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39 Trade-Offs and Synergies Between Biodiversity Conservation and Productivity in the Context of Increasing Demands on Landscapes

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39.1 Introduction

A growing human population coupled with increasing per capita consumption, changing diets, increasing food waste, and ineffective regulation, have led to rising demands on ecosystems for the services they supply [1]. Globally, there have been increases in the amounts of land cleared of natural vegetation, in the intensification of management activities, and in the simplification of landscape structure, for example, through an increase in broad-scale agricultural practices [2, 3]. Areas of high agricultural production, i.e., provisioning ecosystem services, are being increasingly situated in areas of high biodiversity in many regions, especially southern Europe, China, and South America (Fig. 39.1a), and this overlap has grown more pronounced over the last 50 years, most notably in the tropics and subtropics (Fig. 39.1b). The conflicts between biodiversity and the major ecosystem services provided by agricultural production will increase further in the coming decades if, as predicted, tropical and subtropical areas are increasingly converted for agriculture [4]. Suggestions have been made to design agronomic systems shifting from conventional to more closed, regenerative systems, which would reduce energy consumption and emissions [5]. While trade-offs between allocating land to production and biodiversity conservation have resulted in conflict and polarization (e.g. Tscharntke et al. [1]), the scientific understanding of the underlying processes remains limited. These debates have presented an antagonistic set of land-use conditions in which human activities preclude the conservation of biodiversity. Studies that consider land-use gradients have frequently focused on either agricultural production or biodiversity, which limits our knowledge on how to mitigate trade-offs between food production and conservation. There is therefore a need to conceptualize trade-offs between agricultural production and biodiversity conservation, as well as global externalities resulting from the trade in agricultural products in a general, flexible, transferable framework [6].

Which ecosystem services are addressed? Provisioning ecosystem services, agricultural products, supporting ecosystem services (pollination, bio control), biodiversity.

What is the research question addressed? What are possible functional dependencies of biodiversity-production trade-off under changing land composition, configuration, and land use intensity?

Which method has been applied? Connectional and theoretical considerations, review, synthesis.

What is the main result? The framework suggests non-linear relationships caused by the multifaceted impacts of land use (composition, configuration, and intensity).

What is concluded, recommended? We propose solutions for overcoming the apparently dichotomous aims of maximizing either biodiversity conservation or agricultural production and suggest new hypotheses that emerge from our proposed framework.

39.2 Land Use–Production Relationships

Levels of agricultural production depend on a multitude of context-dependent factors including land-use-management practices, land-use history, infrastructure, and access to markets and subsidies, many of which are correlated [3]. Human land use has led to a diversity of land systems worldwide that vary greatly in the amount of land dedicated to agriculture (i.e., landscape composition), the spatial arrangement of natural and agricultural elements in the landscape (i.e., landscape

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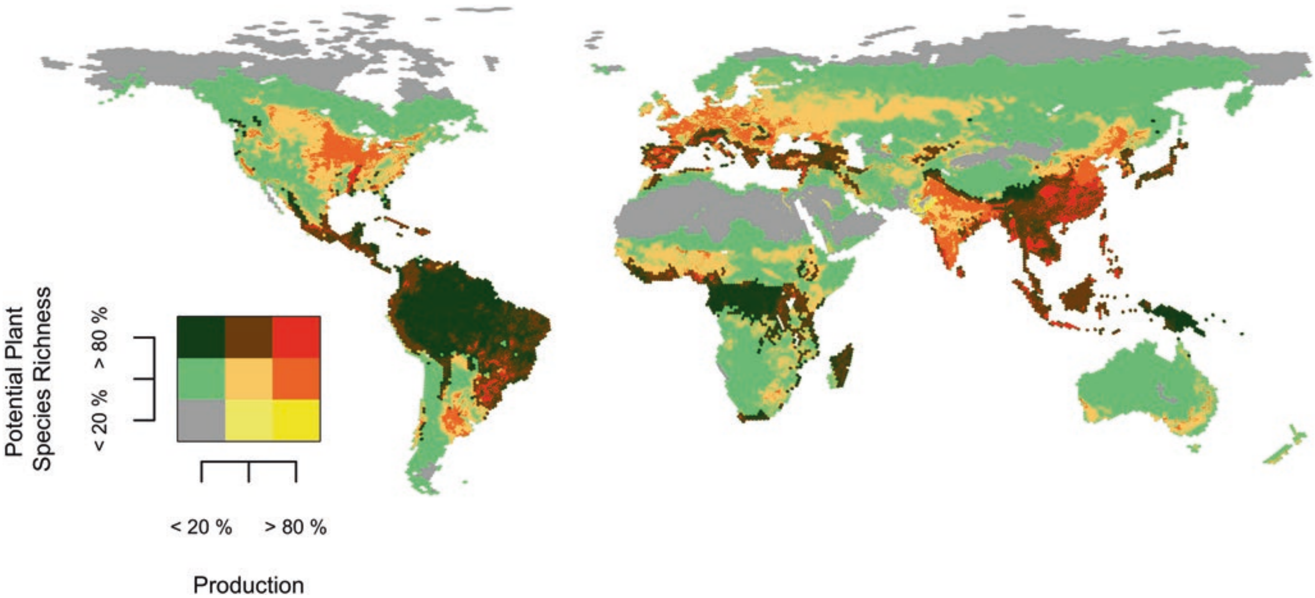

Fig. 39.1 The overlap between agricultural production and plant species richness, based on data on agricultural production and potential species richness of vascular plants. Plant species richness and current crop production were divided into three classes around the 20th and 80th percentiles

configuration), and the kind of management practices applied. The latter is most frequently understood as land-use intensity, characterized by the amount of inputs (chemicals, water, fertilizer, labour) and management aspects (stocking density, tillage regimes).

The most straightforward way to increase production is to increase the proportion of cultivated land. Increased areas of arable land enable a near-linear increase in production (Fig. 39.2a). It also true, however, that once a certain threshold is reached, gains will be reduced by the inclusion of landscape patches that are less suited for agriculture and by the impairment of ecosystem functions in nearby natural habitat. Intensification leads to asymptotically increasing production, with diminishing returns (Fig. 39.2b) owing to limiting factors such as radiation, water availability, and the impairment of important supporting and regulating ecosystem services such as biocontrol or pollination [7]. This pattern of saturation is well known in agricultural economics and is usually referred to as a Cobb-Douglas function [8]. Experimental studies could fully separate the effect of total area from intensity of use, but in real-world landscapes we expect both aspects to interact. The nature of the relationship between production and landscape configuration is less certain (Fig. 39.2c). There might be production benefits to larger farms with more continuous (i.e., less patchy) areas under agriculture, owing to scaling effects or to increased management efficiency [9].

39.3 Land Use–Biodiversity Relationships

Evidence strongly suggests that biodiversity (defined here as the combination of richness and abundance) decreases when the proportion of agricultural land is increased, because this results in the loss and fragmentation of natural habitats (Fig. 39.2d; [10]). The form of this relationship will depend on exactly how landscape composition affects the relative abundances of species [11, but see 12]. Increasing land-use intensity can result in a decelerating decrease in biodiversity (Fig. 39.2e; as shown by, e.g., Gerstner et al. [10]). Small increases in intensity in minimally altered habitat initially lead to large losses of diversity, while further intensification will result in continuing but less dramatic declines (Fig. 39.2e; e.g., Kleijn et al. [13]). The relationship between diversity and landscape configuration, however, is uncertain, and various plausible relationships can be conjectured (Fig. 39.2f). Landscapes of simpler configuration might support a higher diversity of a certain habitat type if the remaining habitats are in larger patches [10], which, however, depend on the surrounding intensity of use and composition. Complex configurations, and a higher proportion of more undisturbed habitats, might support more mobile species. Furthermore, if migration through the agricultural matrix is possible, small-scale extinctions in fragmented landscapes might be reversed through colonization [14].

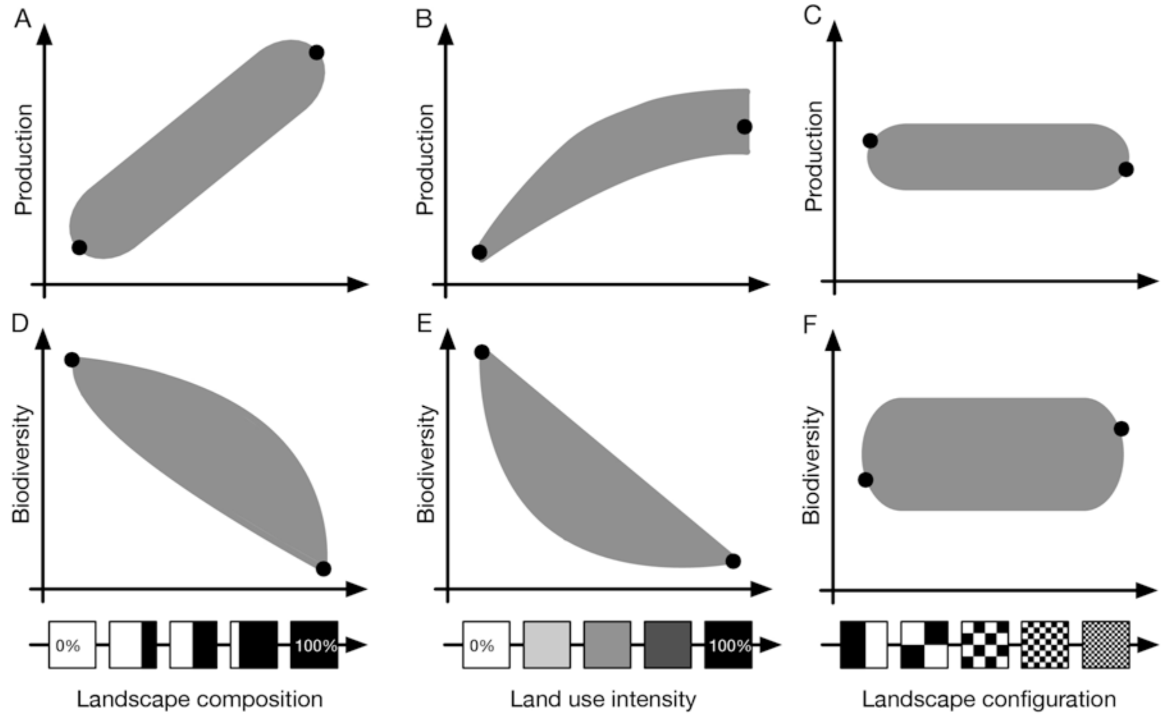

Fig. 39.2 Foundation of the conceptual framework: hypothesized relationships of agricultural production (**a–c**) and biodiversity (measured with abundance-richness metrics; **d–f**) as a function of landscape composition (proportion of agricultural land), land-use intensity, and landscape configuration (reprinted from [6]). Relationships represent a summary of current knowledge as reported in the published literature, with grey shading indicating uncertainty or lack of consensus. Black points illustrate the often-used dichotomous view, comparing just two levels of land use. In the depictions of land use, white colouring indicates areas of natural habitat, and grey or black colouring areas of agriculture (with the intensity of grey indicating land-use intensity)

39.4 Synthesis: Land Use and the Biodiversity–Production Relationship

Figure 39.3a, b show the combined effects of land-use composition, configuration, and intensity on a single axis. The coloured arcs of the smaller upper panels translate directly to the arcs of the same colour in the main panel, and can be associated with different land-use systems. This ranges from best cases, where biodiversity is both maintained within agricultural areas and supports production (upper edge of the grey shaded area in Fig. 39.2c), to worst cases, where agricultural production is at the expense of biodiversity (lower edge of the grey shaded area).

High biodiversity and high agricultural production are possible where biodiversity can provide benefits to agricultural crops, and where agricultural areas are managed to maintain high levels of biodiversity (Fig. 39.3, green arcs). In species that support control of pests, pollination or nutrient cycling contribute to supporting ecosystem services and maintaining higher yields. This requires specific management strategies such as intercropping, agroforestry, and provisioning of nesting habitats (e.g., for pollinators [14]), such as managing complex landscapes that compensate for local high-intensity management by enhancing local biodiversity. This functional relationship could be, e.g., a hump-shaped curve (Fig. 39.3; [15]), although quantitative data along such a complexity gradient are still lacking.

Beyond a certain point, only larger fields, with more efficient production or more energy input and higher land-use intensity, can achieve a further increase of production. Use of chemical inputs is increased, and practices that sterilize, structurally level, and standardize agricultural plots are promoted [1]. The consequences are rapid losses of biodiversity [10] and a comparably slower increase of agricultural yields (Fig. 39.3, blue arcs; [8]).

Where the focus is exclusively on agricultural production, biodiversity is quickly lost. In these cases, increasing production might be less successful if it depends on components of the biodiversity (Fig. 39.2, red arcs). This could lead to a

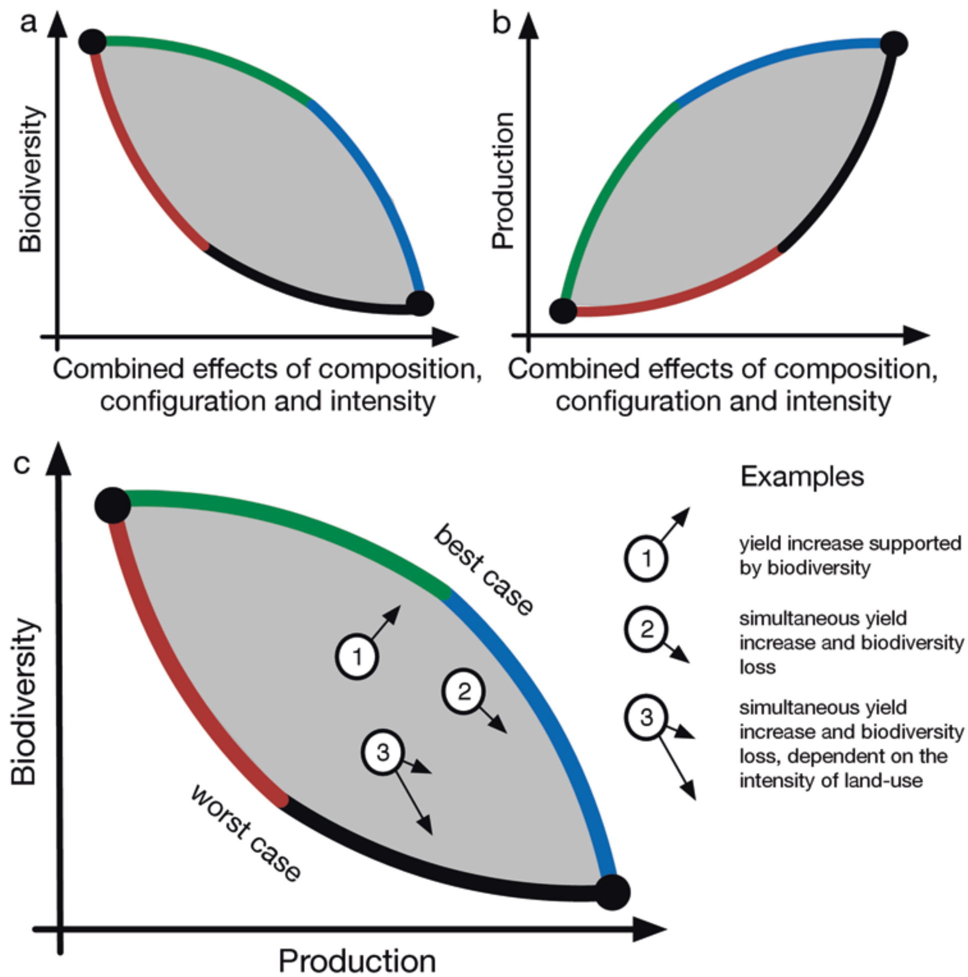

Fig. 39.3 Synthesis of the conceptual framework: Combining the relationships between land use and biodiversity (**a**), and between land use and agricultural production (**b**) leads to hypothesized relationships between agricultural production and biodiversity (**c**) (reprinted from [6]). In the top panels (**a**, **b**) we assume a combined effect of landscape composition, landscape configuration, and land-use intensity, with increased anthropogenic impact to the right. The coloured arcs of the smaller upper panels translate directly to the arcs of the same colour in the main panel and can be associated with different land-use systems. The numbered arrows and corresponding labels in the main panel identify possible options for land management, and correspond to the findings of (1) Finn et al. [17]; (2) Storkey et al. [18]; and (3) Donald et al. [19]

worst-case condition for both biodiversity and production, characterized by antagonistic relationships between wildlife and agricultural production. For example, unsustainable agricultural practices, such as large-scale clearing of vulnerable soils, may cause both large losses of biodiversity and low and declining yields due to soil degradation [16]. On the other hand, there are cases where biodiversity under agricultural production is low, and where agricultural productivity can be achieved only through very high levels of intensification and degradation of the natural area (Fig. 39.2, black arcs). For example, this is the case for highly intense agriculture in the so-called Corn Belt of the US Midwest, with very high soil erosion, depletion of aquifers, water pollution, evolution of herbicide- and pesticide-resistant pests, and so on, leading to a plateauing of agricultural production [3].

39.5 Discussion and Conclusions

The framework helps identify key knowledge gaps and generates hypotheses about trade-offs between agricultural production and biodiversity (Box 39.1). It illustrates how various non-linear relationships in the complex three-dimensional space of land use, biodiversity, and production could be conceptually synthesized into various relationships between production and biodiversity (Fig. 39.3). These relationships encompass the option space for reconciling biodiversity and production. The framework goes beyond the dichotomous views taken in previous discussions, showing that a consideration of gradients in the different facets of land use allows an understanding of the non-linear nature of the relationships.

Box 39.1 Hypotheses Emerging from the Conceptual Framework

Considering the effects of multiple aspects of land use (composition, configuration, intensity) on both agricultural production and biodiversity leads to novel hypotheses about the trade-offs between agricultural production and biodiversity conservation. The following list of hypotheses exemplifies the variety of research questions generated by the conceptual framework and may be extended, especially by considering more landscape contexts and species groups.

1. Landscape **configuration** affects agricultural production less than it does biodiversity. The most pronounced differences in both production and biodiversity are seen in landscapes with intermediate proportions of agricultural land (**composition**).
2. Higher habitat diversity in the landscape (**configuration**) enhances agricultural production, because biodiversity, and thus the ecosystem functions that support production, are supported by a larger number of edge habitats.
3. The higher the habitat diversity in the landscape (**configuration**), the stronger the impact of land-use **intensification** on biodiversity, because of increasing exposure to edge habitats. This will result in land-use intensification being less effective in landscapes with higher habitat diversity because the ecosystem functions supported by biodiversity will decrease more significantly.
4. The larger the fraction of land under agricultural production in the landscape (**composition**), the less effective land-use **intensification** will be for agricultural production (i.e., saturation in Fig. 39.1b appears earlier), because ecosystem functions supported by biodiversity are lacking.
5. Land-use **intensification** can compensate for reduced agricultural productivity caused by lower biodiversity; however, the marginal gain of agricultural production with increasing land-use intensity depends on the crop type(s) and the landscape composition and configuration.
6. Land-use **intensification** negatively affects biodiversity disproportionately more than it increases agricultural production, to different degrees depending on landscape **configuration** and **composition**, and environmental conditions.

(*Reproduced from* Seppelt et al. [6].)

Moving away from a strictly dichotomous view is key to working towards a more complete understanding and more nuanced decision-making. A challenge remains to develop general metrics that combine all aspects of land use (configuration, composition, and intensity), which will allow the application of the proposed framework. It is a high priority for ecologists studying land use–biodiversity relationships to also obtain estimates of agricultural production. We also encourage broadening the set of biodiversity indicators used to include species' abundance information. The framework identifies possible options for reconciling demands for agricultural production with demands for biodiversity conservation. There are multiple unexplored combinations of landscape composition, configuration, and management that might offer the opportunity to manage landscapes optimally to both feed the needs of a growing human population and conserve biodiversity. Conservation of biodiversity needs to be achieved by designing appropriate production systems that contain and benefit from higher biodiversity, rather than focusing only on the protection of pristine habitat.

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