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Restoration of Biodiversity and Ecosystem Services on Agricultural Land

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Abstract

Cultivation and cropping are major causes of destruction and degradation of natural ecosystems throughout the world. We face the challenge of maintaining provisioning services while conserving or enhancing other ecosystem services and biodiversity in agricultural landscapes. There is a range of possibilities within two types of intervention, namely ''land sharing'' and ''land separation''; the former advocates the enhancement of the farmed environment, but the latter a separation between land designated for farming versus conservation. Land sharing may involve biodiversity-based agricultural practices, learning from traditional farming, changing from conventional to organic agriculture and from ''simple'' crops and pastures to agro-forestry systems, and restoring or creating specific elements to benefit wildlife and particular services without decreasing agricultural production. Land separation in the farmland context involves restoring or creating non-farmland habitat at the expense of field-level agricultural production—for example, woodland on arable land. Restoration by land sharing has the potential to enhance agricultural production, other ecosystem services and biodiversity at both the field and landscape scale; however, restoration by land separation would provide these benefits only at the landscape scale. Although recent debate has contrasted these approaches, we suggest they should be used in combination to maximize benefits. Furthermore, we suggest ''woodland islets'', an intermediate approach between land abandonment and farmland afforestation, for ecological restoration in extensive agricultural landscapes. This approach allows reconciliation of farmland production, conservation of values linked to cultural landscapes, enhancement of biodiversity, and provision of a range of ecosystem services. Beyond academic research, restoration projects within agricultural landscapes are essential if we want to halt environmental degradation and biodiversity loss.

Key words: agroforestry; financial support; land separation; land sharing; organic agriculture; reconciliation; secondary succession; tree plantations; woodland islets.

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Introduction

Currently, about 80% of the planet's surface shows evidence of human intervention (Ellis and Ramankutty 2008). This implies large losses of biodiversity (Butchart and others 2010) and of the variety and amount of all ecosystem services (that is, the benefits that people obtain from ecosystems) except certain provisioning services (MEA 2005). A large part of such environmental degradation is due to the expansion of the agricultural frontier in many parts of the world together with intensification of farming methods (BirdLife International 2008; FAO 2010; Mulitza and others 2010). For instance, Ellis and Ramankutty (2008) indicated 14 of the world's 21 major biome types which have agricultural use. Predictions suggest that humanity's footprint will expand in the future (Hockley and others 2008; Pereira and others 2010; WWF 2010).

One of the most powerful approaches to countering the negative impacts of agricultural expansion and intensification is ecological restoration. Ecological restoration aims to recover the characteristics of an ecosystem, such as its biodiversity and functions, which have been degraded or destroyed, generally as a result of human activities (Society for Ecological Restoration International Science and Policy Working Group 2004). Restoration actions are increasingly being implemented in response to the global biodiversity crisis, and are supported by global agreements such as the Convention for Biological Diversity (CBD) (Sutherland and others 2009). Three major targets of the new CBD strategic plan for 2020 arising from the Nagoya Conference in 2010 are to eliminate subsidies harmful to biodiversity, halve or bring close to zero the rate of loss of all natural habitats, and restore at least 15% of degraded ecosystems (Normile 2010). Such policy initiatives are useful, but raise questions about our ability to manage and restore ecosystems to supply multiple ecosystem services and biodiversity (Rey Benayas and others 2009; Bullock and others 2011).

Ecosystem management that attempts to maximize a particular ecosystem service often results in substantial declines in the provision of other ecosystem services (Bennet and others 2009). As a consequence, there is often a trade-off between agricultural production versus other services and conservation of biodiversity (Green and others 2005; Pilgrim and others 2010). Thus, we face the challenge of increasing provisioning services such as food production—by 70% for 2050 according to FAO (2009)—for an expanding population while simultaneously conserving or enhancing biodiversity and the other types of ecosystem services (for example, regulating and cultural services) in agricultural systems (Kiers and others 2008). Rey Benayas and others (2009) showed a positive relationship between biodiversity and provision of ecosystem services in restored versus degraded ecosystems in a wide variety of ecosystems. However, restoration of biodiversity and of services is not the same thing (Bullock and others 2011). For instance, especially in agricultural land, concentration on services such as carbon or water retention may be in conflict with biodiversity (Ridder 2008; Cao and others 2009; Putz and Redford 2009).

In this article, after examining the complex role of agricultural systems in both delivering and harming biodiversity (the "agriculture and conservation paradox"), we review approaches to enhance both biodiversity and ecosystem services in agricultural landscapes. Recent discussions of the future of farming have contrasted "land sharing"—sometimes called "environmental- or wildlife-friendly farming"—with "land separation." The former advocates the enhancement of the farmed environment, whereas the latter advocates a separation of land designated for farming from that for conservation (Green and others 2005; Fischer and others 2008; Hodgson and others 2010; Phalan and others 2011). Land separation is usually referred to as "land-sparing" when high-yield farming is combined with protecting natural habitats from conversion to agriculture (for example, Phalan and others 2011). We will argue that these approaches should not be seen as alternatives, but as representing the range of actions that can be combined to best enhance biodiversity and ecosystem services. On one side, we will examine the potential to produce systems in which agricultural production and conservation or enhancement of biodiversity and of ecosystem services other than agricultural production is in partnership rather than in conflict. We will show an exemplary case study to illustrate examples of existing options to achieve such a goal. Cropland has mostly spread at the expense of forest land and natural grassland (Foley and others 2005). Thus, on the other side, we will focus on forest regrowth and tree plantations on cropland as examples of land separation by natural habitat restoration. Finally, we will discuss the necessity of restoration projects in the real world beyond academic research and the key issues that must be addressed for a wide implementation of such projects.

The Agriculture and Conservation Paradox

Few human activities are as paradoxical as agriculture in terms of their role for nature conservation. Agricultural activities are the major source of negative environmental impacts worldwide (Kiers and others 2008). For instance, agriculture is the main cause of deforestation (FAO 2010), the major threat to bird species (BirdLife International 2008), accounts for approximately 12% of total direct global anthropogenic emissions of greenhouse gases (IPCC 2007), and strongly impacts soil carbon and nutrients (McLauchlan 2006). Cropland and grazing land footprints accounted for approximately 24 and 7%, respectively, of the total human global footprint in 2007 (WWF 2010). These figures vary greatly among countries (Table 1). They are proportionally the lowest, approximately 18 and 4%, respectively, in the 31 OECD countries, which include the world's richest economies, and the highest, about 36 and 14%, respectively, in the 53 African Union countries, which include some of the world's poorest and least developed countries (WWF 2010).

Agricultural land covers over 40% of the terrestrial surface, to the detriment of natural vegetation cover (Foley and others 2005). At the global scale, the conversion of natural ecosystems to agricultural systems has currently reached a plateau (Figure 1). However, there is great variation among countries; agricultural land has declined in some whereas it has increased in others—chiefly developing countries that harbor the highest amounts of biodiversity (for example, Cayuela and others 2006; Table 1).

In recent history, farming practices in many areas have become more intensive, and increasing amounts of water, fuel, fertilizers, pesticides, herbicides, and non-native species are used worldwide to enhance production. For example, the global area serviced by irrigation now accounts for approximately 20% of cultivated land (FAOSTAT 2011; Figure 1). Agriculture is the major form of human water consumption in the world and threatens water security and habitats (Vorosmarty and others 2010). Beyond changes in species richness, agricultural intensification has been shown to reduce the functional diversity of plant and animal communities, potentially imperiling the provisioning of ecosystem services (Flynn and others 2009). Many studies have found negative effects of agrochemicals on biodiversity and ecosystem function (for example, Rohr and others 2008; Geiger and others 2010). Intensification of land use has brought remnant areas of natural vegetation such as steep hillsides, property boundaries, and track edges into mainstream agriculture (Rey Benayas and others 2008). Thus, agricultural expansion and intensification have greatly increased our food supplies at the global scale, but have damaged biodiversity and other services.

In contrast to these negative perspectives, habitats converted to agricultural activities are often viewed positively in terms of nature conservation due to, for example, creation of landscape mosaics and environmental heterogeneity (Dornelas and others 2009; Oliver and others 2010; Sitzia and others 2010), or because they are threatened habitats that support endangered species and cultural values (Kleijn and others 2006; Lindemann-Matthies and others 2010). In the EU-27, 31% of Natura 2000 sites, a network of protected areas, result from agricultural land management. Several taxa including species of birds, insects and plants, some of them endangered, depend on low-intensity farmland for their persistence (Doxa and others 2010; Kohler and others 2011). Thus, regional trends of common farmland birds in Europe show negative trends (−35% since 1980) and are of conservation concern, whereas forest birds show positive trends due to abandonment of agricultural land and afforestation programs (European Bird Census Council 2010). Such declines might affect agricultural production itself. Insects that provide pollination and pest control services in cropland tend to be less common in more intensive landscapes (Tscharntke and others 2005; Potts and others 2010).

Agricultural intensification can have a negative impact on the values linked to traditional agriculture, but so can agricultural abandonment and, particularly, afforestation of former cropland (Rey Benayas and others 2007; Sitzia and others 2010). Abandonment of agricultural land has mostly occurred in developed countries in the last few decades (Table 1) and it is currently happening in developing countries with strong rural migration to urban areas such as in Latin America (Rey Benayas and others 2007; Grau and Aide 2008). The European Agrarian Policy is providing subsidies to afforest land after vineyard extirpation in Spain, an action that is being criticized by conservationists due to negative impacts on esthetic and other values. The Chinese Grain for Green project is a major, but controversial, project related to afforestation of former cropland (Cao and others 2009; see below). It seems that agriculture, woodland, and biological conservation are in a permanent and irreconcilable conflict, the agriculture and conservation paradox (Rey Benayas and others 2008).

Enhancing Biodiversity and Ecosystem Services in Agricultural Landscapes

There is a range of possibilities to reverse the negative environmental impacts of agriculture. Some

Table 1. Statistics, for 20 Selected Countries that are Representative of Different Economies in the World, on Ecological Footprint, Percentage of Cropland and Grassland Footprint in the Ecological Footprint, Percentage of Area of Agricultural Land, Total Forest and Forest Plantations, and their Changes in the Last Few Decades, and Gross Per Capita Domestic Product

Country	Ecological footprint 2007 (global ha/person)	Cropland footprint 2007 (%)	Grassland footprint 2007 (%)	Agricultural area (2008, % on land area)	Change in agricultural land area (% since 1961)	Total forest area (2010, % on land area)	Forest plantations area (2010, % on total forest area)	Change in total forest area (% since 1990)	Change in forest plantation area (% since 1990)	Grosse per capita domestic product (USD)
Afghanistan	0.6	53.33	25	58.2	0.56	2	–	0.00	–	1103
Brazil	2.9	24.83	32.08	31.27	75.71	62	1	−8.86	15	10304
Canada	7.0	13.57	3.71	7.43	−3.19	34	3	0.00	586	39078
China	2.2	24.09	5	56.02	52.24	22	37	28.12	39	5971
Colombia	1.9	20.53	39.47	38.4	6.61	55	1	−2.91	356	8797
Germany	5.1	24.51	4.11	48.54	−12.66	32	48	3.12	1	35374
Guatemala	1.8	23.89	12.22	39.36	59.41	34	5	−20.61	365	4760
India	0.9	43.33	0.04	60.44	2.74	23	16	6.58	68	2946
Jamaica	1.9	27.89	5.26	42.84	−12.95	31	2	−1.93	−23	7716
Mali	1.9	38.42	43.68	32.48	25.02	10	4	−10.12	11158	1129
Mexico	3.0	27.67	10.66	52.73	4.33	33	5	−7.37	232*	14570
Nepal	3.6	10.28	1.38	29.44	19.23	25	1	−24.52	20	1104
Russia	4.4	20.23	2.27	13.16	−2.77	49	2	−0.01	28	15923
Serbia	2.4	27.92	2.5	57.22	−0.20	31	7	3.76	353	10554
Spain	5.4	26.85	5	55.90	−16.04	36	15	28.97	2	31674
United Arab Emirates	10.7	12.62	3.85	6.82	174.04	4	100	28.65	0.00	37442
Thailand	2.4	24.17	0.83	38.46	68.63	44	21	−3.10	54	8086
Togo	1.0	31	0.9	66.74	18.24	5	15	−52.32	328	830
UK	4.9	17.76	5.51	73.10	−10.69	12	77	9.79	2	35468
USA	8.0	13.50	1.75	44.95	−8.11	33	8	2.34	32	46350

**Change since 2000.*

Sources: Footprint Network (http://www.footprintnetwork.org/) for ecological footprint data; FAOSTAT 2011 (http://faostat.fao.org) for percentage of area of agricultural land and its change, updated to year 2008; FAO 2011 for percentage of area of total forest and forest plantations in 2010 and their changes as well as for GDP.

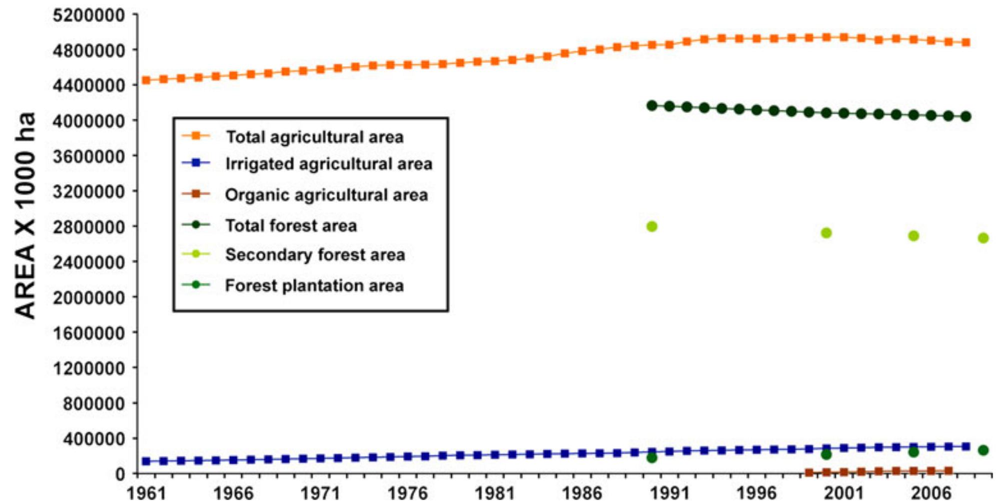

Figure 1. Global total agricultural area, agricultural irrigated area, organic agricultural area, total forest area, forest plantation area, and secondary forest area in the last few decades. Sources: FAOSTAT 2011 (http://faostat.fao.org) for data on total agricultural area and agricultural irrigated area, updated to year 2008; The World of Organic Agriculture. Statistic and Emerging Trend 2009, IFOAM, Bonn and FiBL, Frick (http://www.ifoam.org/), for organic agricultural area; FAO (2011) for data on forest area. The observed trends indicate a general increase in total agricultural area, which peaked in 2001, irrigated agricultural area—an indicator of agricultural intensification—, and forest plantation area, which mitigates the loss of total forest area. The proportion of organic agricultural area is marginal.

of these options have the potential to enhance biodiversity and ecosystem services including agricultural production, but others may enhance biodiversity and ecosystem services other than agricultural production. They can be considered within two major approaches:

(1) Land sharing. We can classify five types of intervention following this approach. Four involve extensive actions on agricultural land with a focus on productivity, that is, making agriculture more wildlife- (and ecosystem service) friendly: (a) adoption of biodiversity-based agricultural practices; (b) learning from traditional farming practices; (c) transformation of conventional agriculture into organic agriculture; or (d) transformation of ''simple'' crops and pastures into agroforestry systems. The fifth (e) involves restoring or creating specific elements to benefit wildlife and particular services without competition for agricultural land use. In practice, these interventions may be carried out concurrently as they are not exclusive (Figure 2).

(2) Land separation in the farmland restoration context involves restoring or creating non-farmland habitat in agricultural landscapes at the expense of field-level agricultural production—for example, woodland, natural grassland, wetland, and meadow on arable land. This approach does not necessarily imply high-yield farming of the non-restored, remaining agricultural land.

Next, we will document some examples of these two types of intervention to enhance biodiversity and ecosystem services in agricultural landscapes.

Land Sharing

Adoption of Biodiversity-Based Agricultural Practices

Conservation of existing biodiversity in agricultural landscapes and the adoption of biodiversity-based practices have been proposed as ways of improving the sustainability of agricultural production through greater reliance on ecological goods and services, and with less damaging effects on environmental quality and biodiversity (McNeely and Scherr 2003; Jackson and others 2007). Management of biodiversity, that is, the biota dwelling in agroecosystems as well as habitats and species outside of farming systems in the landscape (Vandermeer and Perfecto 1995), can be used to benefit agricultural production and enhance ecosystem services.

Examples of agrobiodiversity functioning at different hierarchical levels include (Jackson and others 2007): (1) genetic and population characteristics—for example, the use of traditional varieties and wild species for continuing crop and livestock improvement for increased pest resistance, yield, and quality (Cooper and others 2001; Tisdell 2003); (2) community assemblages or guilds that influence agricultural production, such as pest

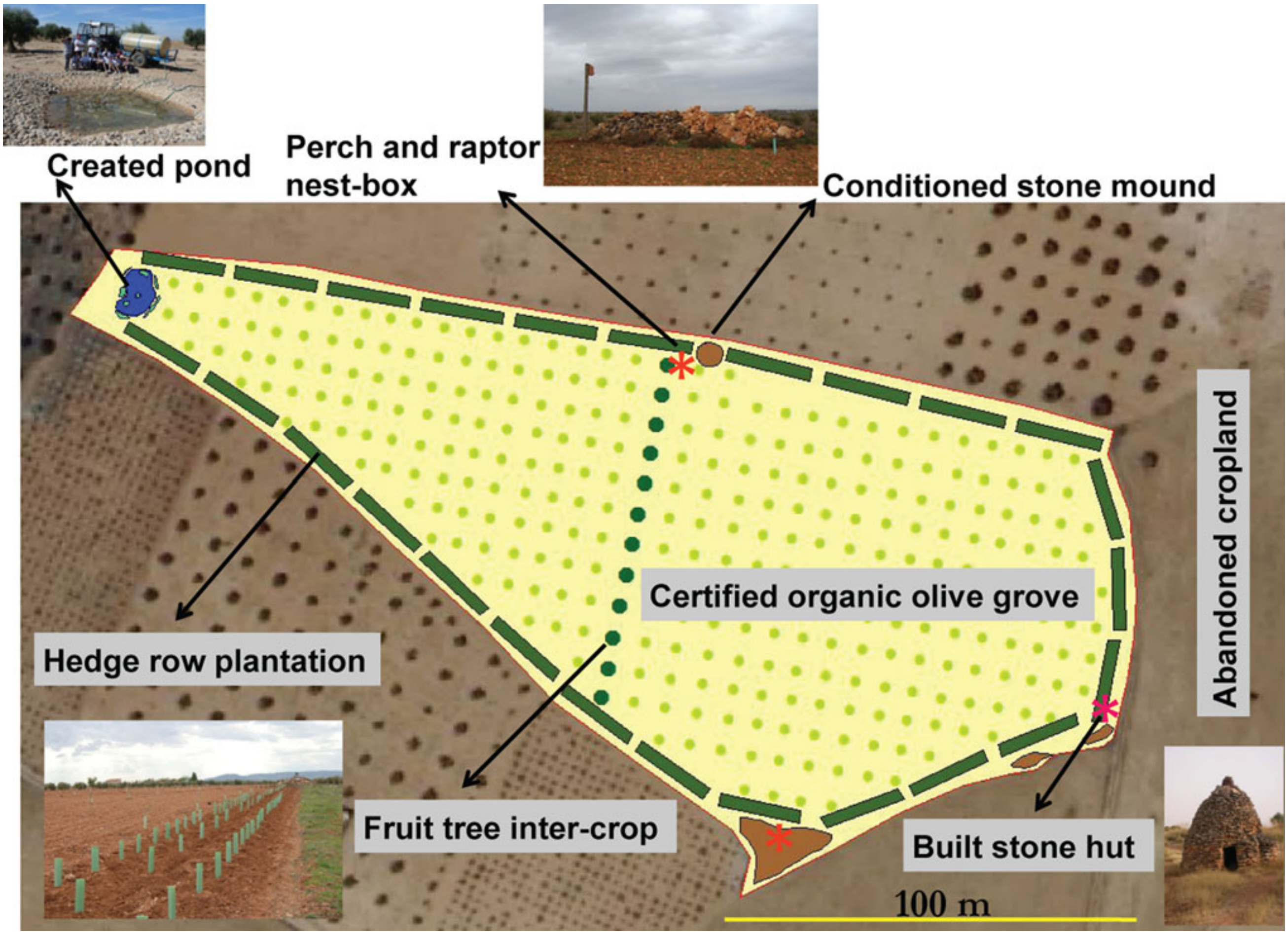

Figure 2. Sketch of a real restoration project based on a range of land sharing types and actions—that are explained in the main text—intended to enhance the farmed environment, which is run by the Fundación Internacional para la Restauración de los Ecosistemas (www.fundacionfire.org) in Valdepeñas (central Spain). This and similar projects have been acknowledged as among the best 13 projects that reconcile agricultural production and biodiversity conservation in this country. The 2-ha field mostly consists of a certified organic olive grove (type c in the text), which was established after a 1-year fallow period (type b). A row of singular fruit tree seedlings, that is, from healthy and locally adapted variety fruit trees, of three different species is inter-cropped with the dominant olive tree crop (types a and c). The following specific elements (type e) have been introduced in the crop system to benefit wildlife and particular services (mentioned in parentheses): (1) a hedge row plantation consisting of approximately 1,100 seedlings of ten native species in the region (to mitigate soil erosion, abrasion of the crop, attraction of pollinators and natural enemies, community diversification, and seed exportation to accelerate passive restoration of nearby abandoned cropland, a means of land separation); (2) a pond (chiefly to favor amphibians and birds, particularly game species such as the red-legged partridge *Alectoris rufa*, which are an input to the local economy); (3) perch and nest boxes (enhancement of small birds of prey that are intensive rodent consumers); (4) conditioning of stone mounds (creation of habitat and refuges for wildlife); and (5) construction of a stone hut, a jewel of the local rural architecture (enhancement of the cultural value of this project).

control based on toxin biosynthesis or other plant defences against herbivore attack, crop mixtures, release of natural enemies, and pest suppression by a complex soil food web (Dicke and others 2004) or increased yield following inter-cropping and crop rotation (Chabi-Olaye and others 2005); (3) heterogeneity of biota in relation to biophysical processes within ecosystems, such as nutrient cycling and retention or carbon accumulation (van Noordwijk 2002); and (4) landscape-level interactions between agricultural and non-agricultural ecosystems that enhance resources for agriculture, and potentially, resilience during environmental change—for example, agricultural landscapes that are composed of a mosaic of well-connected early and late successional habitats may be more likely to harbor biota that contribute to regulating and supporting services for agriculture, compared to simple landscapes (Elmqvist and others 2003; Bianchi and others 2006).

Learning from Traditional Farming Practices

Traditional farming describes practices that developed through human history to produce a variety of agricultural goods, largely for local use. Forms of traditional farming persist in many parts of the world, particularly in developing countries, but also in more developed countries, where such methods are remnants or have been re-introduced to meet specific needs (Altieri 2004; Kleyer and others 2007). Traditional farming methods are extremely diverse, by their nature, but they often share a number of distinguishing characteristics in comparison to intensive systems: on-farm cycling of nutrients and resources, the development of local varieties and breeds, high spatial and temporal structural diversity, use of local pollination and pest control services, and effective exploitation of local environmental heterogeneity (Altieri 2004). Although modern, intensive farming methods are usually better than traditional methods at maximizing production, they do so by increasingly using vast off-farm resources, such as inorganic fertilizers, new crop breeds and specialized machinery (Woods and others 2010). In comparison to these intensive approaches, traditional farming in many countries has been shown to have many environmental and societal benefits, including enhancement of soil carbon sequestration (Ardo and Olsson 2004) and nutrient cycling (Badalucco and others 2010), reduction of soil erosion (He and others 2007), more efficient water use (Prasad and others 2004), and maintenance of crop genetic diversity (Pujol and others 2005; Jarvis and others 2008), as well as providing resources for endangered species (Blanco and others 1998; Olea and Mateo-Tomas 2009).

Continuation of traditional farming is one matter (Altieri 2004), but it is probably not possible or desirable to ''turn back the clock'' in areas of more intensive farming. Wholesale reversion to earlier agricultural methods would reduce food production massively; for example, the current UK wheat yield per hectare is more than threefold that realized in 1945 (UK National Ecosystem Assessment 2011). Furthermore, certain traditional methods, such as swidden agriculture, may sometimes be damaging to biodiversity and to soil and water resources (Ziegler and others 2010). It is therefore more appropriate to learn lessons from traditional approaches which can be applied to modern agricultural systems. Perhaps the most important idea to borrow is to increase within- and between-farm diversity in terms of crops, cropping systems and land use. Such structural diversity at a variety of scales can reduce vulnerability of crop yield to between-year climatic variability (Reidsma and Ewert 2008), as well as increase biodiversity and associated ecosystem services (Benton and others 2003; Tscharntke and others 2005). Local reversions to traditional management approaches are being implemented, for example, through the European agri-environment schemes. Options within these include a return to traditional livestock grazing rates and/or seasons, which can help weed control (Pywell and others 2010) and maintenance of plant and animal diversity (Redpath and others 2010); replacement of inorganic fertilizers with farmyard manure, with positive impacts on soil organic matter (Hopkins and others 2011); or re-creating traditional species-rich grasslands, in which increased plant diversity enhances forage production (Bullock and others 2007). More generally, there is global interest in more traditional approaches to soil tillage involving reduced frequency and depth, which can enhance soil nutrient cycling and stability, and pest control, while also reducing energy use (Roger-Estrade and others 2010; Woods and others 2010).

Transformation of Conventional Agriculture into Organic Agriculture

There has been a considerable expansion of organic farmland area in the world (a threefold increase between 1999 and 2006), chiefly in developed countries. The demand for healthy and environmental-friendly food and subsidies to producers of organic food and fiber has favored this process (Pimentel and others 2005). However, organic farming remains a tiny fraction of the farming activity (Figure 1), comprising 4.1 and 0.42% of the total agricultural area in EU27+ and the USA in 2008, respectively (FAOSTAT 2011).

The benefits of organic farming to the environment are well described, and include less contamination by fertilizers, herbicides and pesticides, increases in biodiversity (Bengtsson and others 2005; Hole and others 2005; Rundlof and others 2008; Aviron and others 2009; Danhardt and others 2010; Gabriel and others 2010; Jose-Maria and others 2010), enhancement of soil carbon sequestration and nutrients (Kimble 2002; Pimentel and others 2005), enhancement of natural pest control (Macfadyen and others 2009; Crowder and others 2010), and conservation of the genetic diversity of local varieties of domestic plants and animals (Jarvis and others 2008). Importantly, other than benefits related to the environment and human health, it has been demonstrated that organic farming usually produces similar or higher quantities of agricultural products (Pimentel and others 2005; Crowder and others 2010) and with higher market prices than conventional farming (Born 2004; Pimentel and others 2005), which can make it extremely profitable (Delbridge and others 2011).

However, recent work has shown that careful spatial planning and targeting of organic agriculture will be required to maximize benefits (Gabriel and others 2010). Meta-analyses of the effects of organic farming on species diversity have shown variable results among studies and taxa, with detrimental effects of organic farming in 16% (Bengtsson and others 2005) or 8.1% (Hole and others 2005) of the individual studies. Bengtsson and others (2005) also found no significant effects of organic farming on soil microbial activity or biomass. Organic farming uses three broad management practices (prohibition/reduced use of chemical pesticides and inorganic fertilizers, sympathetic management of non-cropped habitats, and preservation of mixed farming) that are largely intrinsic (but not exclusive) to organic farming, and that are particularly beneficial for farmland wildlife (Bengtsson and others 2005; Hole and others 2005). Thus, the role of organic farming per se in enhancement of biodiversity and ecosystem services is unclear. Positive effects of organic farming on species richness might be expected in intensively managed agricultural landscapes, but not in small-scale landscapes comprising many other biotopes as well as agricultural fields. Consequently, measures to preserve and enhance biodiversity should be more landscape- and farm-specific than is presently the case (Bengtsson and others 2005; Danhardt and others 2010; Gabriel and others 2010).

Transformation of Simple Crops and Pastures into Agroforestry Systems

Agroforestry is the purposeful growing of trees/shrubs with crops or pasture. These approaches offer opportunities in both tropical and temperate regions (Rigueiro-Rodríguez and others 2009; Bergmeier and others 2010). Agroforestry can augment biodiversity and ecosystem services in agricultural landscapes, while also providing income for rural livelihoods. It can be a management tool of buffer zones and biological corridors to enhance landscape connectivity and landscape-level biodiversity (Vandermeer and Perfecto 2007; Rigueiro-Rodríguez and others 2009; Lombard and others 2010). Agroforestry represents an intermediate step between natural secondary forests (Cramer and Hobbs 2007) and reclamation of severely degraded land (Koch and Hobbs 2007) in terms of high versus low provision of biodiversity and ecosystem services, state of degradation, and time and costs of forest restoration (Chazdon 2008). Agro-successional restoration schemes have been proposed, which include agro-ecological and agroforestry techniques as a step prior to forest restoration (Vieira and others 2009).

Restoring or Creating Specific Elements to Benefit Wildlife and Particular Services

This type of intervention encompasses highly specific actions intended to benefit wildlife and particular services such as pollination and game production. These actions are so characterized because they occupy a tiny fraction of the agricultural land if any at all, meaning that they hardly compete for farmland use. Actions include (1) strategic revegetation of property boundaries, field margins, and track edges to create living fences (Noordijk and others 2010; Pereira and Rodriguez 2010; Poggio and others 2010); (2) planting isolated trees to take advantage of their disproportionate positive value for biodiversity conservation and potential for seed dispersal (DeMars and others 2010; Fischer and others 2010); (3) creation of pollinator-friendly areas using plant enrichment (Kohler and others 2008; Ricketts and others 2008; Carvalheiro and others 2010; Hagen and Kraemer 2010); (4) introduction of beetle banks, stone walls, stone mounds and other strategic refuges for fauna (MacLeod and others 2004); (5) introduction of perches and nest boxes for birds (see example below); and (6) introduction or restoration of drinking troughs; (7) the reconstruction of rural architecture is specifically intended to restore and value cultural services. There will usually be scale effects on biodiversity and ecosystem services depending on how much land is affected by these actions.

GREFA's (http://www.grefa.org/) project for enhancement of birds of prey for rodent control is an outstanding example of this type of wildlife-friendly farming. This project was motivated by periodic field vole *Microtus arvalis* outbreaks, which are often controlled using poisons that may damage wildlife and game. Common kestrel *Falco tinnunculus* and barn owl *Tyto alba* are rodent predators that have declining populations for a number of reasons, including lack of sites for nesting in open landscapes. Thus, more nesting sites (photo in

Figure 2) should increase the populations of these two species and contribute to place their populations at the carrying capacities. To achieve this goal, a 2,000 ha agricultural landscape in central Spain was seeded with nest boxes. We calculate that total rodent consumption could be as high as around 46,250 kg y^{-1} if full nest occupancy by both species were attained, a figure that is expected to contribute to rodent damage control and the maintenance of these birds of prey species.

Land Separation

Land separation and land sharing are sometimes treated as alternatives (for example, Phalan and others 2011). However, as different actions benefit different species and ecosystem services (Brussard and others 2010; Pilgrim and others 2010; Phalan and others 2011), a variety of approaches would likely be the most successful at enhancing biodiversity and ecosystem services. Setting aside farmland to restore or create non-farm habitat rarely happens as farmers tend to use and expand into all available land because this is usually the most profitable choice in terms of direct use value (TEEB 2010). There are, though, some examples of habitat restoration at the expense of farmland, including both terrestrial (see below) and wetland ecosystems (Thiere and others 2009; Moreno-Mateos and others 2010). Two major contrasting approaches for terrestrial ecosystem restoration in agricultural landscapes are (1) passive restoration through secondary succession following abandonment of agricultural land, for example, cropland and pastures where extensive livestock farming has been removed; and (2) active restoration, for example, through addition of desired plant species. These approaches have been contrasted for a variety of ecosystem targets, including species-rich grassland (Pywell and others 2002) and heathland (Pywell and others 2011), but in the following we focus on forest restoration.

The estimated global deforestation rate of 13 million ha y^{-1} over the last 10 years has resulted in a net loss of forest area of 5.2 million ha y^{-1} or 0.13% y^{-1} (FAO 2011). In the past, land abandonment and passive restoration led to the reforestation of a larger surface area than active restoration (e.g. 4.1 versus 3.6 million ha y^{-1}, respectively, in 2000–2005; FAO 2006). Over the period 2000–2010, these figures reversed and they are now 2.9 versus 4.9 million ha y^{-1}, respectively (FAO 2011). Now 36% of forest area is primary forests, 57% is secondary forests, and 7% is forest plantations (FAO 2010).

Passive restoration is cheap (although it may include opportunity costs) and leads to a local vegetation type (Myers and Harms 2009). It is generally fast in productive environments, but slow in low productivity environments as woody vegetation establishment is limited (Rey Benayas and others 2008). The restoration capacity of woody ecosystems depends on the magnitude and duration of ecosystem modification, that is, the ''agricultural legacy'' (Dwyer and others 2010). A key bottle-neck that hinders revegetation in vast agricultural landscapes is the lack of propagules due to absence of mother trees and shrubs (Garcia and others 2010)

Active forest restoration basically comprises the planting of trees and shrubs. It is needed, for example, when abandoned land suffers continuing degradation, local vegetation cover cannot be recovered and secondary succession has to be accelerated. There are differences in the biodiversity and ecosystem services provided by passive versus active restoration, and there is much debate about the ecological benefits of tree plantations. For instance, the mean increment of carbon in young secondary forests of Costa Rica is 4.18 Mg ha^{-1} y^{-1} in the biomass (including below ground biomass) and 1.07 Mg ha^{-1} y^{-1} in the soil (Fonseca and others 2011a). These figures are higher in plantations of the native tree species *Vochysia guatemalensis* (7.07 Mg ha^{-1} y^{-1} in the biomass and 1.66 Mg ha^{-1} y^{-1} in the soil) and *Hieronyma alchorneoides* (5.26 Mg ha^{-1} y^{-1} in the biomass and 1.27 Mg ha^{-1} y^{-1} in the soil) (Fonseca and others 2011b). Plantations are thus better for sequestering carbon and for timber production than secondary forests in this and many other case studies (for example, Piao and others 2009; Rautiainen and others 2010); however, they are less valuable for non-timber forest products and biodiversity (Newton and Tejedor 2011).

Bremer and Farley (2010) analyzed published data on plant species richness in plantations and paired land uses, most often representative of pre-plantation land cover. They found that plantations are most likely to contribute to biodiversity when established on degraded lands rather than replacing natural ecosystems, and when indigenous tree species are used rather than exotic species. Similarly, a meta-analysis of faunal and floral species richness and abundance in timber plantations and pasture lands on 36 sites across the world concluded that plantations support higher species richness or abundance than pasture land only for particular taxonomic groups (that is, herpetofauna), or specific landscape features (that is, absence of remnant vegetation within pasture) (Felton and others 2010). Zhang and others (2010) also found higher levels of plant diversity, soil fertility, and organic matter on land undergoing secondary succession than on tree plantations in northwest China.

China's Grain to Green project and the afforestation of former agricultural land in southern Europe are examples of trade-offs between different types of ecosystem services and biodiversity. Under the former project, which has the intention to restore services and biodiversity (Tallis and others 2008), activities include planting non-native trees on agricultural land to decrease soil erosion. This has led to decreased native vegetation cover and increased water use, suggesting negative impacts on biodiversity and water availability in arid areas (Cao and others 2009; Chen and others 2010). Cropland afforestations in southern Europe are mostly based on coniferous species such as *Pinus halepensis* and *P. pinaster*, although other species are used. The fast-growing plantations are certainly better for carbon sequestration rates than secondary succession of Mediterranean shrubland and woodland (Rey Benayas and others 2010a). However, these plantations may cause severe damage to open habitat species, especially birds, by replacing high quality habitat and increasing risk of predation (Reino and others 2010). Further, they have been shown to be suitable habitats for generalist forest birds but not for specialist forest birds, whereas secondary succession shrubland and woodland favor bird species that are of conservation concern in Europe (Rey Benayas and others 2010a). Navarro-Cano and others (2010) showed that pine litter from afforestations hinders the establishment of endemic plants in semiarid scrubby habitats of the Natura 2000 Network.

Designing Restoration of Forest Ecosystems on Agricultural Land

The agriculture and conservation paradox creates a dilemma in woodland restoration projects, which can only be resolved by considering the relative values of biodiversity and ecosystem services associated with woodland versus agricultural ecosystems (Rey Benayas and others 2008). The reconstruction of vegetation in a landscape (''where and when to revegetate?'') is an issue that deserves to become a research priority (Munro and others 2009; Thomson and others 2009). Rey Benayas and others (2008) suggested a new concept for designing restoration of forest ecosystems on agricultural land, which uses small-scale active restoration as a driver for passive restoration over much larger areas. Establishment of ''woodland islets'' is an approach to designing restoration of woodlands in extensive agricultural landscapes where no remnants of native natural vegetation exist. It involves planting a number of small, densely planted, and sparse blocks of native shrubs and trees within agricultural land that together occupy a tiny fraction of the area (<1%) of target land to be restored. This approach, later called ''applied nucleation'' by Corbin and Holl (2012), allows direction of secondary succession by establishing small colonization foci, while using a fraction of the resources required for large-scale reforestation. Woodland patches provide sources of seed and dispersing animals that can colonize adjacent habitats (Cole and others 2010). If the surrounding land is abandoned, colonists from the islets could accelerate woodland development because dispersal of many woodland organisms will continue over many years. The landscape emphasis on a planned planting of islets maximizes benefits to biodiversity and the potential of allowing the islets to trigger larger-scale reforestation if the surrounding land is abandoned. The islets should be planted with a variety of native shrub and tree species including those identified as nurse species to take advantage of facilitation processes (Butterfield and others 2010; Cuesta and others 2010).

Vegetation dynamics in complex landscapes depend on interactions among environmental heterogeneity, disturbance, habitat fragmentation, and seed dispersal processes. For instance, European jays (*Garrulus glandarius*) are major long-distance (500–600 m) dispersers of acorns in Mediterranean landscapes (Gómez 2003). The introduction of woodland islets planted with oaks at a distance of 1 km from each other in a deforested agricultural landscape could facilitate acorn arrival to all points in a given landscape (Figure 3). In heterogeneous Mediterranean landscapes, jays disperse acorns preferentially toward recently abandoned agricultural fields, forest tracks, and pine reforestations, while they usually avoid dense shrubland, grasslands, and mature holm oak forests (Gómez 2003; Pons and Pausas 2007). Purves and others (2007) found that jay-mediated directed dispersal increases regional abundance of three native oak species. Montoya and others (2008) indicated that animal-dispersed tree species were less vulnerable to forest loss than wind-dispersed species, that is, plant–animal interactions help prevent the collapse of forest communities suffering habitat destruction. Accordingly, Ozinga and others (2009) concluded that the ''colonization deficit'' of plant species due

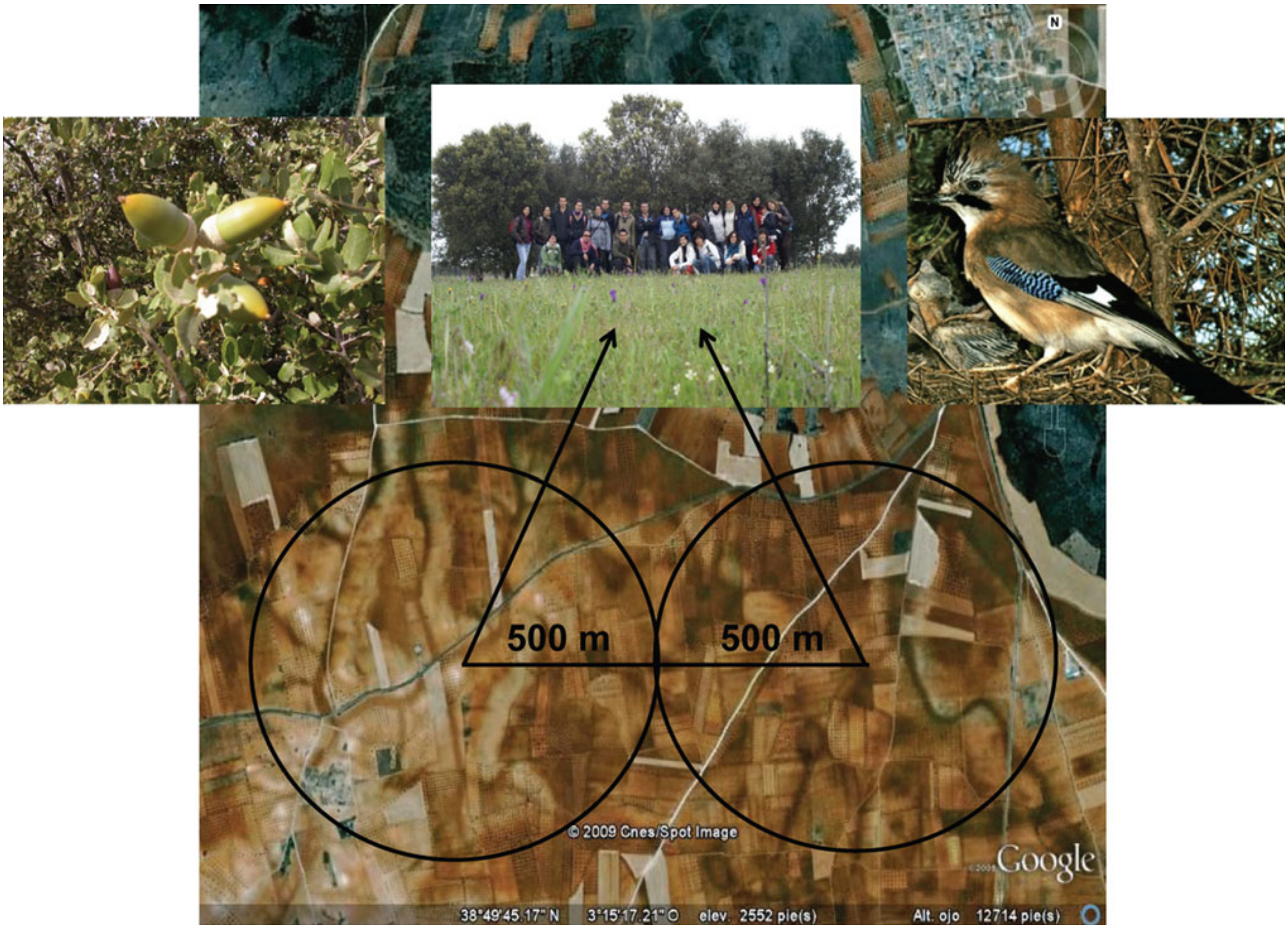

Figure 3. Simulation of the large area (ca. 1.6 km^2) that could potentially receive acorn rain following European jay dispersal from two introduced woodland islets (as shown in the upper photograph) or living fences 1 km apart from each other in a deforested agricultural landscape located in central Spain. The reported figure derives from an estimated dispersion distance of 500 m from each woodland islet or living fence (Purves and others 2007). Without the introduction of these elements, acorn rain and subsequently oak regeneration would not occur because native vegetation has been virtually extirpated in vast areas of this region.

to a degraded dispersal infrastructure is equally important in explaining plant diversity losses as habitat quality, and called for new measures to restore the dispersal infrastructure across entire regions.

The woodland islets approach maintains flexibility of land use, which is critical in agricultural landscapes where land use is subject to a number of fluctuating policy and economic drivers. It provides a means of reconciling competing land for agriculture, conservation, and woodland restoration at the landscape scale. This could increase the economic feasibility of large-scale restoration projects and facilitate the involvement of local human communities in the restoration process. The woodland islets idea has similarities to other approaches involving planting small areas of trees on farms, such as tree clumps, woodlots, hedges, living fences, or shelterbelts and agroforestry systems (see above). These practices provide ecological benefits as well as supporting farm production, whereas the woodland islets approach is primarily designed to provide additional ecological benefits other than agricultural production (Rey Benayas and others 2008).

Restoration of Agricultural Landscapes in the Real World

The response of human society to halt declining biodiversity indicators and environmental degradation shows positive trends, but so far it has been insufficient to achieve such goals (Butchart and others 2010; Rands and others 2010). Production science and conservation biology have long focused on providing the knowledge base for intensive food production and biodiversity conservation, respectively, but the largely separate development of these fields is counterproductive (Brussard and others 2010). Developing and strengthening a more interactive relationship between the science of restoration ecology and agroecology and the practice of ecological restoration and conservation farming has been a central but elusive goal (Gonzalo-Turpin and others 2008; Cabin and others 2010). Further research is needed to produce more sustainable socio-ecosystems (Turner 2010), but that will not be enough to reach the ultimate objective. Restoration actions that enhance both biodiversity and ecosystem services on agricultural land are necessary to reverse the world's declining biodiversity and ecosystem services (Bullock and others 2011; Foley and others 2011).

The adoption of environmental-friendly practices for agriculture, however, is not solely based on services and values that society as a whole obtains from such functions, as individual farmers are ultimately the agents who decide how much natural capital to conserve and utilize based on their own objectives and needs, including the social, economic (for example, markets and policies), and environmental conditions in which they operate (Jackson and others 2007). One key problem is that the private and social values of environmental-friendly farming differ and the markets and policies often do not align such values properly. The privately perceived value is reflected by the financial benefits arising from positive effects on productivity and/or the savings generated when wildlife-friendly farming substitutes for costs of synthetic inputs, for example, pesticides. The total or social economic value of environmental-friendly farming includes the value of the ecological services that it provides to those other than farmers, for example, through environmental quality, recreation, and esthetic values. In general, individual farmers react to the private use value of biodiversity and ecosystem services assigned in the marketplace and thus typically ignore the ''external'' benefits of conservation that accrue to wider society (Jackson and others 2007).

Key issues for widespread ecological restoration on agricultural land are financial support and education to promote farmer and public awareness and training. Land owners must be explicitly rewarded for restoration actions occurring at their properties in a time when society demands from agricultural land much more than food, fiber, and fuel production (Klimek and others 2008). The private financial benefits arising from environmental-friendly agricultural practices explained above may actually be a reward to land owners, but may be insufficient. To reward the total or social value, tax deductions for land owners who implement measures to restore agricultural land and donations to not-for-profit organizations that run restoration projects (most restoration projects are actually run by NGOs), payment for environmental services and direct financing measures related to restoration activities should be put into operation widely. These support mechanisms are very variable across countries. Incentives related to tax deductions are more generous in the US (>90% of the donated amount of money) than in Europe (for example, 60–65% in France and 25% in Spain), and non-existent in many countries.

A potentially major approach to funding restorations is through payment for ecosystem services (PES), which is designed to compensate for actions that secure services such as water purification, flood mitigation, or carbon sequestration (Jack and others 2008). In recent years, many hundreds of PES have been established worldwide for environmental management (Farley and others 2010) and some have focused on restoration, such as China's Grain to Green Program (Tallis and others 2008) and Madagascar's Mantadia PES (Wendland and others 2010). Globally, direct financing measures to support restoration projects have mostly to do with afforestation measures (Bigsby 2009). In the EU, major policy measures to support the provision of environmental public goods through agriculture are (1) agri-environment measures (a budget of € 34 billion including co-financing for 2007–2013, 34 million ha affected); (2) Life + Programme (a budget of € 2.14 billion for the period 2007–2013); (3) Natura 2000 (a budget of € 6.1 billion y^{-1} for the period 2007–2013, with about 15 million ha under agricultural management); (4) Good Agricultural and Environmental Condition standards that specify actions beyond existing legislation focusing specifically on maintaining landscape features, habitats, soil functionality or water quality; (5) aid schemes for forestry measures in agriculture (about 1 million ha have been afforested to date); and (6) structural funds (projects under the heading ''Preservation of the environment in connection with land … and landscape conservation'').

Environmental degradation will continue to increase while the world's citizens do not acknowledge the value of biodiversity and ecosystem services for human well-being. For that shift in understanding to happen, widespread education at various levels is necessary to promote public awareness (Hall and Bauer-Armstrong 2010). Professional training is necessary as well to build up the capabilities to reconcile agricultural production and the conservation or enhancement of biodiversity and other ecosystem services (Rey Benayas and others 2010b). Farmers obviously play a key role, and progress is required in engaging farmers more fully with the concept and methods of land management for purposes other than production (Burton and others 2008).

Conclusions

We conclude that, although agriculture is a major cause of environmental degradation, ecological restoration on agricultural land offers opportunities to reconcile agricultural production with enhancement of biodiversity and ecosystem services other than production. Restoration by land sharing through environmental-friendly farming has the potential to enhance agricultural production, other ecosystem services and biodiversity at both the farmed field and landscape scale. However, restoration by land separation would provide these triple benefits only at the landscape scale as this restoration type is at the expense of field-level agricultural production. Beyond scientific and technical research, an increase in such restoration projects is needed if we want to halt environmental degradation and biodiversity loss and meet the CBD goals. We need widespread expansion of agricultural management based on ecological knowledge: biodiversity-based agricultural practices, organic farming, agroforestry systems, learning from traditional practices, highly specific actions to benefit wildlife and particular ecosystem services, and conversion of some agricultural land into natural ecosystems such as forests. Financial support, public awareness, education and training, particularly of farmers, are necessary to accomplish such objectives. Restoration actions can act as an engine of economy and a source of green employment, so policymakers have an extra incentive to restore degraded farmland habitat.

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