Postprint: Agricultural Landscape Biodiversity Functions and Conservation Strategies

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Abstract

Studies have shown that agricultural intensification and landscape homogenization reduce biodiversity in agricultural landscapes, impairing ecosystem service functions such as wild resource conservation, natural pollination, pest regulation, and soil and water conservation, thereby affecting sustainable agricultural development. This paper comprehensively reviews research and practice on biodiversity in agricultural landscapes and their ecosystem service functions both domestically and internationally. It explores the roles of agricultural landscapes in multiple ecosystem services including biodiversity conservation, pollination services, regulation services, and soil and water conservation, as well as the significance of biodiversity protection, summarizes practical measures adopted by Europe and America for biodiversity conservation in agricultural landscapes, points out that although China has made considerable efforts in biodiversity conservation, it has neglected the protection of agricultural landscapes, and that recent urbanization and intensification have further exacerbated the loss of biodiversity in agricultural landscapes. There is an urgent need to draw on the experience of European and American countries to propose strategies for biodiversity conservation in agricultural landscapes in China. We believe that ecological intensification, which protects and enhances biodiversity in agricultural landscapes, plays an important role in maintaining crop yields and improving varieties. Biodiversity conservation in agricultural landscapes requires integrated landscape management at two scales—the farmland ecosystem and the agricultural landscape—to enhance the diversity and heterogeneity of 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, we recommend implementing biodiversity conservation in agricultural landscapes through policies and regulations, monitoring and assessment, engineering technology research and development, technology integration and demonstration, ecological subsidy systems, training

and extension.

Full Text

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

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Abstract: Research demonstrates that intensive agricultural production and landscape homogenization have caused significant declines in agricultural landscape biodiversity, impairing critical ecosystem services including wild resource conservation, natural pollination, pest regulation, and water-soil conservation, thereby threatening agricultural sustainability. This paper reviews international research and practices on agricultural landscape biodiversity and its ecosystem services. We examine the multifaceted ecological functions of agricultural landscapes—including biodiversity conservation, pollination services, regulation services, and water-soil conservation—and their significance for biodiversity protection. We summarize practical conservation measures implemented in Europe and the United States, noting that while China has made considerable efforts in biodiversity conservation, agricultural landscape protection has been largely neglected. Recent urbanization and intensification have further accelerated biodiversity loss in agricultural landscapes, necessitating the development of China-specific conservation strategies based on Western experiences. We argue that ecologically intensive approaches to conserving and enhancing agricultural landscape biodiversity play a vital role in maintaining crop yields and improving varieties. Biodiversity conservation requires integrated landscape management at both field and landscape scales to increase crop and plant diversity, enhance heterogeneity, and restore biodiversity and ecosystem service functions. Finally, addressing China' s sustainable agricultural development challenges, we recommend advancing agricultural landscape biodiversity conservation through policy and legislation, monitoring and assessment, engineering technology development, technology integration and demonstration, ecological subsidy systems, and training and extension programs.

Keywords: Agricultural landscape; Biodiversity protection; Ecosystem service; Agricultural sustainability; Intensive agricultural development

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Biodiversity encompasses the ecological complexes formed by organisms (animals, plants, microorganisms) and their environment, including genetic, species, ecosystem, and landscape diversity. Numerous studies have shown that biodiversity promotes ecosystem service enhancement across scales from local to landscape levels. Agricultural landscapes—comprising farmland (cropland, orchards, pastures) and surrounding semi-natural habitats such as ditches, roadsides, woodlots, and shrublands—support approximately 50% of global wild endangered species and constitute a crucial component of terrestrial biodiversity. Increasing evidence indicates that agricultural landscape biodiversity provides essential ecosystem services for sustainable agriculture, including genetic resources, pollination, natural pest control, soil fertility maintenance, water-soil conservation, and cultural-recreational values, serving as both a foundation for agricultural sustainability and a critical indicator of agricultural environmental quality.

Currently, China' s biodiversity conservation efforts focus primarily on nature reserves and genetic resource protection, with agricultural landscape biodiversity research and protection lagging seriously behind. This paper synthesizes international research and practices to discuss progress in agricultural landscape biodiversity conservation and explore necessary strategies for China.

Agricultural landscapes and their mosaic of semi-natural habitats provide ecosystem services such as genetic resource conservation, pest biological control, natural pollination, water purification, and soil fertility maintenance—critical guarantees for agricultural productivity and sustainability. However, excessive land development, field scaling, over-hardening of infrastructure, heavy agrochemical inputs, and monoculture planting of high-yield varieties have reduced semi-natural habitats, homogenized landscapes, and diminished biodiversity, creating "silent countryside" phenomena and impairing ecosystem services that threaten agricultural stability and sustainability. Studies show that landscape homogenization and intensification in the EU have caused population declines in approximately 50% of plants, 30% of insects, and 70% of birds, with bird diversity decreasing by 40%, pollinating butterfly density by about 60%, and natural beehives by approximately 20%. As semi-natural habitat area decreases, plant diversity drops sharply, simplifying interaction networks among pollinating butterflies, bees, seed-eating birds, rodents, plants, and parasites—a key factor underlying frequent pest and disease outbreaks.

2 Research on Ecosystem Service Functions of Agricultural Landscapes

Ecosystem services refer to all benefits humans obtain from ecosystems, including provisioning (food and fiber), regulating (water purification, pollination, pest control), supporting (soil retention, nutrient cycling, water-soil conservation), and cultural (landscape aesthetics, spiritual values). In recent years, UNEP, FAO, and European and American countries have emphasized farmland landscape biodiversity conservation, recognizing that agricultural sustainability depends not only on natural resources (heat, land, water) and external inputs (fertilizers, pesticides) but also on maintaining farmland ecosystem service functions [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 indicate that agricultural landscapes sustain approximately 50% of global wild endangered species. In Germany, about 25% of endangered species inhabit nature reserves covering 2% of national territory, while 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. Thus, agricultural landscape conservation directly determines the success of global biodiversity protection initiatives. European research shows that farmland abandonment threatens biodiversity by eliminating certain habitat types, whereas maintaining cultivated land and agricultural landscapes protects biodiversity. Traditional agricultural landscapes converted from forests and grasslands feature high proportions of natural and semi-natural habitats forming mosaic patterns with farmland, providing diverse habitats for 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 and varieties while stabilizing ecosystems. Agricultural evolution has, to some extent, enhanced biodiversity by creating and maintaining unique ecosystems and habitat types. For example, mosaic landscapes of cropland and field margins (hedgerows or ditches) provide shelter and food for certain flora and fauna. Semi-natural habitats in agricultural landscapes protect endangered and native species. 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. Experts from 29 countries analyzed crop management impacts on plant taxa using endangered species catalogs, finding that both fertilizers and pesticides affect plants at different endangerment levels, with fertilizers having greater impacts. Increased agrochemical use in central and northwestern Europe has increased habitat generalists while decreasing specialists, necessitating active conservation measures to address functional diversity decline. Among 582 rare and threatened arable plant species, 193 are nationally endangered. Species-targeted conservation measures alone cannot effectively protect species and their ecosystem functions; landscape-scale approaches that protect and reconstruct habitats are essential for comprehensive agricultural landscape biodiversity and ecosystem service conservation.

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 diverse and abundant pollinators, with over 17,500 species recorded globally and more than 1,000 in China, most being effective pollinators. While domesticated bees dominate numerically in agricultural landscapes, wild pollinators often provide more effective pollination services, with both groups playing complementary roles.

Agricultural landscapes play a crucial role in maintaining biodiversity, including pollinator diversity, which in turn provides vital ecosystem services. Maintaining pollinator species or functional group diversity enhances pollination success, directly affecting crop yield, quality, and economic value. Global analysis shows that approximately 70% of major crops (accounting for 35% of total production) benefit from animal pollination. Among 44 major fruits and vegetables in China, about 57% are insect-pollinated, representing 25.5% of total fruit-vegetable production value. Animal pollination not only increases yields but also enhances nutritional and commercial value—for example, increasing oleic and linoleic acid content in almonds, improving strawberry quality and shelf life, and raising oil content in rapeseed. Pollinated foods show increased vitamins, antioxidants, lipids, and micronutrients, contributing to healthier human diets. Without pollinators, global agricultural output would decline by 3–8%, requiring conversion of two-thirds of terrestrial land to farmland to compensate.

However, pollinators face widespread biodiversity loss. Surveys across Europe and North America show declining pollinator diversity. US honeybee colonies decreased by 59% between 1947–2005, while central European colonies dropped 25% during 1985–2005. Europe has lost 16–20% of its honeybee colonies, with wild pollinators declining particularly severely, significantly impacting yield and quality of insect-pollinated crops. In the UK and Netherlands, bee diversity declined in over half of landscapes, with greater reductions among species with specialized habitats or diets, longer proboscises, poor dispersal ability, and slow reproduction. In the UK, 89% of butterfly species show shrinking distributions and declining populations, while highly mobile, habitat-generalists increasingly dominate communities.

Pollinator diversity is significantly influenced by landscape-scale environmental factors. Pollinator survival and reproduction require suitable nesting sites, materials, and adequate food resources (pollen and nectar) that may be distributed across different habitat patches in agricultural landscapes (natural, semi-natural, and farmland). Spatial heterogeneity and temporal dynamics of resources cause spatiotemporal variation in biodiversity. Pollinator diversity is affected by the proportion of non-crop habitats, agricultural management practices (pesticide use), cropping patterns (crop-grass rotation), and insect-pollinated crops such as oilseed rape. Pollinators' foraging distances vary, making them differentially susceptible to landscape structural changes like habitat area proportions. Pollinator diversity is directly and indirectly affected by agricultural management, which in turn impacts agricultural sustainability. Therefore, pollinator conservation and pollination service management are critical for sustainable agriculture, requiring both appropriate production management measures and landscape-scale strategies based on local landscape structure.

2.3 Natural Enemy-Pest Regulation

Despite increased pesticide use over the past 40 years, global crop losses to pests remain unchanged at 8-15% annually. Consequently, restoring natural regulation and utilizing natural enemies for pest control at the landscape level is crucial. Landscape complexity and diversity significantly enhance natural enemy abundance and diversity. Biological pest control employs natural enemy insects, entomopathogenic microorganisms, insect pheromones, biopesticides, and transgenic technologies. From a biodiversity perspective, these approaches fall into three categories: (1) transgenic technology; (2) mixed planting of multiple genotypes within the same crop, intercropping, and relay cropping—Zhu Youyong et al. revealed that crop genetic diversity 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 for pest control. 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 that natural enemy populations are enhanced by landscape complexity in 74% of studies, including parasitoids, ground beetles, ladybugs, syrphid larvae, rove beetles, and spiders—demonstrating that landscape-driven natural enemy enhancement is a general phenomenon. 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 far more than pests. Field margins, composed of naturally growing or planted vegetation, provide critical habitats and refuges for natural enemies like ground beetles and spiders, while also supporting reptiles, small mammals, and birds. Although many countries actively protect field margins, China has conducted limited research on their ecological functions, and their conservation for pest control remains underappreciated. 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 Functions

Water and soil conservation functions must be elevated to the landscape scale to optimize agricultural landscape patterns, 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 methods for water quality improvement in Europe and America. Integrated agricultural landscape management provides ecosystem services like water-soil conservation and water purification.

For example, buffer strips covering 2–3% of farmland area with 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 are primary decomposers, providing natural filtration and purification, and are dominant factors determining soil self-purification and pollutant assimilation. Some soil fauna, together with microbes, decompose litter, fallen trees, animal carcasses, and feces. Bacterial reproduction softens litter for fauna consumption, while faunal excretion facilitates microbial decomposition. Some soil fauna are "waste processors," while others are predators, forming soil food webs. Earthworms improve soil fertility and structure through intensive soil ingestion and organic matter decomposition, while soil microbes link the atmosphere, lithosphere, hydrosphere, and biosphere, playing crucial roles in global material cycles and energy flow. Since the 1950s, the relationship between biodiversity and ecosystem stability has been a central ecological question. While increased soil fauna and microbial diversity benefits soil fertility and nutrient cycling, research on microbial diversity-system stability relationships remains nascent, particularly regarding conservation methods and service function regulation. Current practices primarily involve protective tillage and organic fertilizer application.

2.6 Maintaining and Improving Crop Yield and Quality

Conserving and enhancing agricultural landscape biodiversity to improve ecosystem services is vital for maintaining crop yields and quality. A six-year UK study on a 900 ha farm compared control treatments with those 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 crop yields and may even increase yields and quality for certain crops.

3 European and American Practices in Agricultural Landscape Biodiversity Conservation

In practice, European and American countries have developed farmer-centered policies and technical measures supported by ecological subsidies. EU biodiversity conservation comprises nature reserves (18% of territory) and farmland biodiversity conservation areas (12.5%). Under the Common Agricultural Policy, direct subsidies since 1992 have supported agri-environmental measures including integrated nutrient management, pest control, resource conservation, landscape stewardship, and biodiversity protection.

In 2001, Europe and America formulated the detailed "Action Plan for Agricultural Biodiversity Conservation," with key technical measures including: (1)

establishing 5–8% of farmland as "ecological focus areas" or retaining 5% as small woodlots and wetlands; (2) requiring each farm to plant at least three different crops, encouraging intercropping, patch heterogeneity, and agroforestry; (3) ecologically landscaping rivers, ponds, and ditches; (4) promoting conservation tillage, winter cover crops, and wildflower buffer strips; (5) restoring habitats for rare birds, butterflies, and wild bees; (6) protecting wild plant landscapes and traditional varieties; (7) conserving biodiverse grasslands; and (8) managing large abandoned lands through moderate cultivation and grazing. In 2005, the EU launched Rural Development Programs to create High Nature Value farmland, with biodiversity conservation subsidies increasing to 30% of agri-environmental investments in some countries, and High Nature Value farmland reaching 20% of agricultural land. Under these programs, countries developed farmer-centered technical measures and ecological subsidy scores, requiring farmers to develop detailed environmental stewardship plans and sign 5–10 year contracts with governments.

In the United States, the Natural Resources Conservation Service (NRCS) develops policies, technical standards, and implements conservation programs for productive landscapes, primarily through subsidies to farmers. NRCS regularly releases projects for natural and cultural landscape protection, watershed conservation, wildlife habitat protection, land retirement, grassland conservation, wetland restoration, and watershed management. These programs operate at farm, landscape, and small watershed scales, integrating comprehensive management of mountains, waters, forests, fields, and villages while incorporating biodiversity conservation engineering. Key technical measures include: conservation tillage, cover cropping, multi-layer planting, strip cropping, integrated pest management, buffer strip construction, hedgerow planting, critical area planting, field margin development, vegetative barriers, farmland vegetation enhancement, shelterbelt construction, shrub management, riparian buffers, ecological ditch construction, fish and wildlife habitat restoration, wildlife water facilities, wetland restoration, and wildlife corridors.

4.1 Necessity

China is rich in biological resources, but decades of highly intensive production and infrastructure development have reduced agricultural landscape biodiversity, severely impairing ecosystem services and agricultural stability. As one of 12 mega-biodiverse countries, China' s traditional agriculture featured intercropping, agroforestry, multi-layer cultivation, and diversified, ecological landscapes with rich biodiversity and high ecosystem services. China has recorded about 600 cultivated species, ranking among the world' s top, with most crops having wild relatives and numerous wild plant resources for agricultural use (e.g., 400–500 edible wild vegetables). Semi-natural habitats and marginal lands in agricultural landscapes harbor important wildlife, including crop wild relatives, rare and relict plants, and medicinal fungi. However, excessive agrochemicals, monoculture high-yield varieties, intensification, landscape homogenization, over-hardened infrastructure, single-species shelterbelts, invasive species, and climate change have caused pollution, semi-natural habitat loss, reduced vegetation heterogeneity, biodiversity decline, impaired ecosystem services, and reduced disaster resilience. Research shows that in intensive agricultural regions, semi-natural habitats comprising only 3.5% of area contain 70% of native plants; converting these to farmland for "balance compensation" could eliminate 50–70% of natural enemies, while monotypic shelterbelts increase malignant weeds and reduce high-nutrient native plants, accelerating invasive species spread. In southern intensive rice regions, field ridges are rapidly disappearing, drastically reducing beneficial organisms like rice field eels (*Monopterus albus*), loaches (*Misgurnus anguillicaudatus*), frogs, birds, snakes, earthworms, spiders, ground beetles, butterflies, and bees, causing extreme imbalances between natural enemies and pests. In the 1950s, China cultivated over 46,000 local rice varieties; by 2006, only 1,000 varieties remained, mostly bred and hybrid varieties. Similarly, 10,000 local maize varieties from the 1950s have been largely abandoned. Wild crop relatives' distributions have also shrunk dramatically, with 60–70% of China's original wild rice locations now extinct or severely reduced.

As an early signatory to the Convention on Biological Diversity, China's government prioritizes biodiversity conservation. In 2010, the State Council approved the "China Biodiversity Conservation Strategy and Action Plan (2011–2030)," targeting 17% of terrestrial area under protection by 2030. However, compared with developed countries, China's production landscape biodiversity conservation lags significantly despite achievements in nature reserves, reforestation, and wild plant protection. Key tasks for sustainable agricultural development include building 800 million mu of high-standard farmland, improving land quality, promoting scaled production, developing ecological circular agriculture, implementing fallow land, restoring ecosystems, enhancing functions, protecting biodiversity, and achieving "one control, two reductions, three basics." These will dramatically transform farmland structure and material cycles, offering opportunities to integrate landscape biodiversity conservation into all activities, reconstruct agricultural landscapes, restore ecosystem services like water-soil conservation, pest regulation, and pollination, and achieve multiple goals of environmental protection and stable or increased food production.

4.2 Conservation Countermeasures for Agricultural Landscape Biodiversity

Scherr and McNeely (2008) proposed the concept of "ecoagriculture landscapes"—mosaics of natural/native habitats and agricultural production land where natural areas are managed to support agricultural activities and agricultural areas are configured to benefit wild biodiversity and ecosystem services. While emphasizing ecological agriculture methods, their concept underconsidered landscape planning and design. Ecoagriculture landscapes integrate landscape ecology principles and ecological agriculture techniques. Restoring and enhancing ecosystem services requires actions at both agroecosystem and landscape scales

[Figure 2: see original paper]. Addressing China' s sustainable agriculture challenges requires: (1) developing national strategies and plans for agricultural landscape biodiversity conservation based on the China Biodiversity Conservation Strategy and Action Plan (2011-2030); (2) conducting biodiversity surveys, monitoring, and evaluation in typical agricultural landscapes across different regions; (3) developing technical protocols through domestic and international research and conducting demonstration projects; (4) integrating and constructing a technology system centered on biodiversity conservation for ecosystem service enhancement; and (5) adapting Western farmer-centered ecological subsidy policies to Chinese contexts, exploring systems based on village collectives, cooperatives, and large-scale producers, developing ecological compensation mechanisms for ecosystem services, and conducting outreach and training to raise awareness of conservation values and functions among managers and farmers.

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