Chapter 14

Designing Multifunctional and Resilient Agricultural Landscapes: Lessons from Long-Term Monitoring of Biodiversity and Land Use

Sabrina Gaba and Vincent Bretagnolle

Abstract In this chapter, we illustrate how the current challenges of agriculture - i.e. maintaining food security while preserving biodiversity, landscapes and ecosystem functions - have been addressed in a long-term social-ecological research site, the Zone Atelier Plaine & Val de Sèvre, operated since 1994. After a presentation of the study area and its research program, we present landscape changes over the past 25 years. Then, we review the most relevant studies conducted in this area that examined the effect of landscape on farmland biodiversity. We focus on biodiversity because it is a central tenet of sustainable agriculture, which delivers ecosystem services that benefit human well-being and ensure ecosystem stability and resilience. Finally, we show that approaches that sustain biodiversity can also support food production, the delivery of multiple ecosystem services and the economy of local stakeholders. One major result from studies in the LTSER ZA-PVS is that biodiversity decline is a severe threat to food security in itself: improving biodiversity can improve yields, gross margins, or both. Biodiversity in arable habitats is, therefore, required to maintain food security, especially through pollination, natural pest regulation and soil services. Long-term monitoring of biodiversity, ecosystem functioning and agricultural practices as well as land use revealed that the interplay between local and landscape factors can provide solutions to reach these goals of multifunctionality (biodiversity, food production and farmers' profitability) in

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S. Gaba (✉)
Centre d'Etudes Biologiques de Chizé, UMR7372, CNRS & Université de La Rochelle, Villiers-en-Bois, France

USC 1339 Centre d'Etudes Biologiques de Chizé, INRAE, Villiers-en-Bois, France

LTSER Zone Atelier Plaine & Val de Sèvre, Villiers-en-Bois, France
e-mail: sabrina.gaba@inrae.fr

V. Bretagnolle
Centre d'Etudes Biologiques de Chizé, UMR7372, CNRS & Université de La Rochelle, Villiers-en-Bois, France

LTSER Zone Atelier Plaine & Val de Sèvre, Villiers-en-Bois, France

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agricultural landscapes. The next step is to engage stakeholders, in collaboration with scientists, and increase awareness of their mutual interdependencies with nature to foster the transition to more agroecological farming.

Keywords Zone Atelier Plaine & Val de Sèvre · Biodiversity · Organic farming · Ecosystem services · Multifunctional landscapes · Agri-environment schemes

1 Introduction

Over the past half century, agriculture has provided increasing food supply but at the same time, contributed massively to greenhouse gases emission, agrochemical pollution and soil degradation (Tilman et al. 2011; Del Grosso et al. 2012; Amundson et al. 2015). The expansion and intensification of agricultural activity is also threatening no less than 5407 animal species — 62% of those listed as threatened or near-threatened, placing agriculture second in the rank of the biggest threats to biodiversity (Maxwell et al. 2016). Apart from biodiversity loss in itself, this is particularly worrying for those crops for which yield depends on ecosystem functions and services such as pollination (Pywell et al. 2015; Tamburini et al. 2016). An increasing world population and concern about the sustainability of crop production has led to calls for producing food differently while creating agricultural systems that enhance biodiversity, promote closed-loop systems, increase soil health, and eliminate the dependence on external synthetic inputs (Altieri 1983; Tittonell 2014; Godfray 2015; Gliessman 2016). However, opinions are divided over the best strategic direction.

One option is to minimize farmland area and spare land for nature, hence reducing the negative environmental footprint of agriculture. In farmland areas, this is usually achieved by retaining on-farm semi-natural elements. Another option is to reduce external synthetic inputs (fertilisers and pesticides) by implementing alternative farming systems. This can be done at the field level, under the European agri-environment policy, MAEC in France, as part of the 2014–2020 reform of the second pillar of the Common Agricultural Policy (Pe’er et al. 2014). This can also be done at the farm level, i.e. by changing the agricultural system of the farm. Organic agriculture is the most popular alternative farming system (Willer and Lernoud 2019), with an increase of 23% of organic cropland between 2014 and 2015 in France (Source: Agence Bio/Organismes Certificateurs). Organic farming (OF) sustains agricultural productivity by avoiding or largely excluding synthetic fertilizers and pesticides (Lampkin 1990). Agroecology is another popular alternative to the massive use of synthetic chemicals (Altieri 1983; Gliessman 2016). Both agroecology and OF rely on the use of the natural functionality provided by the ecosystems to maintain crop production, protect crops against pests and pathogens, and improve the environment and farm profit (Bommarco et al. 2013; Gaba et al. 2014). Indeed, reducing applications of pesticides can maintain and promote natural enemies for pest control as well as pollinators - both major ecosystem services (ES) for global food production and agricultural businesses. On the one hand, invertebrate pests destroy 8–15% of global wheat, rice, maize, potato, soybean, and cotton production (Oerke 2006) and cause more than US$30billion in damage in the US each year (Pimentel et al. 1992). On the other hand, animal pollinators are essential for approximately 35% of global crop production, and 60–90% of all plant species are pollinator-dependent (Klein et al. 2007). The estimated worldwide value of insect-pollinated crops was €153 billion in 2009 (Gallai et al. 2009). However, the diversity and abundance of pests, their natural enemies and pollinators, all depend on both local management and landscape heterogeneity (here heterogeneity refers both to landscape composition and configuration, Fahrig et al. 2011). Therefore, strategies for enhancing pest control and pollination ESs to agriculture require a detailed understanding of the interactive effects of these two factors on predator and pollinator ecology, as well as between predator and pollinator biodiversity.

However, reducing or banning pesticides and fertilisers as well as making space for nature may result in lower yields per unit area (fuelling the long-standing land sharing/land sparing debate; Green et al. 2005, Phalan et al. 2011), and thus may require extending the area of land under production (Phalan et al. 2016). How, then, can we meet the current challenges that agriculture faces? In other words, which spatial arrangement of arable land and semi-natural habitats can make agricultural landscape multifunctional and resilient?

2 The Long-Term Social-Ecological Research Site, Zone Atelier Plaine & Val de Sèvre

2.1 Description of the ZA-PVS

The Long Term Socio-Ecological Research (LTSER) site, Zone Atelier Plaine & Val de Sèvre (ZA-PVS) is part of the French LTSER Research Infrastructure (Réseau des Zones Atelier, Lévêque et al. 2000). This network of 14 research platforms aims to analyse, understand and most importantly, implement management strategies that support socio-ecological system (SES) resilience and robustness. The LTSER ZA-PVS combines long-term monitoring of social-ecological components and their relations, supports interdisciplinary research, and engages stakeholders in transdisciplinary approaches (Bretagnolle et al. 2018b). The LTSER obtained its label in 2008, and has focused since 1994 on agroecology as an alternative agricultural model (*sensu* Altieri 1983), promoting nature-based solutions that integrate agricultural development and biodiversity conservation within resilient multifunctional landscapes. Its research program fits the unified operational framework of the Réseau des Zones Atelier (Bretagnolle et al. 2019) where the coupling between the social and ecological templates is represented by two loops: the “Ecosystem Services interface” (Haines-Young and Potschin 2010) and the

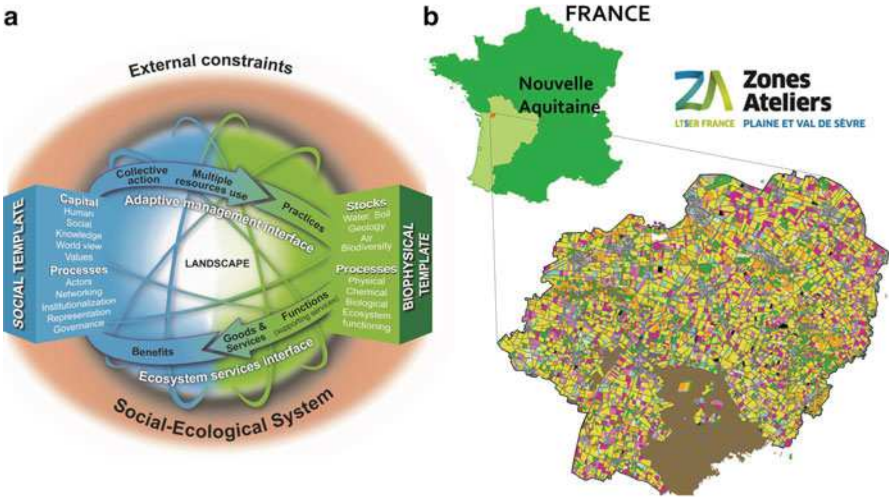

Fig. 14.1 (**a**) Conceptual framework of the French LTSER Zone Atelier Network (from Bretagnolle et al. 2019). The blue box shows the social template and the green one the biophysical template. The socio-ecosystem is represented with the two feedback loops acting in the landscape. (**b**) Location of the Zone Atelier Plaine & Val de Sèvre in West of France

"Adaptive Management interface" (Cumming et al. 2015) (Fig. 14.1). Using approaches such as monitoring and experimentation (and to a lesser extent, modelling), the LTSER ZA-PVS supports place-based knowledge production by both academic and non-academic participants, based on strong stakeholder collaboration (Angelstam et al. 2018; Bretagnolle et al. 2019). Its research program, that involves transdisciplinarity and interdisciplinarity, also aims to identify solutions to improve the capacity of the social-ecological system to reorganise itself in order to maintain its structure and functioning in response to local and global sustainability threats (e.g. food security, economic shocks, health) posed by climate change, agricultural pollution and biodiversity loss. This research program is organised around three main axes: agroecology (from food production to food consumption), ecohealth (joint analysis of human, animal and environment health in response to socio-ecosystem changes) and biodiversity conservation (participatory science and action research to maintain biodiversity, including endangered species).

The research strategy of the ZA-PVS combines three complementary approaches: (i) long-term monitoring of the social-ecological system, including its ecology (the whole trophic chain: plants, insects, spiders, small mammals and birds), landscape (configuration and composition, distribution of semi-natural habitats), and social aspects, such as land use, farmers' agricultural practices and public policies; (ii) experimenting with various stakeholders, management strategies at field, farm, landscape and village scales to foster food supply transition and global health within an agro-ecological and ecohealth frameworks; and (iii) engaging local stakeholders of different types in iterative and collaborative processes to produce place-based

Fig. 14.2 Various landscapes in LTSER Zone Atelier Plaine & Val de Sèvre. From left to right, on the top row a oilseed field and a relict vineyard in a cereal plain; on the bottom row a wheat field and a meadow

knowledge and pathways towards a resilient and multifunctional agricultural landscape.

The ZA-PVS is located south of the city of Niort, in the *Deux-Sèvres* department in the *Nouvelle-Aquitaine* Region, south-west France (Fig. 14.1b). This large study area (435 km^2) is typical of rural landscapes (Fig. 14.2) and is managed almost exclusively for arable and mixed farming. There are 24 administrative *communes* inside the ZA PVS and eight others (including the Niort urban district) partially within the ZA-PVS. The total human population of the ZA-PVS is around 29,000 inhabitants (excluding Niort city). More than half of the study site was designated as a NATURA 2000 site in 2003 under the Bird Directive (NATURA 2000 code FR5412007). Socioeconomic and ecological data have been collected continuously since 1994 (see Bretagnolle et al. 2018a, b for further details). Besides data collection, the ZA-PVS has been used to carry out experiments in real world conditions (i.e. socio-ecological experiments, Gaba and Bretagnolle 2020) at various spatial scales, from fine scale (~1 m^2), to habitats (crops) and landscapes (e.g. by manipulating the proportion of meadows or hedges using agri-environmental measures).

2.2 Temporal Variation of Landscape Composition

The ZA-PVS is an intensive farming area with mainly winter cereals (average 2009–2016: 41.5%). The most common crops are winter wheat (33.8%), maize (9.6%), sunflower (10.4%), oilseed rape (8.3%), pea (2%) and “grasslands” (13.5%), including permanent (meadows) and temporary grasslands (hay, clover, alfalfa). The land cover in the ZA-PVS has been monitored yearly at the field scale since 1994, twice a year (for winter and spring crops, respectively). The detailed knowledge of land cover (i.e. more than 30 categories of crops, plus build up areas, forest fragments, vineyards and hedges) has been used for setting up tightly targeted spatial designs for testing hypothesis on the effect of landscape on biodiversity as well as ecosystem functions.

From 1994 to 2020, field sizes increased and accordingly, the total number of fields fell from c. 19,000 to less than 12,000 today. Winter cereal cover has strongly increased from around 35% in 1995 to 45% in 2018 (Fig. 14.3), being present in almost 100% of the 1km^2 pixels in the ZA-PVS. At the same time, the meadow cover has strongly decreased, both in the long term (60% in 1970 down to 15% in 2016) and recently with a 30% decrease since 2007 with the abandonment of set-asides in the European Union common agricultural policy (CAP).

Organic farming increased in France from 1.7% of farms in 2002 (1.87% of the surface of farmed area) to 9.46% in 2018 (7.55% of the farmed area; Agence BIO 2019). It also strongly increased in the ZA-PVS (Fig. 14.4a). Conversion to organic farming started in 1998 with only three farms. Currently the conversion rate is almost 15% of farmers with more than 12% of the ZA-PVS in organic farming. In some areas, organic farming represents almost 80% of cropland over 2 km^2 (e.g. Henckel et al. 2015). Other agri-environment schemes as well as organic farming have been implemented since 2004 in the entire study site by the CNRS research laboratory of Chizé (Bretagnolle et al. 2011a), covering up to one third of the study area in 2013. Six types of AESs have been implemented (Fig. 14.4b).

The high spatial heterogeneity in the LTSER ZA-PVS is an opportunity to analyse the effects of landscape gradients of interest (i.e. meadows, organic farming and woodland) on biodiversity and ecosystem functions.

3 Contrasting Effects of Landscape on Farmland Biodiversity and Ecosystem Functions in the LTSER ZA-PVS

3.1 Effects of Crop Type

Agricultural landscapes consist of a mosaic of habitat patches whose suitability may vary from beneficial to detrimental for any given species (Fahrig et al. 2011). Many organisms use multiple resources found in a variety of crops and non-crop habitats.

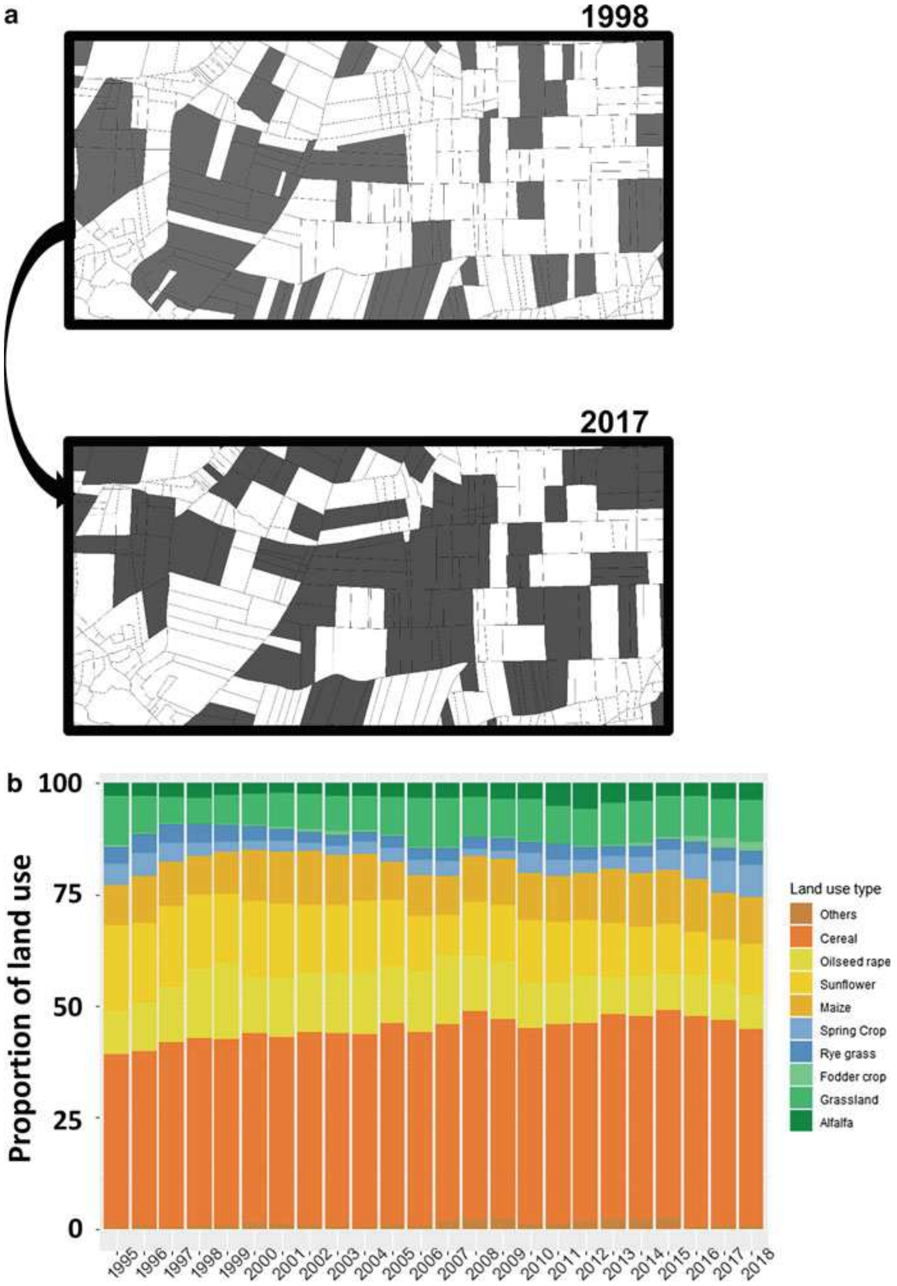

Fig. 14.3 (**a**) Fields in winter cereal (grey) in a part of the LTSER Zone Atelier in 1998 and 2017. (**b**) Temporal variation of land use from 1995 to 2018. Each colour shows a group of land use

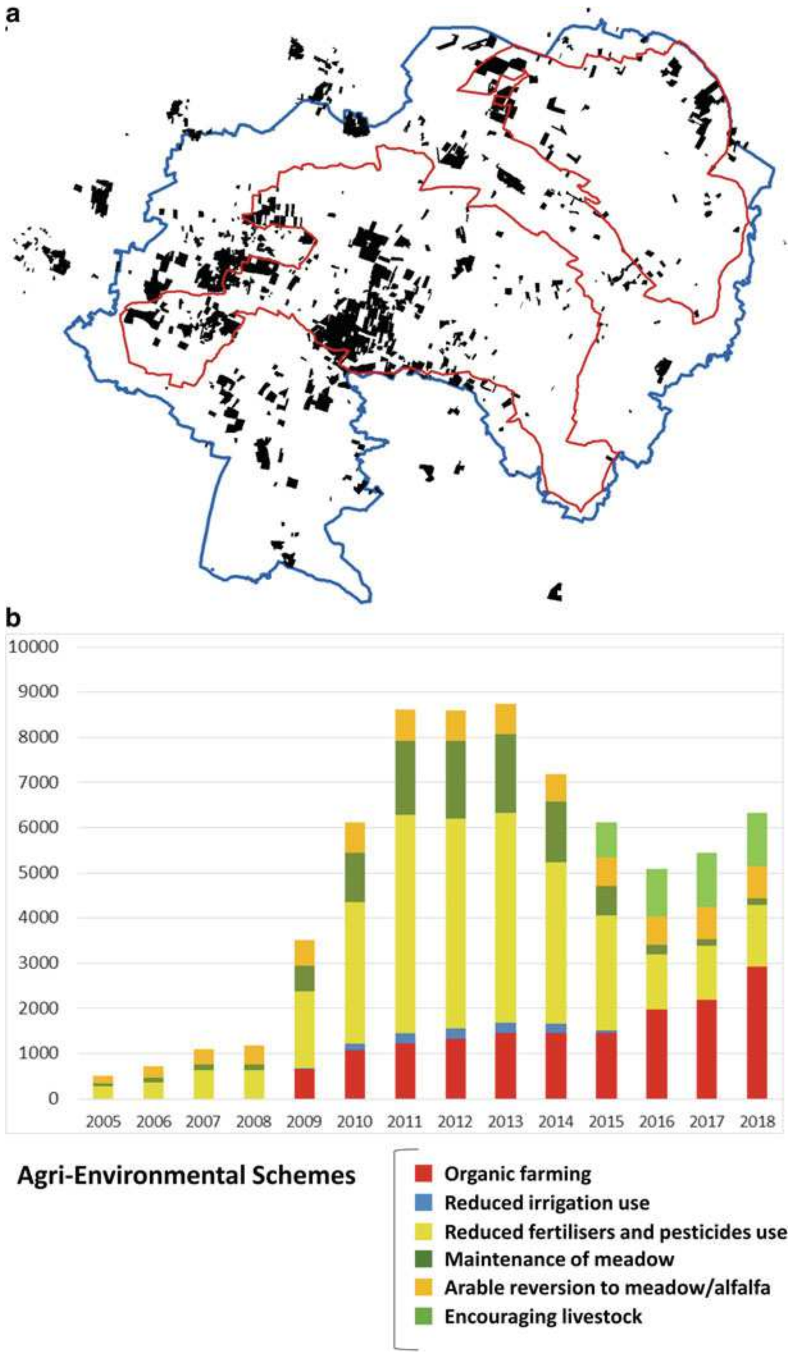

Fig. 14.4 (**a**) Location of the NATURA 2000 area (in red) and fields in organic farming (black polygons) on the LTSER Zone Atelier Plaine & Val de Sèvre. (**b**) Temporal variation of the amount of agri-environmental schemes in the LTSER ZA-PVS from 2005 and 2018. The implementation of AES started in 2004

The distribution in the landscape of these specific resources as well as the suitability of the habitat may be related to the diversity of crops (Vasseur et al. 2013; Schellhorn et al. 2015). Besides providing different environmental conditions and food availability, crop types differ in the intensity and timing of management practices, such as soil tillage, pesticides use and harvesting time. Considering the interplay between local and landscape effects, crop type can have a dual interactive effect on populations: an environmental filtering effect at local scale and a source-sink effect at the landscape scale.

In the ZA-PVS, weed species richness varies significantly between crop types, being highest in oilseed rape with on average, between 2014 and 2019, of 27.76 (± 7.46sd) species per field; and lowest in maize (13.61 ± 6.99) (Bourgeois et al. 2020). Winter cereal and sunflower show intermediate numbers of weed species per field (19.00 ± 9.80 and 18.02 ± 6.89, respectively). Similar patterns are observed for carabid beetles (Marrec et al. 2015; Caro et al. 2016; Marrec et al. 2017): Wheat fields harboured on average 7.4 ± 3.5 species for an abundance activity of 64 ± 123, while alfalfa fields had 8.0 ± 4.0 (61.4 ± 78.8) and meadows 3.9 ± 2.7 (10.4 ± 13.2). *Poecilus cupreus* and *Brachinus sclopeta* are the two most abundant species overall in arable crops as well as meadows and grasslands. Oilseed rape supported higher abundances of *Poecilus cupreus* as well as *Anchomenus dorsalis* than winter wheat (0.46 and 1.09 times more, respectively). Despite the large quantity of insecticides used, the presence of oilseed rape all year round (from August the preceding year to July the following one) in the ZA-PVS, thus provides a suitable habitat over a long period, and may explain this diversity pattern for weeds and carabid beetles (Marrec et al. 2015). Effects of crop types are, however, less pronounced on birds and wild bees. In birds, crop type effects are far less significant than the presence of hedgerows and small woods in predicting species richness, whatever the spatial scale considered; at small spatial scales (200 m), only oilseed rape has a significant contribution, while at larger spatial scales grasslands contributes significantly to species richness (Henckel et al. 2019). However, when restricting analyses to open farmland habitats only (i.e., with no hedgerows), grasslands, alfalfa and to a lesser extent, rapeseed contribute strongly to predicting bird species communities (Henckel et al. 2019). Skylarks (*Alauda arvensis*) were also shown to depend on crop types, but even more on complementarity between crop types, typically cereals and grasslands (Marrec et al. 2017). Corn buntings (*Emberiza calandra*) are also strongly dependent on alfalfa, and to a lesser extent oilseed rape (Brodier et al. 2014). Bee-communities in mass-flowering crops (oilseed rape and sunflower) were three to four times less diversified than in semi-natural habitats (Rollin et al. 2015).

At the landscape scale, oilseed rape was shown to have a positive, negative or no effect on biodiversity depending on the species. The amount of oilseed rape in the landscape in a radius of 1000 m had a negative effect on the abundance of honeybee and *Lasioglossum sp.* supporting a dilution effect (Holzschuh et al. 2016). By contrast, and whatever the considered spatial scales (from 500 to 1000 m), the amount of oilseed rape in the landscape had a positive effect on *Poecilus cupreus* activity-density in oilseed rape. The effect was however negative in winter cereal

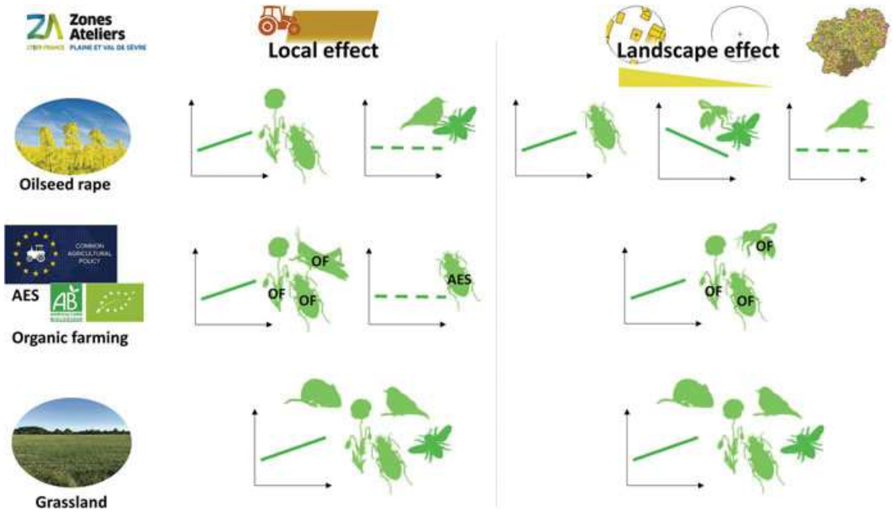

Fig. 14.5 Overview of the local and landscape effects of oilseed rape, grassland and organic farming on biodiversity in the LTSER Zone Atelier Plaine & Val de Sèvre

suggesting dilution-concentration effects (*sensu* Tscharntke et al. 2012) at play for this species when considering crops with different levels of attractiveness. For the carabid beetle *Anchomenus dorsalis*, the effect of oilseed rape in the surrounding landscape was only observed in winter cereals at the small scale (lower than 400 m buffer size) revealing no important long-distance movement for this species. In birds, community assembly is mainly predicted by hedgerows and woodlands, at any spatial scale from 200 to 1400 m, but the explained variation decreases with buffer size, especially in wooded landscapes; the contribution of crops also decreases with buffer size, whatever the species or the landscape types (Henckel et al. 2019). These results are synthesised in Fig. 14.5.

3.2 *Landscape Effects of Grasslands on Biodiversity*

In line with studies conducted in other study-sites (e.g. Chaplin-Kramer et al. 2011; Rusch et al. 2013; Haan et al. 2020), studies performed in the ZA-PVS revealed that the proportion of semi-natural habitat, such as temporary grasslands, meadows or hedgerows, can increase the abundance and the diversity of pest natural enemies, pollinators and to a lesser extent, birds in landscapes dominated by arable crops. Marrec et al. (2017) observed a positive, large-scale (from 500–700 to 1000 m) effect of grassland in the landscape on the activity-density of two main carabid species in oilseed rape and winter cereal; but the proportion of grassland within 250 m and 1000 m radius landscapes had no effect on spider activity-density in sunflower (Badenhausser et al. 2020). Grasslands are also important for common vole (*Microtus arvalis*) spatial and temporal dynamics (Bretagnolle et al. 2011a; Bonnet et al. 2013), and a similar effect was detected for weeds (Henckel et al. 2015). Birds in general are sensitive to the amount of grasslands at landscape scale (Bretagnolle et al. 2018c), and this is particularly the case for several flagship species such as little bustard (*Tetrax tetrax*) and Montagu's harrier (*Circus pygargus*) (Bretagnolle et al. 2011a, b). A strong effect of the proportion of semi-natural habitat in the landscape was also found on local wild bee richness (Rollin et al. 2019). The greatest landscape effect was predicted beyond a 20–25% threshold for herbaceous semi-natural habitats (within a 1000 m radius). However, the magnitude of the effect of semi-natural habitat proportion on bee richness varied with the local abundance of bees. The effect was higher at high compared to low bee abundance. This pattern can be explained by the dual function of semi-natural habitats, as a source of both feeding resources and nesting sites (Öckinger and Smith 2007; Goulson et al. 2010).

Increasing grasslands at the landscape scale further enhances several ecological functions. The proportion of meadows and temporary grasslands increased the predation rates of seeds and aphids in winter cereal (Perrot et al. in review) while this effect was only observed on aphid predation rate (not on seed predation) in sunflowers adjacent to plant-species rich meadows and temporary grasslands with few hedges in the neighbourhood (Badenhausser et al. 2020). These results support the need for using multiple prey sentinels when investigating the effect of landscape on pest control (McHugh et al. 2020). Higher abundance and diversity of pollinators in landscapes with large amounts of semi-natural habitat also improves pollination efficiency. The fruiting success was improved by increasing the contribution of large pollinators to pollination in landscapes rich in semi-natural habitats as shown by a bagged experiment. However, this positive effect was only observed during the flowering peak of oilseed rape suggesting that large pollinators were likely to be attracted by oilseed rape blooming.

3.3 Beneficial Effects of Reduced Agricultural Practices Intensity

Half of the ZA-PVS is a Natura 2000 site, where an extensive program of agri-environmental schemes (AES) has been set up since 2004. Many AES consist in reducing the intensity of agricultural practices, i.e. reducing pesticide inputs, mowing, frequency of cultivations (see for a list of AES, Brodier et al. 2014; Caro et al. 2016). There was little effect of AES on carabid beetles when excluding organic farming (see below), both locally or at landscape scale (Caro et al. 2016). Delayed cutting of alfalfa fields had a small positive effect on carabids, increasing their richness by 11.7%. This local effect was amplified in the landscape with large amount of organic farming, but at large spatial scales (larger than 750 m). The evaluation of the effect of a broad set of agri-environmental schemes (AESs) on carabid abundance-activity and species richness revealed that carabid species richness and abundance-activity only responded to the most restrictive AES. AES were also shown to affect positively grasshoppers, especially delayed cutting (Badenhausser et al. 2009; Bretagnolle et al. 2011a).

Among AES, organic farming has been shown to have the highest effect on biodiversity. Organic fields were found to act as key habitats for weed spatial dynamics (see also Gabriel et al. 2010). We found a strong landscape effect of organic farming in a 1 km buffer size on weed species richness in winter cereal fields (Henckel et al. 2015; Petit et al. 2016; Bourgeois et al. 2020). This effect was observed in both organic and conventional fields, although its magnitude was lower in conventional fields, especially in field cores highlighting the filtering effect of conventional management (especially chemical fertilisers and herbicides; Henckel et al. 2015). Differences in weed richness between organic and conventional fields were mostly explained by the higher diversity of less frequent species in organic fields. Using a structural equation model to quantify the effects of regional dispersal from source habitats in the landscape, local dispersal from field margin and their interplay with local conditions (crop type and field size), Bourgeois et al. (2020) showed that organic farming within the landscape predominantly acts indirectly via field margins. This highlights the key role of field margins in sustaining the local dynamics of weed communities through an improved connectivity between field core and the surrounding landscape; the magnitude of weed propagation from field margin to field core being however largely species-dependent as shown in Wilson and Aebischer (1995). Moreover, the strength of this two-step process (organic field cover plus field margin dispersal) was modulated by crop type, being especially pronounced in winter cereal compared to oilseed rape, sunflower and maize. This may be explained by the fact that most organic fields across the study area are sown with winter cereals. The strong positive effect of the amount of organic farming at the same scale was found to exceed the effect of local agricultural practices on weed richness (Petit et al. 2016). By contrast, the amount of organic farming in the landscape had no effect on weed abundance indicating that the nature and the scale at which the drivers act are not the same for weed abundance and weed richness. Similarly, we detected a strong positive effect of organic farming in winter cereal fields on carabid species richness and their abundance-activity (Caro et al. 2016). Carabid species richness increased by +20.2% in organic than in conventional winter cereal, in line with Tuck et al. (2014) who found an average increase of 25%. This local effect was further increased in landscapes with higher amount of organic farming. This effect was especially detected at small scales (i.e. at a radius lower than 500 m).

Honeybees were also investigated in the ZA-PVS, thanks to the presence of the ECOBEE platform (Odoux et al. 2014). Positive relationships at the local scale (300 m) between organic farming and worker brood area or number of honeybee adults were detected from a 6 year study with 60 apiaries (300 hives) located in landscapes varying in the proportion of organic farmland (Wintermantel et al. 2019). These authors found that organic fields impact colony size especially when they are nearby. There may be several pathways through which nearby organic farming may act on honeybee colonies, including reduce foraging efforts (i.e. lower energy consumption), insecticide reduction (i.e. lower impact on activity and survival), herbicide reduction (i.e. wider diversity of pollen sources) and provision of semi-natural elements. In the dearth period and at the beginning of the sunflower bloom, colonies exposed to organic farmland at the landscape scale had larger honey reserves (Requier et al. 2017; Wintermantel et al. 2019). Colonies in landscapes rich in organic farmland may benefit from increased availability of melliferous flowers after the oilseed rape bloom as well as a higher access to pollen demands more easily, which allowed them to forage more intensively on nectar sources.

3.4 Combined Effects of Past and Current Landscape Composition

Agricultural landscapes are highly dynamic in space and time because of crop rotation. Hence, they represent ephemeral habitats where environmental conditions only allow species to establish and successfully reproduce in a short window of time. Consequently, this temporal environmental heterogeneity directly affects the survival and the movement behaviour of species that use annual crops. In spite of its importance, the effect of temporal environmental heterogeneity on populations and species assemblies in agricultural landscape has been poorly investigated. Even fewer studies consider the combined effects of past and current landscape on population and community dynamics.

In the ZA-PVS, the activity-density of two common carabid beetles, *Poecilus cupreus* and *Anchomenus dorsalis*, in winter cereals and oilseed rape (Marrec et al. 2017) was significantly affected by both current and previous year landscape composition. These effects however varied with crop type and carabid species identity. The activity-densities of *P. cupreus* and *A. dorsalis* were both positively influenced by the amount of oilseed rape in the preceding year's landscape, but only *P. cupreus* activity-density responded positively to the amount of spring crops in the preceding year's landscape. *A. dorsalis* individuals overwinter in perennial habitats, particularly field margins (Marrec et al. 2015). Therefore, it is likely that *A. dorsalis* individuals move from previous oilseed rape fields to grasslands during the summer-fall period, rather than to an alternate annual crop such as spring crops. The colonisation of oilseed rape fields the next year may then occur from these perennial habitats. These results support the hypothesis that carabid beetles respond to the interannual redistribution of resources caused by crop rotation at the landscape level (Russon and Woltz 2015).

A similar response was also observed in pollinators. In agricultural landscapes, oilseed rape and sunflower provide resources during non-overlapping periods for pollinators. Using data collected in 172 fields over 5 years, we found that a high proportion of sunflower in the preceding landscape led to increases in *Lasioglossum* sp. and honeybee abundances in oilseed rape the following year. Sunflower is an important resource for wild bees (Todd et al. 2016) and honeybee (Requier et al.

2015). These results indicate that the management of landscape-scale patterns of mass-flowering crops accounting for delayed response of pollinators can ensure for wild pollinator persistence and crop pollination services.

4 Multifunctional Landscapes and Economic Performance

The benefits of grassland and AES, especially organic farming, for biodiversity on arable farmland are clear, with an average increase in species richness and abundance across taxa. However, the magnitude of these effects are strongly dependent on the guild or the taxon studied, as well as on landscape context. These conclusions are relevant to resolving the long-running argument between food security and the drive to ban chemical pesticides and fertilisers as exemplified by the organic/conventional farming and parallel land-sharing/land-sparing debate (e.g. Green et al. 2005; Phalan et al. 2011; Seufert et al. 2012; Ponisio et al. 2015; Seufert and Ramankutty 2017). Rather than simplifying the debate to “biodiversity vs. food production” (Bennett 2017), we sought in the ZA-PVS to consider agricultural landscapes as multifaceted and, importantly, multifunctional (Landis 2017; Turkelboom et al. 2018). We therefore explore the extent to which spatial arrangements of conventional farming, low-input farming (AES fields or farms) and organic farming, along with remnant semi-natural habitats, may best support multiple goals in multifunctional and resilient agricultural landscapes.

The important role that plant species richness (generally higher in semi-natural habitats) plays in maintaining ecosystem functions and, to some extent, multifunctionality has been highlighted previously (Allan et al. 2015; Soliveres et al. 2016; Wardle 2016; Pennekamp et al. 2018). In the ZA-PVS, we extend those results by revealing that weed diversity was a strong contributor to ecosystem multifunctionality especially when considering the simultaneous delivery of functions and when considering only aboveground ecological functions, i.e. pest control, pollination and bee richness as a proxy of biodiversity conservation (Gaba et al. 2020). This study also emphasizes the critical role of grasslands, including hay crops (particularly alfalfa) and meadows, for maintaining multifunctionality in agricultural landscape. Multifunctionality was greater in hay crops compared to winter cereal and oilseed rape fields. This pattern was mainly explained by less intensive management of hay crops as well as higher weed diversity. However, at the landscape scale, a modelling approach found that the loss of semi-natural habitat (such as grasslands) had contrasting effects on the delivery of three ESs: biodiversity decreases, pollination-independent crop production increases, while pollination-dependent crop production is maximized at an intermediate proportion of semi-natural habitat (Montoya et al. 2019). These results, in accordance with Pywell et al. (2015) and Tamburini et al. (2016), suggest that moderate increases in the amount of semi-natural habitat in simple agricultural landscapes (1–20% semi-natural habitat) allow ecosystem services essential for crop production to be maintained, which, in turn, increases the magnitude and stability of crop yield. This modelling approach also revealed that trade-offs involving crop pollination were strongly affected by the degree to which crops depend on pollination and by their relative requirement for pollinator densities. At the field scale, reducing herbicides and fertiliser inputs does not necessarily decrease yields in wheat (Gaba et al. 2016; Catarino et al. 2019b) nor in oilseed rape (Catarino et al. 2019a), increases average farmers' margins (Catarino et al. 2019b, a) and finally improves biodiversity (as shown by AES effects on biodiversity; see above) which increases yields, e.g. in oilseed rape and sunflower (Perrot et al. 2018, 2019).

4.1 Best Landscape Composition to Meet Various Stakeholders' Demands

The supply and demand components of ESs in agroecosystems are multifaceted because of the multiple ecological processes involved on the supply side and the multiple stakeholders that benefit from them on the demand side. Human demand is one side of the ecosystem-service equation and comprises different agents or stakeholders. These stakeholders vary in both their demand for and their valuation of different ecosystems services, thus have specific perspectives about how to manage efficiently agricultural landscapes (Fig. 14.6).

For example, farmers are mainly interested in maximizing crop yield per area of their cultivated land as this is mostly related to their profitability. Beekeepers, on the other hand, are looking for resource-rich landscapes to settle their beehives in order to maximise honey production and in turn their revenues. Agricultural unions or

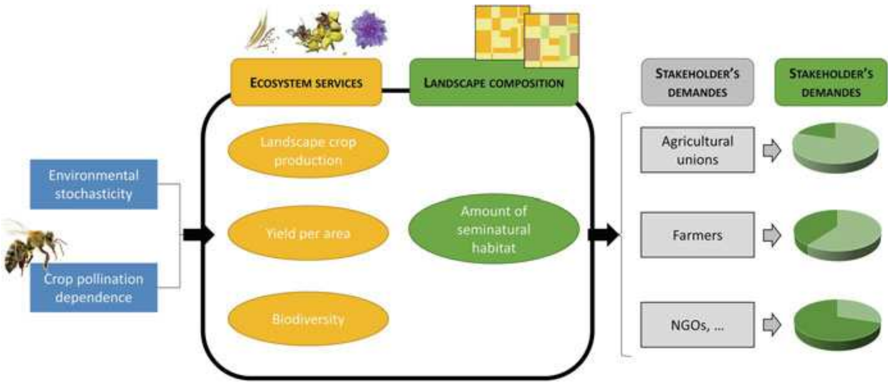

Fig. 14.6 Conceptual diagram of the modelling framework of Montoya et al. (2020) (modified from Montoya et al. 2020). Environmental stochasticity and crop pollination dependence effects the magnitude of three ecosystem services (landscape crop production, crop yield per area and biodiversity conservation) and the effects of landscape composition (amount of semi-natural habitat) associated with the delivery. The three groups of stakeholders are assumed to value each ecosystem service differently. The landscape compositions shows the best landscape compositions to fulfil their demands

cooperatives often aim at maximizing crop production at the regional level to deliver food security. NGO's, wildlife-friendly organizations and even residents expect agriculture not to jeopardise the future of farmland and nature in general. Considering a simple case-study model of three ESs and three groups of stakeholders (i.e. farmers, agricultural unions and NGO), Montoya et al. (2020) concluded that the ideal landscape composition, measured as the fraction of semi-natural habitat within the agricultural landscape, differs among stakeholders. In particular there is a trade-off between agricultural unions on one hand and farmers and NGOs on the other hand. The demands of farmers and NGOs were generally aligned at higher fractions of semi-natural habitat suggesting that farmers' best interest is that the landscape surrounding their land is not farmed. This supports empirical studies showing that higher levels of biodiversity are beneficial for farmers (Binder et al. 2018; Catarino et al. 2019a). However, the degree to which a crop depends on animal pollination and environmental stochasticity are two other main drivers of the best landscape composition. Higher pollination dependence of crops generally shifts the best landscape composition to larger fractions of semi-natural habitat, while high stochasticity, as expected under current global change, shifts maximum landscape production to lower fractions of semi-natural habitat and constrains the range of semi-natural habitat that maximizes farmers' profitability. The social average scenario, which considered multiple demands for ESs with a multifunctionality goal, was more robust to changes in crop type and stochasticity. Consequently, management for social average may be a better option for food security, livelihood opportunities, and biodiversity conservation, thus meeting various stakeholders' demands.

4.2 Policy Instruments for Multifunctional Landscape

In agricultural landscapes, stakeholders generally do not feel mutually dependent, i.e., they do not feel that they need one another to improve their situation. For instance, they typically ignore the cascade effects of their decision-making on the other stakeholders in the shared landscapes. Some ES can lead to mutual interest between ES beneficiaries. For example, pollination ES is of mutual benefit for beekeepers and farmers in agricultural landscapes. When visiting crop flowers, honeybees increase crop yields of mass-flowering crops (i.e. oilseed rape and sunflower; Perrot et al. 2018, 2019) and farmers' incomes (Catarino et al. 2019a). In return, mass-flowering crops provide abundant floral resources for honeybees, therefore ensuring honey production and overwinter survival success (Requier et al. 2017). Although these social interdependencies could contribute to collective action or elucidating potential divergences between related stakeholders' demands (Barnaud et al. 2018), it is not currently taken into account in any public policies. Using a bio-economic model (Fig. 14.7), Faure et al. (in review) explored how agricultural policies could act efficiently by playing on the mutual benefits for beekeepers and farmers of pollination ES to increase the delivery of multiple ESs (food and feed production, water quality and biodiversity conservation) and the

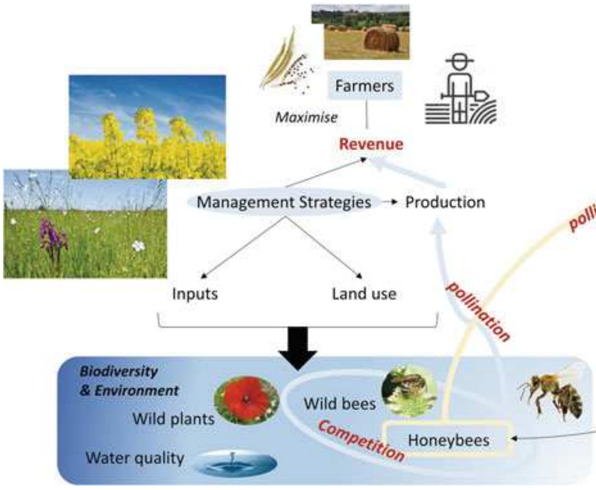

Fig. 14.7 Schematic representation of the bio-economic model of Faure et al. (in review)

economic performances at landscape scale, and both farmer and beekeeper profitability. Following the European beekeepers' recommendations (Breeze et al. 2019), the efficiency of two main incentive instruments were explored: (1) economic subsidies targeting beekeepers, and (2) taxes targeting farmers for reducing the use of agrochemicals. Supporting beekeeping as well as taxing pesticides both increased pollination. This generated a causal chain in the decision-making of the two stakeholders: implementing subsidies supporting beekeeping yielded an increase in the number of hives (change in the beekeeping strategy) resulting in a higher honeybee abundance, hence a higher OSR yield per ha. In turn, the farmers increased the OSR cultivated area and decreased their agrochemical use. Such positive feedback loops between the two stakeholder groups results in mutual benefit of farmers and beekeepers from the two policies. Furthermore, by linking the two stakeholders, the interdependency affected the delivery of ESs and the economy at the landscape scale. The subsidies benefited the economy (higher total wealth) but had low environmental performances (low wild bee abundance and increase of nutrient pollution in water). Tax, on the other hand benefited the environment but resulted in low economic benefits at landscape scale.

5 Conclusions

In conclusion, this chapter provides an overview of the research products from a Long Term Socio-Ecological research site, the Zone Atelier Plaine & Val de Sèvre, which aims to address the current challenges of agriculture, i.e. maintaining food security while preserving biodiversity, landscapes and ecosystems. One major result is that biodiversity decline is a severe threat to food security in itself; several results show that improving biodiversity improves yields, margins, or both; hence reducing biodiversity imperils crop production. Long-term monitoring of biodiversity, ecosystem functioning and agricultural practices, as well as land use, was revealed as a powerful tool for understanding the effect of human actions on biodiversity and the agricultural ecosystem. Furthermore, it paves the way for producing knowledge, shared by various stakeholders, which may contribute to tackling difficult problems such as food security or environmental sustainability in a more efficient way. Here, we show that the interplay between local and landscape factors can provide solutions to maintain biodiversity, crop production and farmers' profitability. Engaging stakeholders in collaboration with scientists, as well as increasing the awareness of stakeholders' mutual interdependencies with nature, is now needed to foster agroecological transition.

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References

Agence BIO (2019) Agence bio. Available at: https://www.agencebio.org/wp-content/uploads/2019/06/DP-AGENCE_BIO-4JUIN2019.pdf

Allan E, Manning P, Alt F, Binkenstein J, Blaser S, Blüthgen N et al (2015) Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. Ecol Lett 18:834–843

Altieri MA (1983) Agroecology: the scientific basis of alternative agriculture. Division of Biological Control, University of California, Berkeley

Amundson R, Berhe AA, Hopmans JW, Olson C, Sztein AE, Sparks DL (2015) Soil and human security in the 21st century. Science 348:1261071

Angelstam P, Manton M, Elbakidze M, Sijtsma F, Adamescu MC, Avni N et al (2018) LTSER platforms as a place-based transdisciplinary research infrastructure: learning landscape approach through evaluation. Landsc Ecol 34:1–24

Badenhausser I, Amouroux P, Lerin J, Bretagnolle V (2009) Acridid (Orthoptera: Acrididae) abundance in Western European grasslands: sampling methodology and temporal fluctuations. J Appl Entomol 133:720–732

Badenhausser I, Gross N, Mornet V, Roncoroni M, Saintilan A, Rusch A (2020) Increasing amount and quality of green infrastructures at different scales promotes biological control in agricultural landscapes. Agric Ecosyst Environ 290:106735

Barnaud C, Corbera E, Muradian R, Salliou N, Sirami C, Vialatte A et al (2018) Ecosystem services, social interdependencies, and collective action: a conceptual framework. Ecol Soc 23:15

Bennett EM (2017) Changing the agriculture and environment conversation. Nat Ecol Evol 1:1–2

Binder S, Isbell F, Polasky S, Catford JA, Tilman D (2018) Grassland biodiversity can pay. Proc Natl Acad Sci U S A 115:3876–3881

Bommarco R, Kleijn D, Potts SG (2013) Ecological intensification: harnessing ecosystem services for food security. Trends Ecol Evol 28:230–238

Bonnet T, Crespin L, Pinot A, Bruneteau L, Bretagnolle V, Gauffre B (2013) How the common vole copes with modern farming: insights from a capture-mark-recapture experiment. Agric Ecosyst Environ 177:21–27

Bourgeois B, Gaba S, Plumejeaud C, Bretagnolle V (2020) Weed diversity is driven by complex interplay between multi-scale dispersal and local filtering. Proc. R. Soc. London. Ser. B, Biol. Sci. 287:20201118

Breeze TD, Boreux V, Cole L, Dicks L, Klein A, Pufal G et al (2019) Linking farmer and beekeeper preferences with ecological knowledge to improve crop pollination. People Nat 1:562–572

Bretagnolle V, Gauffre B, Meiss H, Badenhausser I (2011a) The role of grassland areas within arable cropping systems for the conservation of biodiversity at the regional level. In: Lemaire G, Hodgson J, Chabbi A (eds) Grassland productivity and ecosystem services. CAB International, Cambridge, MA, pp 251–260

Bretagnolle V, Villers A, Denonfoux L, Cornulier T, Inchausti P, Badenhausser I (2011b) Rapid recovery of a depleted population of Little Bustards Tetrax tetrax following provision of alfalfa through an agri-environment scheme. Ibis (Lond 1859) 153:4–13

Bretagnolle V, Berthet E, Gross N, Gauffre B, Plumejeaud C, Houte S et al (2018a) Description of long-term monitoring of farmland biodiversity in a LTSER. Data Br 19:1310–1313

Bretagnolle V, Berthet E, Gross N, Gauffre B, Plumejeaud C, Houte S et al (2018b) Towards sustainable and multifunctional agriculture in farmland landscapes: lessons from the integrative approach of a French LTSER platform. Sci Total Environ 627:822–834

Bretagnolle V, Siriwardena G, Miguet P, Henckel L, Kleijn D (2018c) Local and landscape scale effects of heterogeneity in shaping bird communities and population dynamics: crop-grassland interactions. In: Agroecosystem diversity: reconciling contemporary agriculture and environmental quality. Elsevier Science, San Diego, pp 241–243

Bretagnolle V, Benoit M, Bonnefond M, Breton V, Church JM, Gaba S et al (2019) Action-orientated research and framework: insights from the French long term social-ecological research network. Ecol Soc 24:10

Brodier S, Augiron S, Cornulier T, Bretagnolle V (2014) Local improvement of skylark and corn bunting population trends on intensive arable landscape: a case study of the conservation tool Natura 2000. Anim Conserv 17:204–216

Caro G, Marrec R, Gauffre B, Roncoroni M, Augiron S, Bretagnolle V (2016) Multi-scale effects of agri-environment schemes on carabid beetles in intensive farmland. Agric Ecosyst Environ 229:48–56

Catarino R, Bretagnolle V, Perrot T, Vialloux F, Gaba S (2019a) Bee pollination outperforms pesticides for oilseed crop production and profitability. Proc R Soc B Biol Sci 286:20191550

Catarino R, Gaba S, Bretagnolle V (2019b) Experimental and empirical evidence shows that reducing weed control in winter cereal fields is a viable strategy for farmers. Sci Rep 9004

Chaplin-Kramer R, O'Rourke ME, Blitzer EJ, Kremen C (2011) A meta-analysis of crop pest and natural enemy response to landscape complexity. Ecol Lett 14:922–932

Cumming GS, Allen CR, Ban NC, Biggs D, Biggs HC, Cumming DHM et al (2015) Understanding protected area resilience: a multi-scale, social-ecological approach. Ecol Appl 25:299–319

Del Grosso SJ, Parton WJ, Adler PR, Davis SC, Keough C, Marx E (2012) Daycent model simulations for estimating soil carbon dynamics and greenhouse gas fluxes from agricultural production systems. In: Managing agricultural greenhouse gases. Elsevier, San Diego, pp 241–250

Fahrig L, Baudry J, Brotons L, Burel FG, Crist TO, Fuller RJ et al (2011) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101–112

Faure J, Gaba S, Mouysset L (in review) Designing multifunctional landscapes: the hidden consequences of the interdependency between the stakeholders through pollination. *In revision*

Gaba S, Bretagnolle V (2020) Social-ecological experiments to foster agroecological transition. People Nat. 2(2):317-327

Gaba S, Bretagnolle F, Rigaud T, Philippot L (2014) Managing biotic interactions for ecological intensification of agroecosystems. Front Ecol Evol 2:29

Gaba S, Gabriel E, Chadœuf J, Bonneu F, Bretagnolle V (2016) Herbicides do not ensure for higher wheat yield, but eliminate rare plant species. Sci Rep 6:30112

Gaba S, Cheviron N, Perrot T, Piutti S, Gautier JL, Bretagnolle V (2020) Weeds enhance multifunctionality in arable lands in South-West of France. Front Sustain Food Syst 4:71

Gabriel D, Sait SM, Hodgson JA, Schmutz U, Kunin WE, Benton TG (2010) Scale matters: the impact of organic farming on biodiversity at different spatial scales. Ecol Lett 13:858–869

Gallai N, Salles JM, Settele J, Vaissière BE (2009) Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecol Econ 68:810–821

Gliessman S (2016) Transforming food systems with agroecology. Agroecol Sustain Food Syst 40:187–189

Godfray HCJ (2015) The debate over sustainable intensification. Food Secur 7:199–208

Goulson D, Lepais O, O'Connor S, Osborne JL, Sanderson RA, Cussans J et al (2010) Effects of land use at a landscape scale on bumblebee nest density and survival. J Appl Ecol 47:1207–1215

Green RE, Cornell SJ, Scharlemann JPW, Balmford A (2005) Farming and the fate of wild nature. Science 307:550–555

Haan NL, Zhang Y, Landis DA (2020) Predicting landscape configuration effects on agricultural Pest suppression. Trends Ecol Evol 35:359–367

Haines-Young R, Potschin M (2010) The links between biodiversity, ecosystem services and human well-being. In: Raffaelli D, Frid C (eds) Ecosystem ecology: a new synthesis. Cambridge University Press, Cambridge, pp 110–139

Henckel L, Börger L, Meiss H, Gaba S, Bretagnolle V (2015) Organic fields sustain weed metacommunity dynamics in farmland landscapes. Proc R Soc B Biol Sci 282:1–9

Henckel L, Meynard CN, Devictor V, Mouquet N, Bretagnolle V (2019) On the relative importance of space and environment in farmland bird community assembly. PLoS One 14:e0213360

Holzschuh A, Dainese M, González-Varo JP, Mudri-Stojnić S, Riedinger V, Rundlöf M et al (2016) Mass-flowering crops dilute pollinator abundance in agricultural landscapes across Europe. Ecol Lett 19:1228–1236

Klein A-M, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C et al (2007) Importance of pollinators in changing landscapes for world crops. Proc Biol Sci 274. 66, 95–96, 191

Lampkin N (1990) Farming systems and ecological diversity. In: Organic Farming. Farming Press, Ipswich, pp 574–579

Landis DA (2017) Designing agricultural landscapes for biodiversity-based ecosystem services. Basic Appl Ecol 18:1–12

Lévêque C, Pavé A, Abbadie L, Weill A, Vivien F-D (2000) Les zones ateliers, des dispositifs pour la recherche sur l'environnement et les anthroposystèmes. Natures, Sci. Sociétés 8:44–52

Marrec R, Badenhausser I, Bretagnolle V, Börger L, Roncoroni M, Guillon N et al (2015) Crop succession and habitat preferences drive the distribution and abundance of carabid beetles in an agricultural landscape. Agric Ecosyst Environ 199:282–289

Marrec R, Caro G, Miguet P, Badenhausser I, Plantegenest M, Vialatte A et al (2017) Spatiotemporal dynamics of the agricultural landscape mosaic drives distribution and abundance of dominant carabid beetles. Landsc Ecol 32:2383–2398

Maxwell SL, Fuller RA, Brooks TM, Watson JEM (2016) Biodiversity: the ravages of guns, nets and bulldozers. Nature 536:143

McHugh NM, Moreby S, Lof ME, Van der Werf W, Holland JM (2020) The contribution of semi-natural habitats to biological control is dependent on sentinel prey type. J Appl Ecol 57:914–925

Montoya D, Haegeman B, Gaba S, de Mazancourt C, Bretagnolle V, Loreau M (2019) Trade-offs in the provisioning and stability of ecosystem services in agroecosystems. Ecol Appl 29:e01853

Montoya D, Gaba S, de Mazancourt C, Bretagnolle V, Loreau M (2020) Reconciling biodiversity conservation, food production and farmers' demand in agricultural landscapes. Ecol Model 416:108889

Öckinger E, Smith HG (2007) Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes. J Appl Ecol 44:50–59

Odoux JF, Aupinel P, Gateff S, Requier F, Henry M, Bretagnolle V (2014) ECOBEE: a tool for long-term honey bee colony monitoring at the landscape scale in West European intensive agroecosystems. J Apic Res 53:57–66

Oerke EC (2006) Crop losses to pests. J Agric Sci 144:31–43

Pe'er G, Dicks LV, Visconti P, Arlettaz R, Báldi A, Benton TG et al (2014) EU agricultural reform fails on biodiversity. Science 344:1090–1092

Pennekamp F, Pontarp M, Tabi A, Altermatt F, Alther R, Choffat Y et al (2018) Biodiversity increases and decreases ecosystem stability. Nature 563:109–112

Perrot T, Gaba S, Roncoroni M, Gautier JL, Bretagnolle V (2018) Bees increase oilseed rape yield under real field conditions. Agric Ecosyst Environ 266:39–48

Perrot T, Gaba S, Roncoroni M, Gautier JL, Saintilan A, Bretagnolle V (2019) Experimental quantification of insect pollination on sunflower yield, reconciling plant and field scale estimates. Basic Appl Ecol 34:75–84

Perrot T, Rusch A, Coux C, Gaba S, Bretagnolle V (2020) Proportion of grassland drives biological pest control services in agricultural landscapes. Front Ecol Evol. *in review*

Petit S, Gaba S, Grison A-L, Meiss H, Simmoneau B, Munier-Jolain N et al (2016) Landscape scale management affects weed richness but not weed abundance in winter wheat fields. Agric Ecosyst Environ 223:41–47

Phalan B, Balmford A, Green RE, Scharlemann JPW (2011) Minimising the harm to biodiversity of producing more food globally. Food Policy 36:S62–S71

Phalan B, Green RE, Dicks LV, Dotta G, Feniuk C, Lamb A et al (2016) How can higher-yield farming help to spare nature? Science 351:450–451

Pimentel D, Acquay H, Biltonen M, Rice P, Silva M, Nelson J et al (1992) Environmental and economic costs of pesticide use. Bioscience 42:750–760

Ponisio LC, M'gonigle LK, Mace KC, Palomino J, De Valpine P, Kremen C (2015) Diversification practices reduce organic to conventional yield gap. Proc R Soc B Biol Sci 282:20141396

Pywell RF, Heard MS, Woodcock BA, Hinsley S, Ridding L, Nowakowski M et al (2015) Wildlife-friendly farming increases crop yield: evidence for ecological intensification. Proc R Soc B Biol Sci 282:20151740

Requier F, Odoux JF, Tamic T, Moreau N, Henry M, Decourtye A et al (2015) Honey bee diet in intensive farmland habitats reveals an unexpectedly high flower richness and a major role of weeds. Ecol Appl 25:881–890

Requier F, Odoux JF, Henry M, Bretagnolle V (2017) The carry-over effects of pollen shortage decrease the survival of honeybee colonies in farmlands. J Appl Ecol 54:1161–1170

Rollin O, Bretagnolle V, Fortel L, Guilbaud L, Henry M (2015) Habitat, spatial and temporal drivers of diversity patterns in a wild bee assemblage. Biodivers Conserv 24:1195–1214

Rollin O, Pérez-Méndez N, Bretagnolle V, Henry M (2019) Preserving habitat quality at local and landscape scales increases wild bee diversity in intensive farming systems. Agric Ecosyst Environ 275:73–80

Rusch A, Bommarco R, Jonsson M, Smith HG, Ekbom B (2013) Flow and stability of natural pest control services depend on complexity and crop rotation at the landscape scale. J Appl Ecol 50:345–354

Russon H, Woltz J (2015) Movement patterns of carabid beetles between heterogenous crop and noncrop habitats. Mich Entomol Soc 47:186

Schellhorn NA, Gagic V, Bommarco R (2015) Time will tell: resource continuity bolsters ecosystem services. Trends Ecol Evol 30:524–530

Seufert V, Ramankutty N (2017) Many shades of gray—the context-dependent performance of organic agriculture. Sci Adv 3:e1602638

Seufert V, Ramankutty N, Foley JA (2012) Comparing the yields of organic and conventional agriculture. Nature 485:229–232

Soliveres S, Manning P, Prati D, Gossner MM, Alt F, Arndt H et al (2016) Locally rare species influence grassland ecosystem multifunctionality. Philos Trans R Soc B Biol Sci 371:20150269

Tamburini G, De Simone S, Sigura M, Boscutti F, Marini L (2016) Soil management shapes ecosystem service provision and trade-offs in agricultural landscapes. Proc R Soc B Biol Sci 283:20161369

Tilman D, Balzer C, Hill J, Befort BL (2011) Global food demand and the sustainable intensification of agriculture. Proc Natl Acad Sci U S A 108:20260–20264

Tittonell P (2014) Ecological intensification of agriculture-sustainable by nature. Curr Opin Environ Sustain 8:53–61

Todd KJ, Gardiner MM, Lindquist ED (2016) Mass flowering crops as a conservation resource for wild pollinators (Hymenoptera: Apoidea). J Kansas Entomol Soc 89:158–167

Tscharntke T, Tylianakis JM, Rand TA, Didham RK, Fahrig L, Batáry P et al (2012) Landscape moderation of biodiversity patterns and processes – eight hypotheses. Biol Rev 87:661–685

Tuck SL, Winqvist C, Mota F, Ahnström J, Turnbull LA, Bengtsson J (2014) Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. J Appl Ecol 51:746–755

Turkelboom F, Leone M, Jacobs S, Kelemen E, García-Llorente M, Baró F et al (2018) When we cannot have it all: ecosystem services trade-offs in the context of spatial planning. Ecosyst Serv 29C:566–578

Vasseur C, Joannon A, Aviron S, Burel F, Meynard JM, Baudry J (2013) The cropping systems mosaic: how does the hidden heterogeneity of agricultural landscapes drive arthropod populations? Agric Ecosyst Environ 166:3–14

Wardle DA (2016) Do experiments exploring plant diversity-ecosystem functioning relationships inform how biodiversity loss impacts natural ecosystems? J Veg Sci 27:646–653

Willer H, Lernoud J (2019) The world of organic agriculture. Statistics and emerging trends 2019. FiBL, Frick, and, IFOAM – Organics International, Bonn

Wilson PJ, Aebischer NJ (1995) The distribution of dicotyledonous arable weeds in relation to distance from the field edge. J Appl Ecol 32:295–310

Wintermantel D, Odoux JF, Chadœuf J, Bretagnolle V (2019) Organic farming positively affects honeybee colonies in a flower-poor period in agricultural landscapes. J Appl Ecol 56:1960–1969