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Global biodiversity assessments need to consider mixed multifunctional land-use systems

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Global scenario-based modelling efforts to support biodiversity policies typically consider agriculture only as a pressure factor. Current scenarios typically include the expansion of protected areas combined with higher agricultural productivity (as in land sparing) for reducing biodiversity loss. We argue in favour of a broader perspective on farming practices in scenario-based biodiversity modelling and, specifically, for scenario studies to include mixed multifunctional systems, applicable in land-sharing approaches. The increasing availability of monitoring data and modelling capacity opens up opportunities for more comprehensive quantification of the intricate network of relationships between agricultural land management, biodiversity and ecosystem services and, thus, enables a more balanced evaluation of the benefits and trade-offs of land sparing and land sharing and their intermediates.

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Introduction

Global biodiversity models (GBMs) are essential to support global biodiversity policies [1]. These models are commonly used in scenario-based assessments to project future developments of biodiversity and ecosystem conditions, assess the impact of current and possible future combinations of pressures on biodiversity, and evaluate the effectiveness of policy options in achieving biodiversity targets. Recent examples of scenario-based global biodiversity modelling include the work for the global assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [2–4], the 'bending the curve of biodiversity' analysis [5] and the solution-oriented scenarios for the 4th and 5th Global Biodiversity Outlooks [6,7]. These scenario studies share the outcome that halting biodiversity loss or restoring biodiversity without compromising food security is most effectively achieved by expanding protected areas while increasing agricultural productivity on existing agricultural land, thereby sparing land for nature. This land-sparing approach is in contrast to 'land sharing', which aims to integrate rather than separate food production and nature conservation [8–10]. Land sharing can be applied in mixed-multifunctional systems (MMSs), which combine multiple crops and/or livestock with natural elements, either on the same plot of land or at landscape level [11]. Usually, the size of the land areas with crops is only is small [12]. MMSs provide multiple functions, such as food production, conservation of biodiversity, and the provision of other ecosystem services [13–15]. To date, however, land sharing strategies have hardly been included in global biodiversity scenario studies. One of the reasons could be the coarse representation of land use in GBMs, which typically consider only a few broad, homogeneous land-use types. Rosa et al. [16] highlight this limitation as one of the major challenges for improving global biodiversity scenarios.

In this paper, we argue in favour of a broader perspective on farming practices in global scenario-based biodiversity modelling. To that end, we first outline how MMSs can reconcile land-sharing and land-sparing strategies for conserving biodiversity. We refer to biodiversity as the diversity of wild species in both natural and in agricultural systems. Subsequently, we briefly review recent literature on how GBMs address land use and land management, and how they consider the impacts of land use on biodiversity. Finally, we outline how MMSs can be included in global models to arrive at more comprehensive global biodiversity assessments.

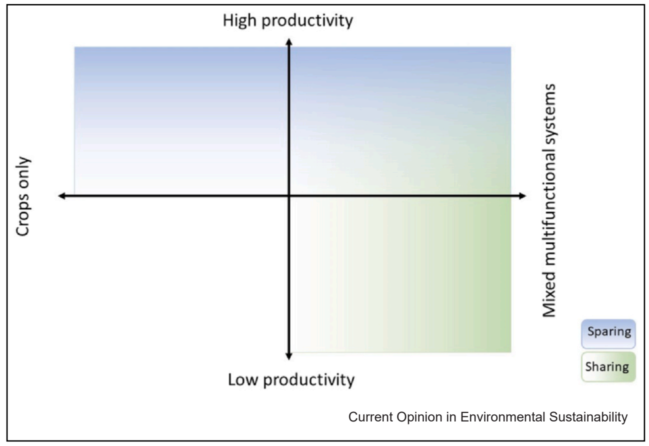
Mixed multifunctional systems: reconciling land-sparing and land sharing

Proponents of the land-sparing approach argue that the population of most species will be larger if agricultural production takes place on an area as small as possible, leaving the area of native vegetation as large as possible [10]. In several world regions, large production increases are still possible on current agricultural land by improving and intensifying water and fertiliser management [17,18]. However, intensification often leads to monocultures of a limited number of genetically homogeneous crops and livestock breeds, which, when inappropriately managed, result in environmental degradation including soil erosion, fertility loss, excessive groundwater and surface water extraction, salinisation, eutrophication, and pollution of natural systems [19,20]. At the global level, fertiliser use for agricultural production even leads to the exceedance of 'safe' planetary limits for nitrogen and phosphorus [21]. In addition, capital-intensive intensification of agricultural systems disproportionately benefits the more affluent part of society, especially in developing countries, increasing social inequality and potential conflict [22].

Proponents of the land-sharing approach argue that it is better to integrate biodiversity conservation and agricultural production, because in the long term isolated protected areas surrounded by a hostile matrix of intensive agriculture will not be sufficient to protect biodiversity [23–25]. The practice of MMSs increases the diversity of crops and natural elements that provide a habitat for many wild species and allow the migration of larger animals [15,26]. The increased biodiversity, on fields and within the larger landscape, in turn leads to more robust ecosystem functioning (e.g. primary productivity, decomposition, carbon storage, pollination and water retention) [27–29]. Pests and plant diseases can be suppressed as their spread and dispersion can be reduced by the surrounding crops or natural elements, such as trees and hedge rows, and by the presence of natural predators [30,31].

A barrier to the implementation of MMSs is the long-held perception that land sharing typically lowers agricultural yield, thus, requiring a larger farmed area to produce a given amount of food [32]. There is increasing evidence, however, that the diversification of agricultural systems does not necessarily compromise agricultural productivity [13,15,33–35]. Depending on the mixtures, MMSs can even achieve higher levels of productivity than conventional systems [36,37]. Although, in the short term, ecological benefits may not outweigh economic costs, diversified farming practices have the potential to lead to higher and more stable yields, increase profitability and reduce risks, in the long term [38,39]. Thus, MMSs may contribute to biodiversity conservation not only via land sharing, promoting on-farm biodiversity and in the surrounding landscape, but also via land sparing, as high yields mean there is no need to convert remaining natural habitat for agricultural purposes (Figure 1).

Figure 1



Farming systems can be characterised by their degree of productivity (vertical axis) and their degree of mixing of crops, livestock, and natural elements (horizontal axis). Land sharing relies on the integration of biodiversity conservation and agricultural production, which can be achieved via mixed multifunctional land-use systems. Land sparing relies on avoiding further conversion of natural habitat by ensuring high agricultural productivity, which can be achieved along a gradient of mixing.

Current representation of land use in global biodiversity models

Land use, especially agriculture, is currently considered the largest threat to biodiversity [2,40,41] and, therefore, features prominently in GBMs [3,5]. Broadly speaking, GBMs follow one of the three approaches below, to quantify the relationships between biodiversity and land use:

1. First correlate the occurrence of single species to different categories of land use and land cover (LULC) and then calculate aggregate metrics, such as species richness or Red List indices (applied in the models InSiGHTS [42,43], AIM-B [44] and Map of Life [45]).
2. First calculate aggregate biodiversity metrics from site observations and then correlate these to LULC categories (the approach taken e.g. by GLOBIO [41]; PREDICTS [46], and BILBI [47]).
3. Estimate the number of species in relation to the areas of various LULC categories, using models based on species–area relationships (countryside-SAR [48,49]).

GBMs typically consider only discrete land-use classes (Table 1). In addition, some GBMs consider cropland and pasture as uniform land-use categories, without considering differences in intensity. Other GBMs consider different degrees of intensity, but only make a relatively rough distinction between 'low intensity' and 'high intensity' categories [41,46]. None of the current

GBMs include MMSs. Hence, current GBMs are only able to evaluate the impacts of changes between coarse monofunctional land-use types and coarse intensity levels on biodiversity.

In global biodiversity assessments, GBMs are typically connected to integrated assessment models (IAMs). IAMs use socioeconomic and demographic changes to assess the demand for food, energy and other materials, and translate this into land demand and spatial patterns of land use [50]. The required area and the spatial patterns depend on the demand for agricultural products, the potential productivity of the land and socioeconomic factors that drive or constrain land use [51]. In global biodiversity assessments, LULC output maps from single or multiple IAMs are entered into the GBMs to provide current state and projections of future biodiversity. Thus, LULC categories distinguished in IAMs should match the LULC categories in the GBMs, often requiring harmonisation, merging and simplification of categories [5,46,52]. In addition, IAMs generally ignore the relationship between intensification and environmental degradation as well as the influence of local biodiversity on ecosystem services (e.g. pollination or pest control that depend on biodiversity), and feedbacks between ecosystem services and productivity in agriculture (i.e. changes in ecosystem services do not influence the models' estimates of the produced food and other products) [53].

Towards including mixed multifunctional systems in global biodiversity assessments

Systematically and comprehensively including MMSs in global biodiversity assessments requires adaptations in both GBMs and IAMs. GBMs should be refined by adding MMSs to the currently included coarse homogeneous land-use types (i.e. cropland, pasture and plantations; Table 1). Species-based GBMs and SAR-based models can be broadened by including the preferences or affinity of species and species groups for specific MMSs. The IUCN Red List database provides broad habitat types for a large number of species, but also detailed habitat descriptions for many of them (www.iucnredlist.org), which offer a starting point for developing more detailed habitat suitability models that include MMSs. Responses of individual species to agricultural diversification measures may also be retrieved from the literature and databases that contain monitoring data of species assemblages in relation to agricultural management [26,35,54,55]. The same observational data can be used to quantify biodiversity responses based on aggregated metrics, such as species richness, abundance or compositional intactness, which can then be used to improve assemblage-level GBMs.

Table 1

Land use categories in global biodiversity models.

PREDICTS [46]	GLOBIO 4.0 [41]	AIM-biod [44]	BILBI (see PREDICTS) [47]	InSIGHTS [42,43]	cSAR Chaudhary [49]	cSAR, Martins [48]	Map of Life [45]
Based on direct relationship between LU and local species richness and biodiversity intactness	Based on direct relationship between LU and biodiversity intactness	Based on singles species distribution models, aggregated to species richness change	Based on direct relationship between biodiversity intactness (from PREDICTS or GLOBIO) and spatial turnover of species	Based on single species distribution models, aggregated to species richness change	Based on the relationships between areas of specific LULC and the number of species	Based on the relationships between areas of specific LULC and the number of species	Based on single species distribution models, aggregated to species richness change
Cropland (M, L, I)*	Cropland (M, I)	Irrigated Rainfed Bioenergy	Cropland (M, L, I)	Cropland	Agriculture	Annual crops Permanent crops	Croplands
Pasture(M, L, I)	Pasture(M, I)	Pasture	Pasture(M, L, I)	Grassland	Pasture	Pastures	Cropland/ Natural vegetation mosaic
Primary	Primary	Forests, other natural vegetation		Forests, other natural vegetation			Forests, other natural vegetation
Secondary Plantation	Secondary Plantation	Afforestation	Secondary Plantation		Managed forest	Managed forest	
Urban	Urban	Settlements	Urban	Urban	Urban	Urban	Urban and built-up

*M=intensity is minimal; L=Intensity is light, L, intensity is high.

In parallel, IAMs and global land-use models need to be extended in order to obtain scenario-based projections of potential future land-use patterns that include MMSs. Information on the agricultural yield of MMSs — which is needed to quantify the demand for land — can be obtained from recently published databases with yield comparisons between different farming systems [35,55] as well as from new biophysical, spatially explicit agricultural productivity modules [39]. Information on opportunities relevant socio-economic opportunities and constraints (e.g., country-specific subsidies for biodiversity-friendly farming) can be included for determining the demand for MMSs and their spatial distribution. For some farming types, global distribution maps exist (e.g. [56]). The increasing availability of high-resolution remotely sensed land-cover data may help to provide a ground truth of present-day fine-grain heterogeneity as well as a starting point for future projections [57].

For a comprehensive evaluation of the benefits and potential trade-offs of MMSs, global biodiversity assessments also need to account for the ecosystem services provided by these systems [58]. This is facilitated by the increasing availability of global ecosystem services models, including, for example, the InVEST model [59]. In addition, updated or new relationships between MMSs and ecosystem services can be quantified by compiling and analysing additional data recently reported in the literature. For example, Albrecht et al. [31] recently quantified how natural pest control and pollination are related to flower strips and hedgerows, thus providing a basis for including the co-benefits of these natural elements in MMSs in biodiversity assessments.

One of the main challenges related to including MMSs in both GBMs and IAMs is to arrive at a typology of farming systems that is detailed enough to discriminate between practices, yet generic enough to be applied globally. The typology should correspond with differential responses of biodiversity, yield and the provisioning of ecosystem services and allow for actually quantifying these responses based on the data available. The farming systems' typology should also include landscape elements in and around farms, as they are essential for crop production [60] as well as for biodiversity [26]. Potential starting points are the diversified production systems and production approaches presented in The State of World's Biodiversity for Food and Agriculture [61] and the land-use-system approach [62]. For reasons of feasibility, it seems worthwhile to start with the inclusion of a few broad types of MMSs and gradually refine these, over time.

Conclusions

Currently, MMSs are not included in GBMs and are, therefore, not considered in global biodiversity scenario studies. The lack of MMSs in GBMs hampers a balanced and comprehensive evaluation of the full spectrum of land-sharing and land-sparing options for preserving biodiversity. As a result, existing models and scenarios consider increased crop yields and expanding protected areas (i.e. land sparing) as the solution to halting biodiversity loss or restoring biodiversity and do not consider combining food production and biodiversity conservation, in the way MMSs do. Including MMSs in global biodiversity assessments would, thus, enable analysing a much larger variety of options in response to decreasing biodiversity than the limited set currently debated by policy-makers in many countries. It would enable to address regional differences and do justice to current practices in terms of MMSs being applied by many farmers in many areas of the world.

Declaration of Competing Interest

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

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