Modelling biodiversity change in agricultural landscape scenarios - A review and prospects for future research

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Abstract

Increased intensity of agriculture and landscape homogenization are threatening biodiversity in landscapes. We reviewed 67 case studies addressing the impact of agriculture on biodiversity in model based scenario approaches and compared the information they provide on biodiversity, spatial characteristics, scenarios, and landscapes. We found an overall large diversity of approaches that we summarized statistically into six groups. “Biodiversity based agent based models”, “Expert based exploration of land use change with GIS” and “Land use approaches of biodiversity with spatially explicit statistical model” are specialized biodiversity studies with high complexity in terms of biodiversity modelling with agent-based models or mechanistic models. On the other hand, “Bioeconomic modelling of policy impacts in favor of restoration of beneficial habitats”, “Participatory simulation studies of landscape futures” and “Large scale multi criteria studies of innovative scenarios with optimization” do not consider species’ behavior or landscape configuration, but do address a large range of socioeconomic and environmental issues. As a contribution to developing quantitative and policy-relevant biodiversity conservation studies in landscape, we present the advantages and disadvantages of each approach. We then suggest combining different approaches, particularly with the use of agent-based models and mechanistic models, integrating spatially explicit drivers of biodiversity change and the socio-economic context of farming in a participatory manner. We give recommendations on the inclusion of more taxa in future studies and collaboration between scientists from different disciplines to develop innovative solutions that can halt the biodiversity decline in agricultural landscapes.

Keywords: species conservation; land use change; farm management; landscape configuration; biodiversity-ecosystem functioning; wildlife-friendly farming

1. Introduction

Conservation of biodiversity (genes, species, and ecosystems) is considered by many to be an ethical imperative (Dramstad and Fjellstad, 2011). Biodiversity also supports 'ecosystem services', i.e., ecological processes and functions that sustain and improve human wellbeing (Daily 1997). Biodiversity can contribute to the provision of ecosystem services such as pollination, biological regulation of pests in agroecosystems, and provision of food and feed (Duffy et al., 2017). The ecosystem services provided by biodiversity can help maintain the productivity of cropping systems, while reducing the use of external inputs responsible for several negative environmental impacts in agricultural landscapes. Agricultural landscapes are mosaics of farmers' fields, semi-natural habitats, human infrastructure (e.g., roads), and occasional natural habitats (Marshall 2004) that together provide a range of services such as provision of food and fiber, carbon sequestration, nutrient recycling and cultural services. Hence, by definition, an agricultural landscape can cover an area as small as a few fields or can encompass an entire continent. Conserving biodiversity in agricultural landscapes can help provide ecological, economic, and social benefits (Estrada-Carmona et al., 2014).

However, the benefits provided by landscapes are decreasing because of the current decline in species and individuals at large scales (Butchart et al., 2010). Agriculture is one of the main activities responsible for this decrease in landscape biodiversity (Isbell et al., 2017; Kehoe et al., 2017). Over the past decades, the expansion of agricultural land, the decline in landscape heterogeneity, the increased use of fertilizers and pesticides, and the conversion to systems with low crop diversity, have had major effects on global biodiversity (Emmerson et al., 2016, Tscharntke et al., 2005). These changes are also decreasing the provision of services to humanity (Bianchi et al., 2006, 2013). For instance, farmland birds are experiencing large declines in all parts of the world, due to agricultural intensification causing habitat losses (Laaksonen and Lehikoinen, 2013; Stanton et al., 2018). Populations of farmland birds, such as skylarks (Alauda arvensis), have been massively reduced, resulting in an associated decrease in the ecosystem services they provide, e.g., in terms of reduction of weed seeds (Eraud et al., 2015). A similar reduction in species richness has been found in aquatic systems, e.g., stream invertebrates have been reduced by up to 42% in Europe and Australia, largely due to pesticide use (Beketov et al., 2013). The practices that are negative for biodiversity are a result of intensification of production that is largely induced by global drivers, such as market demand for more and cheaper commodities (Lenzen et al., 2012; Weinzettel et al., 2013), and recent policy for production of bioenergy on agricultural land (Immerzeel et al., 2014).

Fortunately, agricultural landscapes can be designed and managed to host wild biodiversity of many types, with neutral or even positive effects on agricultural production and livelihoods (Altieri 1999; Scherr and McNeely, 2008). Different landscape-level strategies to find compromises between production and conservation have been widely discussed, the most prominent debate being on land sharing compared with land sparing strategies (Green et al., 2005; Phalan et al., 2011). These strategies can be discussed at different spatial scales ranging from field level (e.g., Colbach et al., 2018) to global level with the creation of biodiversity protection areas such as conservation concessions or indigenous reserves world-wide (Watson et al., 2014; Hoffmann et al., 2018). Since some ecological impacts of agriculture on biodiversity occur at a level above field scale, it is also important to study biodiversity at a larger scale (Pelosi et al., 2010). The relative area and spatial configuration of agricultural and natural components are key landscape design issues (Auffret et al., 2015).

When studying the future of agricultural landscapes for improved consideration of biodiversity aspects, the socioeconomic aspects of landscapes needs to be accounted for by planners (Benoît et al., 2012). Agricultural landscapes are complex adaptive socioecological systems structured and managed by various stakeholders including for instance farmers, local and regional governments, and non-governmental organizations (NGOs) (Biggs et al., 2013). This increases the complexity of the biodiversity issue and the number of drivers that determine the landscape characteristics. Such drivers can be socioeconomic, political, technological, natural, or cultural (Brandt et al., 1999). None of these drivers are fixed in time and space, or independent from each other, and they are evolving continuously. The change in drivers modifies the state of biodiversity in landscapes. One such change is the implementation of agri-environmental schemes for the protection of biodiversity in the European Common Policy (CAP).

In order to monitor the changes in biodiversity, scientists are developing methods for simultaneously studying landscape changes that could affect biodiversity within agricultural landscapes and ecosystem services (e.g., production of food, esthetic value). Most of these methods are based on scenarios, which is a powerful tool to envision how biodiversity might respond to different pathways of future human development and policy choices (Díaz et al., 2015). In models, the landscape and processes that determine biodiversity are simplified in a certain way by the adoption of different modeling approaches for designing agricultural landscapes and assessing changes in biodiversity (e.g., Topping 2011; Drum et al., 2015; Kirchner et al., 2015). The objectives and associated methods of such studies may contribute to different assessments of the impacts of agricultural development on biodiversity in landscapes. It is possible to gain more insights into the nature and complexity of approaches by focusing on their key characteristics: the spatial characteristics and landscape representation, the type of biodiversity studied, the scenario techniques, and the type of models used to design and assess landscapes.

Our objectives with the current review were to describe the diversity of approaches for scenario analysis of biodiversity-related challenges and to suggest guidelines for methodological improvements. To achieve these objectives we, i) reviewed existing studies in the literature and compared the landscape, the spatial emphasis, the scenario characteristics, and the type of models used, ii) identified links between these characteristics, iii) grouped the studies to identify common approaches, and finally iv) scrutinized current methods and pathways in order to identify ways to improve approaches to modeling biodiversity change in landscapes.

2. Material and methods

2.1. Literature research

We conducted the literature research in a systematic way by formulating a search equation in ISI Web of Knowledge. The equation was divided into four topics: i) model, ii) scenarios, iii) landscape and iv) agriculture. According to the IPBES (2016), scenarios and models can provide an effective means of addressing relationships between nature, nature's benefits to people, and, good quality of life. They have a complementary role with scenarios describing possible futures for drivers of change, and models translating them into projected consequences for natures and benefits for people. Scenarios are not predictions of what will happen, but are projections of what might happen, or could happen, given certain assumptions about which there might be great uncertainty (Börjeson et al., 2006). For each topic, we identified potential synonyms to build our equation (Equation 1). For the model topic, only the keyword "Model" was used. Scenarios refer to the construction of different "alternatives" to modify the structure of the system represented. We introduced different scales ("landscape", "watershed" and "water catchment") in the equation to represent landscapes. Watershed and water catchment were introduced because they are important scales in the management of water in landscapes coupled to biodiversity issues. We did not introduce the word "region", because it vastly expanded the search results by selecting many papers stating only their area of study, rather than being performed at the regional level. We introduced the terms "agri*", "agro*", "crop*" and "farm*" to refer to agriculture (e.g., agronomy, agroecology, agriculture, crops, cropping systems, farm or farming systems), in order to capture the diversity of agricultural use of land. Biodiversity was not included in the equation, because many studies focus only on some species without mentioning the word “biodiversity”. Instead of widening the equation by introducing all types of taxa, we decided to introduce an ad hoc filter of the list of papers. The equation was as follows:

Equation 1:

$$\mathbf{TS} = (\mathbf{model}* \ \mathbf{AND}\ ((\mathbf{scenar}* \ \mathbf{OR}\ \mathbf{alternativ}*)\ \mathbf{AND}\ (\mathbf{landscape}* \ \mathbf{OR}\ \mathbf{watershed}* \ \mathbf{OR}\ (\mathbf{water}\ \mathbf{NEAR}\ \mathbf{catchment}*))\ \mathbf{AND}\ (\mathbf{agri}* \ \mathbf{OR}\ \mathbf{agro}* \ \mathbf{OR}\ \mathbf{crop}* \ \mathbf{or}\ \mathbf{farm}*)))$$

The literature search was closed on May 4, 2017 and the results encompassed 1975 papers (Figure 1). Papers that were more recent were not included.

<Insert Figure 1>

We then followed a discarding procedure in which we excluded papers that did not include agriculture (e.g., forest studies only) or scenario (e.g., model calibration/validation only), that were not at landscape scale (e.g., field or farm only), that did not use models (e.g., expert-based knowledge only), or without any case study (e.g., model calibration, validation) and that did not include any biodiversity conservation issue (Figure 1). The order of filters modify the number of papers along the discarding procedure, but not in the final list which comprise 65 papers for a total of 67 case studies, as in one paper three case studies were developed (Groot et al., 2009). These studies came from 33 peer-reviewed journals and were conducted in 17 different individual countries, with two conducted at the European level (Supplementary material).

We described each study with categorical variables (Table 1). The few quantitative variables (e.g., area studied) were turned into ordinal categorical variables. The description of each of the 67 studies was based on 13 categorical variables (4 ordinal, 9 nominal) grouped into five categories: 1) “Spatial characteristics”, gathering variables describing the extent of the study area and the spatial scales considered. 2) “Landscape”, describing the representation of landscape in terms of agriculture and the change considered in the landscape. 3) “Biodiversity category”, gathering information regarding the taxa modelled and the processes driving the change in taxa abundance. 4) “Scenario”, grouping information regarding the type of scenario developed and the process to develop them. 5) “Model”, describing the type of model used to produce landscape and assess the biodiversity change. We describe the categorical variables below.

2.2.1 Spatial characteristics

2.2.1.1 Extent

The extent is the size of the landscape unit included in the study. The extent of the landscape has various effects on the processes studied. For instance, Bianchi et al., (2006a) state that diversified small landscapes are more effective in pest control than large landscapes. We categorized “extent” into three subcategories (“local”, “national/local”, “global/supranational”), as suggested by van Notten et al., (2003). These subcategories corresponded to studies on landscape areas <100 km^2, 100-1000 km^2, and >1000 km^2, respectively.

2.2.1.2 Spatial scale

Different procedures can help change the information from one scale to another to provide an indicator of the impacts of change such as sum, interpolation, or other mathematical formula (Volk and Ewert, 2011). Here, we only considered the number of scales involved in the transfer of information. "Landscape scale only" corresponds to processes simulated at the landscape level only, "from lower level to landscape level" corresponds to two different scales, and "multi-scale" corresponds to more than two scales involved in the transfer of biodiversity information at landscape level (Chopin et al., 2017). Generally, the scale at low level corresponds to fields or pixels, intermediate scale can be farm or hydrological response unit, and large scale can be a water catchment, several catchments, or an administrative area such as a county, a country, or a continent (e.g., the European Union).

2.2.2 Landscape

2.2.2.1 Agricultural land use precision

The landscape represented in the different studies consisted of different land uses. The detail with which these agricultural land uses were described in the selected studies varied from a broad categorization to a very precise description. We divided the variable "land use" into two subcategories. In the subcategory "land cover", the land use was described roughly as "grassland", "arable land", "forest " or similar and did not describe the species present (Drum et al., 2015). For "land cover", there was generally only one associated management parameter across the studied landscape, such as one cattle density for grassland. We called "crops" the agricultural land use for which crops at plot level are known and generally, several management systems of the same crop are accounted for (e.g., intensive or extensive wheat production).

2.2.2.2 Change in agricultural landscapes

The selected studies described various characteristics of agriculture responsible for the change in biodiversity: i) a change in activity of cropping or land cover, and/or ii) a change in intensity, which corresponds to the type of management (e.g., pesticide application, soil management, etc.) applied to the crops or land cover types. For instance, Dormann et al., (2008) show that hoverflies and spiders are more affected by land cover than crop management, while the opposite trend is observed for birds, bees, bugs, and beetles in Europe. We considered these two types of processes in the variable "change in agricultural landscapes": "Change of activity", i.e., reorganization of current uses in the landscape and "change of intensity", i.e., a change of land use intensity not affecting the land cover. These two changes can also be simultaneously changed in the simulations and were then categorized as "change of activity and intensity".

2.2.3 Biodiversity

2.2.3.1 Spatially explicit processes driving biodiversity change

An important characteristic of the study of landscape change linked with biodiversity is the spatial organization of landscape driving the abundance of taxa. Several spatially explicit processes, called landscape factors by ecologists (Bianchi et al., 2006b), influence biodiversity and are related to the organization of the landscape, which is the spatial location of the different types of land use within the landscape. In the literature, the spatial organization is referred to as "landscape structure", "aggregation", "arrangement", or "configuration", but these terms often describe the same property of the landscape. We chose to represent spatial organization with a binary variable with two levels ("yes"/"no"), indicating whether or not spatial organization of landscape was included in a study.

2.2.3.2 Species behavior

The variable "species behavior" describes the integration of variables linked to the biology of species in the modelling of biodiversity. Such variables include e.g., foraging or nesting requirements of birds (Cardador et al., 2015). Potential competition for land area also appears between species and can be integrated, e.g., co-specific abundance of species where the level of one species population is linked to that of another (e.g., Casado et al., 2014). For plant species diversity, suitability or preferences for some biophysical conditions were included in this species behavior variable. If any process characterizing landscape suitability for a given species or behavior was included in the study, the variable value was set as “yes”, otherwise it was “no”.

2.2.3.3 Number of taxa

About 66% of the studies considered a sole taxon as an indicator of the general state of the system, 13% considered several taxa, and the remainder considered general biodiversity (see Supplementary material). The most common taxon used as an indicator of biodiversity was birds, in 22 studies, most of them focusing on farmland birds (e.g., Guillem et al, 2015). Birds were often considered indicators of the state of biodiversity even if only one species was studied (e.g., skylarks in Guillem et al., 2015). However, some studies included several species with contrasting niches (e.g., five farmland birds (Brandt and Glemnitz, 2014)). Insects, such as grasshoppers (Steck et al., 2007) or bees (Baveco et al., 2016), fish (Weinberg et al., 2002), bivalvia (Randhir & Hawes 2009), mammals (Jepsen et al., 2005) and plants (Egan and Mortensen, 2012) were also used as single taxon indicators of biodiversity. In our set of 67 studies, only nine included more than one taxon. For instance, Gottschalk et al., (2007) focused on changes in birds and carabids. Finally, in some studies, biodiversity was assessed in a general manner. Dormann et al., (2008) focused on seven groups of organisms (plants, birds, spiders, wild bees, ground beetles, true bugs, and hoverflies) to depict the impact of landscape change on biodiversity. We categorized species diversity into the subcategories “single taxon”, “set of taxa”, or “general biodiversity”.

2.2.4 Scenario

2.2.4.1 Participatory

Participatory modelling is a tool to enhance stakeholder knowledge and understanding of a system and to clarify the impacts of changes to help decision making (Voinov and Bousquet, 2010). There are different typologies of participation, with increasing degrees of engagement of stakeholders in scenario studies (Reed 2008). Here, we used a binary variable for which the value was set as “no” when there was no stakeholder engagement in the study or simply an expert consultation phase, and “yes” when there was active involvement of stakeholders in the scenario definition or assessment.

2.2.4.2 Issues addressed

The importance of biodiversity in the selected studies varied from studies that focused only on biodiversity change in the landscape to broader studies where multiple issues were targeted.

To display this range, we categorized this variable into three classes: “Biodiversity-centered”, depicting studies that only addressed biodiversity change; “biodiversity coupled to one or two other issues”, gathering studies where biodiversity was addressed coupled mostly to economic or food production aspects with e.g., a focus on land sparing vs. land sharing strategies (e.g., Egan and Mortensen, 2012); and “multi-issues”, gathering studies in which an integrated assessment was performed with many indicators, including e.g., food provision, economic viability of farming, water quality and quantity, esthetic value (e.g., Bryan et al., 2011; Gutzler et al., 2015) (See Supplementary material).

2.2.4.3 Drivers of landscape change

Different types of drivers can modify the landscape, thus potentially affecting biodiversity. Among these drivers we identified policy change, biophysical change, and direct land conversion. Some studies examined the impact of only one driver, while some studies considered a combination of several drivers of change. We categorized the studies into those with a “single driver” and those with “multiple drivers”.

2.2.4.4 Scenario type

We classified this variable into three categories: “simple change”, “system change”, and “transformative change” scenarios following existing typologies of change (e.g., Roggema and Dobbelsteen, 2012). The level “simple change” mostly concerns incremental change of landscape with, for instance, conversion scenarios in which a given area was turned into another land use based on some simple rules (e.g., the authors decided to switch a given area from pasture to bioenergy). In “system change” scenarios, also defined as transitional scenarios, modification of a set of known biophysical and socio-economic variables allows the transition of the system, such as a change of subsidies. In this type of scenario, several parameters were modified to produce new landscapes, which would imply a change in biodiversity. Finally, “transformative” scenarios are descriptions of change with storylines where complex scenarios of high complexity are developed and translated to model parameterization (Cardador et al., 2015).

2.2.5 Modeling

In the selected studies, models were used to i) design new agricultural landscapes and/or ii) assess the change in biodiversity in these landscapes. We also included studies for which models to design landscapes were not used, as our main focus was on the assessment of biodiversity.

<Insert Table 1>

2.2.5.1 Model to design landscapes

We divided the type of model used to design landscapes into five categories: “Optimization model”, “agent-based model”, “mechanistic model”, “statistical model”, and “no model for design” (Table 1):

- **Optimization model**. In most approaches, the decision-making process of farmers was the core process modelled. It assumes that individual farmers make land use decisions to maximize their utility, very often represented as their revenue, under resource constraints, mainly land and labor (see reviews by Janssen and van Ittersum (2007) and Reidsma et al., (2012)). Optimization can be at different scales, e.g., farm level (Weinberg et al., 2002) or landscape level (Chopin et al., 2015). In optimization models, farmers´ decisions are simulated and produce new agricultural landscapes. For these newly produced landscapes, other types of model are used to assess the level of biodiversity.

- **Agent-based model (ABM).** An ABM describes decision making by several entities, such as farmers, that interact across time through individual transactions in a market with potential spatial interactions (Bousquet and Le Page, 2004; Kremmydas et al., 2018). It is specifically the interactions among agents that make the “agent-based model” different to the “optimization model” where agents are simulated individually (Nolan et al., 2009).

- **Statistical model**. Describes land use changes using probabilities of change of land use from one category to another based generally on historical changes (Verburg et al., 2004). Such models include cellular automaton (Campagne et al., 2009), Markovian models (Coppedge et al., 2007), or regression models linking land use with different biophysical and/or socioeconomic variables at local level (e.g., soil, rainfall, land tenure) or global level (elevation of temperature, demand of commodities), which is the case with the widely used CLUE model (Veldkamp and Lambin, 2001).

- **Mechanistic model**. Models system functioning by a set of equations linking the inputs of the system (e.g., crop, fertilizers) with outputs (e.g., yields, development of habitats).
- **No model to design**. In some studies, no model is used to describe the change in landscape. The change in landscape is driven by expertise or prior studies that describe changes in land use types.

2.2.5.2 Model to assess biodiversity

We gathered the type of model used to assess biodiversity into five categories, namely “agent-based model”, “mechanistic model”, “statistical model”, “landscape indicators”, or “habitat suitability”.

- **Agent-based model.** In the case of assessment of biodiversity change, the agent-based model simulates changes in populations and communities by following individuals in time and space and their associated properties (DeAngelis and Grimm, 2014). Each individual has a set of state variable or attributes and behavior. State variables can include spatial location, physiological traits, and behavioral traits. These attributes vary between individuals and can change in time and space. Behaviors can include growth, reproduction, habitat selection, foraging, and dispersal. Running such a model provides information regarding population dynamics and changes in abundance across space and time.
- **Statistical model**. It describes change in biodiversity abundance as an equation linking abundance as independent variable with a set of explanatory variables at landscape level, including e.g., land use within a certain radius or distribution of patches.
- **Mechanistic model**. Also called a process-based model, it links the change in biodiversity state to the system state through a range of equations.
- **Landscape indicators**. These variables provide indications on the state of biodiversity, usually with a simple formula with no explicit model structure.
- **Habitat suitability.** Different habitat values are attributed to all land uses/land cover or crops in a region and the increase in habitat induces the increase in biodiversity (and vice versa). The higher the habitat value, the higher the increase in biodiversity. Bird abundance values for each habitat in the models included here were mostly obtained from previous studies.

In Supplementary material, we provide a list of examples for each category of model used to design landscapes and to assess biodiversity, extracted from our list of case studies.

2.3. Statistical Analysis

<Insert Figure 2>

To analyze the dataset, we used four types of statistical approaches (Figure 2). First, we analyzed the relationships among the 13 initial variables that described the case studies. Second, we conducted multi-correspondence analysis (MCA) to decrease the complexity of the dataset. Third, we selected the main components from the MCA to group studies based on their similarity using ascending hierarchical clustering (AHC). Fourth, we used a regression tree (CART) to describe the main differences between groups.

2.3.1. Step A: Correlation study

Among the 13 categorical variables, nine were nominal variables and four were ordinal variables. The bivariate association among the ordinal variables was tested using Goodman-Kruskal´s gamma for ordinal variables in R package DescTools 0.99.24 (Signorell 2018). Goodman-Kruskal's gamma measures correlations among variables (Pearson 2016), with values from −1 (negative association) to +1 (positive association). Association among nominal variables and between nominal and ordinal variables was assessed using the Chi-square. If the null hypothesis is rejected, the strength of the association is assessed with Cramér's V (Signorell 2018), a number between 0 and 1 that indicates how strongly one nominal and one ordinal variable, or two nominal variables, are associated. If the results denote a significant association between variables, this means that the pattern of distribution of studies between two variables can present some very low numbers.

2.3.2. Step B: Multi-correspondence analysis (MCA)

In order to identify trends in terms of approaches to model-based scenario analysis of biodiversity change in agricultural landscape, we grouped the existing approaches based on their level of similarity. We started by reducing the number of variables used in our analysis, through performing MCA on the 13 variables using the FactoMineR package (Husson et al., 2015) in R software (R Development Core Team 2008). MCA is a data analysis technique for categorical data, used to detect and represent underlying structures in a dataset. It is an alternative to principal component analysis (PCA) for categorical variables including both nominal and ordinal variables. The first components, accounting for as much of the variability in the data as possible, summarize the greatest amount of information from the dataset.

2.3.3. Step C: Ascending hierarchical clustering (AHC)

MCA was used as a method for de-noising data by producing non-correlated components and then for performing hierarchical clustering analysis of studies based on these components. We selected the components derived from the 13 variables that explained 70% of the variance of our sample of case studies (Higgs 1991). Ascending hierarchical clustering was performed on these components. We used Ward's method to classify the studies into groups in order to minimize the intra-group variability and maximize the inter-group variability. With this method, we did not need to pre-select a given number of groups. We then characterized the groups by the main categories of the categorical variables (Husson et al., 2010). To evaluate the relationship between these, we compared their proportions through a statistical test based on the hypergeometric distribution. The null hypothesis was that the proportions of each variable treatment should be equal in groups (Lê and Worch 2015). Categories of the variables significantly linked to the groups were identified with p-value and V value (Husson et al., 2011). The overrepresented categories of all categorical variables were thereby identified, with values ranging from 2 to 3 indicating "slight overrepresentation", 3-5 "moderate overrepresentation" and >5 "important overrepresentation" (Husson et al., 2011). Only the overrepresented categories characterizing the groups are described in the results section, to ease interpretation.

2.3.4. Step D: Regression tree

In order to identify the initial variables that best contributed to the partitioning of the set of studies, we performed a regression tree. Classification and regression trees (CART) are part of a recursive partitioning method. We used it here to model the group classification from the AHC as a function of our 13 initial variables. CART provided several advantages considering our dataset: (1) nonparametric basis,

(2) no implicit assumption of linearity, and (3) simplicity of results for interpretation. CART tools are available in the R package “rpart” (Therneau and Atkinson n.d.), based on the function developed by (Breiman 1984). The regression tree produces threshold values of initial variables that allow allocation of studies to a given new group called “leaf”. The classification of studies in the leaves is compared with groups from the AHC. Tree depth level was limited here to three levels and minimum leaf size to five studies, in order to avoid overfitting. Tree performance was tested by calculating Pseudo-R^2 and by cross-validation with the “rpart” algorithm.

3. Results

3.1. Crossing of variables describing approaches

Overall, 19 pairs of the variables described in Table 1 were significantly correlated (Table 2). The variable “issues addressed” was positively correlated with “extent” of the study area, i.e., the larger the size of the landscape unit studied, in general the more issues investigated. In most large-scale studies, “species behavior” was not accounted for. The variable “crops” was accounted for in all studies with several “spatial scales”, but almost never in studies at “landscape level only” (n=6). The one exception was a study by Bathgate et al., (2009) that targeted farming system change directly relating to a change of pasture management, without accounting for the farm-scale level (Table 2).

<Insert Table 2>

“Species behavior” was not accounted for in studies comprising a “set of taxa”, probably due to the need for very complex models to address such processes, and particularly when the “issues addressed” were numerous. Similarly, “spatially explicit process driving biodiversity change” tended not to be accounted for in studies targeting “multi-issues” (1 study out of 15).

The inclusion of “participatory” was related to a way to build scenarios with “transformative change”, while it was poorly used for “simple change” of land for biomass production. Similarly, transformative scenarios were often associated with “multiple drivers” of landscape change (Table 2).

<Insert Figure 3 and 4>

Figures 3 and 4 illustrate the gaps in current methodological approaches by crossing sets of variables with the type of “model to design landscapes” and the type of “model to assess biodiversity”, respectively. It was only when no model was used for the design of landscapes that studies approached the landscape level directly (Figure 3A). All studies with a model approach included different scales, illustrating studies examining changes performed directly at the landscape scale by scientists or stakeholders. Very few studies accounted for more than two scales without a model to design (Figure 3A). In most cases (6 out of 8), studies using “mechanistic” and “statistical” models did not consider “cropping systems (Figure 3B). It was only when “mechanistic” models were used that the majority of studies (5 out of 8) used a participatory approach (Figure 3C). The link between “issues” and any particular model was not obvious, but a large proportion of the studies (16 of 25) that did not use a model for design were “biodiversity-centered” (Figure 3D). In all but one case, “agent-based models” and “statistical models” were used to target biodiversity, either “biodiversity coupled to others” or “biodiversity-centered”, and not “multi-issues”. On the other hand, only one study that was “biodiversity-centered” used an optimization model (Figure 3D). Finally, all model types except statistical models were used to develop scenarios with “transformative change”, i.e., complex storylines (Figure 3E). Studies combining “optimization model” for design, and storylines, are very scarce. When “no model to design” was used, “conversion” scenarios or “system change” were used to develop scenarios (Figure 3E).

In terms of “model type to assess”, studies using “landscape indicators” did not integrate the behavior of species and those using a “statistical” model did so only in two studies out of 15 (Figure 4A). On the other hand, other models, “agent-based models”, “habitat suitability”, and “mechanistic”, were used to simulate “species behavior” of species targeted. The “general” state of biodiversity was mostly addressed through “landscape indicators” and “habitat suitability” functions (Figure 4B). A “mechanistic” model or “agent-based model” was not used for wide appraisal of biodiversity, but mostly for “single taxon”. “Statistical” models followed a similar trend except for two studies targeting “several taxa” and two others focusing on the “general” state of biodiversity (Figure 4B). In terms of issues targeted, biodiversity in “multi-issues” studies was generally assessed with a “habitat suitability” model or “landscape indicators” (Figure 4C). Furthermore, “landscape indicators” were mainly used in “multi-issues” studies to chart changes in “general biodiversity” in landscape, along with “multi-issues” linked to agriculture. “Habitat suitability” models were used in a wide range of studies, ranging from “biodiversity-centered” to “multi-issues” (Figure 4C). Agent-based models were only used to assess biodiversity change in “biodiversity-centered” studies. Coupling the type of “model to design landscapes” and “model to assess biodiversity” revealed some gaps (Figure 4D). “Statistical models” used to produce landscapes were usually assessed using “habitat suitability” models or “statistical models”. Biodiversity in landscapes produced from “optimization models” was never assessed using “agent-based models”. Biodiversity in landscapes produced with “mechanistic models” was never assessed using “statistical models” in our dataset.

3.2 A typology of six diverse approaches

The first and the second principal components of MCA explained 24 and 10 % of the variance, respectively. The first component was largely determined by the variables “issues” and “model to assess biodiversity”. The second component was significantly linked to the variable “issues” and to “scales” and the “model to design landscapes” (Supplementary material).

<Insert Figure 5 and Table 3>

From the AHC, six groups of studies were identified in terms of similarity of individual studies in groups (Table 3) and important inter-class inertia (Supplementary material):

Group 1 (n=9). In this group, agent-based models were used to simulate the decision-making process of farmers, generally in terms of land cover or crop choice, linked to their resources, behaviors and relationships. These studies encompassed several spatial scales (“multi-scale”), combining (a) the field level at which crops or land cover were allocated (e.g., Schouten et al., 2014) (b) the farm scale, which was the scale at which farmers took decisions regarding their activity and (c) the landscape level, at which the impacts were measured. The agent-based models used encompassed individual-based models simulating the behavior of animals, mostly birds (Guillem et al., 2015) or mammals (Hammershoj et al., 2006) in the landscape and their population dynamic in relation to feeding or reproduction requirements. These studies were all “biodiversity-centered”, focusing on how conservation of species could be achieved (Schmitt et al., 2016) or how predators or invasive species could be limited in the landscape (Hammershoj et al., 2006). All studies in this group focused on the impacts of “simple change” within the landscape (6 studies out of 9) such as direct conversion of land for bioenergy (Gevers et al., 2011) or “system change” (3 studies out of 9) with e.g., a policy change such as a regional groundwater protection strategy (Jepsen et al., 2005).

Group 2 (n=14). This group gathered approaches of strict assessment of biodiversity change, with eight “biodiversity-centered” studies (e.g., Baveco et al., (2016) on bee exposure to pesticides) and six studies examining “biodiversity coupled to other issues” (e.g., Everaars et al., (2014) on the biodiversity response to increased bioenergy production). In 11 out of 14 studies, “no model” was used to produce landscapes. The studies of landscapes were based on existing landscapes where changes were applied randomly in the landscape, such as the conversion of fields to organic agriculture (Bredemeier et al., 2015). The evolution of biodiversity population was assessed using “mechanistic model” or “habitat suitability” model to assess biodiversity (5 and 7 studies out of 14, respectively). Mechanistic models link the variation of land use area to the population dynamic of species with for instance the change in area of interest for bee foraging (Baveco et al., 2016) or, habitat variation that modifies the species population proportionally, such as the occurrence of sage-grouse with cropland (Smith et al., 2016). All these studies focus on a “single taxon”. Land use was re-organized at low level in 11 studies, mainly through field change (six studies) or pixel change (two studies) with GIS, and consequences were assessed directly at landscape level.

Group 3 (n=14). In this group, studies use a statistical model or no model to represent the change in “land cover” in agricultural landscape (in 13 out of 14 studies). Usually aggregated land uses are adopted such as grassland, oilseed crops or cereal. The statistical model links the area of each land cover to global drivers, such as the demand for commodities and their associated price by way of regression. The assessment of biodiversity in the landscape is also undertaken using regressions that are built to explain the initial level of population of a given species in relation to the proportion and location of “land cover”. In such regressions, the characteristics of landscapes, such as fragmentation or connectivity, is accounted for in 9 studies that consider “spatially explicit process driving biodiversity change” (e.g., Blanchard et al., 2015). Some suitability models are also used in some studies. (e.g., Fonderflick et al., 2010). The behavior of species was not accounted for in any of the studies. Most studies (12 out of 14) were biodiversity-centered”, with no pattern regarding the “number of taxa” considered (Table 3).

Group 4 (n=14). In this group, studies use optimization models (11 out of 14 studies) with a bioeconomic approach at farm or regional level that focus on the impacts of farmers’ decisions on regional crop change and the subsequent impact on biodiversity. In 12 studies, the model integrates a precise description of crops with different management options and the management is linked with the issues targeted. In 12 out of 14 studies, only a few issues were targeted with biodiversity, mostly economic return and production, while only two studies were “multi-issues”. Of the studies in this group, 11 targeted policy analysis in “system change” scenarios and three examined conversion to increase favorable habitats for biodiversity. The policies studied included taxes and/or subsidies for different agricultural activities, such as, changes of the Common Agricultural Policy in the European Union (Mouysset et al., 2012). In these studies, the state of biodiversity is assessed with habitat suitability approaches in which the crops’ suitability for species of interest is assessed and these species serve as proxy of the overall state of biodiversity. For instance, Chiron et al (2013) uses an index of specialization of bird to either arable or grassland habitat.

Group 5 (n=5). This group was smaller than the other groups and predominantly used a “participatory” approach, with stakeholders in several workshops. The agricultural landscape is represented as the interplay between the land manager´s behavior, vegetation change, and other biological processes such as carbon sequestration. The demand for different sectors for resources drives the amount of land use and their allocation within the region. Mechanistic models are used in 4 out of 5 studies to represent and simulate the evolution of landscape in scenarios. Such model is a chain of process-based models that targets different parts of the modelled landscape. These included a series of “prototype models” (Drum et al., 2015), input-output models coupled to resource flux model (Walz et al., 2007), models of socioeconomic and biophysical processes (Reed et al., 2013), and agricultural landscape change models (Berger and Bolte, 2004). Scenarios were predominantly complex storylines built during several workshops with a large range of stakeholders, encompassing for instance local governments, local agencies related to agriculture or other sectors, and, general public. Stakeholders usually share their vision of local development, such as, opportunities and threats of the agricultural landscapes. During these workshops, a shared representation of the system under study was developed, and storylines were then drawn based on how the region could develop in the future.

Group 6 (n=11). This group comprised studies that were large-scale, with eight out of 11 ">1000 km^2" (median = 10,000 km^2). The agricultural landscape is represented as the result of the decisions of multiple landowners in terms of land use governed by their resources and preferences for given land categories in "Optimization models". The utility of the landowner is maximized to produce scenarios in which "multiple drivers" are accounted for and targeting multiple issues. The impact of "multiple drivers", such as price change, change of demand, and climate change, are tested in "transformative change" scenarios that are produced along with a storyline explaining the evolution of the system modeled (Penker and Wytrzens, 2005). Once the model is run to produce the alternative agricultural landscape, indicators are calculated on "Multi-issues". These issues are mainly the production of food and fiber with aggregation of yields per area and also other services, along with biodiversity conservation such as carbon sequestration or water provision and the trade-offs among these services (Briner et al., 2013). In eight studies, "landscape indicators" are used for the assessment of biodiversity change such as the proportion of natural vegetation land in part of a region (Bryan et al., 2011).

The multidimensional space contained two distinct clusters of groups: A cluster with groups 1, 2, and 3 and a cluster with groups 4, 5, and 6 (Figure 5). The description of groups 1, 2, and 3 tended to be oriented towards the study of biodiversity, while the description of groups 4, 5, and 6 was more oriented towards multi-issues.

3.3 The importance of issues targeted in approaches to biodiversity change in the landscape

<Insert Figure 6>

The regression tree split the population of studies into five leaves (A-E) using three variables: "issues", "model to design landscapes" and "species behavior" (Figure 6). CART gathered all studies from group 6 into leaf E because they all targeted many different issues (level "multi-issues" within variable "issues"). Most studies from the group 4 (11 out of 14) were gathered in leaf D. They corresponded to studies combining "no model" for design, and targeting "biodiversity coupled to one or two other issues". Leaf B gathered 10 out of 14 studies of group 2 and leaf A encompassed 13 out of 14 studies of group 3. No specific leaf captured the studies from group 5, which were spread between leaves A, B, and E. This can be explained by the low number of studies (n=5) and by the few specificities of the studies in this group. In fact, only three salient variables emerged in the group description for this group, while there were 5-6 salient variables for the other groups (Table 3). Despite the absence of group 5, the overall quality of the regression tree was good, with 52 studies out of 67 well-classified (78%). The regression tree revealed that "issues" was a main variable discriminating the different studies in the dataset (Figure 6). The variable "issues" actually appeared twice in the regression tree, as a first-level and third-level node. The studies were then discriminated based on whether they used/did not use a model to design the agricultural landscape. The left part of the regression tree was discriminated based on whether or not the behavior of species was accounted for in studies. The tree showed that the number of issues targeted initially drives the type of approaches to study biodiversity change in landscape. Assessment of many trade-offs, in terms of delivery of services, drives scientists towards "large scale multicriteria studies of innovative scenarios combined with optimization". It also showed that using a model to modify landscapes explains the type of approaches to study biodiversity change and that generally, when models are used to explore landscape, the same models are re-used to assess the level of biodiversity. This is the case for the group 1 "Biodiversity based agent based models" and 4

"Bioeconomic modelling of policy impacts in favor of restoration of beneficial habitats" that use respectively agent-based and optimization models, coupled to indicators to produce landscape and assess their response to biodiversity.

4. Discussion

Based on the diversity of the approaches highlighted, we discuss the advantages and disadvantages, the objectives and type of data used, which can explain the choice of the method. Then, we make some suggestions for methodological improvement in terms of potential combination of methods and characteristics among groups for a better use of scenario analysis in regards to biodiversity conservation. Our suggestions comprise: 1) Increasing the precision of biodiversity modelling in multi-issues studies by combining approaches from groups 1 and 3 with groups 4 and 6; 2) coupling empirical studies of taxa to broad biodiversity modelling to integrate the use of species' behavior in groups 1 and 2; 3) transferring the more transformative scenarios used in groups 5 and 6 to other groups; and 4) combining the methodologies of groups 3 and 4 to better account for agricultural activities and landscape organization as a driver of biodiversity.

4.1 Advantages and disadvantages of approaches in linked with their objective and data use

Firstly, we argue that the approaches highlighted by the typology do not have the same objectives and present advantages and disadvantages regarding the challenge of improving biodiversity conservation in agricultural landscapes. Group 2 "Expert-based exploration of land use change with GIS" and group 3 "Land use approaches of biodiversity with spatially explicit statistical model" can be considered as disciplinary ecological studies that aim to observe the population dynamics change in scenarios with precise biodiversity data available on the area of interest and covering a large time frame. They tend to focus on a single species in relation to some requirements, such as nesting or foraging for group 2, and in relation with landscape complexity in group 3. Their disadvantages include the limited range of issues targeted, and especially the lack of trade-offs among biodiversity conservation as well as other issues of interest in landscape planning, such as production, economic profit, or nitrogen cycling. In Group 1 "Biodiversity-based agent-based models", the focus of the study moves to a decision-making perspective with the use of ABM simulating a landowner´s decision and the trade-off between biodiversity conservation and production or economic profitability. The landowner decision is simulated, along with a precise assessment of biodiversity change in the landscape, with the use of species' behavior. In this group, the focus is still biodiversity, and the effect of landowner´s management on it, with limitations in addressing other landowners' or stakeholders´ concerns. The other approaches expanded the scope of the assessment to multiple issues linked to the sustainability of agricultural landscapes. Group 4 "Bioeconomic modelling of policy impacts in favor of the restoration of beneficial habitats" and group 6 "Large-scale multicriteria studies of innovative scenarios combined with optimization" present approaches that target policy making. Their main difference is the spatial extent, larger in group 6, which prevents the use of habitat suitability approaches. In these two groups, policy recommendations are made on a large range of issues, but the assessment of biodiversity is more uncertain due to the use of simplified approaches of habitat modeling and landscape indicators. These also hamper the understanding of scenario consequences on species temporal dynamics. Finally, group 5 is more oriented towards long-term decision-making aid by co-building scenarios to strengthen decision making regarding the future of agricultural landscapes.

The accuracy with which the dynamic of biodiversity is assessed in agricultural landscapes is greater in groups 1,2 and 3, than in groups 4, 5 and 6. It is not only related to the objective of approaches, but also to the data used. Local to regional studies will most often provide specific complete measurements of richness and abundance with small time steps. This captures precise population dynamics in relation to landscape characteristics (Chiarucci et al., 2011). These time steps allow the use of mechanistic or agent based models of evolution of biodiversity. For instance, the skylark population model used in Guillem et al., (2015) is based on multiple continuous observations, which allowed the simulation of population change on a daily basis. On the contrary, larger spatial analyses will primarily use species-area relationships (e.g., Kreft et al., 2008) (as we observed in group 4, 5 and 6) which require less accurate data in a larger extent and is less constraining in terms of time step with less regular measurements. The need for precise data on a broad scale hampers the development of mechanistic or agent based models, and, scientists therefore need to rely on metrics to assess biodiversity, such as the share of extensively cultivated meadows (Briner et al., 2013). Indeed, large sampling with small time steps are logistically very complicated (Palmer et al., 2002). Therefore, large-scale studies rely on metrics developed in the literature, or on limited data to address the complex processes of biodiversity.

Improving biodiversity conservation in agricultural landscapes requires more precise assessment of the population dynamic of multiple taxa as well as other issues linked with the landowner´s decision and other stakeholders that participate in the management of agricultural landscapes. Combining approaches from disciplinary studies at small scale, understanding species dynamics and its links with landscape complexity, with approaches at a broader spatial scale, using landscape indicators or proxies studied on several species and integrating socio-economic issues and other environmental aspects, could improve biodiversity conservation in agricultural landscapes.

4.2. Increasing the precision of biodiversity modelling in multi-issue studies

The choice of issues targeted by scientists appeared to be a major variable driving the characteristics of approaches. The number of issues and the type of model used were strongly linked. With an increase in the number of issues targeted in studies, the type of model tended to switch from complex types, namely agent-based models and mechanistic models, to more simple habitat models or landscape indicators that do not integrate species behavior or spatially explicit landscape processes. More complex tools, at large scale, could provide a better assessment of the impacts of landscape change on biodiversity, accounting for more drivers of abundance change, which are simplified in groups 4 and 6. In these groups, optimization models were used to design landscapes, but this type of model is only partially spatially explicit (Delmotte et al., 2013) and cannot embrace the full range of spatially explicit drivers and species behavior in biodiversity-based landscape studies. Mechanistic and agent-based models are more appropriate tools because they can account for processes such as behavior, evolutionary and physico-chemical principles that drive the survival and reproduction success of species (Grimm et al., 2017), and also socio-economic aspects of landscape design such as farmers' behavior (Kremmydas et al., 2018). Group 1 "biodiversity-based agent-based models" is a type of approach that models biodiversity change in such a way. This group only focused on biodiversity, although agent-based models were frequently used in policy analysis to improve the sustainability of agricultural landscapes. In these approaches, biodiversity was not included (e.g., Valbuena et al., 2010; Delmotte et al., 2013) and changes in farmers' cropping plans were addressed rather than the consequences of such changes on local or global issues. This supports findings in a recent review of agent-based model application in agriculture by Kremmydas et al., (2018), where two studies out of 32 included biodiversity (Brady et al., 2012; Guillem et al., 2015) (these two studies were also included in our review). Combining the approach of group 1 using agent-based models with findings on species dynamics from approaches from group 3, would help to integrate the influence of landscape complexity on population dynamic in agent-based scenario studies. More interdisciplinarity in the development of agent-based models with landscape indicators developed in approaches from the group 6 to assess economic, social and environmental processes, could allow assessing trade-offs among biodiversity conservation as well as a range of issues of interest for agricultural landscape planning.

4.3. Coupling empirical studies of taxa to broad biodiversity modelling

As our correlation table shows, the behavior of species was seldom accounted for when studies targeted several taxa. Studies focusing on one taxon were very specialized but, when the number of taxa was increased, the processes driving species population were simplified. Typically, in group 2 studies (“expert-based exploration of land use change with GIS”), biodiversity change was integrated with species behavior but the focus was on only one taxon. No study in our dataset approached a broad range of taxa using a mechanistic model or agent-based model that integrated the behavior of species. This reduced number of taxa in the assessment could be limiting in addressing the health of agroecosystems, considering that different taxa respond differently to biotic and abiotic changes. Although some species are indicators that represent the general health of a landscape in terms of biodiversity, we stress the need for accounting for more indicator species. For example, some studies aimed at finding species indicators of agricultural landscapes to represent the overall species richness of other taxa have not been successful (Billeter et al., 2007). This is particularly true in a changing context where global drivers such as climate change modify the state of agricultural landscapes to conditions that could have unknown consequences on species. In these new states, indicator species may react differently than other species. Large biodiversity studies should focus on species with different traits, to monitor the change in the landscape and the trend in biodiversity richness. Typologies of species or individuals based on traits could allow studies such as that by Hoffmann et al., (2016), which split the population of skylarks into individuals i) with territorial behavior, ii) only resting and feeding guests, and iii) overflying individuals without specific territories.

The low number of taxa included in the studies we reviewed is probably due to (1) low availability of data on numerous taxa on a large spatial and temporal extent, which does not allow its use in agent-based models, and (2) lack of information regarding the impacts of some changes in parameters on the population trends of some taxa. This calls for i) better systematization of data collection on populations of a large spectrum of taxa, and ii) more disciplinary studies on parameters driving species change of taxa abundance across agricultural landscapes. According to Wetzel et al., (2018), there is a need to unlock biodiversity data and form large-scale networks for systematic data collection, to help understand species location and drivers and integrate these data in models and scenario studies. Moreover, prediction of biodiversity change would improve future disciplinary studies addressing various drivers of population related to landscape characteristics, e.g., habitat requirements (Steen et al., 2012), predation (Luo et al., 2018), and biotic parameters (temperature, light, etc.). Grimm et al., (2017) call for the development of “re-usable sub models to represent behaviors and mechanisms such as growth, uptake of nutrients, foraging, that could be applied to large areas of study. Typically, this type of model is used in group 2 and 3 and focuses on the species’ behavior and landscape complexity impact on biodiversity conservation. We believe that a generic model of species populations could be built and calibrated following the same type of structure as crop models developed for modeling crop growth that encompass large numbers of species, from annual to perennial, growing under different climate conditions (Brisson et al., 2003; Jones et al., 2003; Keating et al., 2003). Ecological studies at small scale could provide information on key processes related to species’ behavior, such as reproductive rate and nesting conditions, as well as landscape complexity. This production of knowledge on several taxa could be combined with the search and application of landscape indicators that could be used on larger scales such as the approaches in group 6.

4.4. Participatory process to develop more transformative scenarios

Solving complex and dynamic environmental problems requires flexible, transparent decision-making and innovative solutions (Reed 2008). Such solutions are embodied in complex “system” or "transformative" scenarios. In the studies reviewed here, this type of scenario was more frequently developed in a participatory process. This is due to the amount of knowledge needed in order to describe how a set of drivers may change in time following several directions, and the impacts of local agricultural systems. The choice of model to represent the landscape seems to guide the type of scenario that can be built. To develop complex scenarios, models should be able to represent several inputs of landscape that can be manipulated by the modeler. Statistical models seem inappropriate, because the processes behind land use change are not clearly described, but based on regression coefficients describing the probability of change from one land use to another. Hence, this type of model is rarely used in participatory processes, as mentioned by Verburg et al., (2006), who showed that stakeholders question the results of such models. For optimization models, the literature shows the same problem, with some difficulties for stakeholders in understanding the functioning of the model and being able to modify the model to produce scenario impacts (Sterk et al., 2007). However, this issue could be overcome with iterative modelling steps and indicator contextualization with stakeholders (Delmotte et al., 2017). In agent-based models, stakeholder participation often occurs and they may even contribute to building the model, using it, and assessing scenarios, as in the companion modelling approach (Antona et al., 2005; Hossard et al., 2013). In group 5 "participatory simulation studies of landscape futures", stakeholders are typically involved in the choice of models, the scenario definition, and the assessment process. They are not simply consulted or asked to provide expertise. In the study by Drum et al., (2015) for instance, stakeholders worked in several workshops to develop a conceptual framework that describes the complex components of landscape and biodiversity change. This participatory process allows for more exchange on the functioning of the system and on concepts across disciplines. The inputs of stakeholder participation in scenario analysis have been recognized as an important contribution to build knowledge and implement actions. Landis (2017) states that "Designing agricultural landscapes will require that scientists work with stakeholders to determine the mix of desired ecosystem services, evaluate current landscape structure in light of those goals, and implement targeted modifications to achieve them". The future of biodiversity depends on actions taken today by a variety of stakeholders to overcome the complexity that creates its conservation (Couix and Hazard, 2013). More participatory scenario generation and collective visioning are urgently required to enable policy developments and broad societal consensus on biodiversity conservation based on sound science (Hill et al., 2013).

4.5. Merging agronomy and ecology into landscape science

Integrating stakeholders is a necessary condition in the development of complex scenarios, but improving the biodiversity abundance and the sustainability of agricultural landscapes will also require more integrated studies with various disciplines and scientists, especially agronomists and ecologists. In this review, we found that the distinct group 3 studies on "land use approaches of biodiversity with spatially explicit statistical model" and group 4 studies on "bioeconomic modeling of policy impacts in favor of restoration of beneficial habitats" used different representations of the landscape, with a land cover description for group 3 and a crop perspective for group 4. Both types also used different model types, with group 3 using statistical models very typical of ecologists and group 4 using bioeconomic model that are typical of agronomists/agro-economists. These two groups thus display a disciplinary difference in model use. Both types of approaches could be combined to better account for the diversity of cropping systems, species behavior and landscape complexity. The combination would allow disaggregating land uses in regression models and accounting for the area covered by the different cropping systems, rather than only land cover. Using a typology of farming or cropping system at landscape level could benefit the analysis, by grouping cropping systems based on traits affecting biodiversity population (soil disturbance, pesticide use). Moreover, for each type of cropping system, the habitat value could be measured or estimated based on the characteristics of the system (Puig-

Montserrat et al., 2017). On the other hand, studies of agricultural system change impact on biodiversity are seldom addressed with statistical models describing the spatial configuration of agricultural landscapes. There is a general lack of landscape variables addressing the configuration of landscape, the aggregation of crops, or the connectivity of habitats. In addition, we noted that optimization models were usually used for optimization of farmers' revenue, while maximization of biodiversity abundance could provide some interesting solutions to solve the biodiversity issue. This disciplinary difference has already been noted by some authors, e.g., Benoît et al., (2012) call for landscape agronomy that is the "interdisciplinary integration of farming systems in wider landscape research". Agronomy to date has predominantly focused on field performance, with a lower interest in interactions between farming practices and landscape processes through which biodiversity change occurs. When addressing landscape dynamics, scientists should focus on the interactions between landscape organization, natural resources like biodiversity status, and farming practices applied at field level.

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List of Figures and Tables

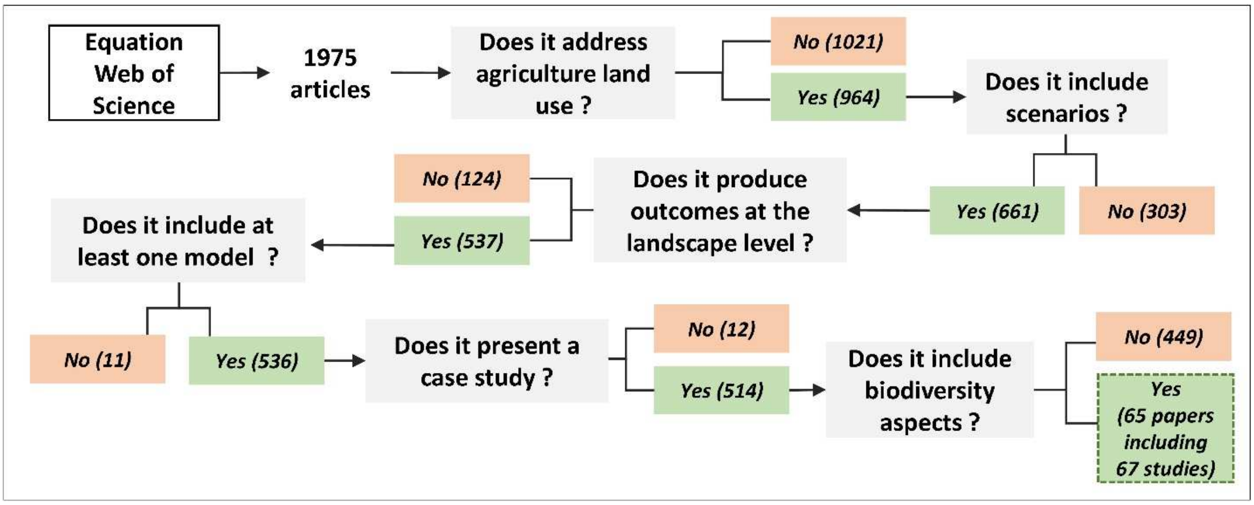

Figure 1: Procedure followed in the selection of published studies for this review.

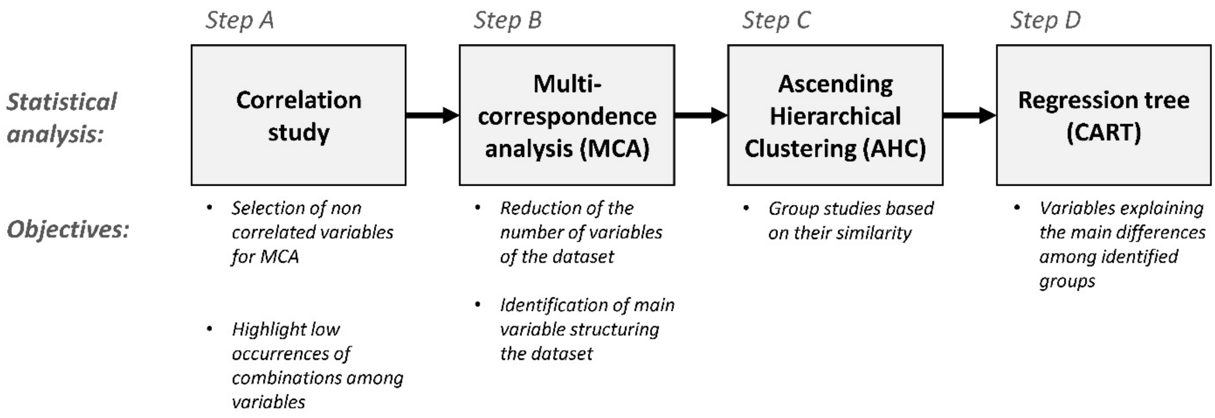

Figure 2: Statistical analysis of variables extracted from the case studies.

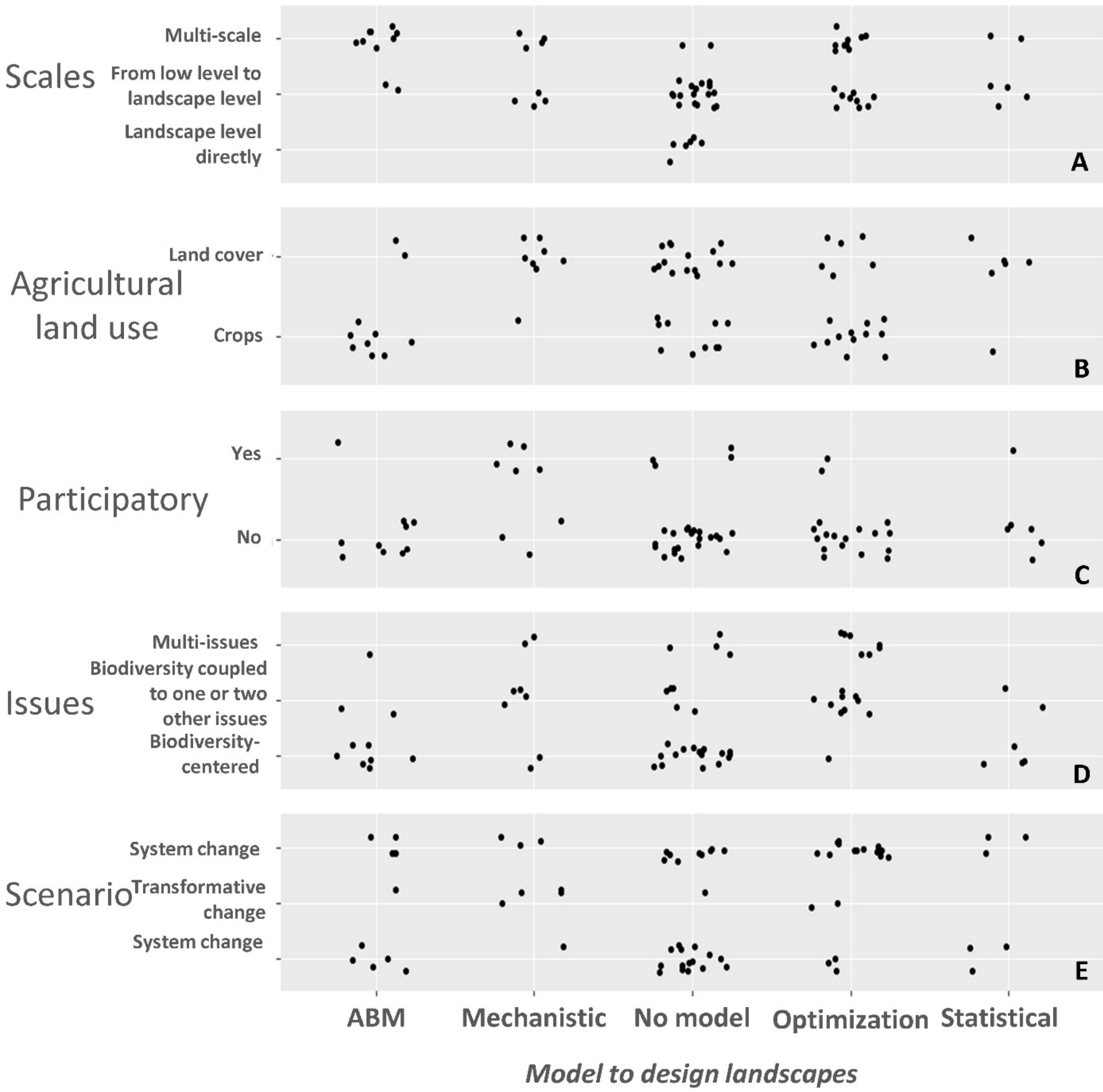

Figure 3: Plot of studies crossing "model to design landscape" with significantly correlated variables.

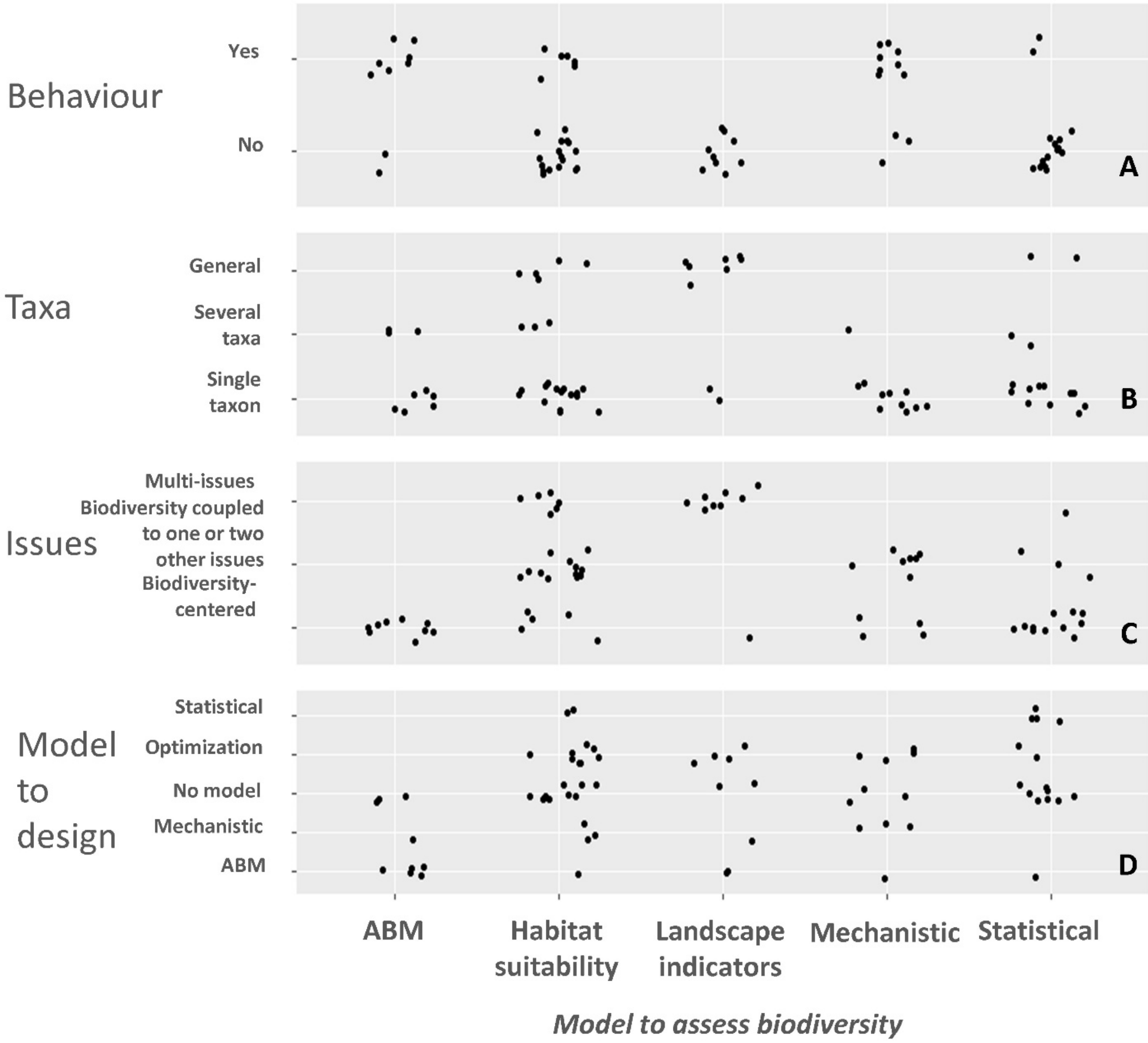

Figure 4: Plotting of studies crossing "model to assess biodiversity" with significantly correlated variables.

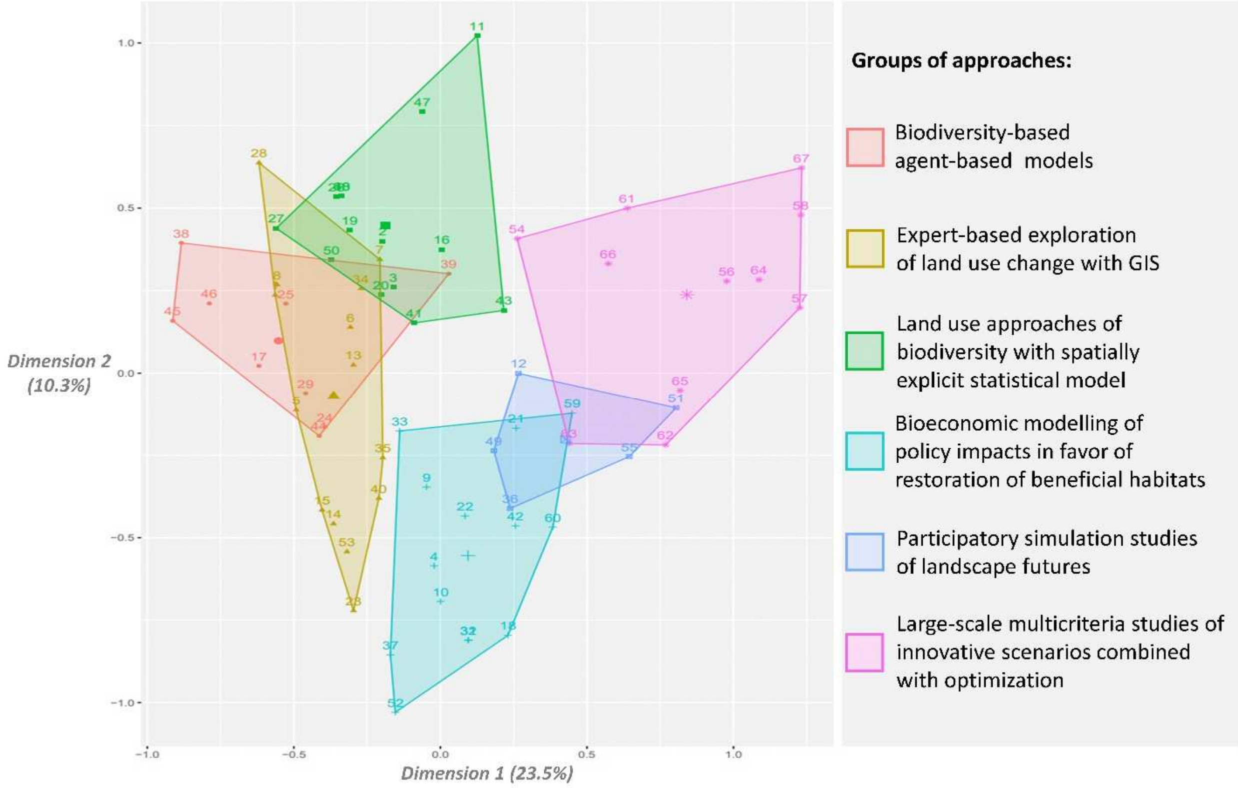

Figure 5: Location of studies on the two first multiple correspondence analysis (MCA) axes.

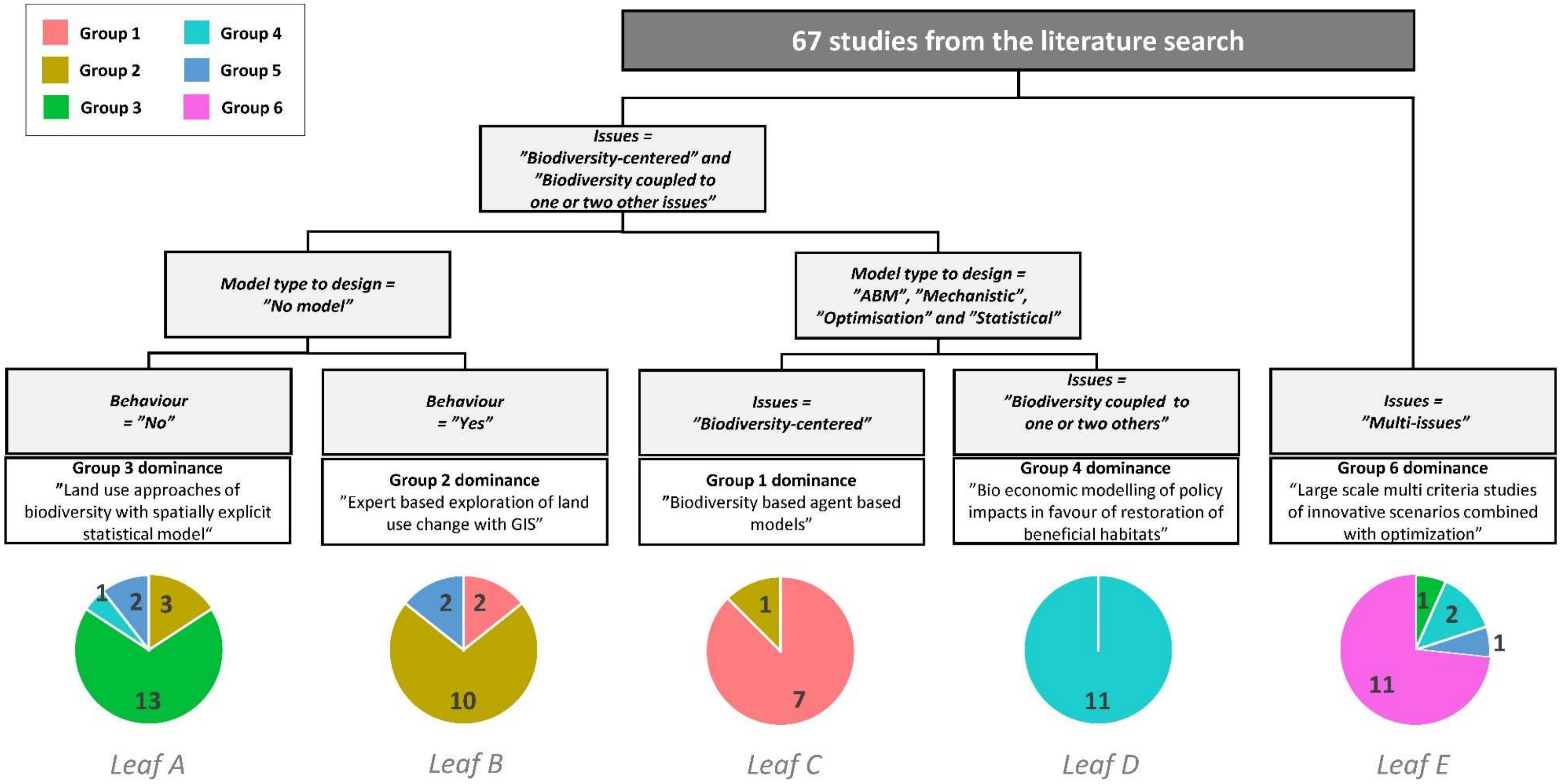

Figure 6: Regression tree showing the variables best explaining the classification of studies obtained with ascending hierarchical clustering (AHC). Thresholds for categorizing studies are enclosed in light grey boxes and the different groups of studies identified by the regression tree are given in white boxes. The pie charts represent the proportion of each group from the AHC included in each group obtained with the regression tree represented as leaves (A-E).

Table 1: The five variable categories, variable name, abbreviation, type, and sub-categories, and frequency of occurrence (n) in the selected papers

Category	Qualitative variable	*Abbreviations*	Ordinal/ Nominal	Subcategories	n
Spatial characteristics	Extent	*Extent*	Ordinal	<= 100 km^2	17
				100-1000 km^2	24
				>1000 km^2	26
	Spatial scales	*Scales*	Ordinal	Landscape level only	6
				From low level to landscape level directly	36
				Multi-scale (at least three scales)	25
Landscape description	Agricultural land use precision	*Agricultural land use*	Nominal	Land cover	35
				Crops	32
	Type of change of land use	*Landscape change*	Nominal	Change of activity	33
				Change of intensity	7
				Change of activity and intensity	27
Biodiversity	Spatially explicit process driving biodiversity change	*Landscape system factor*	Nominal	Yes	26
				No	41
	Species behavior	*Behavior*	Nominal	Yes	23
				No	44
	Number of taxa	*Taxa*	Ordinal	Single taxon	44
				Set of taxa	9
				General biodiversity	14
Scenario	Participatory	*Participatory*	Nominal	Yes	13
				No	54
	Issues addressed	*Issues*	Ordinal	Biodiversity coupled to one or two other issues	22
				Multi-issues	15
				Biodiversity-centered	30
	Drivers of landscape change	*Drivers*	Nominal	Single driver	54
				Multiple drivers	13
	Scenario types	*Scenario*	Nominal	Simple change	27
				System change	32
				Transformative change	8
Modeling	Model to design landscapes	*Model to design*	Nominal	Agent-based model	10
				Mechanistic model	8
				Optimization model	18
				No model to design	25
				Statistical model	6
	Model to assess biodiversity	*Model to assess*	Nominal	Agent-based model	9
				Mechanist model	11
				Habitat suitability	23
				Landscape indicators	9
				Statistical model	15

Table 2: Correlations among the 13 variables. Chi-square tests were performed to test the significance of correlation among nominal variables and between nominal and ordinal variables. Strength of the correlation was assessed using Cramer´s test value, with a value between 0.2-0.4 indicating a slight correlation, 0.4-0.6 indicating a moderate correlation and a value above 0.6 a strong correlation. Correlations among the ordinal variables were tested using the Goodman-Kruskal gamma test, with values ranging between 0 (no correlation) and 1 (perfect positive correlation)

		Extent	Scales	Agricul-tural land use	Landscape change	Landscape factor	Behavior	Taxa	Participa-tory	Issues	Drivers	Scenario	Model to design	Model to assess
		Ordinal	Ordinal	Nominal	Nominal	Nominal	Nominal	Ordinal	Nominal	Ordinal	Nominal	Nominal	Nominal	Nominal
Extent	Ordinal		-	-	-	-	X^2 = 11.08 pval<0.01*** Cramer= 0.41	-	-	X^2 = 16.87 Pval<0.01*** Gamma= 0.36	-	-	-	-
Scales	Ordinal			X^2 = 7.57 Pval =0.02** Cramer= 0.34	-	-	-			-	-	-	X^2 = 25.19 Pval<0.01*** Cramer= 0.43	-
Agricultural land use	Nominal				-	-	-	-	-	-	-	-	X^2 = 13.66 Pval<0.01*** Cramer= 0.45	-
Landscape change	Nominal					-	-	-	-	-	-	-	-	-
Landscape factor	Nominal						-	-	-	X^2 = 7.36 Pval<0.025** Cramer= 0.33	-	-	-	-
Behavior	Nominal							X^2 = 14.26 Pval<0.01*** Cramer= 0.33	-	X^2 = 6.59 Pval=0.04** Cramer= 0.31	-	-	-	X^2 = 23.06 pval<0.01*** Cramer= 0.59
Taxa	Ordinal								-	-	X^2 = 7.43 Pval<0.02** Cramer= 0.33	-	-	X^2 = 26.34 Pval<0.001* Cramer= 0.59
Partici patory	Nominal									-	-	X^2 = 20.08 p-val<0.01*** Cramer= 0.55	X^2 = 11.07 Pval=0.02** Cramer= 0.41	-
Issues	Ordinal										X^2 = 10.38 Pval<0.01*** Cramer= 0.39	-	X^2 = 21.52 Pval<0.01*** Cramer= 0.40	X^2 = 50.55 Pval<0.01*** Cramer= 0.61
Drivers	Nominal											X^2 = 13.88 p-val<0.01*** Cramer= 0.46	-	-
Scenario	Nominal												X^2 = 21.88 pval<0.01*** Cramer= 0.40	-
Model to design	Nominal													X^2 = 32.10 pval<0.01*** Cramer= 0.35

Table 3: Description of the six groups of approaches and the most frequent category of each variable when one was overrepresented. Overrepresentation was tested with V-test. A value between 2 and 3 denotes slight overrepresentation of the factor value in the group (*), a value between 3 and 5 denotes moderate overrepresentation (**) and a value above 5 represents important overrepresentation (***) (Husson et al. 2015). No overrepresentation is indicated with "–"

	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**
Name given to the group	Biodiversity-based agent-based models	Expert-based exploration of land use change with GIS	Land use approaches of biodiversity with spatially explicit statistical model	Bioeconomic modelling of policy impacts in favor of restoration of beneficial habitats	Participatory simulation studies of landscape futures	Large-scale multicriteria studies of innovative scenarios combined with optimization
Case study in the center of the group	Study 45 Topping et al. 2015	Study 15 Everaars et al. 2014	Study 2 Benett et al. 2014	Study 9 Chiron et al. 2013	Study 12 Drum et al. 2015	Study 66 Kniess et al. 2016
Number of studies the group	9	14	14	14	5	11
Extent	-	-	-	-	-	>1000 km^2 **
Spatial scales	Multi-scale*	From low level to landscape level directly*	-	-	-	-
Description of land use	-	-	Land cover **	Crops **	-	-
Type of change of land use	-	-	-	-	-	-
Spatially explicit process driving biodiversity change	-	-	Yes*	-	-	-
Species behavior	Yes *	Yes**	No*	-	-	-
Number of taxa	-	Single taxon **	-	-	-	General biodiversity**
Participatory	-	No*	-	-	Yes**	-
Issues addressed	Biodiversity centered **	-	Biodiversity centered **	Biodiversity coupled to other issues **	-	Multi-issues ***
Drivers of landscape change	-	-	-	Single driver *	-	Multiple drivers**
Scenario types	-	-	-	System change *	Transformative change**	Transformative change**
Model to design landscapes	Agent-based model **	No model to design **	Statistical model** No model to design**	Optimization model**	Mechanistic model **	Optimization model **
Model to assess biodiversity	Agent-based model **	-	Statistical model**	Habitat suitability**	-	Landscape indicators ***