

## Biodiversity Functions and Conservation Strategies in Agricultural Landscapes: Postprint

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**Date:** 2017-11-09T00:00:00+00:00

### Abstract

Studies have shown that agricultural intensification and agricultural landscape homogenization lead to reduced biodiversity in agricultural landscapes, causing impairment of ecosystem service functions such as wild resource conservation related to biodiversity, natural pollination, pest regulation, and soil and water conservation, thereby affecting sustainable agricultural development. This paper provides a comprehensive review of research and practice on biodiversity in agricultural landscapes and its ecosystem service functions both domestically and internationally. It respectively explores the role of agricultural landscapes in multiple ecological service functions including biodiversity conservation, pollination services, regulation services, and soil and water conservation, as well as the significance of biodiversity conservation, summarizes the practical measures adopted by Europe and America in agricultural landscape biodiversity conservation, points out that although China has made considerable efforts in biodiversity conservation, it has neglected the conservation of agricultural landscapes, and that recent urbanization and intensification have further exacerbated the loss of biodiversity in agricultural landscapes, necessitating urgent action to draw on the experience of European and American countries to propose conservation strategies for agricultural landscape biodiversity in China. We believe that ecological intensification that protects and enhances biodiversity in agricultural landscapes plays an important role in maintaining crop yields and improving varieties. Conservation of biodiversity in agricultural landscapes requires integrated agricultural landscape management at two scales—the farmland ecosystem and the agricultural landscape—to enhance the diversity and heterogeneity of farmland crops and landscape plants, and to restore and enhance biodiversity and its ecosystem service functions. Finally, in response to the problems and needs facing sustainable agricultural development in China, it is recommended to undertake conservation of agricultural landscape biodiversity from aspects including policies and regulations, monitoring and assessment,

engineering technology research and development, technology integration and demonstration, ecological subsidy systems, and training and extension.

## Full Text

### Functions and Countermeasures of Biodiversity Conservation in Agricultural Landscapes: A Review

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Biodiversity refers to the ecological complexes formed by organisms (animals, plants, microorganisms) and their environment, encompassing genetic diversity, species diversity, ecosystem diversity, and landscape diversity. Extensive research demonstrates that biodiversity enhances ecosystem services across scales from local to landscape levels [1-2]. Agricultural landscapes—comprising farmland (cropland, orchards, pastures) and associated semi-natural habitats such as field margins, ditches, roadsides, and small woodlots—support approximately 50% of global wild endangered species and constitute a vital component of terrestrial biodiversity [3]. These landscapes provide essential ecosystem services for sustainable agriculture, including genetic resources, pollination, natural pest control, soil fertility maintenance, water conservation, and cultural/recreational values, making them a critical indicator of agricultural environmental quality [4].

Currently, China's biodiversity conservation efforts prioritize nature reserves, focusing on protection of plant and animal genetic resources and prevention of invasive species, while largely neglecting agricultural landscape biodiversity research and conservation. This paper synthesizes international research and practices to discuss progress in agricultural landscape biodiversity conservation and proposes strategies tailored to China's needs.

Agricultural landscapes and their mosaic of semi-natural habitats deliver crucial ecosystem services such as genetic resource conservation, biological pest control, natural pollination, water purification, and soil fertility maintenance—foundations for agricultural productivity and sustainability. However, excessive land development, field enlargement, over-hardening of ditches and roads, heavy agrochemical inputs, and monoculture planting of high-yield varieties have caused agricultural landscape homogenization and biodiversity decline [5-6], creating “silent countryside” phenomena and impairing ecosystem services that threaten agricultural stability and sustainability [7]. Studies indicate that landscape homogenization and agricultural intensification in the EU have reduced plant pop-

ulations by approximately 50%, insects by 30%, and birds by 70%, with bird diversity declining by 40%, pollinating butterfly density decreasing by about 60%, and natural beehives dropping by roughly 20% [7-8]. As semi-natural habitats shrink, plant diversity diminishes substantially, simplifying interaction networks among pollinating butterflies, bees, grain-eating birds, rodents, plants, and parasites—contributing significantly to frequent pest outbreaks.

## 2 Research on Ecosystem Service Functions of Agricultural Landscapes

Ecosystem services encompass all benefits humans derive from ecosystems [5], including provisioning (food and fiber), regulating (water purification, pollination, pest control), supporting (soil retention, nutrient cycling, water conservation), and cultural (landscape aesthetics, spiritual values, recreation). In recent years, UNEP, FAO, and European and American countries have emphasized farmland biodiversity conservation, recognizing that agricultural sustainability depends not only on climate, land, water resources, and external inputs (fertilizers, pesticides), but also on maintaining ecosystem services provided by farmland and landscape mosaics (Figure 1 [Figure 1: see original paper]).

### 2.1 Conservation of Endangered and Wild Species

Since the 1980s, international research has recognized agricultural landscape biodiversity as a vital component of global biodiversity. Studies show that agricultural landscapes sustain approximately 50% of the world's wild endangered species [8-10]. In Germany, while nature reserves covering 2% of national territory harbor about 25% of endangered species, the remaining 75% depend on agricultural and forestry production areas occupying 75% of the land. In Sweden, 50-70% of threatened vascular plants rely on open, diversified agricultural landscapes. Consequently, the success of global biodiversity conservation initiatives directly hinges on agricultural landscape protection. European research reveals that farmland abandonment threatens biodiversity by eliminating certain habitat types, whereas maintaining cultivated land and agricultural landscapes protects biodiversity [13]. Traditional agricultural landscapes converted from forests and grasslands feature high proportions of natural and semi-natural habitats forming mosaic patterns that provide diverse niches, conserving both habitat specialists and generalists. Landscape homogenization, however, drives habitat specialists toward extinction.

Biodiversity underpins all crops and livestock and their varietal diversity. Non-intensive agriculture maintains diversity among wild and domesticated species while stabilizing ecosystems. Agricultural evolution has even enhanced biodiversity by creating unique ecosystems and habitat types. For instance, landscapes mosaicking cropland with field boundaries (hedgerows or ditches) provide shelter and food for various organisms. Semi-natural habitats in agricultural landscapes protect endangered and native species [4,14-15]. The Red-billed Chough

(*Pyrrhocorax pyrrhocorax*) depends on regions maintaining traditional livestock practices, while the Great Bustard (*Otis tarda*) breeds in fallow land, grasslands, and extensively managed cereal fields in Spain and Portugal. Analysis of plant endangered species catalogs from 29 countries revealed that fertilizer and pesticide applications affect threatened plants, with fertilizers having greater impact. Increased agrochemical use in central and northwestern Europe [16] has expanded habitat generalists while reducing specialists, necessitating active conservation to address declining functional diversity and growing threats. Among 582 rare and threatened arable plant species, 193 are nationally endangered. Species-targeted measures alone cannot effectively protect species and their ecosystem functions; landscape-level approaches that protect and restore habitats are essential for comprehensive conservation of agricultural landscape biodiversity and its services.

## 2.2 Pollinating Insects and Pollination Function

Numerous animal species provide pollination services, with insects being the dominant group: Hymenoptera (43.7% of pollinators), Diptera (28.4%), Coleoptera (14.1%), plus Lepidoptera, Thysanoptera, Hemiptera, and Orthoptera. The bee superfamily (Hymenoptera: Apoidea) comprises the most numerous and diverse pollinators, with over 17,500 species recorded globally and more than 1,000 in China. While domesticated bees dominate numerically in agricultural landscapes, wild pollinators often provide more effective pollination services, creating complementary functions [1].

Agricultural landscapes play a crucial role in maintaining pollinator diversity [8,17-18], which in turn delivers vital ecosystem services. Sustaining species or functional group diversity among pollinators enhances crop pollination success, directly affecting yield, quality, and economic value. Globally, approximately 70% of major crops (accounting for 35% of total production) benefit from animal pollination. In China, about 57% of 44 major fruit and vegetable crops are insect-pollinated, representing 25.5% of total production value. Animal pollination not only increases yields but also enhances nutritional and commercial value—improving oleic and linoleic acid content in almonds, strawberry quality and shelf life, and oil content in rapeseed. Pollinated foods contain higher levels of vitamins, antioxidants, lipids, and micronutrients, contributing to healthier human diets. Without pollinators, global agricultural output would decline by an estimated 3-8%, requiring conversion of two-thirds of terrestrial land to cropland to compensate.

However, pollinators face widespread biodiversity loss. Surveys across regions, particularly Europe and North America, show declining pollinator diversity. US honeybee colonies decreased by 59% between 1947-2005, while central European colonies declined by 25% from 1985-2005. Europe has lost 16-20% of its honeybee colonies, with particularly severe reductions in wild pollinators severely impacting yield and quality of insect-pollinated crops [16]. In the UK and Netherlands, bee diversity declined in over half of landscapes, with greater losses

among species with specialized habitats or diets, longer proboscises, poor dispersal ability, and slower reproduction. In the UK, 89% of butterfly species have experienced range contraction and population declines, while mobile, habitat-generalists increasingly dominate communities [19].

Pollinator diversity is directly and indirectly affected by agricultural management, which in turn influences sustainable development. Effective management of pollinator diversity and services requires both appropriate production practices and landscape-scale strategies based on local landscape structure [23]. Pollinators require suitable nesting sites, materials, and adequate food resources (pollen and nectar) within their foraging ranges, which may be distributed across mosaic patches of different habitat types (natural, semi-natural, and farmland) [20]. Spatial heterogeneity and temporal dynamics of resources in agricultural landscapes create spatiotemporal variation in biodiversity [21]. Pollinator diversity is influenced by the proportion of non-crop habitats, agricultural practices (pesticide use), cropping patterns (crop-grass rotation), and insect-pollinated crops like oilseed rape (*Brassica campestris*) [22]. Different foraging distances mean pollinators are affected by landscape structural changes at different scales.

### 2.3 Natural Enemy-Pest Regulation

Despite 40+ years of increased pesticide use, global crop losses to pests remain unchanged at 8-15% annually [24]. Restoring natural regulation through landscape-level natural enemy control is therefore critical, as landscape complexity and diversity significantly enhance natural enemy abundance and diversity. Biological pest control employs natural enemies, entomopathogens, pheromones, biopesticides, and transgenic technologies. From a biodiversity perspective, three approaches exist: (1) transgenic technology; (2) mixed planting of multiple genotypes, intercropping, and relay planting—Zhu Youyong et al. [25] demonstrated that genetic diversity planting controls diseases through genetic heterogeneity, dilution effects, physical isolation of resistant plants, induced resistance, and coevolution; and (3) habitat management to increase natural enemy populations. The first two require substantial basic research, while habitat management offers the most effective and feasible approach.

Agricultural landscape biodiversity conservation has evolved from focusing on local-scale production management to emphasizing habitat and landscape-scale management. Increasing evidence shows pollinator diversity is significantly influenced by landscape-scale environmental factors. Habitat management utilizes biodiversity for pest control by creating suitable habitats and plant diversity in agricultural landscapes to meet natural enemies' resource needs, thereby protecting and attracting them to enhance pest control or directly interfering with pest damage. Compared to other biological control methods, habitat management reduces agrochemical inputs, labor costs, and development expenses while decreasing pest damage and increasing yields.

Landscape composition and spatial configuration also affect natural enemy di-

versity and pest damage. Recent meta-analyses [26] show that 74% of studies indicate landscape complexity enhances natural enemy populations, including parasitoids, ground beetles, lady beetles, hoverfly larvae, rove beetles, and spiders—suggesting a general pattern. Nine out of ten natural enemy species require more than one type of semi-natural habitat (woodland, field margins, ponds), while only five out of ten pest species do, indicating that landscape homogenization impacts natural enemies more severely than pests. Field margins, composed of naturally growing or planted vegetation, provide critical habitats and refugia for natural enemies like ground beetles and spiders, as well as food and shelter for reptiles, small mammals, and birds [27-28]. While many conservation measures for field margins have been implemented abroad, research on their ecological functions remains limited in China, and their importance for pest control has not received adequate attention [29]. Overall, increasing landscape diversity—including crop diversity and natural/semi-natural habitat diversity—benefits natural enemy populations and pest control.

#### **2.4 Water and Soil Conservation Function**

Water and soil conservation functions are more effectively addressed at the landscape scale through optimizing agricultural landscape patterns to enhance conservation capacity and achieve comprehensive non-point source pollution control from source to receptor. Landscape-scale biodiversity conservation and agricultural non-point source pollution control have become important approaches in Europe and America for water quality improvement [30-31]. Integrated agricultural landscape management provides ecosystem services including water conservation and purification. For example, buffer strips along rivers and ditches, covering just 2-3% of farmland area but hosting rich species diversity, can control 30-50% of nitrogen and phosphorus entering water bodies.

#### **2.5 Soil Fauna and Microbial Diversity**

Soil fauna and microorganisms are key drivers of soil formation and transformation, playing irreplaceable roles in maintaining soil structure, fertility, and vegetation. Soil microbes, as primary decomposers, naturally filter and purify the environment and dominate soil self-purification and pollutant attenuation. Some soil animals collaborate with microbes to decompose litter, fallen trees, animal carcasses, and manure. Bacterial proliferation softens litter for soil animal consumption, while soil animal excretion facilitates microbial decomposition. Some soil animals are “waste processors,” while others are predators, forming soil food webs. Earthworms ingest large amounts of soil, decompose organic matter, improve fertility, and promote aggregate formation and physical properties. Soil microbes also link the atmosphere, lithosphere, hydrosphere, and biosphere, playing vital roles in global material cycles and energy flow [32].

Since the 1950s, the relationship between biodiversity and ecosystem stability has been a central ecological question. Research shows that increasing soil fauna and microbial diversity benefits soil fertility, nutrient cycling, and retention, but

studies on microbial diversity and system stability remain nascent, particularly regarding conservation strategies and regulation of soil ecological services [32]. Currently, protective tillage and organic fertilizer application represent the primary conservation practices.

## 2.6 Maintaining and Improving Crop Yield and Quality

Conserving and enhancing agricultural landscape biodiversity to improve ecosystem services is crucial for maintaining and increasing crop yields [1,9,16-17]. A six-year UK study on a 900 ha farm compared control plots with treatments converting 3% and 8% of productive land around fields into functional plant buffer strips to enhance natural enemy-pest regulation, pollination, nutrient loss control, and bird diversity. The study demonstrated that ecological intensification does not reduce overall farm crop yields and may even improve yields and quality of certain crops.

## 3 Practices of Agricultural Landscape Biodiversity Conservation in Europe and America

In practice, Europe and America have developed policies and engineering measures centered on farmers with ecological subsidies. EU biodiversity conservation comprises two main components: nature reserves covering 18% of territory and farmland biodiversity conservation areas covering 12.5%. Under the Common Agricultural Policy, direct subsidies have supported agri-environmental measures since 1992, including integrated nutrient management, integrated pest management, resource conservation, landscape stewardship, and biodiversity protection [20-23,34].

In 2001, Europe and America formulated a detailed “Action Plan for Agricultural Biodiversity Conservation” with key technical measures: (1) establishing 5-8% of farmland as “ecological focus areas” or retaining 5% as small woodlots and wetland ponds; (2) requiring each farm to cultivate at least three different crops while encouraging intercropping, heterogeneous planting patches, and agroforestry; (3) ecologically landscaping rivers, ponds, and ditch networks; (4) promoting conservation tillage, winter cover crops, and wildflower buffer strips along field margins; (5) restoring and protecting habitats for rare birds, butterflies, and wild bees; (6) conserving wild plant landscapes and traditional variety orchards; (7) protecting biodiverse grasslands; and (8) implementing moderate tillage and grazing management on large abandoned lands.

In 2005, the EU launched Rural Development Programs proposing High Nature Value (HNV) farmland, with increasing ecological subsidies for agricultural landscape biodiversity conservation. In some EU countries, biodiversity conservation investments account for up to 30% of agri-environmental stewardship funding, with HNV farmland targeting biodiversity conservation covering 20% of agricultural land. Under these programs, countries have developed farmer-centered technical measures and ecological subsidy scoring systems, requiring farmers

to develop detailed farm environmental stewardship plans and sign 5-10 year implementation contracts with governments.

In the United States, the Natural Resources Conservation Service (NRCS) administers policies, engineering standards, and implementation for productive landscape conservation, primarily through financial subsidies to farmers [24,34]. NRCS regularly publishes conservation programs covering natural and cultural landscape protection, watershed environmental protection, wildlife habitat conservation, cropland retirement, grassland protection, wetland restoration, and watershed ecological management. These programs feature integrated management of farms, landscapes, and small watersheds, incorporating biodiversity conservation engineering into various projects. Key engineering techniques include: conservation tillage, cover crop rotation, multi-story planting, strip cropping, integrated pest management, buffer strip construction, hedgerow planting, critical area planting, field margin development, vegetative barrier establishment, farmland vegetation enhancement, shelterbelt construction, shrubland management, riparian buffer development, ecological ditch construction, fish and wildlife habitat restoration, wildlife water facilities, wetland restoration, and wildlife corridors.

## 4 China' s Agricultural Landscape Biodiversity Conservation

### 4.1 Necessity

China is among the world' s 12 most biodiverse countries, with traditional agricultural practices like intercropping, agroforestry, multi-story cultivation, and ecological landscaping that historically supported rich biodiversity and high ecosystem services [35-36]. The country has recorded approximately 600 cultivated species and 400-500 wild edible plants, with numerous important wild species persisting in semi-natural habitats and marginal lands, including crop wild relatives, rare and relict plants, and medicinal fungi. However, excessive agrochemical use, monoculture high-yield varieties, agricultural intensification, landscape homogenization, over-hardening of farmland infrastructure, simplified shelterbelt composition, invasive species, and climate change have caused soil and water pollution, loss of semi-natural habitats, reduced vegetation heterogeneity, declining ecosystem biodiversity, impaired ecosystem services, and reduced resilience to natural disasters [37].

Research shows that in intensive agricultural regions, semi-natural habitats comprise only 3.5% of area but contain 70% of native plants. Converting these habitats to farmland for “balance compensation” could eliminate 50-70% of natural enemies, while monotypic shelterbelts increase pernicious weeds and reduce high-nutrient native wildflowers, accelerating invasive species spread. In southern China' s intensive rice regions, field ridges are rapidly disappearing, causing drastic declines in beneficial organisms like rice field eels (*Monopterus albus*), loaches (*Misgurnus anguillicaudatus*), frogs, birds, snakes, earthworms, spiders,

ground beetles, butterflies, and bees, disrupting natural enemy-pest balance. In the 1950s, China cultivated over 46,000 local rice varieties; by 2006, only 1,000 varieties remained, primarily bred and hybrid varieties. Similarly, 10,000 local corn varieties from the 1950s have been virtually eliminated from production. The distribution ranges of crop wild relatives are also shrinking, with 60-70% of China's wild rice locations now extinct or severely degraded.

As one of the first signatories to the Convention on Biological Diversity, China's government approved the "China Biodiversity Conservation Strategy and Action Plan (2011-2030)" in 2010, targeting protected areas covering 17% of terrestrial area by 2030. However, compared with developed countries, China's efforts in productive agricultural landscape biodiversity conservation lag significantly behind achievements in nature reserves, reforestation, and wild plant protection [36]. Current priorities for sustainable agricultural development—including building 800 million mu of high-standard farmland, improving land quality, promoting large-scale production, developing ecological circular agriculture, implementing fallow systems, restoring agricultural ecosystems, enhancing ecological functions, protecting biodiversity, and achieving "one control, two reductions, and three basics"—will substantially transform farmland structure and material cycles. Integrating agricultural landscape biodiversity conservation into these initiatives through landscape restructuring and quality improvement can restore ecosystem services like water conservation, pest regulation, and pollination, achieving multiple goals of environmental protection and stable or increased grain production.

#### **4.2 Countermeasures for Agricultural Landscape Biodiversity Conservation**

Scherr and McNeely [30] proposed the concept of "ecoagriculture landscapes" in 2008, defining them as mosaics of natural/native habitats and agricultural production land managed to mutually support agricultural operations and biodiversity conservation. While highlighting the importance of landscape ecology perspectives, their concept emphasized ecoagricultural management methods with relatively limited consideration of landscape planning and design. Ecoagriculture landscapes integrate landscape ecology principles and ecoagricultural techniques to restore and enhance ecosystem services, requiring management at both agro-ecosystem and landscape scales (Figure 2 [Figure 2: see original paper]) [37].

Addressing China's sustainable agricultural development challenges requires several approaches: (1) Building on the "China Biodiversity Conservation Strategy and Action Plan (2011-2030)," recognize existing problems and the significance of agricultural landscape biodiversity conservation for sustainable development, and develop top-level strategies and plans; (2) Conduct biodiversity surveys, monitoring, and evaluation in typical agricultural landscapes across different farming regions; (3) Develop technical protocols for agricultural landscape biodiversity conservation through domestic and international research, and imple-

ment demonstration projects in representative landscapes; (4) Integrate and construct a technology system centered on agricultural landscape biodiversity conservation for enhanced ecosystem services through technology screening, R&D, and integrated demonstrations; (5) Learn from farmer-centered ecological subsidy policies in Europe and America, explore conservation systems centered on village collectives, farmer cooperatives, and large-scale producers, develop ecological compensation mechanisms for ecosystem services, and conduct diverse outreach and training activities to increase awareness among managers and farmers about the value and functions of agricultural landscape biodiversity conservation.

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