15 Vulnerability of Ecosystem Services in Farmland Depends on Landscape Management

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15.1 Introduction

Forty-four percent of Europe's terrestrial surface is covered with agricultural land. Thus, agriculture strongly influences Europe's environment, including ecological functions and processes. Agriculture provides direct benefits to humanity, such as food, feed, fuel, and fiber. In addition to agricultural production, farmland plays an important role for regulating services, such as carbon sequestration, water capture and retention, biological pest control, and pollination. As an interface between nature and human activities, agricultural landscapes endow people with a sense of place, enable livelihoods, ways of living, and offer space for recreation [1]. These and several other ecosystem services constitute the multifunctionality of the agricultural landscape that European agricultural policy seeks to achieve and maintain. Hence, ecosystem service management needs to navigate trade-offs between competing interests from local to landscape scales.

Two processes, land use intensification and land abandonment, are the main drivers of current changes in European agroecosystems. The consequences of these changes for human well-being have been only fairly explored. On the one hand, production of agricultural goods increases, either through the expansion of agricultural land or, more frequently, by intensification on existing farms. This happens through the use of higher yielding crop varieties, increased input of agrochemicals, and simplification and shortening of the crop rotation. Intensification also aims at higher cost-effectiveness in the short term, which involves consolidation of field sizes and the removal of semi-natural landscape elements such as hedgerows, field margins, and tree lines [2]. The consequences of intensification include landscape simplification, nutrient leaching, soil compaction, loss of soil fertility, and loss of biodiversity. On the other hand, land abandonment might also lead to a loss of landscape heterogeneity through biotic homogenization, thereby eroding habitats for open-land species.

Which ecosystem services are addressed? Multifunctionality of agricultural landscapes with particular focus on crop pollination and biological pest control

What is the research question addressed? What is the relative importance of local and landscape management for maintaining or enhancing functional biodiversity that provides ecosystem services such as biological control and pollination?

Which method has been applied? Mixture of literature review, experts' opinions, and case studies on pest predation and crop pollination in farmland in response to changing landscape heterogeneity

What is the main result? The multifunctionality of agricultural landscapes calls for managing trade-offs between ecosystem services. Enhancing functional biodiversity for pollination and biocontrol at a landscape scale requires a minimum of approx. 20% of semi-natural habitat, but improved cropland and fallow management may allow reducing this percentage. Measures to enhance biocontrol and pollination are most efficient in simple, but not complex or fully cleared landscapes. Scattered semi-natural habitat across regions and countries maintains dissimilarity of communities (beta-diversity) and resulting functional redundancy

What is concluded, recommended? EU policy should tailor its agri-environmental schemes at the landscape scale to increase its effectiveness. Regulations to minimize agrochemical use need to be implemented to reduce hostility of cropland, thereby allowing spillover of functionally important biodiversity between local and landscape habitats. Such management should promote functional complementarity and insurance of ecosystem service delivery in times of environmental changes

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15.2 Biodiversity as Integral Part of Ecosystem Services

Agroecosystems are pivotal for the conservation of biodiversity in Europe. Biodiversity, in terms of species richness, trait diversity, and biotic interactions, affects ecosystem functions and their stability [3] by, e.g., promoting soil-supporting services, pollination, or biological pest control. In a political context, biodiversity conservation is often justified to ensure human well-being via the supply of ecosystem services. Notwithstanding, conserving a wide range of species, including those that are rare and endangered, may serve as an insurance and complementation strategy for safeguarding ecosystem functions under changing environmental conditions. Despite a huge body of experimental approaches [3], our knowledge about the relationship among biodiversity, ecosystem functions, and ecosystems services in agricultural landscapes is still fragmented and ambiguous. This relationship is most likely non-linear and depends upon interacting field and landscape-scale effects.

Pollination through insects and biological pest control are two ecologically and economically important agroecosystem services. Production of 75% of all major crops, especially fruits, nuts, and vegetables, benefits from or even relies on insect pollination. Wild pollinators such as bumblebees and solitary bees are usually the most effective pollinators for many economically important crops [4]. Pollination rates may increase with the number of species present in a site due to functional complementarity. However, the majority of pollination service is delivered through few common species [5]. Thus, the relationship between pollination rates and the number of species levels off at a particular point, which means that additional species only marginally increase the ecosystem service of interest. Under changing environmental conditions, however, these species may play an important role in maintaining the resilience of the ecosystem.

For pest control, both success and failure are possible with increasing numbers of natural enemies, but despite the context dependency, enemy diversity appears to generally increase biocontrol [6]. In a systematic re-analysis of aphid pest control across Europe and North America, Rusch et al. found consistent negative effect of landscape simplification on the level of natural pest control, despite interactions among enemies [7]. The average level of pest control was 46% lower in homogeneous landscapes dominated by cultivated land, as compared with more complex landscapes. There is thus a huge potential to support natural pest control through counteracting homogenization of farmland.

15.3 Landscape Heterogeneity Determines On-Farm Biodiversity and Ecosystem Services

The field and the landscape are intricately interconnected and constitute heterogeneity [8]. Both landscape compositional and configurational heterogeneity can affect biodiversity [9]. Landscape compositional heterogeneity increases with the diversity of habitat types, while landscape configurational heterogeneity increases with high amounts of edges and small crop fields. Ongoing research shows that increasing configurational heterogeneity at a landscape scale is at least as important for keeping biodiversity as the switch to organic farming [10]. Landscape composition and configuration at different spatial scales explained species richness of plants, bees, and butterflies [8, 11], and the presence of pest enemies in agricultural landscapes [12]. Many other ecological studies confirm that landscape characteristics influence biodiversity patterns at different spatial scales [8]. Moreover, heterogeneity can mitigate adverse effects of local land use intensification [13].

Semi-natural habitats and crop diversity are two important components of compositional and configurational heterogeneity in agricultural landscapes that affect biodiversity at the landscape scale [9]. Semi-natural habitats in agricultural landscapes play an important role as source habitats for many species, such as wild bees that pollinate crops [14] and natural enemies of pests [15]. However, the amount of semi-natural habitat is not the only factor that determines biodiversity at a landscape scale; the quality, in terms of resource availability, is also important to consider from an agroecological perspective. For example, conservation management of set-aside or fallows contributes to landscape complexity, but set-aside that is agronomically managed may not differ from cropland [16]. Enhancing functional biodiversity for pollination and biocontrol on a landscape scale requires a minimum of ca. 20% of semi-natural habitat, but improved cropland and fallow management may allow a reduction of this percentage [16].

The crop production area itself is often ignored and considered as undifferentiated matrix [9], although it greatly varies in its heterogeneity (e.g., field size or diversity of crops). In a recent study, we found that both configurational and compositional heterogeneity of the cropland influence predation rates on aphids, which indicates a higher success of pest control in more heterogeneous cropland (Fig. 15.1). Furthermore, fewer cereal aphids were present in farmland comprising spatial and temporal heterogeneity represented

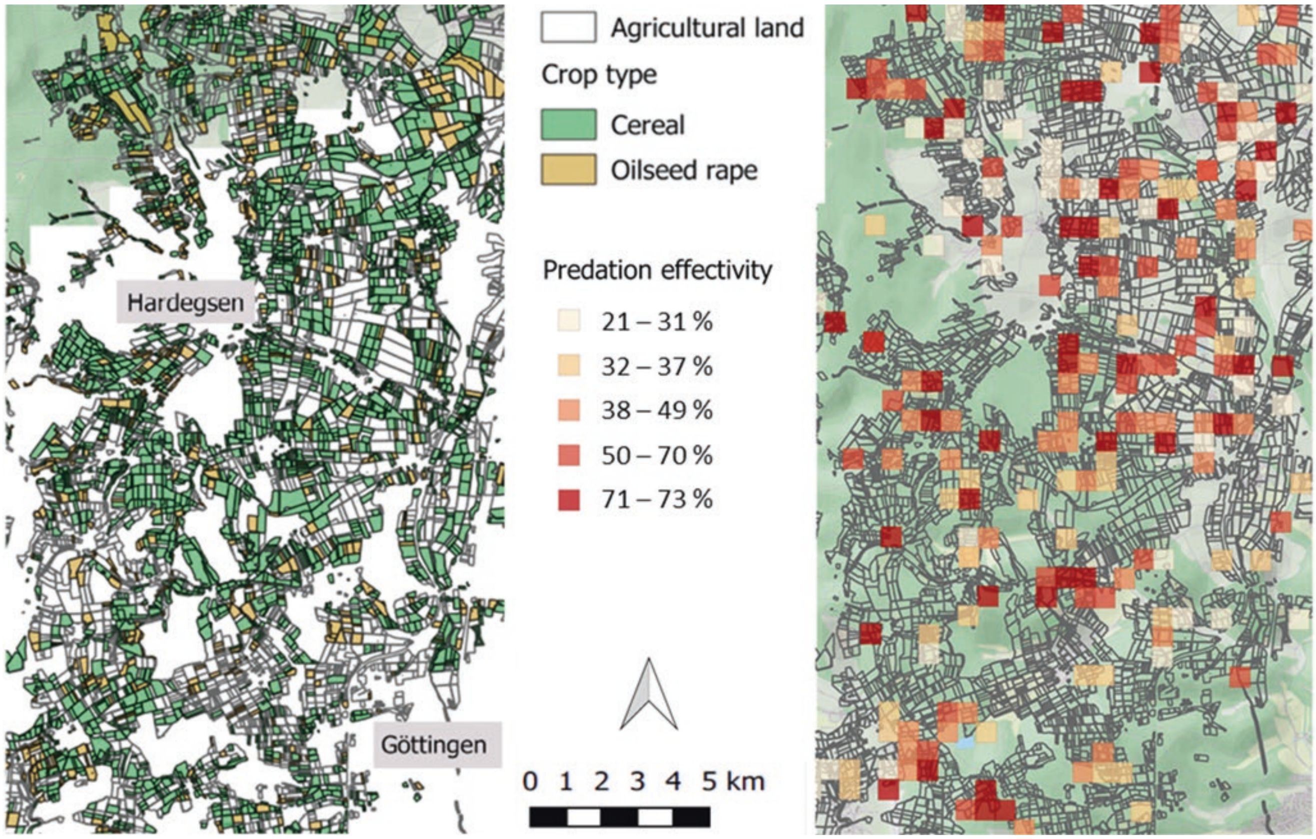

Fig. 15.1 Predicted predation effectivity in 52 agricultural landscapes in the Leinetal, Lower Saxony. The prediction is based on a comprehensive study on aphid predation rates in 104 cereal fields and 52 oilseed rape fields with different compositional and configurational heterogeneity of crops in the surrounding (Aliette Bosem-Baillod [Agroscope, Reckenholz] and Annika Hass [Agroecology, Georg-August University, Göttingen], unpubl. data). Information on the predation rates of aphid cards were collected during the summers of 2013 and 2014. Predation rate was used as a response variable in a generalized linear mixed model using the landscape as random effect and heterogeneity of the landscape as predictors. The results of this model were then extrapolated to the entire agricultural landscape in the Leinetal to predict pest control based on landscape heterogeneity

through small field sizes and high cover of field margins [17]. Consequently, ecological effectiveness through, e.g., pest control and pollination, interacts with heterogeneity of the landscape at local and landscape scales (Fig. 15.2) [18, 19]. However, measures to enhance biocontrol and pollination (e.g., by implementing field boundaries or hedges) are most efficient in simple landscapes rather than in complex or fully cleared landscapes [18]. We assume that this positive relationship between landscape complexity (i.e., the presence of semi-natural habitats) and the presence of natural enemies and pollinators may prove to be beneficial for crop yield (Fig. 15.2c).

Other ecosystem services may also be affected by landscape-scale characteristics and their interaction with local scale conditions [14]. Knowledge of such interacting effects can improve the planning of agriculture for specific ecosystem services. Mass flowering crops, for example, may serve as complementary resource for pollinators (Fig. 15.3) [20]. This complementarity effect, however, calls for assessments not only of local species' richness and related ecosystem services, but for a stronger focus on larger-scale species turnover (beta-diversity) among habitats, as well as total landscape diversity (gamma-diversity). Measures to increase semi-natural habitat and cropland heterogeneity across regions and countries promise to keep dissimilarity of communities (beta diversity). Higher beta-diversity, in turn, increases the likelihood of functional redundancy and may stabilize the capacity of a system to sustain its service provision.

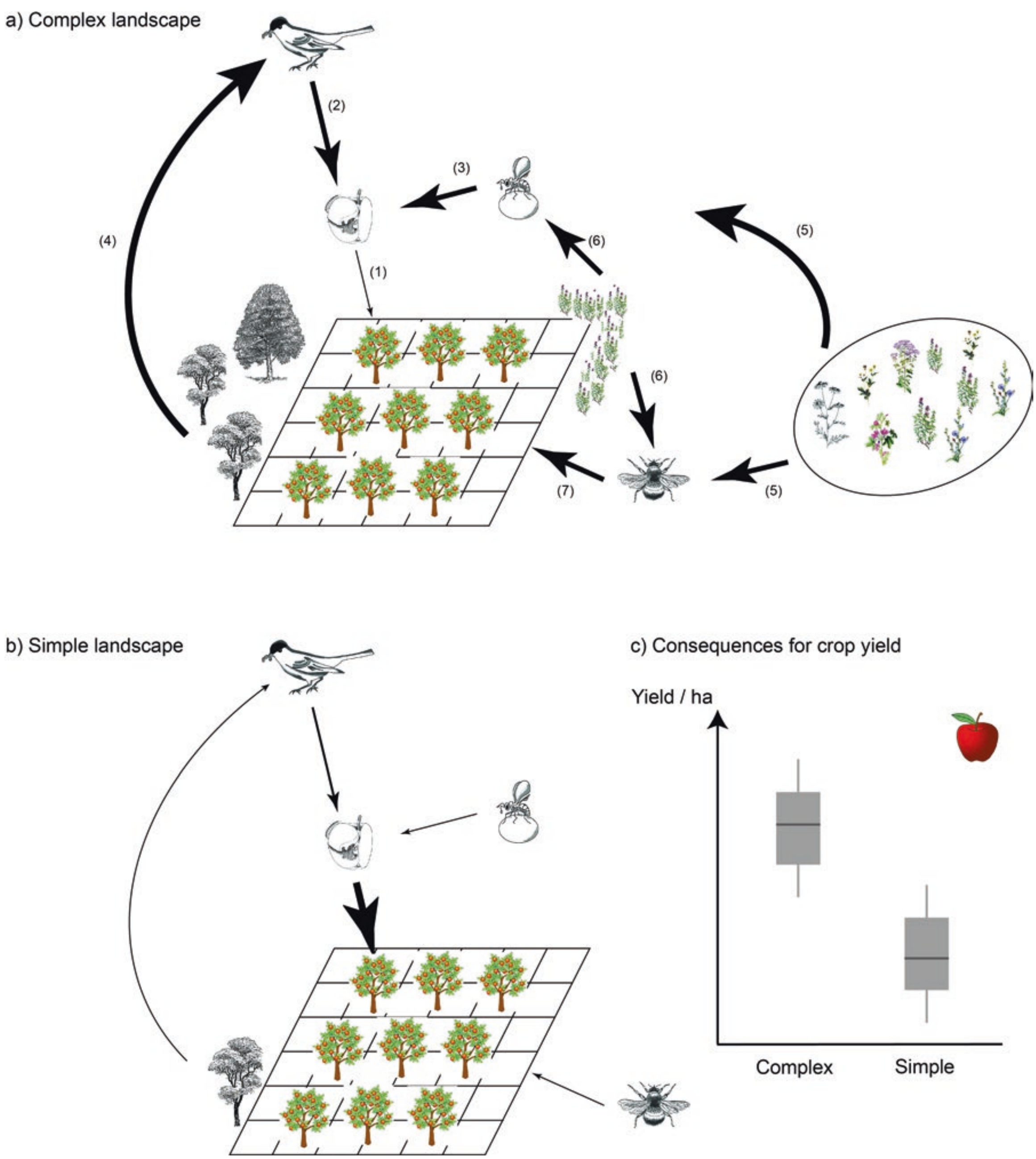

Fig. 15.2 Hypothesized consequences of landscape complexity for ecosystem service delivery and crop yield. **1**, Pest damage to apple fruits is often caused by the codling moth (*Cydia pomonella*). **2**, Insectivorous birds can suppress adult codling moths. **3**, Similarly, *Trichogramma* wasps are egg-parasitoids of codling moths, reducing codling moth damage in apple orchards when released. **4**, Trees and hedges in the landscape surroundings provide nesting habitat and food for insectivorous birds, increasing their biological control potential. **5**, Similarly, high-value habitats in the landscape surroundings as well as **6**, local establishment of flower strips benefits parasitoids as well as wild bee pollinators. **7**, Wild bees in particular are often more efficient pollinators of crops than commercial honeybees. While (**a**) complex landscapes provide ecosystem services, (**b**) landscape simplification results in losses of these services, which at the same time leads to higher pest outbreaks. Consequently, (**a**) complex landscapes should benefit crop yields at the farm-level by facilitating ecosystem service

15.4 Local Adaptation and Targeted Measures Required for Ecosystem Service Maintenance

The EU Common Agricultural Policy includes environmental measures that are intended to increase both biodiversity and ecosystem functions of the EU's farmland. As an example, management practices used in diversified farming systems result in more complex and heterogeneous agricultural landscapes and thereby have the potential to generate higher levels of biodiversity at the local scale. Flower strips represent such widely used agri-environment schemes, and the benefits related to pollination have the potential to outweigh the loss of area [21]. However, EU policies mainly target farm and field levels and usually disregard the landscape

Fig. 15.3 Pollination and natural pest control are two important ecosystem services in agricultural landscapes. (**a**) While the majority of pollination service is delivered through few common species (such as the honeybee *Apis mellifera*), rare pollinators are more efficient pollinators and may play an important role under changing environmental conditions. (**b**) The configuration and composition of cropland and the surrounding landscape influences the effectivity of natural pest control, as provided by parasitoids like parasitic wasps

context. The effectiveness of these measures, however, strongly depends on the landscape structure [22]. Thus, flower strips may or may not be beneficial for a specific conservation target. For example, perennial strips with few forbs may enhance the richness of soil-dwelling arthropod predators in the field margins, whereas nectar-rich flowers in an annual field strip may attract more pollinators. Hence, a set of measures need to be implemented to enhance a diversity of important services. These measures, moreover, need to fit the biophysical and socio-economic conditions of the region in which they are to be applied.

Heterogeneity of agricultural landscapes has often been found beneficial for biodiversity; however, diversification of cropland showed strongest impacts on biodiversity in simplified landscapes [22]. Moreover, not all functional groups of species may be similarly affected by variables at the field or at the landscape scales. For example, small solitary bees forage at small ranges, whereas large bumblebees (and honeybees) on large scales [23]. Generalist predators of cereal aphids, however, benefit from simplified cereal-dominated landscapes, while specialist enemies do not [24]. In contrast, earthworms and other organisms that increase soil quality and long-term soil fertility thrive best through on-site management, such as tilling and crop rotation. Rare or endangered species and species that fulfill keystone functions in an ecosystem may need specific and targeted conservation measures in order to support their contribution to ecosystem services.

15.5 Conclusion

Neither single agri-environment measure nor single conservation action targets the range of benefits that humans derive from agricultural land. Maintaining or restoring the ability of agricultural landscapes to provide various ecosystem services requires regionally adapted schemes, which are most effective if embedded at both the farm level and the landscape level. To ensure the provisioning of many different ecosystem services in a landscape, allocating priorities for smaller units of the landscape may prove helpful in navigating potential trade-offs between ecosystem services. One well-known trade-off between different ecosystem services is yield increase through intensification, on the one hand, and increases of semi-natural habitats for pollinators and natural pest enemies on the other hand. However, it is possible to balance these trade-offs through appropriate management. The implementation of flower strips at the local scale and increasing heterogeneity at the landscape scale are promising strategies to allow spillover of functionally important biodiversity between local and landscape habitats. In combination, these measures reduce the hostility of cropland and achieve synergy effects between facilitation of pollination and increased yield. Consequently, use of agrochemicals can be minimized, which decreases detrimental impacts on, for example, important soil functions. More research is needed to identify synergies between apparently conflicting ecosystem services, and this will inform the management of multifunctional landscapes. Moreover, farmland should be recognized as social-ecological systems that are strongly influenced both by the local society and by contextual legislation that spans the continuum from local to EU policies. Eventually, a comprehensive management system for the maintenance of multifunctional landscapes needs to tackle meaningful ecological scales and match various governance levels.

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