Land-use and climate change within assessments of biodiversity change: A review

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ABSTRACT

Projected changes in biodiversity are likely inadequately estimated when climate and land-use change effects are examined in isolation. A review of studies of the effects of these drivers singly and in combination highlights little discussed complexities in revising these estimates. In addition to considering interactions, different characterisations of climate change, land-use change and biodiversity greatly influence estimates. Habitat loss leading to decreased species richness is the most common land-use change and biodiversity relationship considered with less attention being given to other land-use changes (e.g. other conversions, fragmentation, different management intensities) and biodiversity characterisations and responses (e.g. selected groups of species, increased species richness). Characterisations of more complex relationships between climate change, land-use change and biodiversity however are currently limited by a lack of process understanding, data availability and inherent scenarios uncertainties.

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1. Introduction

Climate change and land-use change are both key drivers of biodiversity change (Sala et al., 2000; Hansen et al., 2001; Travis, 2003; Duraliapppa et al., 2005; Fischlin et al., 2007). Interactions between these drivers are complex and currently not well understood (Duraliapppa et al., 2005; Lepers et al., 2005; Fischlin et al., 2007), and may have a greater overall impact on biodiversity change than either of these drivers operating in isolation (Thomas et al., 2004; Root and Schneider, 2006; Brook, 2008). In spite of this, most biodiversity studies assess the impacts of climate change (e.g. Thomas et al., 2004; Malcolm et al., 2006) or land-use change and associated habitat fragmentation (e.g. Fahrig, 2003; Fazey et al., 2005) in isolation. Furthermore, only a small number of biodiversity studies include the effects of land-use change in contrast to the large number of studies of climate change. Calls have been made for studies that integrate both drivers (e.g. Hansen et al., 2001; Hannah et al., 2002; Thomas et al., 2004; Balmford and Cowling, 2006; Fischlin et al., 2007; Brook, 2008; Thuiller et al., 2008) however only a few such studies have been undertaken to date (e.g. Sala et al., 2000, 2005; Bomhard et al., 2005; Jetz et al., 2007).

An implication of the lack of integrated analysis is that studies of biodiversity change that examine the effect of either climate change or land-use change in isolation are likely to either over- or under-estimate the potential effects. Interactions between climate and land-use change may also lead to surprising outcomes. The individual and combined effects of climate change and land-use change on biodiversity are also determined by how these drivers as well as biodiversity are defined with different definitions resulting in a range of effects and interactions. In this paper we explore these issues in detail, highlighting the complexities that are associated with multi-driver analyses.

We explore this complexity by examining how the addition of projected land-use change affects estimates of biodiversity change arising from projected climate change only. A large number of studies have examined future biodiversity changes under a range of different scenarios of climate change and these are described elsewhere (e.g. recent reviews include McCarthy et al., 2001; Hitz and Smith, 2004; Fischlin et al., 2007). Here we focus on the less studied area of land-use and biodiversity change, restricting our analysis to the small number of studies that either examine projected biodiversity change as a result of both of these drivers (e.g. Sala et al., 2000, 2005; Bomhard et al., 2005), or otherwise the few studies of biodiversity change resulting from projected land-use change.
We also present a brief review of the current state of the art for land-use models and scenario development and their relationship with biodiversity models. This includes a discussion of some of the limitations of these models in representing simple through to more complex characterisations of land-use change and the associated range of biodiversity responses. We conclude with some suggestions for how land-use change might be better integrated into climate change impact studies on biodiversity.

2. Charactetisations of and relationships between climate change, land-use change and biodiversity

Climate change, land-use change and biodiversity encompass a range of definitions and respective characterisations, which in turn generates a range of different relationships between and as a consequence of these two drivers. We examine some different characterisations of land-use change and biodiversity, and to a less extent, climate change, as applied to impact assessments below.

Climate change usually refers to change over time in variables such as temperature, precipitation and wind with increases in temperature being a particular focus (Parry et al., 2007). Climate change is typically considered in terms of having a negative impact on biodiversity, although a range of other responses are also reported, albeit less considered (e.g. Thomas et al., 2006).

Land-use (the purpose for and manner in which biophysical attributes of the earth’s surface and immediate subsurface are manipulated) as distinct from land cover (the biophysical state of the earth’s surface and immediate subsurface) change (Turner II et al., 1995) represents a wide range of conversions including to and from forest, grassland, cultivated land, and urban land. The most commonly considered is a conversion of (native) forest or grassland habitat into cultivated or urban land. This land-use conversion has been the most important conversion in terms of land areas in the recent past and potentially will continue to be so in the future (Alcamo et al., 2006). It also represents the key conversion leading to the greatest loss of biodiversity (see below for a discussion on what is commonly meant by biodiversity) (Fahrig, 2003; Lambin et al., 2003; Duraipappah et al., 2005). Other important aspects of land-use change include habitat fragmentation (Fahrig, 2003), and differences in management intensity within the same land-use.

Biodiversity or biological diversity variously refers to diversity at the genetic, species or ecosystem level (Magurran, 1988; Noss, 1990; Marcot, 2007). Diversity can refer to structural, functional or compositional components (Noss, 1990) with a range of indexes in use such as number of species (species richness) or the more complex index (Shannon and Weaver, 1949) or Simpson index (Simpson, 1949). In the context of climate change and land-use change, biodiversity is typically associated with species, most often referring to native or endemic species richness or species diversity (including species number and relative abundance). However, it is also used to represent a single species through to selected groups of species. In this paper we only discuss biodiversity in terms of species level responses.

Species responses to the various characterisations of climate change and land-use change vary considerably, depending on which species are considered, the way each species respectively responds to each driver, whether there are any interactions between drivers and between species and the spatial and temporal scale considered. Species may respond positively, negatively or exhibit no change in response to each driver. In the case of no interactions between drivers, a response to both drivers represents the sum of the individual responses. In the case of interactions between the drivers, the collective response variously represents more than the sum of the individual responses (exacerbation) or less than the sum (amelioration). We illustrate some of these responses and the consequences for estimates based on climate change alone below.

2.1. No interactions between drivers (equal to sum)

A typical characterisation of the impact of climate change and land–use change on biodiversity is to characterise climate change as an increase in temperature, land-use change as a conversion of native habitat to cropland or urban area, biodiversity as native species richness or diversity and for both drivers to have a negative effect on biodiversity. The study by Sala et al. (2005), forming part of the Millennium Ecosystem Assessment, represents one of the few global studies that examine future biodiversity change as a result of several drivers and provides a good example of this characterisation. This study suggests that when taking three drivers into account (climate change, land-use change and nitrogen deposition), vascular plant species number and relative abundance may decrease by 12–16% by 2050 relative to species present in 1970 (Sala et al., 2005). Drawing on this work, when looking at projected losses due to land-use change alone (native habitat loss), habitat reduction in tropical forests and woodland, savanna and warm mixed forest account for 80% of the lost species (~30,000 species) under the four scenarios considered. Fig. 1 shows the relative contribution of land-use change and climate change to biodiversity change as a result of both drivers for a range of biomes (modified from Sala et al., 2005). Land-use change accounts for between 23 and 36% of the change for biomes where climate change is the most important driver (cool conifer forests, savannas, and tundra) through to between 82 and 93% for biomes where habitat conversion to cultivated land or urban is the most important driver (warm mixed forests, temperate deciduous forests and tropical forests). Even with no assumed interactions between the drivers (as was the case for this study), biodiversity assessments based on climate change alone under this circumstance would lead to a significant under-estimation of biodiversity loss.

Wisz et al. (in press) measured biodiversity in terms of a single species, the migratory pink-footed goose (Anser brachyrhynchus). Changes in future habitat suitability of this species were examined in north-western Europe under several land-use change scenarios. The indirect effect of climate change on land-use was considered in this study, but the direct effect of climate on the pink-footed goose was not. In recent decades the goose has increased in population size by taking advantage of foraging in cropland in addition to its traditional grassland habitat. In this case a conversion from forest or grassland into cropland represents a benefit (forest to cropland) or has little effect (grassland to cropland) on the selected species. Substituting this sort of response to land-use change in the above study (Sala et al., 2005), estimates based on climate change alone would result in an over-estimation.

The conversion of cropland or grassland into forest is a less typical characterisation of land-use change, although quite common in Western Europe as a result of agricultural land abandonment (e.g. Rounsevell et al., 2006). This land-use conversion produces a range of different biodiversity responses. For example, Giupponi et al. (2006) project an increase in the distribution of a forest species, hop hornbeam Ostrya carpinifolia and a decrease in the distribution of two open habitat species, concrake Crex crex and steppe grasshopper Chorthippus dorsatus as a result of a projected conversion from grassland to forest in the Italian Alps. This study also highlights how different characterisations of biodiversity determine the reported response. If, for example, biodiversity had been measured in terms of species richness just based on the hop hornbeam and the concrake then
no change would have been reported, as one species replaces another.

Differences in management intensity within the same land-use are also typically not included in studies, and may lead to a range of different biodiversity responses. For example, Audsley et al. (2008) show how three cereal field margin species in the UK show different responses in habitat suitability due to projected differences in fertiliser use in arable fields (Fig. 2). Biodiversity can also respond differently to climate change. For example, in the Giupponi et al. (2006) study described above, 

![Fig. 1](https://example.com/figure1.png)
species distributions did not significantly change under the selected climate change scenarios. In a study by del Barrio et al. (2006), two species of the cereal field margins habitat in East Anglia, UK, small-flowered catchfly Silene gallica and long-headed poppy Papaver dubium showed a projected increase in their northern distribution under the range of climate change scenarios considered.

The del Barrio et al. (2006) study also serves as an example of how biodiversity can show a contrasting response to climate change and land-use change. In this study, most of the gains in range projected under climate change for these two species are lost due to a projected decrease in grassland. Similarly, in a study of the effects of climate change and habitat change on butterflies for the period 1970–2000 in the UK (Warren et al., 2001) shows that although species may all have been expected to respond positively to climate warming, over three-quarters of them declined, particularly habitat specialists and sedentary species as a result of habitat fragmentation.

2.2. Including interactions

Interactions between land-use change and climate change can work to further modify the range of responses to the individual drivers that have been described above. These interactions can work to respectively exacerbate or ameliorate the effects of the other driver. Some examples of this are given below.

2.2.1. More than the sum (exacerbate)

Opdam and Wascher (2004) in a review of the potential synergistic effects between climate change and habitat fragmentation propose an integrated concept explicitly considering meta-population dynamics, in which habitat fragmentation lowers the density of species per patch and the percentage of patch occupancy through less effective distribution of species over the habitat network. Smaller patches may also have lower habitat quality. Fragmented populations are therefore relatively more vulnerable to environmental drivers such as climate change than if they were not fragmented. These populations can suffer greater decline and this coupled with a lower rate of recovery increases the chance of local extinctions. For example, a rapid decrease in the population of the green salamander (Aneides aeneus) with a highly fragmented habitat in the southern Appalachians, U.S.A. was linked to an increase in July temperatures and a greater fluctuation in January temperatures since 1970 (Corser, 2001). Similar findings have also been reported for the checkerspot butterfly (Euphydryas editha bayensis) in the U.S.A. (McLaughlin et al., 2002), tiger moth (Arctica caja) in Britain (Conrad et al., 2002) and butterflies in the Mediterranean (Stefanescu et al., 2004). Modelling work by Travis (2003) shows similar findings where the extinction threshold for species occurs much sooner under the combined effects of habitat loss and climate change.

Opdam and Wascher (2004) also propose that these effects are particularly pronounced where conditions for species are least favourable such as at species range limits. They refer to a study by Mehlman (1997) as an example of this. In this study, the range of American songbirds contracted after a series of harsh winters accompanied by reduced population densities where the marginal zones showed greater changes in abundance compared to the central parts. The range boundaries showed a great deal of fluctuation due to a higher frequency of extinction and recolonisation events.

2.2.2. Less than the sum (ameliorate)

Climate change can also work to ameliorate the effects of habitat fragmentation (Opdam and Wascher, 2004). Studies by Thomas et al. (1999, 2001) suggest that an increase in temperature could result in species increasing their distributions due an expansion of areas currently unsuitable to the species becoming suitable. For example Thomas et al. (2001) showed how a butterfly species (Hesperia comma) was able to further extend its northern expansion under climate change as an increase in temperature enabled the species to increase its habitat choice from chalk grasslands to a broader set of vegetation types.

In summary, biodiversity responses to changes in climate and land-use can result in a complex set of relationships depending on how each driver is characterised, the type of interactions involved
and how biodiversity is characterised. Responses variously represent species loss, gain, or no change depending on the type or types of land-use change together with the choice and particular ecological requirements of the species or set of species. Interactions between land-use change and climate change can work to either exacerbate or ameliorate these effects on biodiversity, further complicating the possible biodiversity response. Species loss as a result of native habitat removal is the most common way in which land-use change and the associated biodiversity response is represented in models, with less attention being paid to other land-use conversions, fragmentation and management intensity effects, as well as possible interactions with climate change.

3. Projections of future land-use change and associated biodiversity change

3.1. Land-use change scenarios and models

Whilst a wide range of climate change scenarios have been available to the impacts community for several years, the development of land-use change scenarios is more recent (Alcamo et al., 2006; Verburg et al., 2006). Existing land-use change scenarios, as well as the emissions scenarios that underpin climate change projections (Nakićenović et al., 2000), are usually constructed using the storyline and simulation (SAS) approach (Alcamo, 2001). Storylines are narrative descriptions of plausible and alternative socio-economic development pathways that lead to different visions of future worlds (Nakićenović et al., 2000). Qualitative storylines can be translated into quantitative land-use change scenarios using simulation models. This translation involves the estimation of the model input parameters commonly using subjective, expert judgment, although more objective methods have been attempted based on pairwise comparison techniques that seek to ensure internal consistency (Ahlström et al., 2006). Other techniques used for parameter estimation include analogues and stakeholder elicitation (e.g. Rotmans et al., 2000; Berger and Bolte, 2004).

Many different simulation models at a variety of spatial scales have been used in the construction of land-use change scenarios. The IPCC Third Assessment Report (McCarthy et al., 2001) concluded that Integrated Assessment Models (IAMS) were the most appropriate method for the development of land-use change scenarios, and this remains the case for global scale studies. More than with any other studied global change driver, climate change was from the first instance conceived and treated as global. By contrast most other drivers have been studied at regional levels because important local effects are often independent of the global scale. IAMS also adopt a global perspective because they were often constructed in response to the need to assess climate change impacts. IAMs include the SRES land cover scenarios (Nakićenović et al., 2000; IMAGE-team, 2001) and the Millennium Ecosystem Assessment (Carpenter et al., 2005).

More recently a number of new models of land-use change at the regional scale have emerged. Regional scale land-use models often adopt a two-phase approach with an assessment of aggregate quantities of land-use for the entire region using global scale supply/demand variables from IAMs or economic models such as General Equilibrium models (van Meijl et al., 2005) or input/output approaches (Fischer and Sun, 2001) followed by ‘downscaling’ procedures to create fine resolution land-use patterns. Methods of downscaling vary considerably and include proportional approaches to estimate regional patterns from global scenarios (Arnell, 2004), regional scale economic models (Fischer and Sun, 2001), spatial allocation procedures based on rules (Rounsevell et al., 2005), micro-simulation with cellular automata (de Nijs et al., 2004), linear programming models (Holman et al., 2005) or empirical-statistical techniques (e.g. CLUE/EURURALIS Verburg et al., 2002). An emerging method is the use of Agent-Based Models (ABMs) to address climate change impacts on land-use, as well as decision processes of adaptation and vulnerability assessment (Acosta-Michlik and Rounsevell, 2005).

Comparative studies across similar scenarios (Busch, 2006) have shown that IAMs can generate land-use changes that are very different from those of regional land-use models, often with opposing directions of change. For example, Fig. 3 (Busch, 2006) shows the projected changes in European cropland areas for a range of land-use change scenario studies in which the scenarios labelled 6 and 7 are derived from regionally focused modelling studies and the rest are broadly global. Even though these model runs were undertaken in independent studies and in many cases for similar storylines, it is noticeable that the regional studies (scenarios 6 and 7) consistently give similar results, and these are often different from the global models. This demonstrates that different land-use change models can give very different future land-use scenarios even for the same (or similar) storyline assumptions. The results for the regional models are probably different from those of the global models because they are able to represent processes of land-use change at appropriate scale levels. Land-use depends upon the decisions of individual land-users at the local scale, although these decisions are moderated by economic and policy drivers at broader scale levels. The need, therefore, to define exogenous input variables to regional scale land-use scenario analyses remains a challenge (e.g. Alcamo et al., 2006) and IAMs have an important role to play in characterising the global boundary conditions for regional land-use change assessments (van Meijl et al., 2005).

Most land-use scenario projections are based on mean trends in the socio-economic and climate change baselines, although responses to extreme weather events have also been assessed (Kok and Winograd, 2002). Probabilistic approaches in the development of land-use futures are rare with the exception being the effects of uncertainty in alternative representations of land-use change for hydrological variables (Eckhardt et al., 2003). Not all land-use scenario exercises have addressed the effects of climate change even though they consider time frames over which a changing climate would be important. This may reflect a perceived lack of sensitivity to climate variables (e.g. studies on urban land-use, Barredo et al., 2004), or is simply an omission (Ahn et al., 2002).

Many land-use scenario studies, especially at the global scale, have been based on the IPCC SRES storylines (e.g. IMAGE-team, 2001; Arnell, 2004) and this has the advantage of providing coherence with climate change projections. A number of regional land-use change studies have also used the SRES storylines as a starting point (e.g. Rounsevell et al., 2005; van Meijl et al., 2005). Fig. 4, for example, shows a range of future changes (%) in European cropland areas (for food production) by 2080 compared with the baseline (2000) for four SRES storylines (A1FI, A2, B1, B2) based on the HADCM3 model (Schröter et al., 2005). Whilst account was taken of climate change in the modelling approach, these scenarios were found to be more responsive to the socio-economic assumptions than to the changes in climate (Rounsevell et al., 2006). In terms of associated biodiversity change, the striking thing about Fig. 4 is the variety of plausible scenarios in terms not only of the quantities of land-use change, but also their spatial patterns reflecting the range of uncertainties in land-use futures. Such wide-ranging land-use changes would have very different impacts on habitat loss, gain and fragmentation, as discussed above. Indeed changes in the spatial patterns of land-use may have greater consequences than the overall changes in land-use quantities.
The A1FI, A2 and B1 scenarios presented in Fig. 4 all lead to substantial areas of agricultural land abandonment (up to 50% of the current, total agricultural area by 2080 (Rounsevell et al., 2005, 2006) and this may have important consequences for biodiversity because of the influence of the intensity of land management on biodiversity (see previous section).

Thus, existing studies demonstrate that there is considerable uncertainty in estimating both the quantity and location of future land-use change. These uncertainties derive not only from differences between alternative visions of the world encapsulated in storylines, but also in the simulation models that are used to translate these storylines into quantitative scenarios. The difference between the results of global and regional scale modelling approaches is notable in this respect.

### 3.2. Some technical limitations of integrating land-use and biodiversity models

Whilst the development of land-use scenarios has a number of inherent limitations, there are also technical challenges that constrain the integration of land-use and biodiversity models in the assessment of climate change impacts. Data resolution and lack of models at appropriate scales are key limitations. Land-use scenarios derived from IAMs operating at the global scale generate coarse resolution outputs that are often not compatible with the data resolutions and the types of processes considered by biodiversity models. Projected estimates of biodiversity as an output of these models tend to be constrained to quite general estimates. For example, projected biodiversity changes modelled by the (Sala et al., 2005) study discussed in the previous section were estimated only in terms of native habitat loss as a result of an increase in the area of land converted to cropland or urban land, and did not include any other likely biodiversity responses discussed in the previous section such as increases as a result of native habitat gain (e.g. land abandonment, reforestation) or that many species are able to continue to persist in the newly converted agricultural land.

The availability and resolution of species data is also a limitation. Models of species distributions based on climate envelope approaches depend for their calibration on observed datasets of species presence and absence. For studies that cover large geographic areas (e.g. Berry et al., 2003; Thuiller, 2003) these datasets are often at coarse spatial resolutions (e.g. the 0.5° resolution Atlas Florae Europaeae, Lahti and Lampinen, 1999). At these resolutions a wide range of land-use classes will be identified, so that statistical models that attempt to incorporate land-use related variables will not be able to distinguish one grid
cell from another. The models are then not sensitive to land-use change scenarios. This problem would be avoided if these data were available at the finer spatial resolutions at which they were presumably collected. Data resolution problems can also occur at relatively fine resolutions, although in general the problem diminishes as the resolution becomes finer. However, even small changes in the resolution of land-use data (as these are aggregated) have been shown to cause large changes in landscape representation (Dendoncker et al., 2008; Schmit et al., 2006) which has serious implications for biodiversity modelling.

Whilst data availability may limit the capacity to model biodiversity change, it is still necessary to have satisfactory models of the ways in which biodiversity will respond to land-use change. Such models depend on an understanding of the underlying processes that determine how species interact with and adapt to the changing environment. In many cases, and for many species, this fundamental process knowledge is lacking and so there is a concurrent lack of appropriate modelling tools that represent causality adequately. For example, many models of species distributions are based on empirical approaches that do not provide insight into processes. Moreover, it has been shown that for such approaches to modelling it is the model itself rather than the changes in climate that explain more of the variance in future projections of species distributions (Thuiller, 2004). This is somewhat analogous to the problems faced by land-use models discussed above, and will be discussed again in the following section.

Another example where the lack of process understanding affects insight into land-use and species relationships is the role of land management (see earlier discussion). The management of land as much as the use of land influences biodiversity, e.g. the relative proportions of intensive versus extensive agriculture represented within a general classification of ‘agriculture’, whether grasslands are mown or grazed, or the range of forest felling regimes represented within forestry. Very few models are, however, able to account for management changes, with the work of Audsley et al. (2008) concerning nitrogen fertiliser use being a notable exception (see Fig. 2). Furthermore, it is difficult to develop future scenarios of land management. This is partly because management decisions are highly variable between individuals (e.g. why should farmers mow or graze their grassland?) that are strongly dependent on social values, traditions and experience, but also because of the potential of technological change for modifying management strategies. The evolution of technology in the future is also highly uncertain (see, for example, Ewert et al., 2005).

Many land-use and species models adopt equilibrium approaches that provide snap shots of a moment in time in the future. Whilst such models may be useful in identifying general directions of change they are limited in their representation of dynamic processes such as the feedbacks between habitat changes and biodiversity and the dispersal ability of species (e.g. Pearson and Dawson, 2005). Some of these models are very selective about ecosystem types and inference would have to be made about

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Fig. 4. Change in cropland area (for food production) by 2080 compared with the baseline (% of EU15+ area) for the 4 SRES storylines (A1FI, A2, B1, B2) with climate calculated by HADCM3 (from Schröter et al., 2005, Fig. 1). Reprinted with permission from AAAS.
species’ responses within them. Dynamic process models that are applied over large geographic extents (e.g. LPJ, IMAGE-team, 2001) require past land-use data to spin-up the models. There is a lack, however, of these data at appropriate spatial and temporal resolutions and for long time series. This strongly limits the use of such models and their capacity to represent ecosystems.

Thus, analysis of future land-use and biodiversity change is limited by a number of uncertainties that relate to the quality of data, the understanding of relevant processes, the capacity of the models to represent these processes and the range of plausible, alternative futures in addition to the uncertainties inherent to climate models.

4. Progress towards better integration

We propose several developments that would represent progress toward better integration of land-use change into climate change impact studies on biodiversity as well as better incorporation of the range of characterisations of climate change, land-use change and biodiversity discussed in the previous section.

First, we propose that assessments of biodiversity change must at the very least include both climate and land-use change as drivers, or better still include other drivers of change such as pollution or invasive species (Reid et al., 2005; Fischlin et al., 2007). Secondly, studies that include land-use change would benefit from consideration of a wider set of land conversions and associated biodiversity relationships beyond a conversion of native habitat into cultivated or urban land that is directly correlated with biodiversity loss. Including the effects of fragmentation, differences in land management and any interactions between drivers would further refine the characterisation of land-use change and associated biodiversity estimates. Improved process understanding of species responses to changing habitats together with more sophisticated representation of these processes in biodiversity models would be necessary to underpin this more comprehensive characterisation of land-use change. Such models would be greatly improved if they also included dynamic feedbacks and could be applied to fine resolution species and land-use data at the local scale rather than the current emphasis on producing coarse level generalizations at global or continental scales. Finally, improved availability and the development of past time series of land-use change data would enhance the calibration and spin-up of dynamic biodiversity models.

5. Conclusions

Given the importance of both climate change and land-use change in influencing biodiversity, studies that include only one or the other driver are likely to inadequately assess impacts. Moreover, depending on how each of these drivers as well as biodiversity are characterised and whether any interactions exist between them a range of biodiversity responses can result. We have examined some potential under- and over-estimations highlighting that biodiversity changes are likely to be more complex than often assumed. We have discussed some limitations of these models to represent simple through to more complex characterisations of land-use change and the associated range of biodiversity responses. We have also discussed the limitations of the few studies that include land-use change as a driver, and suggest that these limitations such as the wide range of uncertainties in biodiversity responses associated with the present set of land-use change scenarios is not widely appreciated or acknowledged. We suggest that a better approach for continued research in this field is to at the very least include both climate and land-use change as drivers, or better still include other drivers of change. Moreover, giving priority to the development of land-use research in terms of better understanding of land-use change processes and their consequences that is equal to the effort that has gone into climate change research would greatly assist this progress. Some of the priority areas include improved process understanding of the interactions between changing land-use and biodiversity response and greater use of dynamic approaches to represent these interactions and feedbacks.

Acknowledgements

This work was carried out as part of research undertaken at the Université catholique de Louvain with funding from the Belgian Federal Science Policy Office.

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