Chapter 8
Review of the Impacts on Biodiversity of Land-Use Changes Induced by Non-food Biomass Production

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Abstract Over the last few decades, much emphasis has been put on using biomass and other renewable resources for energy production. In a context of increasing human population, global biodiversity decline and rapid climate change, expanding land clearance for bioenergy crop cultivation raises many concerns about the competition for agricultural land use between food, feed, and fibre production. Expanding land for bioenergy therefore challenges the sustainability of agricultural systems as well as its environmental impact. Several studies have attempted to quantify these impacts of land use change (LUC), however they do not take into account the causal chain from "the drivers of LUC to the impact assessment" which is required to understand the underlying mechanism.

The work is part of a global project assessing the impact of LUC toward bioenergy crops cultivation considering the causal chain. Here, we review studies assessing how land-use shifts towards bioenergy crops impact biodiversity. The review first reveals that very few studies have assessed biodiversity by considering the whole causal chain. Despite this, a general consensus emerges on a negative impact on biodiversity of bioenergy crops cultivation. This study also points out the diversity of metrics used to assess biodiversity, from species richness to proxies such as habitat quality. Overall, this review suggests that a sounder quantification of the effect of LUC toward bioenergy crops cultivation could be obtained by using more accurate metrics both for biodiversity (i.e. coupling taxonomic and functional diversity indices, and selecting relevant taxa) and the characterization of the environment (i.e. landscape configuration and composition, and the integration of management practices).

Keywords Biofuels · Bioenergy · Biomass · Land-use change · Biodiversity · Landscape configuration · Landscape management · Pollinators · Birds

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8.1 Introduction

Agricultural land covers nearly one quarter of the Earth's terrestrial surface (Vitousek et al. 1997) being the principal land use at the French (~ 52%) and European levels (~ 42%). For long, agricultural lands have been managed to provide food, fibre, and wood product. In order to meet a growing demand for these products, human activities disrupted the global environment, resulting in profound and unsustainable alterations to land use, water fluxes, biogeochemical cycles, atmospheric chemistry and distribution and dynamics of biodiversity worldwide (Pimm 1995; Chapin et al. 2000; Lambin et al. 2013). Over the last few decades, due to concerns about the negative impacts of human dependence on fossil resources, much emphasis has been put on relying more on biomass and other renewable resources for energy production Chum et al. (2011) calling for the production of biofuel (liquid fuel derived from plant material). In a context of increasing human population, global biodiversity decline and rapid climate change, expanding land clearance for bioenergy crop cultivation raises concerns about the competition for agricultural land between food, feed, and fibre production, hence challenges the sustainability of agricultural systems.

Expanding land use for bioenergy feedstock production can cause direct land-use changes (dLUC) on a farm or forest plantation as well as indirect LUC (iLUC) through the displacement of previous land uses to other locations. Several studies have therefore been conducted to investigate the consequences of land-use, LUC and iLUC toward non-food feedstock production (reviewed in Fritsche et al. 2010). LUC and iLUC concerns both the production of first-generation liquid biofuels from food crops (such as sugarcane, palm oil, oilseed rape, corn, wheat) and ligno-cellulosic feedstocks for second-generation biofuels (such as miscanthus, switch-grass, salix, and eucalyptus). However, most of the studies investigated LUC (or iLUC) without taking into account the drivers of LUC and their impacts (Van Vliet et al. 2016), thus limiting the ability to elucidate the mechanisms relating feedstock production to LUC and their impacts on the environment.

A project was therefore set up to fill this gap. This study consisted in reviewing the studies that analysed the impact of LUC and iLUC induced by bioenergy crops cultivation as a three-step causal chain: drivers of feedstock production, LUC occurring in response to this demand – whether direct or indirect, and impact assessment along various dimensions, such as greenhouse gas (GHG) emissions, biodiversity, water resources, soil quality, or atmospheric pollution. The review presented here is part of this project and aims to provide an overview of the issues relating to direct and indirect land use changes that could result from growing energy crops and their impact on biodiversity. Biodiversity plays a crucial role in the delivery of a range of ecosystem services such as nutrient and water cycling, pollination and soil formation (Hooper et al. 2005; Balvanera et al. 2014). At the same time biodiversity is increasingly threatened by climate change and human activity through the massive use of pesticides and habitat loss.

8.2 Materials and Methods

8.2.1 Literature Survey, Definition and Analysis of a Relevant Set of References

The general review (see Réchauchère et al., Chap. 1, this volume) covers studies (i) published from 1975 to early 2015, (ii) featuring keywords related to land-use changes, (iii) including the three steps of the drivers to impact causal chain, and (iv) in which the types of end-product(s) and biomass feedstocks were specified. At least one category of environmental impacts among the following had to be assessed: climate (including GHG emissions), consumption of non-renewable resources, biodiversity, water resources, soil quality, atmospheric pollution, human health, and ecotoxicity. We performed a comprehensive search on Web of Science and Centre for Agricultural Bioscience last updated in February 2015. It provided a preliminary list of 5730 articles. The abstract, title and keywords of each article were read independently using an automated textual analysis (for more details see Réchauchère et al., Chap. 1, this volume). A subset of articles (i.e. 1785 articles) studying the impact of biomass/bioenergy through LUC effects was further screened by a dozen of experts in the fields covered by this literature (economics, ecology, agronomy, forestry, and sustainability assessment), and winnowed down to 241 references. These were further analysed in details in terms of scope, LUC types, methodologies employed, and overall impacts of biomass production.

8.2.2 Description of the Set of Articles

Among the 241 articles retained by the experts, only 15 articles investigated the impact on biodiversity of land use or land use changes incurred by bioenergy production (Table 8.1). The studies were generally performed in developed countries (Europe and the US). LUC was either directly studied or investigated by comparing the impact of a biomass crop with another land use in the same landscape (e.g. Stanley and Stout 2013). The impact of LUC on biodiversity was a topic more recently addressed in comparison with other impacts in the overall set of articles (see e.g. Bessou, Chap. 4, in this volume on soil quality or Bamière and Bellassen on greenhouse gas emissions, Chap. 6, in this volume) since more than 80% were published after 2009. From a qualitative point of view, the last decade was characterized by the development of studies investigating biodiversity and ecosystem services (Villamor et al. 2014).

Table 8.1 Description of the studies. An empty indicates that the information was not found in the article

References	Publication Year	Study Localization	Drivers	Scale	Number of energy crop species	Type of enery crop species	Type of biodiversity metrics
Alkemade *et al.*	2009	All world regions	Climate change mitigation through energy policy	Continent global		Wood	Mean species abundance (MSA)
			Shift of wood production toward sustainable managed plantations				
Alvarenga *et al.*	2013	Brazil (Amazonia)	Production of bioethanol to fit an increasing demand	Region	1	Sugarcane	LCIA
Baral *et al.*	2013	Australia	European settlement in the early 1850s	Region	2	Pinus Eucalyptus	Relative capacity of each land use and land cover to support habitat of flora and fauna based on the presence of threatened species, patch size and connectivity.
Brandt and Glemnitz	2014	Germany	Cultivation of biomass crops for energy supply	Farm	1	Maize	Habitat suitability
Death *et al.*	2003	New Zealand		Stream catchments	1	Pinus	Species richness, abundance, several diversity and community indexes.

Einheuser *et al.*	2013	US	Demand for biofuel crops with prices not competitive enough with other agricultural production on fields	Watershed	4	Canola maize	Habitat suitability estimated with Hil-senhoff biotic index (HBI), family index of biological integrity (family IBI), and number of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT taxa)
			Demand and price for biofuel crops is higher than all other agricultural production			Miscanthus switchgrass	
Engel *et al.*	2012	Germany	Cultivation of biomass crops for energy supply	Field	1	Willow	
Garcia-Quijano *et al.*	2005	Belgium		Region	5	Association of oak and Beech Miscanthus Pine Poplar	Species richness
Haughton *et al.*	2009	UK		Region	2	Miscanthus and willow	Skylark abundance, breeding success, availability of food and habitat diversity
Helin *et al.*	2014	Scandinavia		Country	1	Reed canary grass	LCIA
Lindborg *et al.*	2009	Sweden	Cultivation of biomass crops for energy supply	Region		Bioenergy crops i.e. short rotation coppice, annual energy crops and permanent leys.	Amount of suitable habitat area, number of suitable habitats, and number of connected groups of habitats.

(continued)

Table 8.1 (continued)

References	Publication Year	Study Localization	Drivers	Scale	Number of energy crop species	Type of enery crop species	Type of biodiversity metrics
Louette *et al.*	2010	Europe	Policy of large-scale second generation bioenergy crops cultivation throughout Europe	Country	2	Willow and poplar	Sensitivity scores to land use changes
Murdiyarso *et al.*	2002	Sumatra		From field to region	1	Rubber	Species richness
Stanley and Stout	2013	Irland		Field	2	Oilseed rape and miscanthus	Abundance and diversity
Villamor *et al.*	2014	Sumatra	Payments for ecosystem services (PES) schemes to sustain rubber agroforests	Region	2	Rubber and oil palm	Species-area relationship

8.3 Results

8.3.1 Drivers of Land-Use Change

Although a wide range of LUC drivers have been investigated in the overall set of articles on LUC and bioenergy, all of those involving biodiversity impact were anthropogenic. The main driver was the cultivation of biomass crops for energy supply (25% of the set of articles). Another important driver studied in the set of articles was the impact of public policies such as climate change mitigation through energy policy, or policies targeting a large-scale second generation bioenergy crops cultivation (Table 8.1).

Considerable attention has been given to annual crops from which biofuels can be produced, including maize, oilseed rape and sugar cane (Table 8.1). However, little attention has been paid to other feedstock options based on stems, stalks, or woody components of trees (so-called ligno-cellulosic feedstocks). Perennial crops, which do not need to be replanted after each harvest, such as grasses and fast-growing trees, were also of studied.

8.3.2 Land-Use Change Scenarios

Several types of LUC were studied in the set of articles (Table 8.2). LUC occurred over a broad range of spatial scales from small territories (ca. 300 km^2 in area), through watersheds, to continents (Table 8.1). The majority of the studies (9) investigated the impact of LUC induced by biomass crops cultivation using both retrospective and prospective approaches. The retrospective approach alone was rarely used (only in two studies). Fourteen LUC scenarios were analyzed in the set of articles, the majority of which investigated the conversion of forest into forest, arable land, perennial crop or grassland. As examples, (Alkemade et al. 2009) investigated the impact of an increase in forest plantations to meet the growing demand of 30% wood by 2050 on biodiversity, while Einheuser et al. (2013) and Stanley and

Table 8.2 Description of the Land Use Change in the set of articles. The number represents the number of scenarios for which a LUC from a land use in column to a land use in row was studied. For example, 3 scenarios studied the impact of a LUC from grassland to forest on biodiversity. Some LUC can occur within a category. For instance, a winter wheat crop (arable crop) can be replace by an oilseed rape crop for energy production

From To	Forest	Arable crops	Grassland	Wetlands	Artificial land	Perennial crops
Forest	3	1	3	0	0	0
Arable crops	2	2	2	1	0	0
Perennial crops	3	7	5	1	1	1
Grassland	2	0	0	0	0	0

Stout (2013) were interested in the impact of meadow conversion to second generation biomass crops.

In the set of articles, the drivers generally affected changes in landscape composition. However, LUC driven either by an increase in bioenergy supply or by public policies can also affect landscape configuration. Only two studies among the 15 investigated the impact of LUC on landscape configuration (Engel et al. 2012; Brandt and Glemnitz 2014), that is to say the distribution of new land-uses (aggregation *versus* random) and/or their cultivated area (i.e. patch size for bioenergy crops).

LUC were characterized with three methodologies: (i) models parameterized with data from meta-analyses or literature reviews for most of the articles (e.g. Alkemade et al. 2009; Nelson et al. 2010), (ii) empirical analysis of land cover data (e.g. based on aerial photographs) or (iii) in fewer cases, *in situ* measurements (usually for estimating species abundances).

8.3.3 Metrics Measuring Biodiversity

A variety of metrics was used to analyze the impact of LUC on biodiversity based either on populations, species or group of species or through proxies. In the latter case, biodiversity was addressed indirectly by (i) a valuation of the suitability of the habitats (biodiversity value being higher in grasslands than in plantations (Baral et al. 2013), (ii) the impacts of human activities as proxy of their effects on biodiversity such as the risk of pesticide pollution (Viglizzo et al. 2011) or the artificial change of water balance (Garcia-Quijano et al. 2005), as well as (iii) measurements through life cycle impact assessment (LCIA) in which biodiversity is estimated through land use following (de Baan et al. 2013a). When biodiversity was directly measured, the studies analyzed the change in species richness (i.e. the number of species) or number of families (Louette et al. 2010; Einheuser et al. 2013), in the abundance of a given species (Engel et al. 2012), or the change of groups of species (Stanley and Stout 2013; Brandt and Glemnitz 2014). Species richness was mainly estimated by *in situ* measurements, although species richness was sometimes estimated indirectly using species-area relationship (Preston 1960). Several studies mainly focused on the impact of LUC on a single guild or a smaller number of species to the exception of (Louette et al. 2010) who retained a set of 754 species that were considered as a representative sample of terrestrial European biodiversity. Two other studies also focused on species typical of the studied environments taking into account the species needs in terms of habitat (e.g. cover and vegetation height, amount of food available) and the dynamics of their populations (e.g. breeding period, reproductive success; (Engel et al. 2012; Brandt and Glemnitz 2014)). The species studied were farmland bird species such as skylarks (*Alauda arvensis*) or lapwing (*Vanellus vanellus*) (Brandt and Glemnitz 2014).

8.3.4 Methods for Analysis the Impact of LUC

The impact of the LUC on biodiversity was generally explored with mechanistic models (e.g. Alkemade et al. 2009; Engel et al. 2012; Brandt and Glemnitz 2014; Villamor et al. 2014) or comparative approaches (e.g. biodiversity in arable crop *versus* biodiversity in bioenergy crops (Stanley and Stout 2013)).

Changes in abundance were usually estimated using a reference abundance value. For instance, (Alkemade et al. 2009) quantified the impact of LUC on biodiversity using the remaining mean species abundance (MSA) relative to their abundance in pristine or primary vegetation which are assumed to have been disturbed by human activities for a prolonged period. MSA was estimated from 89 studies selected in the WoS taking into account the minimum area necessary for organisms, and co-variables such as land use (forest plantations, grasslands, agroforestry …). Others, such as Helin et al. (2014), used indicators such as the biodiversity damage potential (de Baan et al. 2013a) or the potential of non-endemic species loss (de Baan et al. 2013b).

8.3.5 Impacts of LUC on Biodiversity

Whatever the metric used, the approach (modeling or empirical analysis), or the organism of interest, studies showed that land-use shifts (i.e. crop or forest establishment) toward bioenergy crops resulted in a significant loss of biodiversity. For example, 18% of species were negatively affected by the production of wood energy; reptiles, butterflies, birds being the most affected (Louette et al. 2010). Losses of 30% of biodiversity were predicted with a 20% increase of agricultural land to produce non-food biomass (Alkemade et al. 2009).

LUC also lead to changes in species community composition through species replacement or change in the relative abundance of the species in the community. For instance, Brandt and Glemnitz (2014) observed an increase of lapwings (*Vanellus vanellus*) and pies backed Shrikes (*Lanius collurio*) due to a potential increase of food availability in the new habitats (here maize grown to provide biofuel instead of winter barley and oilseed rape). Change in the composition of plant communities was also observed across Europe in dLUC from non-forested lands toward second generation bioenergy crops (mainly willow Salix spp. and poplar *Populus spp*.) (Louette et al. 2010), although this effect was much lower than on reptiles, butterflies and birds. The logging of *Pinus radiata* in New Zealand had also a strong effect on the composition of invertebrate communities of streams draining the catchment: species richness decreased, while the total abundance of invertebrates increased resulting in a less even community (Death et al. 2003).

Although rarely tested (in only two studies (Engel et al. 2012; Brandt and Glemnitz 2014), the spatial organization of dLUC had a significant role on farmland birds by changing landscape configuration. This effect was even more important than change in land use as such change in crop richness (landscape composition). An aggregated distribution of bioenergy crops had a greater impact on skylark (*Alauda arvensis*), corn bunting (*Miliaria calandra*), lapwing (*Vanellus vanellus*), whinchat (*Saxicola rubetra*) and red-backed shrike (*Lanius collurio*) than a random distribution (Brandt and Glemnitz 2014), resulting in a stronger population abundance decline. Similarly, an increase in the average field size was associated with a considerable decline in the abundance of skylarks, up to 86% in the bioenergy crop scenario (Engel et al. 2012). These findings also raise questions about the minimum distances between favorable biodiversity habitats to sustain biodiversity. Overall, these results question the type of scenarios that need to be examined when considering the impact of dLUC on biodiversity. For instance, Garcia-Quijano et al. (2005) addressed the environmental impact of dLUC (multifunctional forest, short rotation coppice and miscanthus). They suggested to favour scenarios with little land use and a moderate impact per hectare (e.g. local short rotation coppice) over scenarios with high land use and low impact per hectare (e.g., local multifunctional forest scenario), to reduce the impact of the LUC. Such output could be useful to define management options for biodiversity conservation.

8.3.6 Lignocellulosic Crops: A Dual Effect on Biodiversity

Although we observed a consensus on the negative impact of the implementation of bioenergy crops (1st or 2nd generation biofuels) on biodiversity, lignocellulosic crops') could have a beneficial effect on biodiversity compared to arable crops. For example, Einheuser et al. (2013) have demonstrated a positive impact of bioenergy crops, such as miscanthus, switchgrass, and native grasses, compared to arable crops on macroinvertebrates through the upgrading of water quality. However, this effect was balanced by the negative impact of the cultivation of these bioenergy crops on fish species through a detrimental effect on the quality of the water draining from the field (Einheuser et al. 2013). This highlights the importance of simultaneously considering several guilds. Replacing winter wheat by miscanthus crops can also result in an increase in the abundance of hoverflies (up to 17%) or wild pollinators (Stanley and Stout 2013). This result was expected since miscanthus crops have abundant floral units that provide nectar and pollen resources for pollinators, which is not the case of winter wheat. The same results were observed when increasing rape crops for bioenergy production instead of alternative crops without floral resources. Therefore, bioenergy crops can be beneficial to pollinators in landscape with poor floral resources, when instead of non-flowering crops.

8.4 Discussion

Two major findings emerged from this literature review on the impact on biodiversity of LUC toward bioenergy crops: the unexpected small number of studies on the impact of LUC on biodiversity, and the large consensus on the negative impact of LUC on biodiversity.

The limited number of studies investigating the impact of LUC toward bioenergy crops on biodiversity can be explained by the delineation of the set of articles. It was performed to fit specific criteria among which the necessity to analyze the LUC toward bioenergy crop as a three-step causal chain (drivers of feedstock production, LUC occurring in response to this demand, and impact assessment). Indeed a recent study found 59 meta-studies that assessed the impact of land use in the broader sense on biodiversity, species richness or related indicators are dominant (van Vliet et al. 2016). Therefore, we may expect that more articles investigating the impact on biodiversity of LUC due to bioenergy crops if we relax some criteria. However, this number of studies may remain limited compared to the studies assessing the impact of LUC due to energy crops on air, water or climate. Indeed, energy crops have been implemented to reduce the environmental footprint of fossil energy such as the emissions of CO_2 (see Bamière and Bellassen, Chap. 6 and Réchauchère et al., Chap. 1, this volume).

The consensus on the negative impact on biodiversity of LUC toward bioenergy crops is in accordance with outcomes of earlier studies assessing the impact of bioenergy crops cultivation as well as those investigating the impact of land use or LUC for food production on biodiversity (Mendenhall et al. 2014; Newbold et al. 2015). Similarly to food production, cultivating energy crops generally required the conversion of natural or semi-natural habitats into cropland. However forests or semi-natural habitats provide food and shelter for many organisms (Tscharntke et al. 2012), and are thus important to sustain biodiversity. Consequently, annual crops, perennials grasses and woody species cannot be considered as similar with respect on their effect on biodiversity, and separate assessment of the effects of this different LUC needs to be performed.

The analysis of the set of articles raises several methodological questions. Most of the studies used qualitative or empirical relationships between habitat characteristics and biodiversity, species richness or changes in average local species abundance according to global repository (e.g. MSA). Species richness, for instance, may not be sufficient to accurately assess this impact of the LUC. Species richness, i.e. the number of species, does not take into account all aspects of biodiversity such as species turnover, or change in species abundance. For instance, LUC may change community evenness by increasing the number of rare species, without affecting or only to a slight extent species richness. Moreover, none of the 15 articles investigated the effect of implementing bioenergy crops on the functional diversity although it can be a reliable proxy for the processes driving community assembly

(McGill et al. 2006) or the role of biodiversity on ecosystem functioning (Diaz et al. 2011). Using a set of metrics covering species richness, species relative abundance and functional diversity would be a useful approach to consider simultaneously the impact of LUC on biodiversity and its consequences on ecosystem functioning.

Most of the assessments of the impact of LUC on biodiversity were performed with mechanistic models or life cycle impact assessment. The outcome of the studies mainly relies on the values of parameter estimates which were generally taken from the literature. However, none of the articles in the set we identified here included a sensitivity analysis to evaluate the robustness of their results with regard to the parameter values. Moreover, the modeling approach usually considered fixed landscapes. Agricultural landscapes are highly variable environments that change rapidly from year to year because of annual crops (among which first generation biofuel feedstocks). These environmental changes can greatly affect the demographic characteristics of organisms, because of changes in the availability of resources or habitats. Therefore, including the temporal dynamics of the landscape, even for assessing the impact of perennial crops, may be very valuable to investigate the impact of energy crop on biodiversity. Improvement is that needed while using mechanistic models or LCA for assessing the impact of LUC on biodiversity. Seven best-practice recommendations that can be implemented immediately to improve LCA models have been recently proposed based on existing approaches in the literature (Curran et al. 2016).

In addition, the dynamic nature of biodiversity was rarely (if at all) included in the analyses. In fact, environmental changes induced by LUC can be temporarily buffered depending on the response time of organisms. For instance, large organisms such as birds or organisms with resting stages respond with a significant time-lag. Similarly, few studies include population dynamics and demographic parameters. In the set of articles, only two studies assessed the impact of LUC toward bioenergy crops using farmland birds such as the skylark. The use of birds in these studies was motivated by the fact that birds have been adopted as indicators of the quality of landscape and habitat conditions by the European Union (Furness and Greenwood 1993; BirdLife International 2010). Indeed, birds are almost the top of the food chain and are therefore directly affected by changes at all levels within this chain (Furness and Greenwood 1993). Therefore, since environmental changes are difficult to measure directly, they can be inferred through the analysis of bird populations dynamics (BirdLife International 2010).

Finally, the analysis of the set of articles highlighted the need to incorporate the effect of changes in landscape configuration induced by the establishment of bioenergy crops and their cultivation. Indeed, some organisms are more affected by the spatial organization of landscapes or the size of fields (Fahrig et al. 2011). The analysis of the separate effects of landscape composition and configuration on biodiversity, functions and provision of ecosystem services is therefore also a major issue for the sustainable management of agricultural landscapes. Attention should also be paid to feedstock management since agricultural practices such as tillage, fertilizers or pesticide use are known to significantly affect biodiversity (e.g. wild plants e.g. Gaba et al. (2016)); pollinators e.g. Dicks et al. (2015); soil micro-organisms e.g. Levine et al. (2011). For instance, the comparison of arable crops that do not pro-

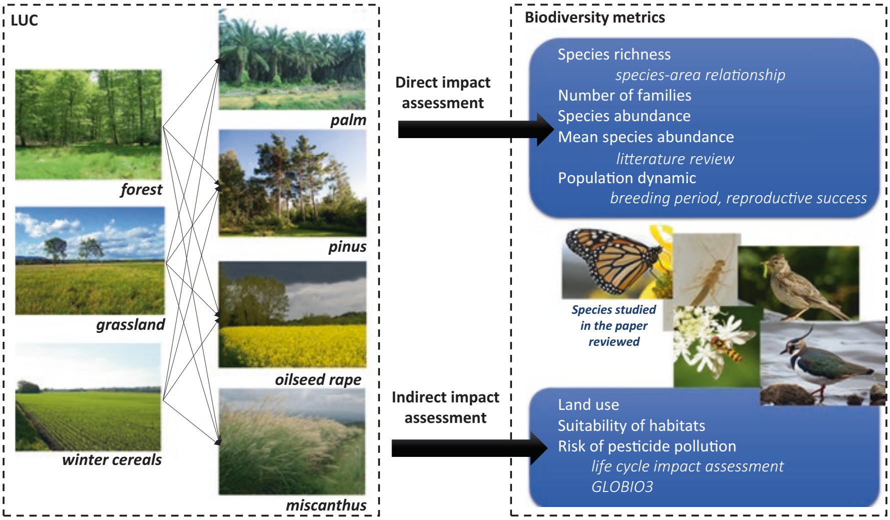

Fig. 8.1 Synthetic representation of the LUC and biodiversity metrics used either for a direct or indirect assessment in the set of articles reviewed (see Table 8.1 for details on the individual studies). The words in italics on the right panel indicate the methods used to estimate the metrics

vide floral resources for pollinators with miscanthus or oilseed rape was shown to be beneficial for insect pollinators. To go deeper, futures studies should investigate the mid-term effects of these crops by taking into account agricultural practices such as the application of insecticides (Henry et al. 2015), the reduction of herbicides applications or the implementation of field margin to increase weed species abundance (Requier et al. 2015) known to strongly affect the dynamics of pollinators or beneficial insects.

To sum up, a multiple scale assessment of biodiversity (at field and landscape scales) is needed due to the year-to-year variations in landscape composition and configuration. Consequently, a time perspective is also needed, especially in the case of LUC which are generally associated with habitat fragmentation. Indeed, little is known on the occurrence of extinction debts across ecosystems and taxonomic groups as well as the temporal and spatial scales at which extinction debts occur (Cousins 2009; Kuussaari et al. 2009). This also calls for a multiple taxa assessment, which can be subsequently translated into multifunctionality and ultimately into multiple services delivery (Fig. 8.1).

8.5 Conclusion

This analysis revealed the small number of studies on the impact of bioenergy crops on biodiversity that account for the entire causal chain: from drivers to impacts. This could lead to an extreme lack of knowledge on LUC-mediated impacts of bioenergy development on biodiversity. Despite this small number of studies, a consensus emerged on the negative impact of LUC toward bioenergy on biodiversity, and this whatever the methodology or the biodiversity metric used. In already intensively managed ecosystems, however, replacing winter cereals by bioenergy crops can favored pollinators through the availability of floral resources. Future studies need to better characterize biodiversity by using relevant metrics exploring the various facets of biodiversity (species richness, species abundance, functional diversity …). Moreover, since species of different taxa may respond differently to changes in landscape composition and configuration, these studies should investigate the impact of LUC toward bioenergy on several species covering the trophic network, including microbial biodiversity. As monitoring several species is not always possible, an alternative could be to focus on farmland birds or emblematic bird species, i.e. those which can be considered umbrella species in the sense that their habitat requirements cover those of many other species. In other words, these species have such specific habitat conditions requirement that when they are met, they cover those of many other species. Coupling models with long-term monitoring of biodiversity is therefore a promising avenue of research to improve knowledge on LUC on biodiversity at multiple spatial and temporal scales.

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