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Agricultural Land Sharing and Land Sparing and Their Potential Biodiversity Effects: Postprint

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Abstract

Agriculture plays an important role in biodiversity maintenance, serving as both a transmitter of biodiversity and a major driver of biodiversity loss through intensification. "Land sharing" and "land sparing" represent important land-use strategies for reconciling food production with biodiversity conservation. The former emphasizes the improvement of farmland environments, while the latter involves land-use intensification to increase crop yields per unit area, thereby releasing additional land for nature conservation. Currently, which land-use approach is more beneficial for biodiversity conservation remains controversial. This study reviews the advantages and disadvantages of these two land-use strategies and their impacts on biodiversity, and analyzes and summarizes factors that should be considered when applying and selecting land-use approaches, such as: intensification-sensitive species; landscape context, landscape scale, and landscape structure; socioeconomic factors, etc. Based on this analysis, the paper outlines prospects for the implications of this theory for China' s future agricultural development, including: planning agricultural landscape patterns according to local conditions, such as considering regional yield potential and endemic species; developing sustainable intensive agriculture and strengthening the management of "spillover effects" to enhance ecosystem self-recovery capacity; establishing land sharing-sparing hybrid models at different landscape scales, and moderately restoring agroforestry in intensive agricultural areas.

Full Text

Abstract

Agricultural systems are complicated by both the efforts to produce food and protecting biodiversity. Intensive agriculture is the main reason for the decline in agro-biodiversity across the world. Land sparing and land sharing have been important land use strategies in maintaining a balance between food production and biodiversity conservation. The former advocates the improvement of farm environments and therefore expected to be a wildlife-friendly landscape. However, the latter proposes that the land should divide into two categories, one for intensive land utilization, the other one for biodiversity conservation. Thus a debate has risen as to which approach was better for biodiversity. In this review, we highlighted the benefits and limits of the two land use strategies and the effects of each on biodiversity. Furthermore, the factors were discussed, which guided the choice towards any of the land use strategies, including plant species sensitive to intensive farming, landscape-specific conditions, landscape scale/structure and socio-economic factors. On this basis, the resourceful application of the two land use approaches in future agriculture development was proposed. This included: 1) designing agricultural landscape structure suitable for local circumstances, e.g., yield potential and conservation of endemic species; 2) promoting sustainable agricultural intensification and enhancing the management of "spillover effects" to increase the recovery ability of the ecosystem; and 3) developing intermediate approaches or mixtures of land sharing and land sparing at different spatial scales, e.g., planting trees on farms in intensive agricultural areas.

Keywords: Biodiversity; Provisionment; Land sharing; Land sparing; Agricultural landscape; Intensive agriculture; Organic agriculture

Introduction

Agriculture plays a crucial role in biodiversity conservation, serving as both a conduit for biodiversity and, paradoxically, a primary driver of biodiversity loss through intensification. Biodiversity conservation depends not only on nature reserves but also on agricultural land, which constitutes important habitat for many species [1-2]. Historically, maximizing crop yields has been the primary objective of agricultural ecosystem services, while biodiversity conservation in agricultural landscapes has received insufficient attention [1,3-4].

Since the 1950s, the transformation from traditional to intensive agriculture has represented the most significant revolution in agricultural history [5], accelerated by food demand pressures and technological innovations. Substantial evidence demonstrates that biodiversity decline in agricultural landscapes, at both landscape and local field scales, correlates with this production shift [5-8]. On one hand, extensive natural and semi-natural habitats have been cleared, with 70% of grasslands and 45% of savannas worldwide converted to agricultural use, making agriculture the primary driver of deforestation [6]. On the other hand, agricultural intensification has simplified landscape patterns, reducing spatial and temporal heterogeneity, while intensive management practices and heavy agrochemical inputs have degraded environmental quality, compromising biodiversity maintenance and sustainable agricultural development [7-9].

As an important sustainable agricultural system, organic farming is considered a key pathway to achieving both biodiversity conservation and ecosystem service functions in agricultural landscapes [10-12]. Unlike conventional agriculture, organic farming prohibits synthetic pesticides, chemical fertilizers, growth regulators, and genetically modified organisms throughout the production process [13]. Although organic agriculture positively impacts biodiversity, approaches that modify field-scale production activities to promote agricultural landscape biodiversity have not gained widespread support, likely due to complex influences from larger-scale landscape structural characteristics [14-16]. Furthermore, critics argue that organic agriculture reduces food yields, necessitating conversion of additional natural habitats to farmland to maintain production levels [17]. Global food supply must increase by over 70% between 2005 and 2050 to meet population growth demands [18], presenting severe challenges for simultaneously ensuring agricultural production while promoting biodiversity conservation and ecosystem service maintenance [19].

Many scholars have explored methods that generate both economic benefits and improved agricultural biodiversity [2,17,20-22], focusing on two primary land use strategies: land sharing and land sparing. The former emphasizes improving farmland environmental quality and is often considered wildlife-friendly, while the latter advocates increasing crop yields per unit area to release more land for nature conservation [18,22]. First proposed by British scholars Green et al. [4], these concepts address land use choices within limited spaces to achieve win-win outcomes for food supply and biodiversity. This paper examines the impacts of land sharing (associated with organic agriculture) and land sparing (associated with intensive agriculture) on agricultural biodiversity, and discusses key factors for selecting and applying these approaches. The findings provide insights for agricultural biodiversity conservation and sustainable development.

1. Land Sharing

Land sharing integrates crop production and biodiversity conservation within the same land unit [17,22-23] [Figure 1: see original paper]. This approach reduces external chemical inputs (herbicides, pesticides, chemical fertilizers, and fossil fuels) while retaining natural habitat patches within farmland (such as tree and shrub communities, ponds), creating wildlife-friendly environments [Figure 2: see original paper].

1.1 Advantages of Land Sharing

Land sharing creates agricultural landscapes with habitat structures similar to early successional stages, resembling traditional agriculture or agroforestry systems. This high habitat heterogeneity helps maintain substantial biodiversity [5,24]. Europe' s extensive Agri-Environment Payment (AEP) policies support land sharing, primarily because agricultural land maintains a considerable proportion of biodiversity. Low-intensity agricultural landscapes provide more resources for species survival and can support more species than natural habitats or protected areas [7,19]. For example, many farmland birds have adapted to the regular, spatiotemporally heterogeneous habitats created by traditional agricultural practices. In tropical regions, numerous open-habitat bird species depend entirely on farmland when their natural habitats (such as savannas) disappear [25]. Thus, agricultural activities are essential for the survival of wildlife adapted to low-intensity agricultural landscapes.

Land sharing balances agricultural landscape biodiversity and crop yields at the field scale, typically through organic management with minimal or no agrochemical use. Numerous studies demonstrate that organic agriculture positively affects biodiversity [8,16,26], increasing richness of birds [27], beetles [28], and butterflies [29]. However, organic agriculture’ s effects on biodiversity vary considerably, influenced by landscape complexity, particularly at larger spatial scales [8,14-15,30]. Brittain et al. [31] found that flower-visiting insect diversity did not significantly improve in organic farms within simple landscapes. Natural habitat proportion represents the most important indicator of landscape diversity; Kremen et al. [32] studied the effects of natural habitat proportion and farmland management on local bee diversity, finding that intensive agriculture was the primary factor causing bee population declines. Habitat diversification, such as shrub patches, ponds, weed strips, and hedgerows, plays a crucial role in biological pest control [33-34]. Fischer et al. [8] demonstrated that retaining at least 5% natural habitat within each farm represents an effective approach for biodiversity maintenance.

1.2 Limitations of Land Sharing

Land sharing’ s limitations manifest in two primary aspects. First, its impacts on biodiversity remain ambiguous, lacking extensive experimental data support. While small-scale land sharing programs for specific species have achieved success, effects on large-scale species conservation vary considerably. In Europe, land sharing management designed to maintain farmland biodiversity has shown minimal conservation effects on vascular plants, birds, and arthropods, failing to meet expectations for protecting some endangered species [22]. Land sharing’ s biodiversity impacts vary with landscape scale and taxonomic groups, possibly related to how functional groups respond to environmental changes at different scales [25,35]. For instance, Tuck et al. [16] conducted a comprehensive study showing that compared to intensive agriculture, organic agriculture had the greatest impact on carnivores and the least on pollinators, with the order of impact being: decomposers > carnivores > herbivores > plants > pollinating insects. Impact variation also correlates strongly with species’ local activity, mobility, and chemical use within landscapes. Some pollinators may be particularly sensitive to certain insecticides; if organic farmers avoid these chemicals, native pollinator abundance increases, but if used, pollinators relocate to nearby fields [16].

Second, land sharing typically relies on minimal or no agrochemical use, resulting in yields often lower than intensive farmland. To compensate for yield reductions, additional land must be converted to agriculture, accelerating transformation of other terrestrial ecosystems with higher biodiversity into farmland [Figure 2: see original paper]. Developing countries requiring high crop yields therefore apply organic management less frequently. Low yields necessitate clearing more land to meet production demands, leading some scholars to term this "the land cost of sustainability" [36], which clearly contradicts increasingly tight land supply trends.

2. Land Sparing

Land sparing involves intensifying production on some land to release more area for non-agricultural habitats (such as forests, natural grasslands, wetlands) for ecological conservation [Figure 1: see original paper]. Unlike land sharing's focus on improving farmland environmental quality, land sparing emphasizes separating small portions of land from planned agricultural use for nature conservation, aiming to combine high crop yields with natural habitats [19,22].

2.1 Advantages of Land Sparing

Land sparing' s biodiversity benefits typically manifest at regional or larger spatial scales. By intensively utilizing land and increasing yields per unit area through external auxiliary energy inputs, this approach reduces conversion rates of natural vegetation to agricultural land. Research indicates that after 1940, increased cereal crop yields in the United States saved 15 million hectares of land [2,37], while yield increases in developing countries reduced deforestation rates [38]. Additional studies have found land sparing to be a better food security policy with minimal negative effects on bird and plant diversity [22]. Furthermore, because intensive land use increases yields per unit area, it effectively mitigates climate change pressure; although environmental costs of fertilizers and other auxiliary energy increase, these costs are offset by reduced contributions to greenhouse effects from deforestation [22]. Nevertheless, farmland-scale biodiversity maintenance and related ecosystem services remain essential and should not be neglected due to the existence of regional-scale protected areas, as pollination, biological pest control, and other services significantly impact yields.

2.2 Limitations of Land Sparing

Land sparing integrates biodiversity conservation and yield maximization at the landscape scale. Consequently, intensive agriculture constitutes a natural component of this approach. The transformation from traditional to modern intensive agriculture has dramatically improved global food supply functions, but agricultural intensification simultaneously represents the primary driver of biodiversity loss, further affecting ecosystem services such as pollination, pest control, and nutrient cycling. Over the past 50 years, modern agricultural intensification has caused declines in richness and abundance of many farmland birds [39], weeds [40], pollinating insects [41], ground-dwelling arthropods [42], soil animals [43-44], and soil microorganisms [45]. For farmland birds, key impacts include increased harvest frequency, fertilizer application, pesticide and antibiotic use, lowered water tables, altered crop rotations, and large-scale hedgerow removal. Early harvesting affects egg and chick survival, while lowered groundwater tables cause many soil invertebrates to migrate deeper in the soil profile, beyond the foraging reach of birds [46].

Agricultural intensification' s impacts extend beyond intensively used land, as heavy agrochemical inputs negatively affect other ecosystems, creating "spillover effects." Additionally, most farmers lack relevant technical knowledge for intensive production. Agricultural intensification depends on massive use of agrochemicals including chemical fertilizers, pesticides, and insecticides, yet the utilization efficiency of these auxiliary energy inputs remains low. Statistics show nitrogen use efficiency is less than one-half, while phosphorus use efficiency is less than one-quarter. Phosphorus accumulates in soil and is not readily available, whereas nitrogen is highly mobile, easily entering the atmosphere through denitrification or leaching into deep soil and water bodies [47]. Pimentel [48] estimated that only 0.1% of insecticides reach target pests. Moreover, intensification increases demand for upstream products (e.g., agrochemicals) and downstream products (e.g., mechanical harvesting), further expanding environmental impacts [49].

2.3 Development of Sustainable Intensive Agriculture

Against this background, the concept of sustainable intensification of farming has emerged in recent years [17,22,50]. Sustainable intensification aims to increase crop yields while minimizing environmental and biodiversity impacts, making the negative effects of intensification as small as possible [17,22]. The core principle involves strengthening farmland management to reduce "spillover effects." These management practices include rational crop density planting, control of yield-reducing factors (weeds, pests, diseases), and improved water and fertilizer use efficiency. Fertilizer use can be optimized by adjusting application rates according to crop needs, selecting appropriate application timing, promoting balanced fertilization, and deep nitrogen placement to improve utilization efficiency. Vertical nutrient losses in soil can also be reduced through recycling by planting crops with different root types. Furthermore, maintaining self-recovery capacity and certain ecosystem service functions in intensive agricultural ecosystems can reduce spillover effect risks, with biodiversity likely being key to improving system resistance [2]. For example, mixed planting of multiple rice (*Oryza sativa*) varieties not only preserves traditional cultivars but also reduces rice pest and disease incidence, thereby decreasing pesticide use and environmental risks [51]. Species interactions among pollinators, predators, and seed dispersers are important for ecosystem self-recovery capacity. Rice-duck and rice-fish composite farming systems, for instance, show clear effects on weed control [52] and reductions in spider predator populations [53].

3. Selection and Application of Land Sharing and Land Sparing Approaches

Few studies have proven which land use strategy is superior for balancing biodiversity conservation and yield in agricultural landscapes [17,23]. Land sharing has potential to increase agricultural yields and biodiversity ecosystem services at both field and landscape scales, while land sparing provides these benefits only at regional scales [19]. Nevertheless, land sharing and land sparing should not be viewed as opposing methods but as different pathways to solving problems; both are equally important. Selection should consider: species sensitive to intensification; landscape context, scale, and structure; and socioeconomic factors.

3.1 Species-Based Considerations

The shape of species density-yield relationship curves provides important insights for method selection [21-22]. In endemic cash crop production systems, such as cocoa (*Theobroma cacao*) farmland in Indonesia, biodiversity is not significantly affected by yield increases, making land sharing a viable conservation approach in these agricultural landscapes [54]. More commonly, however, species abundance declines sharply with increasing farmland intensification. For example, population density-yield relationships for European butterfly communities, ground-dwelling arthropods, and field plants show concave curves, suggesting these groups would benefit more from land sparing under yield maximization [55]. Some species, such as many open-habitat birds (farmland or grassland birds), can only maintain diversity under low intensification, showing convex density-yield curves that would be better protected through land sharing [37].

3.2 Considerations Based on Landscape Structure, Scale, and Context

Landscape structure may be more important than intensive agriculture for biodiversity impacts [2]. Landscape structure selection represents a trade-off between land sharing and land sparing approaches. Agricultural landscapes can be divided into agricultural matrix and natural habitat patches. The assumption that patches are biodiversity-rich while the matrix is biodiversity-poor overlooks the matrix’ s important role in biodiversity maintenance [7,56-57]. Habitat fragmentation, patch size, and isolation are key factors measuring patch habitat quality, significantly influencing species spatial distribution, abundance, and behavior [14,58]. If species dispersal is blocked, or if minimum patch area for suitable settlement is not reached and edge effects occur, ensuring patch connectivity becomes crucial. However, improving connectivity alone cannot compensate for habitat loss, and habitat quality is also critical. Different species respond to ecological processes at different landscape scales depending on their life history and dispersal ability. Therefore, agricultural landscape scale should be determined according to species responses to ecological processes at different scales. Landscape patterns also relate to land history and geomorphology. For example, small-scale farmland in northern Europe with high habitat heterogeneity tends toward land sharing, while large-scale farmland landscapes in western Australia tend toward land sparing [59].

Land sharing and land sparing choices may also be influenced by biophysical processes such as topography and yield potential. Regions with abundant rainfall and heat, fertile soil, and high agricultural potential are suitable for intensive production, thus favoring land sparing approaches, while spared land can maintain high biodiversity. In such agricultural landscapes, land sharing is not an effective way to maximize biodiversity and agricultural yields. Conversely, mountainous or hilly areas unsuitable for mechanized cultivation or low-yield regions tend toward land sharing, particularly where agricultural land itself can support higher biodiversity [2].

3.3 Socioeconomic Factors

The choice between land sharing or land sparing essentially represents individual farmer decisions between intensive production and traditional or organic farming methods. These choices are influenced by complex socioeconomic factors including population density, financial and technical support, market input-output ratios, and policies. Intensive agriculture emerged against a background of tightening land supply and food security pressures. Compared with traditional agriculture, intensification relies more heavily on external auxiliary energy inputs such as agrochemicals, requiring substantial material, technical, information, and financial support from industrialization. This includes industrial technical support for agriculture (information, logistics, storage technology), mechanized production processes, state financial subsidies for most agricultural products, capitalized production factors, and specialized farming operations. Additionally, transformation from traditional to intensive agriculture requires government policy support and financial insurance industry backing to share natural disaster risks through financial instruments. Government policy support includes technical barriers to international trade, cooperative organization protection, and green channel logistics policies [60].

Future Prospects for Agricultural Development in China

Agricultural landscapes occupy nearly 40% of Earth’ s land area [61], making biodiversity maintenance in these landscapes globally significant. China’ s land use practices have predominantly employed land sparing approaches, such as designated nature reserves, with limited application of land sharing strategies [62]. As environmental and ecosystem service function losses from intensive agriculture become increasingly prominent, the relationship between agriculture and biodiversity conservation has gained widespread attention. Future agricultural development will focus on these two land use approaches, and deeper understanding of them provides several insights:

1) **Design agricultural landscape structures according to local conditions.** First, consider regional landscape characteristics and yield po-

tential. Flat areas with high yield potential (e.g., Jianghan Plain) tend toward land sparing and intensive agriculture development, while rugged hilly and mountainous areas and low-yield regions tend toward land sharing. Second, consider sensitivity to intensification of endemic species [63] and other species of concern (e.g., major cash crops) within the region. Endemic species represent an important criterion for identifying biodiversity priority conservation areas [64], and their distribution ranges and population density-yield relationship curves can inform method selection. For endemic species, even in regions selecting land sparing approaches, attention should be paid to natural habitat connectivity. However, whether efforts targeting one or a few species (such as habitat improvement through landscape planning and farmland management) can ultimately restore the species diversity once present in the agricultural landscape remains a question requiring further research and conservation planning attention.

2) **In regions selecting land sparing and intensive agricultural production, pursuing yield increases should not sacrifice farmland biodiversity.** Developing sustainable intensive agriculture, strengthening "spillover effect" management, and improving ecosystem self-recovery capacity are urgent issues. Similarly, in regions selecting land sharing approaches, although this method aims to create biodiversity and wildlife-friendly environments, biodiversity conservation is not cost-free, and crop yields remain important considerations.

3) **Land sharing and land sparing represent different problem-solving pathways that can complement each other, and mixed land sharing-sparing models can be established at different spatial scales [58].** For example, moderately restoring agroforestry (trees on farm) in intensive agricultural areas to establish agroforestry systems or tree-shrub-grass integrated farming systems can play important roles in agricultural production and ecosystem service maintenance. Meanwhile, from policy and financial support perspectives, investment should shift from traditional agriculture or forestry to increased agroforestry investment.

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