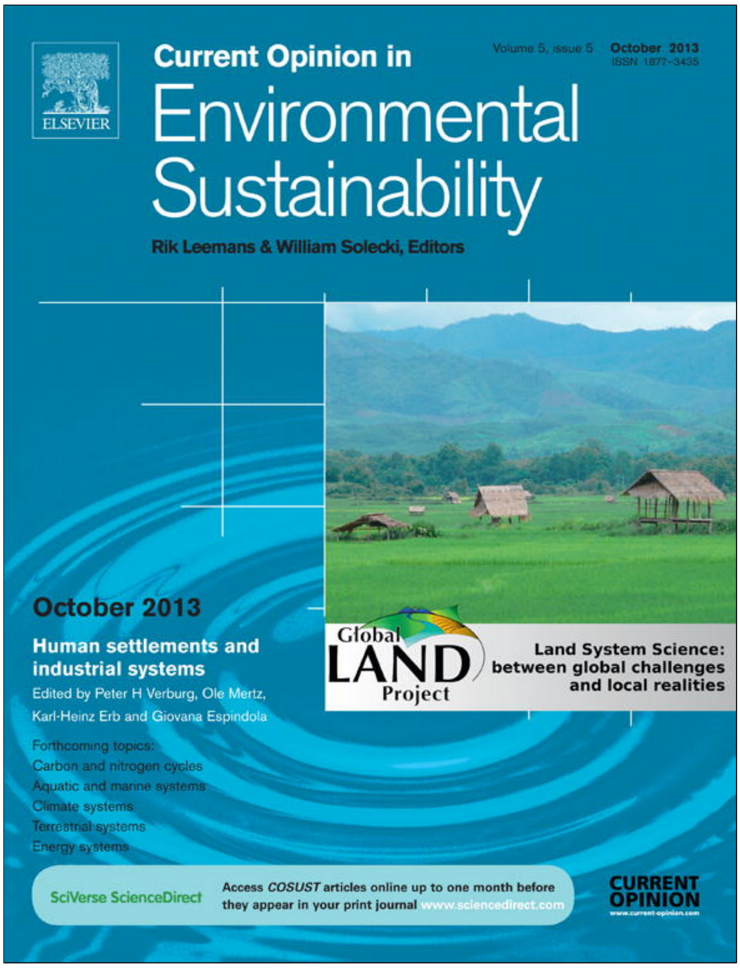
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Beyond 'land sparing versus land sharing': environmental heterogeneity, globalization and the balance between agricultural production and nature conservation

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By addressing the trade-offs between food production and biodiversity conservation at landscape and ecoregion scales, the land sparing/sharing debate has made a significant contribution to land use science. However, as global population and food consumption grow, and urbanization and transnational trade intensify, land use trade-offs need to be analyzed at broader scales. These analyses should specifically consider the role of environmental heterogeneity on biodiversity distribution and agricultural suitability, the costs and benefits transferred far away from the focal land use, institutional and economic factors influencing stability and resilience, technology-related factors as mediators of agriculture suitability, and bundles of different environmental services. In addition, land use strategies to balance agriculture and biodiversity conservation must consider local socioeconomic constraints and trade-offs.

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Introduction

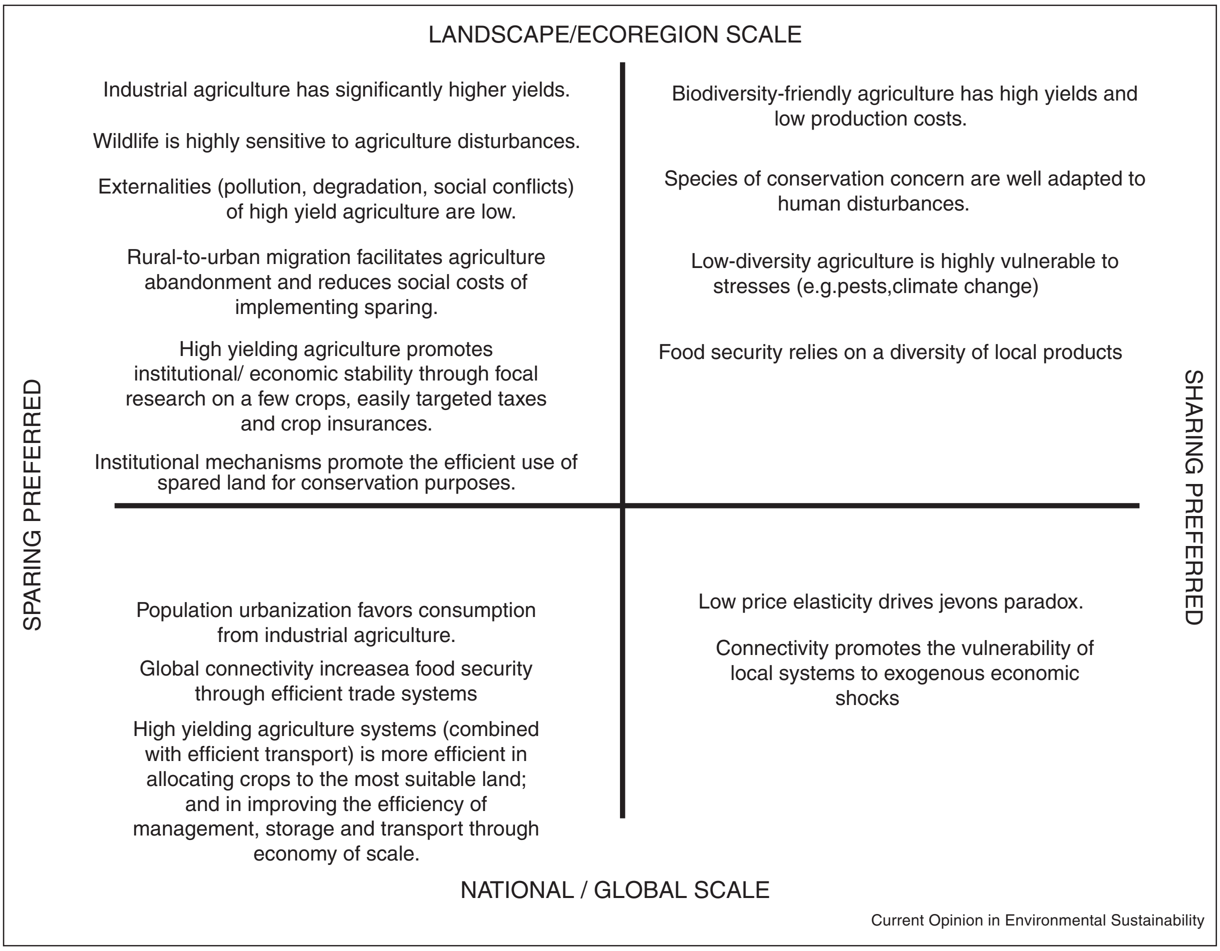
Identifying which activities can be usefully combined on the same land and which are better separated spatially is a key question for land use theory and practice (e.g. [1]). Two often conflicting land uses are agriculture production and biodiversity conservation, and as land becomes scarce there is a growing need to study trade-offs between them [2••]. Most of the literature on how biodiversity responds to farming has missed an evaluation of agricultural productivity. However, there has been a recent move towards more holistic analyses which incorporate information on multiple objectives [3,4]. One influential conceptual framework has been the land sharing/land sparing dichotomy [5,6]. Here, we synthesize the main findings of this line of research, which started almost a decade ago and expanded significantly during the past five years. On the basis of this, we explore emerging topics related to balancing agriculture and conservation in the context of global land use trends and socioeconomic globalization.

Two important issues need to be mentioned before we proceed. First, trade-off analyses are based on valuing the 'competing' variables, and while agriculture production can be expressed in relatively objective and straightforward ways (e.g. calories, proteins, money), valuing biodiversity is much more difficult [7]. We assume here that biodiversity is worth conserving, although we acknowledge its value can differ substantially among individuals, societies, and cultures. Second, while we recognize that redistributing food access and reducing overall demand would help to mitigate conflicts between biodiversity conservation and food production [8•], such conflicts will likely remain regardless of the patterns of food distribution. Optimizing land use is therefore a valuable goal, coherent with, but distinct from achieving a fair and economically efficiency income distribution. It is likely, however, that by influencing consumption patterns, food distribution and access feedback on food demand and land use patterns. While a detailed analysis of these complex relationships is beyond the scope of this article, we briefly discuss them as an emergent research need.

The land sparing-land sharing dichotomy as the basis for landscape and regional planning

While land sharing favors the spatial co-occurrence and integration of production and conservation goals [6,9•], land sparing approaches favor the spatial segregation of intensive agriculture and natural areas, assuming that a smaller area needed for production could be used as part of a strategy to 'spare' land for nature conservation [5,10]. Sparing strategies are more consistent with 'classical' conservation practice, which focused on setting aside well preserved natural areas, while sharing strategies have gained popularity more recently under the assumption that conservation is locally compatible with agriculture, particularly within locally diversified traditional uses.

Figure 1



Conditions providing comparative advantages of land sharing and land sparing strategies at different geographical scales.

Both sharing and sparing approaches have particular advantages and disadvantages that vary across socioeconomic and biophysical contexts (Figure 1) and case studies comparing their relative merits differ in their outcome (Table 1).

Empirical studies interpreted as supporting sharing have been conducted in extensive livestock systems [11,12] and tropical cocoa and coffee plantations [13,14•] which can support high biodiversity while achieving moderately high yields. Opinions in favor of sharing assume that sparing approaches are often based on conventional monoculture agriculture dependent on pesticides, fertilizers, and intensive mechanization. This may translate into pollution, the loss of agrobiodiversity and traditional landscapes [15], and the degradation of non-provisioning ecosystem services [8•]. Adopting a sparing strategy could compromise the resilience of the land system [16•], and is possible that sharing could better preserve bundles of ecosystem services including carbon storage, pollination, soil and watershed protection. Additionally, increasing agricultural yields may not result in land 'spared' for nature, and may instead favor further agriculture expansion and non-conservation uses [17].

In contrast, results supporting sparing typically include high-energy crops (e.g. oilseeds, cereals, sugarcane [18,19,20••,21]). Fertilized monocultures of these crops usually attain very high agriculture yields, thus potentially requiring less transformation of natural areas to meet production targets. The largest share of global calories and proteins production falls on cereals and oilseeds, which typically achieve significantly higher yields when cultivated as conventional agriculture [22], and a much larger cropland area would be needed if food were not largely produced in modern mechanized systems [23,24]. Optimal conservation strategies vary among species in relation to their habitat requirements and tolerance to agriculture [5,20••], and species intolerant to human activities (e.g. large predators, mature-forest

Table 1

Selected empirical studies providing direct or indirect comparisons between sparing and sharing strategies by considering biodiversity/agriculture yield trade-offs

Reference	Main strategy supported	Natural setting	Production system	Biodiversity variable
[11] Dorrough *et al.*, 2009	Sharing	Temperate savannah, Australia	Sheep livestock	Native vegetation
[12] Mastrangelo and Gavin 2012	Sharing	Subtropical dry forest, Argentina	Livestock and pastures	Birds
[13] Gordon *et al.*, 2007	Sharing	Tropical forest, México	Coffee plantations	Birds and mammals
[14•] Clough *et al.*, 2011	Sharing	Tropical Rainforests, Indonesia	Cocoa	Plants, insects, vertebrates
[18] Aratrakorn *et al.*, 2006	Sparing	Tropical forest, Thailand	Rubber and oil palm plantations	Birds
[19] Grau *et al.*, 2008	Sparing	Subtropical dry forests, Argentina	Soybean, cereals and livestock	Forest cover and degradation
[20••] Phalan *et al.*, 2011	Sparing	Tropical forest, Ghana, India	Oilseeds, cereals, cocoa, sugarcane	Trees and birds
[21] Egan and Mortensen, 2012	Sparing	Temperate forests, USA	Corn, soybean, alfalfa, other grains	Vascular plants
[25•] Hodgson *et al.*, 2010	Depending on yields	Temperate grasslands, USA	Cereals and pastures	Butterflies

'Main strategy supported' refers to the overall author's interpretation.

species) necessarily require some level of sparing for their conservation.

While the sparing/sharing dichotomy has sparked valuable research, we think is unlikely that it will result in the discovery of a single strategy for all ecosystems. The most efficient way to balance agriculture and conservation depends on many idiosyncratic properties, including the proportion of biodiversity in different categories of tolerance to human disturbance [20••,25•], and the relative value of agriculture products, biodiversity, and other ecosystem services. Empirical studies framed in the sharing/sparing scheme with clear objectives and rigorous data quality [2••], and carried out in different environmental and societal settings will likely continue contributing to a better understanding and management of land use trade-offs. However, to make further progress in the context of increasing socio-economic globalization they should expand beyond the landscape and ecoregion scales. To do so, two critical issues require further theoretical and empirical research: firstly, the role of environmental heterogeneity and secondly, the increasing long-distance interactions in a globalized world.

Agriculture and nature conservation in environmentally heterogeneous regions and countries

The relatively local scale (i.e. landscapes, ecoregions or biogeographic 'provinces') at which most sharing-sparing studies have been conducted (Table 1) is small enough to limit variation in social, political and environmental conditions, while being large enough to encompass populations of wildlife species. However, heterogeneity in environmental conditions and high species turnover should not be overlooked. This heterogeneity is problematic for current sparing/sharing analyses, which assume a common species pool and a homogenous physical environment over which biodiversity patterns are mainly driven by agriculture yields; and/or use matching methods to meet this assumption. Agriculture tends to concentrates in flat areas and well-drained fertile soils. Wildlife species with the same environmental requirements are more threatened than species with broader niches or species that thrive in areas less suitable for agriculture. Environmental heterogeneity (which increases with the scale of analysis) would likely generate complex relationships between agriculture yield and biodiversity, and this complexity is not well captured in present-day sparing/sharing models.

Countries, the organizational level at which land use policies are often implemented, exemplify the challenges of adopting the sparing/sharing framework when environmental heterogeneity is considered. Countries are not natural ecological units, and vary dramatically in size and geography. However, they are politically and economically coherent units and provide opportunities to set legal frameworks for land management based on identifying areas of high conservation value which are appropriate targets for sparing; as well as areas where agriculture expansion or intensification will be least damaging such as abandoned and degraded lands (e.g. [26,27]). Country-level land-use strategies should prioritize some areas for conservation (whether in agricultural land or in natural habitats) and others for intensive agricultural production, but this implies some significant challenges. Population-level data on species responses to land use are often limited. By limiting agriculture outputs in one area, biodiversity protection in this area may inadvertently expose another set of species to increased impacts from agricultural intensification elsewhere and these geographically de-coupled tradeoffs would require complex and spatially explicit tools to understand them (e.g. [28]).

Most agriculture is limited to intermediate levels of temperature and rainfall (e.g. 600–2000 mm/year), and mechanized agriculture is further limited to flat slopes and well drained fertile soils. Agriculture adjustment (the re-location of agriculture into areas with such characteristics) has been proposed as a driver of the so-called 'forest transition' [29,30], in which a country or region reverses its trend of agriculture expansion into the recovery of forests or other natural vegetation. Forest transition can be considered an endogenous process of change in land use configuration which follows a sparing fashion, increasing agriculture production while reducing pressure on areas marginal for agriculture. Typical areas of land disintensification (e.g. mountains, poorly drained areas and deserts [31,32•]) often harbor high biodiversity value and other ecosystem services but so do some focal areas for intensification. Subcountry ecological heterogeneity plays a key role in defining the effects of such transition processes in conservation. For example, Redo *et al.* [33•] found that in Central America, during the pathway towards socioeconomic development, dry forest and conifer forest biomes are experiencing forest recovery, but at the same time lowland tropical rainforests are becoming rapidly deforested.

The role of environmental heterogeneity needs to be better studied in country-scale analyses, but also the role countries and regions play in generating ecological homogeneity through institutional and economic cohesion. On the one hand, increasing agricultural yields is rarely associated with the reduction of country-scale agriculture area [34,35]. As countries increase their production targets in response to growing global food demand and resulting inelastic prices, increasing yields may not 'spare' any land for nature without policy intervention if there are enough wild areas suitable for agriculture expansion. It remains to be rigorously assessed if this lack of a direct 'sparing' effect results from increased consumption indirectly stimulated by agriculture intensification ('Jevons Paradox' [36]), with negative consequences for biodiversity. Or, if instead there is a hidden beneficial effect, either by reducing the agriculture area relative to what would happened in the absence of land use intensification, or by reducing pressure on other regions less suitable for agriculture. On the other hand, at the scale of countries or large regions, low-diversity agriculture systems can achieve efficiency, stability and resilience (e.g. [37]) by means of economy of scale, focused research on target species (e.g. on pests management, and genetic improvement) and crop insurance among others.

Emerging tradeoffs and synergies between agriculture and conservation at broad geographic scales

Agriculture is an increasingly globalized pursuit and few farmers remain unaffected by national and global markets. This results in a number of important trends which are currently reshaping global land use, with important implications for balancing agriculture and conservation.

First, there is an overall increasing global demand for land products, resulting from population growth and dietary changes associated with increasing population and income [38] and the growing use of land for bioenergy crops [39]. Yield increases on already high-performing croplands appear to be leveling off in some places [40], but increasing yields on currently underperforming croplands will play an important role for increasing agriculture production [24]. When they compromise yields, sharing strategies may be increasingly hard to maintain in many regions; and in many areas, yield increases on existing cropland can be a realistic way of reducing deforestation.

Second, by 2050 about 70% of the global population is projected to live in cities, while rural population will decrease by about 300 million people [41]. By rising productivity and salaries, urbanization often results in an increase in consumption (although possibly in more efficient ways), and a shift from local to distant sources of agriculture products [42]. Rural population declines will likely amplify the ongoing decline of traditional farming systems and agrobiodiversity associated with them [43]; which in turn may provide opportunities for reconfiguring land use and for implementing sparing strategies at lower social costs in many areas [31,44].

Third, economic globalization implies increasing long distance connections via trade and other linkages [32•,45,46•]. Rising food demand in one place (e.g. China, India) can exert pressure on biodiversity in another (e.g. South America, Africa). Conversely, agriculture intensification and expansion in one area might relax pressures on natural ecosystems in another area. The solutions identified to balance conservation and agriculture may differ when considering trade [47], which may give rise to leakage and displacement effects. Distant consumers from developed countries may exert favorable feedbacks to the places where food and bioenergy are produced (e.g. via demanding certification, REDD mechanisms, etc.) but food importing countries are exporting their environmental impacts [48,49]. Implementing conservation policies in one place, whether by maintaining wildlife-friendly practices with a potential yield penalty or by keeping land out of agricultural production, risks shifting the problems that agriculture creates out of sight.

While the connectedness among regions provides opportunities for a better allocation of land use, surging global demands for agricultural products threaten natural habitat and their biodiversity in fertile regions. In consequence, land use pressure may decrease in ecoregions with low quality for modern agriculture, and continue to increase in regions suitable for modern agriculture [32•,50]. Emerging technological changes may further influence this general pattern. For example, global climatic and soil patterns have historically 'protected' tropical forests by being less suitable for conventional agriculture [51]. However, this pattern is changing as some significant commodity crops used both for food and biofuels (e.g. palm oils) are well adapted and rapidly expanding into acidic tropical soils [52].

An additional complexity emerges when we consider the role of land use geography on the distribution of food access. The sharing/sparing debate has focused on food production instead of food security, but food distribution can influence land use efficiency (e.g. redirecting excessive consumption from the rich to undernourished people should reduce pressure for deforestation). Therefore, if the spatial configuration of land use affects food access, it indirectly affects land use efficiency. For the rural poor that consume their own production, sharing strategies may improve their food access and diversity [8•]. In contrast, for the urban poor and the non-farmer rural poor, food access largely depends on the ratio between income and food price, which sparing strategies may help increase. The relative importance of these contrasting patterns will likely vary with the differences in rural versus urban population in each region or country.

Conclusions

By explicitly addressing the trade-offs between food production and biodiversity conservation, the sparing/sharing debate has made a significant contribution to land use science and conservation biology. Empirical research can be improved in terms of conceptual design and data quality to yield most rigorous assessments of sharing and sparing comparative advantages [2••,53•]. Most importantly, as globalization intensifies, local and regional land use strategies result in costs and benefits at broader geographic scales, mediated by population growth, urbanization, long distance trade, and transnational policies. Environmental heterogeneity becomes a significant factor in defining biodiversity patterns and agriculture suitability, so this heterogeneity needs to be specifically addressed. Environmental factors that affect high-capital technology application (e.g. slope, access) are becoming more important to define agriculture suitability, and institutional and macroeconomic factors acquire increasing importance to regulate agroecological efficiency and stability. Land use planning should be based on a hierarchical framework that specifically focus on different geographic scales (e.g. transnational, national, local), acknowledging that overall land use efficiency may be based on the combination of sparing and sharing strategies (e.g. [54•]) and the explicit consideration of environmental heterogeneity (e.g. [55•]).

Developing the theoretical framework to understand the hierarchically framed trade-offs between agriculture and conservation from local to global scales is an emerging research frontier. To date, both the theoretical and empirical analyses related to the sharing/sparing framework have focused on the biophysical aspects. To make a richer contribution to land use policy making, they need to be expanded to better represent the societal subsystem of the coupled human-natural systems. This will require ecologists and conservation biologists to be more deeply engaged in interdisciplinary research with the social sciences (e.g. economy, anthropology, sociology, human geography) to understand and quantify the social constraints and trade-offs associated with conservation and land use strategies.

We suggest that the following research topics should receive more attention in this context:

i Trade-off analysis of biodiversity and agriculture production would be richer if they additionally consider bundles of ecosystem services. When possible, analysis should derive some general guidelines that can apply when data availability is limited.

ii These guidelines should be combined with context-specific analyses to derive place-based strategies, which include local socioeconomic conditions, environmental history, and social trade-offs. In addition to searching for optimal solutions, it could be beneficial to assess second and third-best solutions as well, as alternatives with potentially lower barriers or implementation costs (environmental, economic, social).

iii Analytical tools to balance land use and conservation goals should consider trade and connectedness among regions as an inherent feature of land systems, for example, by assessing the ecosystem and biodiversity loss 'embodied' in imported products, as well as the potential global benefits of negatively affecting local biodiversity.

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While most sparing/sharing analyses have focused on a dominant gradient of intensification from one reference natural environment (typically forest) and an intensive agriculture system, this article exemplifies that in savannas (and likely in other biomes) the complexity of natural environments includes more than one reference natural condition (e.g. forests and grasslands).