridors are considered important tools in farmland management because they could increase the movement of animal and

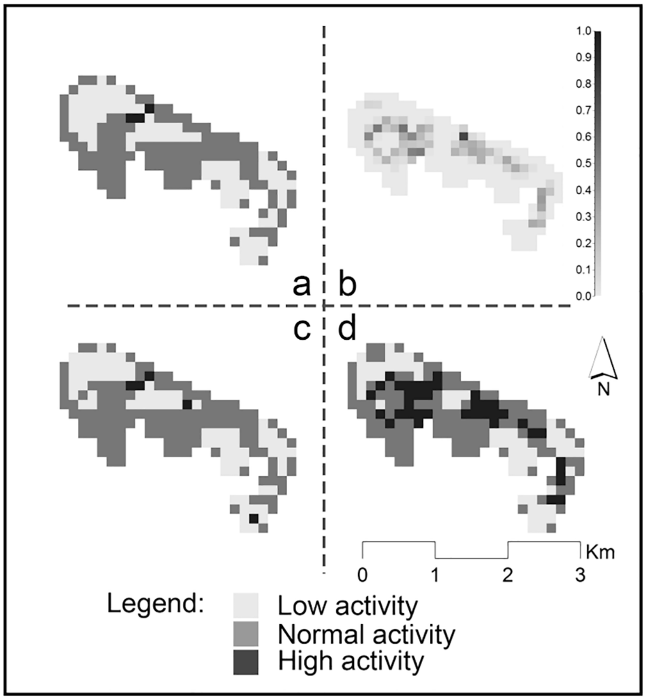

Fig. 6. Predicted changes in bat activity for the Aciprestes farm: (a) bat passes for the actual LULC and management; (b) areas selected for the creation of the ecological corridors (with LULC of the ecological corridors on a scale from 0 to 1 ha for each ha of the farm; (c) bats passes in response to shrubland/hedgerows corridors (CS); (d) bat passes in response to shrubland and waterbodies corridors (CSW). Low activity is considered for values below first quartile of monitored data (1), normal activity is considered for values between the first and the third quantile of monitored data (1-3) and high abundance is considered for values above the third quantile (3).

plant species between habitat patches (Gilbert-Norton et al., 2010; Hofman et al., 2018). The importance of shrublands/hedgerows in farm areas for birds and bats was highlighted in several studies (Bolger et al., 2001; Russ and Montgomery, 2002; Morelli, 2012, 2013; Morelli et al., 2012; Davidai et al., 2015; Wuczyński, 2016; Cleary et al., 2017; Wilson et al., 2017; Monck-Whipp et al., 2018). Contrariwise our study predicted a decline in bird abundance and bat activity with the installation of shrubland/hedgerow corridors, probably related with the recent implementation of these structures in the studied farms (simplified and small structured vegetation). However, when simulating the installation of an ecological corridor composed by green and blue infrastructures, the simulations illustrate a positive influence in bird abundance and bat passes. As noticed for the simulated farm, the construction of ponds is of particular importance, providing a rich source of food and foraging habitats, suitable for many species of birds and bats (Russ and Montgomery, 2002; Longcore et al., 2006; Toffoli and Rughetti, 2017; Froidevaux et al., 2019).

4.2. StDM framework usefulness for managing vineyard landscapes

Conducted in the Alto Douro Wine Region, inscribed in the World Heritage UNESCO List because of its importance as traditional European wine-producing region, this study highlights the potential conflicts between LUCC, conservation strategies and farm management. Vineyards (and vineyard landscapes), more complex and heterogeneous than annual crops, are fundamental for several species known to provide core ecosystem services and nature's contributions to people (ESNCP) in agroecosystems but also to the conservation of rare and declining species (Katayama et al., 2019). Winter et al. (2018) demonstrated that both, vineyard biodiversity and ESNCP, are highly jeopardized by current viticulture, namely by pesticides application, soil tillage and landscape simplification, emphasizing the importance of vegetation management in this scope. Also, ESNCP that influence vineyard performance and production are predominant in most studies, highlighting the importance of multifunctionality research to support sustainable management (Winkler et al., 2017). Conservation actions for bats and birds in agricultural contexts are associated with overall biodiversity and specifically to functional diversity, namely by creating favorable habitats that satisfy requirements of many other species in the vineyard landscapes (Guerrero et al., 2011; Morelli et al., 2014; Monck-Whipp et al., 2018). In fact, the significant increases in bird abundance and bat passes simulated for specific scenarios might be a proxy of biodiversity and, hopefully of ESNCP. As in most viticultural regions, one of the main threats to the productivity is the European grapevine moth, *Lobesia botrana* (Gonçalves et al., 2013). Birds and bats, mostly insectivorous, can be considered a fundamental strategy to reduce crop damage and therefore to provide potential economic advantages as documented by several studies (Cumming and Spiesman, 2006; Lindell et al., 2018; Thiéry, 2018). Nevertheless, some risks are associated with this increase in abundance/activity of flying vertebrates - tritrophic predation can provide disservices, disrupting pest control by altering invertebrate interactions (e.g. bats and birds preying on predatory arthropods) (Martin et al., 2013).

The framework presented was considered an useful method to simulate and understand system changes within spatio-temporal dynamics, by combining different modelling approaches and enabling information transfer at a local scale (Santos et al., 2016a). StDM hybrid framework captures the complexity of environmental characteristics, such as temporal and spatial gradients of LULC dynamics (Santos et al., 2013) and enables simulating the influence of prevailing conditions and changes on the biodiversity indicators. However, if we consider that validation is fundamental to show the accuracy of the model and, in this way, its applicability (Rykiel, 1996) two main questions remain within the present work.

(1) the results only gain final validity after several years of collecting information about the real tendencies of the indicators facing the implemented management changes (e.g. shrublands/hedgerows will take time to mature and to attract a complex animal community) (Glenz et al., 2001) and (2) as only two years of field work were implemented, the demographic stochasticity of bird and bat communities was not included in our calculations (Chaloupka, 2002).

Also, it is likely that the activity of more elusive bird and bat species in the studied farms was probably not detected by point counts and by the acoustic monitoring technique used. Bat and bird records took place during limited periods, which might not be representative of full activity patterns. In particular for bats, data could have been missed when scanning between frequencies and using time expansion detectors not detecting high frequency bats when scanning at lower frequencies and during time expansion of calls, when the detector was not recording. The use of real-time continuous sampling was not possible for logistic reasons but this technology is becoming widely available and could increase the quality of the database (Roscioni et al., 2014) and, consequently the StDM model performance and applicability.

In this humble academic application, generalized linear models (GLzM) were used to parametrize the StDM hybrid framework. More powerful statistical techniques such as generalized linear mixed models (GLzMM) could have been applied, (e.g. Bolker et al., 2009; Stroup, 2013) namely using robust databases (e.g. including more farms and/or wine regions) although with risks associated with the interpretation and simulations (e.g. Bolker et al., 2009; Santos et al., 2013) (additional discussion in Appendix A).

Although conceptually simple, the StDM hybrid framework has been used in diverse contexts and scenarios (Santos and Cabral, 2004; Cabral et al., 2007; Bastos et al., 2012, 2016, 2018; Santos et al., 2013, 2016a, 2016b, 2018; Lomba et al., 2015; Mulatu et al., 2016; Silva et al., 2017) – exemplified here by birds and bats indicating agricultural management effects on farmland biodiversity and ESNCP. Albeit this simplification increases the understanding of whole-system processes, the combination of StDM with bottom-up approaches, such as Agent-based-models, will probably result in promising future tools for ecosystem management (Strauss et al., 2017).

Our findings suggest that when using ecological modelling to support the decision-making regarding the management options in viticultural landscapes, considering multiple biodiversity indicators might be fundamental in order to obtain the most integrative results. Additionally, robust indicator simulations might support, in advance, managing decisions such as the design and the implementation of agri-environment schemes, ecological infrastructure development and landscape planning (Billeter et al., 2007; Bockstaller et al., 2011; Santos et al., 2016a, 2018; Bastos et al., 2018).

5. Conclusion

Our hybrid modelling framework represents a contribution to understand the relevance and usefulness of management practices on key biodiversity indicators in the scope of ecosystem services promotion in vineyard landscapes. Nevertheless, since biodiversity of the studied vineyards can be only partly assessed by bird abundance and bat passes, our results should be complemented with information from other indicators, interactions and interferences (such as the specific agricultural practices and specific bird and bat species) with precise applicability conditions. Despite the limitations inherent to a preliminary demonstration, the framework proposed is applicable to other viticultural regions and even to other type of agroecosystems. Moreover, this approach also provides a starting point, allowing the precise development of more instructive protocols for environmental managers and farmers, based on the potential added-value of our proposal, namely in order (1) to anticipate the changes in biodiversity induced by LUCC and management options, and (2) to provide guidance of pertinent management strategies aimed at reconciling wine production with biodiversity conservation.

CRediT authorship contribution statement

Alis-Luciana Petrescu Bakış: Conceptualization, Formal analysis, Investigation, Software, Writing - original draft, Writing - review & editing. **Irina Macovei:** Conceptualization, Formal analysis, Investigation, Software, Writing - original draft, Writing - review & editing. **Paulo Barros:** Data curation, Investigation, Writing - review & editing. **Carla Gomes:** Data curation, Investigation, Writing - review & editing. **Diogo Carvalho:** Data curation, Investigation, Visualization, Writing - review & editing. **João Alexandre Cabral:** Funding acquisition, Resources, Project administration, Writing - review & editing. **Paulo Travassos:** Data curation, Funding acquisition, Investigation, Project administration, Writing - review & editing. **Laura Torres:** Funding acquisition, Project administration, Writing - review & editing. **José Aranha:** Data curation, Investigation, Writing - review & editing. **Liviu-Daniel Galațchi:** Supervision, Writing - review & editing. **Mário Santos:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Visualization, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2020.107012.

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