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Effects of organic farming on biodiversity and ecosystem services: taking landscape complexity into account

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The recent intensification of the arable landscape by modern agriculture has had negative effects on biodiversity. Organic farming has been introduced to mitigate negative effects, but is organic farming beneficial to biodiversity? In this review, we summarize recent research on the effects of organic farming on arable biodiversity of plants, arthropods, soil biota, birds, and mammals. The ecosystem services of pollination, biological control, seed predation, and decomposition are also included in this review. So far, organic farming seems to enhance the species richness and abundance of many common taxa, but its effects are often species specific and trait or context dependant. The landscape surrounding the focal field or farm also seems to be important. Landscape either enhances or reduces the positive effects of organic farming or acts via interactions where the surrounding landscape affects biodiversity or ecosystem services differently on organic and conventional farms. Finally, we discuss some of the potential mechanisms behind these results and how organic farming may develop in the future to increase its potential for sustaining biodiversity and associated ecosystem services.

Keywords AES; biological control; pollination; review

Introduction

Agriculture has historically enriched and diversified the arable landscape in Europe.[1] Increased food and energy demands from a growing world population have resulted in agricultural intensification, which has had effects at both the local field or farm scale and the larger landscape scale. Negative effects of agricultural intensification have been demonstrated for many organism groups and associated ecosystem services.[2,3] Organic farming is gaining ground because it is assumed to counteract the negative effects of modern farming on, for example, soil organic matter, nutrient balances, and biodiversity. However, the impacts of organic farming on biodiversity and abundance have appeared to vary between taxa and seem to be affected by the surrounding landscape.[3–5] In this paper, we review some of the effects of organic farming on biodiversity and ecosystem services in the agricultural landscape and discuss if organic farming is important as an alternative farming practice now and in the future.

Traditional agricultural landscapes are often very species rich, especially in Europe.[1] They include a number of habitats and succession stages, and centuries of management have enabled a large number of species to adapt to management disturbances and inhabit the arable landscape. The human population and per capita food consumption is growing, and consequently biodiversity in arable landscapes has become negatively affected by agricultural intensification. On the local scale, agricultural intensification includes a number of interrelated processes such as higher inputs of energy, fertilizers and pesticides, a reduction of the area devoted to seminatural habitats such as hedgerows and field islands, and increased field sizes. On the larger landscape scale, natural habitats such as grasslands, wetlands, and forest are converted to arable land, thus decreasing the amount of natural and less intensively managed habitats in the landscape.

Organic farming and other agri-environment schemes (AES) have been suggested as a means to

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mitigate the negative effects of agricultural intensification in the European Union (Box 1). In organic farming, no inorganic pesticides or chemical fertilizers are used, and animal husbandry should be integrated in farm management, thus ideally producing a farmland that is of higher habitat quality than modern high-intensity farmlands. Twenty-five percent of the world's organically managed land is in Europe, and many studies of organic farming are European, but organic farming is a worldwide phenomenon. In 2009, certified organic farming in various forms existed in 160 countries. In total, 37.2 million hectares were organically farmed arable land (two thirds of which were grasslands or grazing areas), which represents 0.9% of the world's agricultural land.[6]

Box 1

"Organic production is an overall system of farm management and food production that combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards, and a production method in line with the preferences of certain consumers for products produced using natural substances and processes." Council Regulation (EC) no. 824/2007 of 28 June 2007 on organic production and labeling of organic products and repealing Regulation (EEC) 2092/91.

Organic farming means different things to different people; some people are interested in soil quality and nutrient recycling, others in carbon emissions or the quality of nutrient levels of foods produced, and still others are interested in effects on biodiversity or ecosystem services. In this review, we summarize some recent findings regarding the effect of organic farming on agricultural biodiversity and associated ecosystem services in the light of landscape complexity. It is more or less established that organic farming results in higher species richness and greater abundance of many taxa.[3,4] Results, however, vary greatly between organisms, between studies with different designs, and according to the region or country in which the studies have been conducted. The effectiveness of organic farming to enhance biodiversity and ecosystem services may be affected by the composition of the surrounding landscape,[7–9] but such studies are still rare.

Biodiversity and ecosystem services

Many earlier studies of organic farming and other AES focus on a single organism group; plants tend to show the strongest positive responses to AES, followed by invertebrates, with birds and mammals showing the smallest responses.[10] Recently, multiple trophic levels or networks are increasingly being studied. Macfadyen *et al*. found that organic farms have higher species richness at three trophic levels, plant, herbivore, and parasitoid, and in a later study it was concluded that network modules on conventional farms had fewer links than on organic farms, which may reduce the stability of these networks.[11,12]

The surrounding landscape is now sometimes incorporated in studies (Table 1A and 1B). In a recent field study across five regions in Europe, the abundance and species richness of birds and plants were higher on organic fields, but ground beetles (Coleoptera: *Carabidae*) were no more abundant, when compared to conventional fields.[9] At the same time, birds and plants decreased both in species richness and in abundance with an increase in the percentage of arable land in the surrounding landscape, whereas the activity density of ground beetles increased.

Other information about the large-scale effects of organic farming on diversity can be gained by partitioning biodiversity into alpha-diversity (mean diversity of a site), between site beta-diversity, and between region beta-diversity.[13] Farm management acts on both the local and landscape scale, and different taxa respond at different, often multiple, scales.[14]

The effects of organic farming on biodiversity have been thoroughly studied and have been subject to several meta-analyses.[3,15] However, the effects of organic farming on ecosystem services and ecosystem functions have not received as much attention, especially not in a landscape perspective (Table 2). Ecosystem services are the benefits that humans derive from ecosystems.[16] Some of the services that are produced and consumed in the arable landscape include pollination, biological control, respiration, decomposition, and weed seed predation. Some earlier studies of pollinators were the first to discover interactions between farming practices and the surrounding landscape,[5,17] and this has now also been detected for ecosystem services such as pollination,[18] biological control,[9] and seed removal.[7]

Table 1. Results from recent studies on the effect of organic farming, landscape complexity, and their interaction on the species richness (A) and the abundance (B) of organisms in the arable landscape. For information regarding the definition of landscape in each study, see the main text.

A

Organism	Organic	Landscape	Interaction	References
Decomposers	ns	ns	ns	Diekötter *et al.*[35]
Ground beetles	ns	ns	*	Diekötter *et al.*[35]
Spiders	ns	ns	ns	Diekötter *et al.*[35]
Plants	***	*	ns	Winqvist *et al.*[9]
Ground beetles	ns	ns	ns	Winqvist *et al.*[9]
Breeding birds	*	*	ns	Winqvist *et al.*[9]
Pollinators	ns	ns	ns	Brittain *et al.*[18]

B

Organism	Organic	Landscape	Interaction	References
Decomposers	ns	ns	*	Diekötter *et al.*[35]
Springtails	ns	ns	ns	Diekötter *et al.*[35]
Ground beetles	ns	ns	ns	Diekötter *et al.*[35]
Spiders	ns	ns	ns	Diekötter *et al.*[35]
Plants (cover)	***	*	ns	Winqvist *et al.*[9]
Ground beetles	ns	**	ns	Winqvist *et al.*[9]
Breeding birds	*	**	ns	Winqvist *et al.*[9]
Small mammals	ns	ns	*	Fischer *et al.*[7]
Slugs	ns	ns	ns	Fischer *et al.*[7a]

$P < 0.1$ (ns), $P < 0.05$ (*), $P < 0.01$ (**), $P < 0.001$ (***).
[a]Additional effects were significant in the model: distance to field edge (**).

Plants

Plants are the most studied organisms in the agricultural landscape, since they are important for many other organisms and vital for some functions and services such as improving microclimate and, of course, to produce oxygen. Plants in arable fields are often considered to be weeds and are the main targets of many management practices. Therefore, plants often benefit from organic farming and other AES,[2,3,9] and they seem to respond quickly to conversion to organic farming in terms of species richness.[19] The most straightforward mechanism to explain these findings is that organic farmers do not use herbicides. In a pan-European study, the negative effects on plant species richness of increased frequency of insecticide and herbicide applications and the applied amount of active ingredients of fungicides was found.[2] Furthermore, weed species richness may be reduced by increased cereal cover, at least on organic farms.[20] Other potential explanations may have more to do with differences in the surrounding landscape between organic and conventional farms. The number of years with grass crops in the rotation may increase both weed abundance and species richness in the field as well as weed abundance in the seed bank, whereas the number of winter crops and the amount of inorganic nitrogen (N) and herbicide applied may have a negative effect on weed abundance and species richness in the field.[21]

The responses of plants to organic farming are often species specific. In a Mediterranean study, four of the 51 weed species found were more abundant in conventional fields, even though both a higher abundance, cover, diversity, and species richness of weeds was found on organic fields.[21]

Table 2. Results from recent studies on the effect of organic farming, landscape complexity, and their interaction on the ecosystem services in the arable landscape. For information regarding the definition of landscape in each study, see the main text

Ecosystem service	Organic	Landscape	Interaction	References
Biological control (b)	ns	*	0.057	Winqvist *et al.*[9]
Pollination (a)	ns	ns	0.054	Brittain *et al.*[18]
Seed predation	*	ns	ns	Diekötter *et al.*[35]
Seed removal	ns	ns	**	Fischer *et al.*[7a]
Litter decomposition	ns	ns	ns	Diekötter *et al.*[35]

$P < 0.1$ (ns), $P < 0.05$ (*), $P < 0.01$ (**), $P < 0.001$ (***).
[a]Additional effects were significant in the model: seed species (***) and predator exclusion (***), (a) = abundance of visits, (b) = removal of aphids from plastic labels placed in the field for 24 h.

Landscape structure such as the proportion of arable fields, grasslands or forests, and field boundary type may be more important for plants than organic farming.[22] The properties of the soil such as the percentage of N and carbon (C), pH, or clay content may be more important than farm management.[21] Sometimes, both farm management and the surrounding landscape are important for biodiversity. Winqvist *et al.* found positive effects on both plant species richness and plant cover of organic farming as well as a lower percentage of arable fields in the surrounding landscape, but there was no interaction between the two measures.[9] Finally, contrary to expectations, plants did not respond faster to organic farming in heterogeneous landscapes with a lower percentage of arable land than in homogeneous landscapes with more arable land.[19] Hence, the role of the surrounding landscape in plant responses to organic farming remains ambiguous, even though it seems well established that weeds are more species rich and abundant under organic management.

Arthropods

Arthropods are abundant in most habitats, including agricultural landscapes. Some are pests of crops; others are beneficial as pollinators or as naturally occurring predators of pests. Arthropods are directly affected by insecticide use and indirectly affected if food resources become less abundant as a result of pesticide use.[23] A conversion to organic farming may accordingly increase arthropod abundance, and this appears to occur gradually. Butterfly (Lepidoptera: *Rhopalocera* and *Zygaenidae*) abundance had increased 100% 25 years after the transition from conventional to organic agriculture.[19] Butterfly species richness, on the other hand, was not affected by time since the transition and was much higher on organic farms directly after transition. However, such studies are too rare to allow more general conclusions about the temporal responses of arthropods to changes in farm management.

A recent development is to analyze different taxa or functional groups in more detail, since it has become clear that responses are not general to all pollinators or predators. In a study from the Mediterranean area, organic fields had a overall higher richness than conventional fields, but for important groups such as spiders (Araneae), beetles (Coleoptera), and flies (Diptera), there were no differences, indicating that they are affected by different factors than those that vary between organic and conventional fields.[20] Using meta-analysis, Garratt *et al.* found that most natural enemy groups, as well as pests, increased in numbers, impact, or performance on organic farms, although this was not true for beetles. Even if the abundance and species richness of some natural enemy groups is increased in organic systems, individual species responses are often more specific and may be determined by one or a few specific elements of farming practices.[23] Most studies do not take factors such as soil structure or the surrounding landscape into account. Many arthropods utilize different habitats during a year—for instance, for overwintering or reproduction—making the surrounding landscape important. Bee species richness and the number of brood cells in trap nests have been shown to be enhanced by high proportions of noncrop habitats when both nesting sites and floral resources are present in the nearby landscape. In contrast, wasp species richness and brood cell numbers were enhanced by connecting corridors.[24] In a study designed to minimize differences in landscape complexity between organic and conventional farms, no effect of organic farming on ground beetles was detected, but these organisms were more abundant in homogenous landscapes.[9]

It is also becoming popular to study functional groups as defined by various traits, since the perception of crop–noncrop boundaries or the availability of their food resources differs between such groups.[24] The sensitivity to agricultural intensity may, for instance, differ between specialist and generalist parasitoids,[24] and the percentage of arable fields in a landscape may influence species with different dispersal abilities differently.[25]

Not much work has been done regarding differences in, for instance, body condition or fecundity between organic and conventional farming. Wolf spider females (Araneae: *Lycosidae*) have been found to be in better condition in landscapes with large fields of annual crops, but fecundity was unaffected by the proportion of arable land, number of crops grown, or field size; additionally, their body condition and fecundity were unaffected by farming practice.[26] Predatory ground beetles have been shown to be in better condition on organic farms than on conventional farms and in fields with a high perimeter-to-area ratio.[27]

To conclude, arthropod taxa have, until recently, been clumped together as "beetles" or "bees," but in order to examine the mechanisms behind responses to organic farming or landscape complexity, species-specific traits must be taken into account. This may be especially important when understanding effects on ecosystem services.

Pollination. Pollination is one of the most well-known and important ecosystem services in the arable landscape, and many crops rely on naturally occurring pollinators or honeybees. Many studies of "pollination" primarily focus on pollinators or insect–plant networks, and both pollinators and pollinator networks seem to be more diverse on organic farms.[28,29] In a German study, organic fields had a hundred times greater abundance of pollinators than conventional fields, but no attempt to study actual pollination was made.[28] In Ireland, insect–flower networks on organic farms have been found to be larger and more asymmetrically structured than networks on conventional farms, which may increase pollination.[29] Bees (Hymenoptera: *Apidae*) were found to be more abundant on organic fields partly because of higher floral abundances. Since organic farms produced more flowers that attracted more pollinators, pollination was improved.[29] Hoverfly (Diptera: *Syrphidae*) evenness was greater in organic farms, but this was not related to floral abundance, suggesting that organic farms provide additional and more diverse resources for this organism.[29]

Both organic farming and the surrounding landscape have been shown to affect pollinators, but to assess pollination, studies on pollination—not just pollinators—are needed. In a study of vine fields in Italy, flower-visiting insect abundance species richness did not differ between organic and conventional fields.[18] Instead, the abundance of visitors to potted plants was negatively affected by the proportion of uncultivated land in conventional fields only. The fruit set, weight of seeds per plant, and seed weight were negatively affected by the proportion of uncultivated land in the surrounding landscape on both field types.

More studies of pollination and the outcome on seed quality, etc. are badly needed, especially studies taking the surrounding landscape into account. To secure or restore pollination services, it seems important to reduce local management intensity and to restore or maintain natural or seminatural vegetation, providing nesting habitat and food resources.[30]

Biological control. Biological control of pests by naturally occurring (arthropod) predators is another well-known ecosystem service. As with pollination, very often only potential predators are studied or predation is studied in an inactive way, not revealing actual predators. Already 10 years ago, Östman *et al.* showed that organic farming as well as landscapes with abundant field margins and perennial crops contributed to biological control of cereal aphids during their establishment phase. During the aphid population growth phase, biological control was only greater in landscapes with more arable land.[27] Cereal aphids have often been shown to have lower abundance on organic fields in Germany; at the same time, predator abundances and predator–prey ratios were higher, but no actual study of predation was performed.[28] Pesticide-sprayed conventional fields had a higher abundances of aphids and lower abundances of predators late in the season, indicating that spraying only had a short-term effect on aphids but affected predators negatively over a longer period.[31]

Sometimes molecular methods are used to pinpoint predators or prey. Using stable isotope ratios, generalist predators have been found to consume higher proportions of herbivore prey in organic systems.[32]

In a recent European study using data from five regions, organic farms in complex landscapes with a low proportion of arable land had the highest biological control, but on conventional farms, the biological control potential was the same in all landscapes.[9] The mechanism behind this remains unclear, but Crowder *et al.* argue that organic agriculture promotes evenness among predators,[33] which in turn may be negatively affected by landscape simplification. Another possibility is that different species are the main predators in different landscapes and on farms with different management. Omnivorous ground beetles have been shown to be relatively more abundant in homogeneous landscapes with a high proportion of arable land, but they did not differ in abundance between organic and conventional farms.[25] Until we know which predators to promote under which circumstances, conserving a diverse natural enemy community of species with different traits may be a good strategy.[32]

Seed predation. The ecosystem service of weed seed predation can be carried out by, for instance, birds,[34] small mammals, or invertebrates.[7] Weed seed predation borders on the ecosystem disservice of weed seed dispersal (burial, movement), where weed seeds are not being predated but dispersed. Some seed predation studies do not include the surrounding landscape[34] or find that it is not important,[35] whereas other studies have found it very important.[7] In a German study, seed predation and removal increased in conventional fields, but decreased in organic fields as the proportion of arable fields increased. Of the studied potential seed predators, this pattern corresponded most closely to the activity density of slugs.[7] Slugs do not always predate on seeds, only disperse them, thereby performing an ecosystem disservice. Small omnivorous and herbivorous mammals showed the opposite response as slugs to seed removal; they decreased in conventional fields but increased in organic fields as landscape complexity decreased, corresponding to more arable land. In this study, ground beetles were more abundant on organic farms than on conventional ones, and they were unaffected by the surrounding landscape. Fischer *et al.*[7] concluded that "weed seed predation is provided by small mammals and invertebrates, whereas the disservice of seed dispersal and movement is provided by slugs."

It is too soon to draw any general conclusions regarding seed predation, since results differ between weed species, depending both on, for instance, seed size and its nutritional value and on which potential predators are being studied.

Soil biota

Soil quality and soil biodiversity have been widely studied since the soil is the base of farming and the ability to sustain high yields.[36] Soil organisms are important for the functioning of the soil and recycling of nutrients, and soil biota are believed to benefit from a reduction in the intensity of use of mechanical and manufactured inputs and by integrating biological inputs.[36] Negative direct and indirect effects of tillage have previously been shown on soil microfauna,[37] and epigeic springtails (Collembola) have been found to be vulnerable to certain fungicides since they reduce their fungal food supply.[38] In a recent review by Gomiero *et al.*, it was concluded that alternative (for instance, organic) farming practices in most cases enhance soil biodiversity regardless of climate and soil conditions.[39] Earthworms are usually more abundant in organic farming;[3] in the Netherlands, they were 2–4 times more abundant on organic farms.[40] Earthworms have large effects on both soil structure and the resources available to other soil organisms, and a higher abundance of earthworms may therefore result in decreases among other soil organism groups.[41]

Even though soil biota may be less mobile and utilize fewer habitats during their lifetime, the surrounding landscape has been shown to be important.[35] In a recent German study, Flohre *et al.* found an interaction between organic farming and landscape complexity for earthworm species richness.[8] The microbial biomass showed the same response but on a smaller landscape scale. Respiration (microbial activity) was higher on conventional farms and dependent on landscape complexity, measured as the proportion of arable fields. Species richness of earthworms and microbial biomass were low in organic farms in complex landscapes but increased with an increase in arable land, and the opposite was found in conventional farms, where higher species richness in complex landscapes decreased with increasing arable land. For earthworms, this is believed to be a result of greater predation in organic fields in complex landscapes. Springtails, on the other hand, were more abundant on conventional farms, regardless of the surrounding landscape.

Soil biotas have been thoroughly studied in organic farming, but the effects vary between studies. The effects of the different groups of soil biota, and the effects on surrounding landscape and ecosystem services and functions provided by soil biota, should be given more attention.

Decomposition and other soil ecosystem services. Sustaining the quality of the soil in arable ecosystems can be considered a supporting ecosystem services and reactive N and water quality can be considered regulating services,[16,42] but there are still few studies simultaneously examining soil ecosystem services, organic farming, and landscape complexity. Additionally, it is not possible to translate findings from organisms to services; even if decomposers were found to be affected by interactions between organic farming and landscape complexity, the associated ecosystem service of litter decomposition was not.[35] Millipedes (Diplopoda) and woodlice (Isopoda) were less abundant on conventional fields surrounded by other conventional fields than in either conventional or organic fields surrounded by organic fields. Litter decomposition, on the other hand, did not differ between farming types or landscapes.

Snapp *et al*. studied some of the potential mechanisms behind the effects of organic farming on soil ecosystem services and found that organic management, but not crop diversity, sustained soil fertility, augmented soil carbon, enhanced N retention, and improved N-use efficiency.[42] At the same time, grain quality, quantity, and temporal yield stability were lower under organic management than in conventional, integrated management. Therefore, improving soil quality through organic farming may come with the cost of reduced yields and lower quality crops that need to be considered in the light of higher energy, nutrient, and pesticide input on conventional farms. However, it is clear that a more complete and nuanced picture of soil ecosystem services in relation to organic farming requires more research.

Farmland birds

Birds often benefit from organic farming,[3,9] and one likely explanation of lower species richness and abundance of birds on conventional farms is that herbicides and insecticides reduce food resources. Geiger found a higher soil–seed density and weed biomass on organic farms, and seed density correlated both to bird abundance and species richness.[43] There are other differences between organic and conventional farms that may affect birds; the often increased rate of mechanical weed control on organic farms and mowing of green manure crops may be detrimental to many species.[17,43,44] Lapwings (*Vanellus vanellus*) have been shown to have a higher nest density on organic farms, but they may suffer from lower nesting success due to farming activities.[45,46] Skylarks (*Alauda arvensis*) on organic farms initiated nests throughout the season, but in conventional farms they did so only early and late in the season due to differences in the height of crops between farm types.[46] Later in the season, skylarks initiated nests in vegetable fields, available on both farm types, thereby reducing the difference between farm types; this indicates that differences between organic and conventional fields may be seasonal. Organic farms have been shown to enhance the species richness of birds during the breeding season in Germany, but not in the winter.[47] The opposite was found in the Netherlands by Geiger; species richness and abundance was positively influenced by organic farming in the winter, but not in the summer, but responses were species specific.[43]

Since birds are very mobile and often use resources not just from a single field, many studies are taking the surrounding landscape into account. Landscape complexity affected the diversity of birds both in the summer and in the winter in a German study, and responses differed between groups of birds. Forest and farmland bird species abundance, species richness, and diversity decreased as the percentage of arable land in the landscape increased, presumably owing to the reduced availability of nesting and sheltering places in noncrop habitats. The abundance of birds known to breed and feed in fields increased with decreasing landscape complexity, and they seem to require high proportions of arable land.[47]

The effect of the surrounding landscape also differed between species in a study from the Netherlands. Some bird species such as skylarks were more abundant in larger fields, whereas others such as yellowhammers (*Emberiza citronella*) preferred smaller fields. An increase in habitat diversity increased the abundance of some species, whereas an increase in the percentage of arable land in the landscape enhanced, for instance, skylarks.[43] In Sweden, organic farms had higher species richness in homogenous landscapes with a high proportion of arable fields and larger fields, especially for passerine invertebrate feeders, indicating that organic farming improved foraging conditions in these landscapes.[48]

Birds are also important for some ecosystem services, but this has not yet been widely studied in the light of organic farming and ecosystem services. Navntoft *et al*. filmed seed predation on organic and conventional farms but did not take landscape complexity into account. They found that birds were the most important seed predators, but mice and slugs were also observed predating seeds.[34]

Mammals

A number of mammals, such as mice, deer, hares, and foxes can be found on arable fields or in the arable landscape. Some species of bat also hunt in the arable landscape. Mammals are not very often well studied in the context of organic farming.

Wickramasinghe *et al*. found that bat activities and feeding activity were higher on organic farms than conventional farms. Taller hedgerows and better water quality may explain the difference, as might greater prey availability.[49,50] A more recent study of Pipistrelle bats, on the other hand, found lower bat activity and prey availability on farms participating in AES associated with hedgerows and water margins.[51] This finding may indicate that organic farming is more important than more specific AESs for some organisms.

In a British study, Bates and Harris did not find a difference in small mammal (seven species of mice, voles, and shrews) abundance and diversity between organic and conventional farms when hedgerow management and structure were studied. They argue that increasing the area of noncrop habitats may be more important.[52] Many mammals are mobile and utilize different habitats throughout their lives and may therefore be very dependant on the quality or structure of the landscape. Small omnivorous and herbivorous mammals have been shown to decrease in conventional fields but increase in organic fields in landscapes with a higher proportion of arable fields.[7] In this study, small mammals showed the opposite response to the ecosystem service of seed removal, which was highest on organic fields in complex landscapes and decreased as landscapes grew more homogeneous, whereas on conventional fields it increased with increasing homogeneity.[7] Mammals such as bats may also be important for pollination and pest control of, for instance, moths, but this is largely unstudied in an organic farming and landscape context.

Discussion

Sometimes the issue of organic versus conventional farming turns into a very polarized and unproductive debate. Instead of arguing which farming system is the worst or the best, we should try to see the strengths and weaknesses in these as well as other farming systems and try to improve them and make them more sustainable. Organic farming is not the only solution to the problem caused by modern agriculture, but where biodiversity is concerned, organic farming generally performs better than conventional farming. Both conventional and organic farms are very diverse in their management, resulting in a huge variation and overlap in farm management.[53] Organic farmers cannot use chemical fertilizers and inorganic pesticides, but conventional farmers can decide not to use or minimize these external inputs, thus reducing the differences between the systems. Some farmers have both organic and conventional fields, and many farmers adopt other AES than organic farming.

One step forward may be a stronger focus on integrated farming and management practices, so that farmers willing to adjust the number of pesticide applications to pest pressure and economical thresholds can be compensated. Compared to organic farming, integrated farms can have a higher species richness of, for instance, weeds on the regional or landscape scale as a result of these farms having a greater range of crop types and cropping practices between fields than both organic and conventional farms.[21] Integrated farm management is thus one way to increase the variation in the landscape, but the questions of how the complexity of the surrounding landscapes should be taken into account in policies such as organic farming is yet unresolved.

Is organic farming most beneficial in heterogeneous or homogeneous landscapes? Heterogeneous landscapes with plenty of natural, seminatural, and traditionally managed habitats may already have high biodiversity, and thus organic farming may not result in higher biodiversity in these landscapes, suggesting that organic farming has the greatest effect in homogeneous landscapes.[5,17] Perfecto and Vandermeer suggested that managing the matrix between natural habitats and seminatural grasslands was important for both preserving biodiversity and sustainable farming based on ecosystem services, just as is being done in organic farming.[54]

In regions where the presence of agriculture increases rather than decreases habitat heterogeneity, the positive effects of agriculture on biodiversity are more likely to occur.[55] In many countries and regions, there is intensification in arable landscapes but extensification in more forested areas as unproductive farms close down. In the arable landscape, organic practices lower farming intensity, and in forested areas, the subsidy for organic farming and the higher payment for organic products can save farms from closing.

In a meta-analysis of landscape-moderated biodiversity effects on agri-environmental management, Batáry *et al.* found that such schemes significantly increased species richness in simple, but not in complex, landscapes.[15] Still, the question of actual management of the surrounding landscape has not yet been properly addressed. Kleijn *et al.* studied whether AES in five European countries benefited diversity, and they concluded that common species may be enhanced with relatively simple modifications, whereas endangered species require more elaborate conservation methods.[56] The benefit of more specific AES is that they can be more precisely targeted at a specific species or service. In a recent European study of agricultural intensification, the percentage of land under AES in the landscape had a beneficial impact on biological control potential, whereas no significant positive effects of organic farming in itself were found.[2]

In recent years, the importance of studying not only biodiversity per se, but also associated ecosystem services has been emphasized.[57] More importantly, it is time to include ecosystem services in regulations and schemes in order to promote them in a sufficient way. Studies on ecosystem services so far show diverse results, but most agree that the landscape aspect is important for ecosystem services as well (Table 2). There is also a need for more studies on the actual outcome of, for instance, pollination—e.g., seed set, seed quality, and germination, or the increase in crop yield and quality resulting from the predation of pests. Since a high yield and quality of crops is essential to farming, a functioning pollination service and biological control are vital. Any measures to increase pollination and predation of pests are worthwhile, and in this respect, organic farming seems to be a good start. But since most pollinators and some predators only visit arable fields during a short period of their lifetime, the surrounding landscape with alternative natural and seminatural habitats is very important, and this is not included in the regulation of organic farming.

Rather than just discussing organic farming, we should be talking about (organic) farmers, the main actors in the arable landscape. Farmers decide farm management practices, including what crops to grow, whether to use pesticides or not, and whether to convert to organic farming or not. Conversion to organic farming often depends on the opportunity cost of farmers (or the farms); what will be the net economic gain when the frequently lower yield but higher payment is considered? These factors are landscape specific; the uptake of organic farming is higher in less-intensive agricultural landscapes or low-productive and high-diversity fields. This can be called the selection effect, where AES are preferentially located on fields with high biodiversity.[58] Alternatively, schemes could be implemented in low-diversity locations to enhance biodiversity in areas where it is needed, which may result in no increase in species richness since species are not present in the surrounding landscape. In addition, responses can be hard to measure, since time-lags and long response times are common in nature. The duration of many studies is just one season, and we therefore fail to incorporate "background variation" or demographic effects of organic farming. In addition, it seems like policies are expected to give swift responses to be proven useful. It has been argued that AES should result in quick responses on biodiversity and ecosystem services to make validations of costs and benefits easier.[19] This is quite a harsh requirement, since the effect of organic farming can take a long time to emerge. For example, these effects have been shown to be rapid for butterfly and plant species richness, whereas butterfly abundance increased gradually with time since transition over a 25-year period.[19] We can assume that the latter is likely to be the case for ecosystem services as well.

Another opportunity cost is that of the farmer's identity and social capital.[59] The conversion to organic farming is a process in which the farmer has to accept weedier fields and maybe endure negative comments from other farmers regarding organic farming. Weeds are not desired by organic farmers and other methods for reducing weeds are used, but these seem to be less effective than the use of herbicides. In organic farming, but also more and more in conventional farming, there is a discussion on the importance of management, instead of eradication, of weeds; the intent is to have appropriate, in an economic and ecological sense, populations of weeds.[60]

There is also an opportunity cost associated with the need to learn about techniques, to buy new machinery, and to join new environmental subsidies and certification bodies.

GM technology may help overcome some of the negative aspects of modern agriculture. In Europe, genetically modified organisms and products from them are incompatible with the concept of organic farming.[61] There may be both pros and cons with GM technology, but studies so far have not come to a general consensus, and studies on potential effects on ecosystem services are missing.[62]

Concluding remarks

So, where do we go from here? We need to raise the production of food, feed, fuel, fiber, and ecosystem services in a sustainable and resilient manner that is also economically and socially valid without exhausting resources, biodiversity, or ecosystems. It has been claimed that "existing farming systems and the knowledge system that supports them are no longer fit-for-purpose and that a new approach is called for."[63] These authors also argued that future agricultural production systems will need to produce food and other products using much scarcer resources than today, in terms of inputs of energy and nutrients such as phosphorus.[63] Can organic farming play a role in the developing these future systems? Different ways forward to resolve this conundrum have been proposed.

One of the most important issues is that enough funding should be allocated to AES such as organic farming, not only toward sufficient subsidies to farmers, but also toward adaptive management[10] and, importantly, toward monitoring results. Baseline data must be collected, and improvements or failures must be monitored, documented, and analyzed after implementation. We also need to calibrate our AES and farm management to be up to date with recent scientific findings. To make AES fulfill their goals, they need to have been developed together with stakeholders at all levels.[64] Previous uptake of AES has been associated with AES that demand the least changes from current farm management; that is, farmers keep doing what they have always done. It is important that the connection between management and positive effects on biodiversity, ecosystem services, or other aspects of organic farming is stated clearly and widely communicated. Farmers may refuse to join schemes because they do not understand why the management measures should be done, and they might also doubt whether the measures really have the effects that they are said to have.

Many agri-environment policies are too short term to be useful. Time lags in responses to AES may be common, and long-term effects would need to be included in management recommendations and policies.[19] AES are not currently designed specifically to deliver improved ecosystem services, but to include payment for ecosystem services from, for instance, organic farming could be a way to achieve a more long-term approach.[10]

Another maybe more radical idea is to make some measures compulsory—for instance, protective zones without pesticides or fertilizers lining water bodies, seminatural, and natural habitats. In many countries, some basic measures are mandatory—for instance, in Finland, some basic measures covered 93% of arable land in 2002.[64] Perfecto and Vandermeer suggested the matrix quality model to achieve small-scale sustainable agriculture.[54] According to this idea, a high-quality matrix within which fragments of high-diversity native vegetation can persist along with biodiversity-friendly agroecosystems to form an integrated landscape. If this is to work, much more focus on the landscape as a whole is needed, both by farmers and by policy makers, and policies concerning the landscape level need to be developed. To be able to answer questions like "how much organic farming in homogenous landscapes will lead to a 30% increase in biodiversity?" we need to study organic farming on a wider landscape scale and also take the amount of organic farming in the surrounding landscape into account in study design (see, for instance, Diekötter *et al.* [35]).

Active management of noncrop habitats is often not included in organic farming, but this may be included in other AES. For pollinators, a deliberate manipulation of nesting resources may be important, not just floral resource management. The provision of dead wood, bare soil, and areas of natural flooding may also be important for many organisms in the modern arable landscape. Studies of organic farming and other AES have demonstrated the importance of landscape effects on other than the target environment to record the total benefits of AES on biodiversity. The first step could be to offer financial support to farmers linked to spatial arrangements of organic fields.[65] For researchers to give the best recommendations, we need multiyear, multiscale, multibiodiversity, and multifunctional studies to guide us. We must make sure to not only study biodiversity per se, but also include the associated services!

Scope and method

This review is an attempt to bring together recent findings regarding effects of organic farming on biodiversity and ecosystem services and studies on how these effects may be affected by the surrounding landscape. Our aim is to give a broad overview on this matter regarding terrestrial biodiversity and associated ecosystem services in the arable landscape. We focused mainly on studies published from 2009 and onward, but for some important reviews or meta-analyses we refer to older studies. For some organism groups, we also included older studies simply because there are only few recent studies. We have used keywords such as "organic or biological farming," "biodiversity," "ecosystem services," "landscape complexity," "pollination," and "predation" when searching for studies. Most studies have been conducted on arable crops such as cereals, whereas some have been conducted in grasslands such as ley. Additionally, because of our background, most studies are European, with a few exceptions covering, for instance, the United States.

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Conflicts of interest

The authors declare no conflicts of interest.

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