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Global food security, biodiversity conservation and the future of agricultural intensification

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ABSTRACT

Under the current scenario of rapid human population increase, achieving efficient and productive agricultural land use while conserving biodiversity is a global challenge. There is an ongoing debate whether land for nature and for production should be segregated (land sparing) or integrated on the same land (land sharing, wildlife-friendly farming). While recent studies argue for agricultural intensification in a land sparing approach, we suggest here that it fails to account for real-world complexity. We argue that agriculture practiced under smallholder farmer-dominated landscapes and not large-scale farming, is currently the backbone of global food security in the developing world. Furthermore, contemporary food usage is inefficient with one third wasted and a further third used inefficiently to feed livestock and that conventional intensification causes often overlooked environmental costs. A major argument for wildlife friendly farming and agroecological intensification is that crucial ecosystem services are provided by "planned" and "associated" biodiversity, whereas the land sparing concept implies that biodiversity in agroecosystems is functionally negligible. However, loss of biological control can result in dramatic increases of pest densities, pollinator services affect a third of global human food supply, and inappropriate agricultural management can lead to environmental degradation. Hence, the true value of functional biodiversity on the farm is often inadequately acknowledged or understood, while conventional intensification tends to disrupt beneficial functions of biodiversity. In conclusion, linking agricultural intensification with biodiversity conservation and hunger reduction requires well-informed regional and targeted solutions, something which the land sparing vs sharing debate has failed to achieve so far.

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1. Introduction: setting the scene – land sparing vs wildlife friendly farming?

Combining efficient agricultural land use with biodiversity conservation is a challenge. With the global population approaching 9 billion people in the next few decades, it is often asserted (e.g., from United Nations (UNs) and Food and Agricultural Organization (FAO)), that there is a need for 70–100% more food (Godfray et al., 2010). At the same time, the UN declared the current decade (2011–2020) the 'Decade of Biodiversity' with the EU (2011; the EU Biodiversity Strategy to 2020) setting the targets of halting the loss of biodiversity and degradation of ecosystem services as major goals and setting 2020 as the target for restoring at least 15% of degraded ecosystems.

In some recent analyses (e.g., Phalan et al., 2011a,b; Green et al., 2005) the question is posed whether (or alternatively, at what scale) farming and conservation land management should be separated; segregating land for nature from land for production (land sparing), or integrated with production and conservation on the same land (land sharing or wildlife-friendly farming). As many wild species cannot survive in even the most wildlife-friendly farming systems, protection of wild land is essential (Barlow et al., 2007; Schulze et al., 2004; Maas et al., 2009; Phalan et al., 2011a,b; Kleijn et al., 2011). This fact led Phalan et al. (2011a) to the conclusion that yield increase from agricultural intensification could be used as a strategy to restrict human requirements for land. The general argument for land sparing is that increased food production per area farmland can help to reduce encroaching on natural habitats (see also Fischer et al., 2008, 2011; Green et al., 2005; Vandermeer and Perfecto, 2005; Gabriel et al., 2010; Hodgson et al., 2010; Phalan et al., 2011b).

In this essay we aim to highlight the shortcomings of a dichotomic view between land sharing and land sparing for real world application. The strategy put forward by Phalan et al. (2011a) may appear to maximize both biodiversity conservation and yield via efficient ecological-economic trade-offs at first glance. But upon closer examination, it fails to take into account the complexity of the real world and the opportunities for agricultural landscapes to provide multiple ecosystem services beyond food production and wild land biodiversity.

In the following, we outline major caveats inherent to the land sparing vs sharing debate. We discuss important drivers of global food security to indirectly address whether sparing land for nature needs higher intensity of farming to produce adequate food. In the third and fourth section, we directly question the land sparing vs sharing dichotomy and present evidence that agroecological approaches can support high yields. We also provide facts to challenge the strategy of Phalan et al. (2011a) to increase yields without explicitly considering the actual and potential cost of biodiversity losses, which can compromise ecosystem functionality and resilience in agriculture.

2. Global food security is not directly linked to global food production but rather is determined by many important drivers

2.1. Food production from smallholder farms, not large-scale commercial farms, is the backbone of global food security

Food security and food sovereignty are needed where the hungry live, which is often within a landscape matrix of ecosystems that are rich in biodiversity (Perfecto and Vandermeer, 2010). Hunger – somewhat counter intuitively – is not so much linked to the quantity of food that is globally produced but to poverty (Adams et al., 2004; Sachs et al., 2009). The majority of poor people live in rural areas with little or no access to productive agricultural lands. Hence, hunger is linked to farm size: 90% of farmers worldwide farm on <2 ha, producing food where it is needed – in much of the developing world. Eighty percentage of the hungry live in developing countries with 50% being smallholders (World Bank, 2007). Therefore, smallholders rather than large-scale commercial farmers are the backbone of global food security (Horlings and Marsden, 2011; Chappell and LaValle, 2011).

The "conventional" vs "agroecological" dichotomy is a simplified and heuristic device, as much of the world's agriculture lies somewhere between these categories (e.g. traditional smallholders with heavy pesticide use, e.g. Wanger et al., 2010, or large-scale organic farms). However, in general the potential for increasing food production with conventional intensification of agriculture is geared towards high-input agriculture, whereas the low-input agriculture of the poor relies more strongly on biodiversity and associated ecological processes (beneficial trophic interactions, soil food webs, stress-adapted crop genotypes; Lewis et al., 1997; Jackson et al., 2007). Moreover, it is well established that small and diversified farms rather than large monocultures show greater productivity per area; a phenomenon referred to as the 'paradox of the scale' or the 'inverse farm size-productivity relationship' (Cornia, 1985; Halweil, 2006; Barrett et al., 2009; de Schutter, 2011; Horlings and Marsden, 2011). For resilient and productive smallholder systems, food security policies must emphasize an increase in agroecological capacity. This includes eco-efficient (Keating et al., 2010), environmentally friendly and sustainable techniques to typically manage highly diversified cropland (Ratnadass et al., in press), avoiding pesticide use as much as possible, integrating soil fertility strategies (combining organic and inorganic fertilisers) and intensifying production in combination with preservation of functional biodiversity, thereby avoiding environmental risks smallholders face (see Fig. 1). The latter is often differently perceived by risk-averse farmers relying on long-

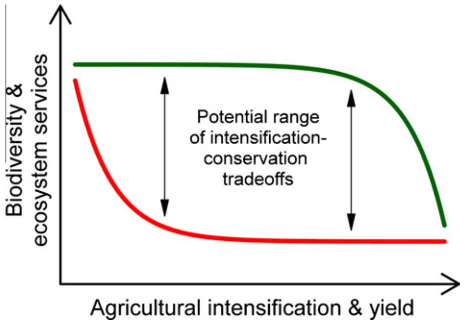

Fig. 1. The relationship between intensified agriculture (increasing yield) and biodiversity (including associated ecosystem services). In European agriculture, a slight increase in (high-input) intensification can cause a steep drop in biodiversity (Kleijn et al., 2009) or, alternatively, only a linear relationship (Geiger et al., 2010). In tropical agroforestry, biodiversity is often not related to yield, at least up to a certain level of intensification (Steffan-Dewenter et al., 2007; Clough et al., 2011). In all cases, the variability in the yield-biodiversity relationship is high suggesting potential for the identification of agroecological practices in favor of biodiversity-conservation trade-offs or even synergies, while similar biodiversity does not mean similar community composition or functionality *per se*.

term resilience of their farms, in contrast to short-term yield-maximizing farmers (Baumgärtner and Quaas, 2010; Tscharntke et al., 2011).

Environmentally friendly land use contributes to biodiversity conservation, but poor rural based population tends to encroach forests to extract forest products, thereby endangering the sensitive forest fauna and flora (Schwarze et al., 2007; Michalski et al., 2010). On the other hand, participation of rural communities can be important: community-managed forests suffer from lower deforestation rates than protected forests, shown by a recent review across the tropics (Porter-Bolland et al., 2012).

2.2. Global food production is sufficient, but not available to the hungry

Current global food production is sufficient to feed the world, but the hungry cannot afford the food (>1 billion of people are hungry and >2 billion malnourished today; Chappell and LaValle, 2011; FAO, 2011). The Millennium Development Goals (UN Millennium Project, 2005) target of halving the number of hungry before 2015 is more related to food distribution than to agricultural intensification. Hence, food security is largely independent of the land sharing vs sparing debate. The UN Special Rapporteur on the Right to Food, Olivier De Schutter (2011), highlights in his recent report that small-scale ecological farming is already very productive and can do even better (see also IAASTD, 2009). He calls for increases of food production where the hungry live and the use of agroecological methods. These methods of improving yields are more accessible and viable for poor smallholder livelihoods than high agrochemical inputs. The notion of eco-farming for food security can be expanded to include the matrix of adjacent wild land, given the importance of landscape complexity for agroecological functions such as pest management, pollination, soil and water quality (Tscharntke et al., 2005, 2007a; Bianchi et al., 2006; Perfecto et al., 2009; Ricketts et al., 2008; Jackson et al., 2009; Blitzer et al., 2012).

The huge surplus production of large commercial farms generally contrasts with the low surplus of smallholder enterprises. While increasing urbanization in the tropics necessitates high food production for regional and global markets, it often leads to cheap retail prices. However, this does not indicate eventual inefficiency of smallholdings (Barrett et al., 2009; see Badgley et al., 2007), but simply their limited importance for large-scale markets. Increasing migration from the tropical countryside into big cities is driven by poverty, hunger and income opportunities offered by industrialization of urban centres. Hence, support for more efficient, profitable and sustainable production of smallholder farming enterprises and more independence (sovereignty) from large commercial operations (at national and international levels) may help to better secure access to food of the rural poor.

2.3. Food usage is inefficient – one third is wasted and one third fed to livestock

Why focus on increasing food production when the efficiency of food usage is low? A recent report commissioned by the FAO estimates that globally a third of harvested food is thrown away (Gustavsson et al., 2011; or even half of all food is lost, Foley et al., 2011). These food losses occur in industrialized countries as well as in developing countries, but in the latter 40% losses occur at post-harvest and processing levels, whereas in the industrialized countries, 40% occur at retail and consumer levels (Gustavsson et al., 2011). Improving post-harvest technologies (in particular for smallholders) and reducing food waste is a major challenge for our future.

Inefficient use of food stocks also occurs by feeding cereal and fodder starch to animals, which are poor converters of energy into meat. Livestock requires on average 7 kcal input (cereal grain feed) for every kcal generated (range: 16 kcal for beef to 3 kcal for broiler chickens). Currently, cereals fed to livestock make up 30–50% of global cereal production (FAO, 2006; de Schutter, 2011). With meat consumption predicted to rise from 37 to 52 kg/person/year (2000–2050; FAO, 2006) cereals are increasingly diverted to animal feed streams, a trend that should be reversed. Cereals and grain legumes convert energy into protein much more efficiently than animals do. Shifting diets from beef to poultry or from grain-fed to pasture-fed beef would already meaningfully increase food supplies by closing a 'diet gap' (Foley et al., 2011). Efforts to promote more efficient food systems (Ericksen, 2008) must be seriously considered before championing the widespread adoption of increasing food production with high-input agricultural intensification (independent of the land sharing vs sparing debate).

2.4. The EU '10% biofuel directive' causes increased food prices and contributes to rainforest destruction

The EU biofuel directive (2008) requires that 10% of all transport fuel should come from biofuel by 2050 (Vidal, 2010). In general, bioenergy production tripled in the last decade and until 2020, 15% of global cereal and plant oil production as well as 30% of sugarcane production is expected to go into biofuel (OECD-FAO, 2011). This is a policy with unintended consequences and does not help mitigate hunger. On the contrary, this directive increases the rate of land grabs (see the next section below) and increases food prices. According to a World Bank Report (2008) and many other expert opinions, biofuels were responsible for a meaningful part of the global food price spike in 2008. Further, large-scale destruction of rainforests for oil palm plantations (mainly in Indonesia and Malaysia) results in the destruction of major global carbon and biodiversity reservoirs. While the elimination of oilpalm-based biofuel production is unlikely, designing landscapes that integrate smallholder agroforestry systems between plantations and conservation areas may provide a more sustainable solution, especially if climate policies allow REDD credits to be traded (Koh et al., 2009; Koh, 2011).

2.5. Land grabbing and speculation on food commodities jeopardizes food security

Food security and food sovereignty is further hindered by direct and indirect ''land grabbing'', because local food security, especially in developing countries, can be undermined by the export of agricultural products. According to von Witzke and Noleppa (2011), indirect land grabbing applies, for example, to the European Union (EU), the world's largest net importer of agricultural products, which are grown on an agricultural area larger than the territory of Germany. More than half of these imported products are soybeans, mainly from South America (most of the soy is genetically modified and 50% of it is used for animal feed). Direct land grabbing refers to the fact that international investors are increasingly leasing or buying farmland in Africa, Asia, and Latin America for food and fuel production. This is a serious threat to food self-sufficiency and food sovereignty in most cases (La Via Campesina, 2010). Policy instruments that incorporate the views and land rights of communities of local smallholders have been difficult to design and implement (Horlings and Marsden, 2011).

Economic markets for primary food commodities are increasingly taking on the role of a new kind of investment product (incorporated into new derivative investment instruments) enhancing speculation and contributing to rising food prices and insecurity of supply. The 2008 price spike of food (cereals) was at least partially due to a speculative food bubble (Kaufmann, 2011). Recently, speculation pushed cocoa to a 33 year high (Allen, 2010). Speculation on food commodities therefore suggests negative effects on rural dwellers in the developing world. It brings uncertainty, loss of global food security, less rural self-reliance and weakened local markets.

3. Increasing yields need not translate into biodiversity loss or more land spared for nature

The land sparing vs sharing dichotomy is based on the argument, demonstrated mostly for temperate regions, that yields are negatively correlated to wildland biodiversity (Kleijn et al., 2009; Geiger et al., 2010). High yields and high biodiversity, however, can co-exist in tropical smallholder agricultural systems (Perfecto et al., 2007; Perfecto and Vandermeer, 2010; Clough et al., 2011). In cacao agroforestry, for example, management could be further optimized for more diversity in the different strata (litter, herbs, cacao itself and the shade trees), and conserving surrounding forests, without compromising food production (Clough et al., 2011). In addition, it is well-known that traditional coffee production systems are biodiversity friendly both in their biodiversity content and in the quality of the matrix they create, as well as producing reliable yields (Perfecto et al., 2005; Perfecto et al., 2009). There may not be the need to consider trade-offs (see Fig. 1, de Fries et al., 2004), although similar biodiversity does not mean similar community composition or functionality *per se*.

There is little evidence for a substantial decrease in cropland as yield in tropical crops increases (Ewers et al., 2009). Higher yield and profitability tend to attract migrants and hence, to frequently increase deforestation rates (Angelsen and Kaimowitz, 1999; Angelsen, 2010). This is contrary to the widespread assumption (also called the Borlaug hypothesis) that yield increases take pressure off forests. As such, allowing intensification does not necessarily increase the amount of land that will be spared for nature (Perfecto and Vandermeer, 2010). Given that there is no link between yield increases and forest conservation, it is really not the question here whether yield is based on agroecological or conventional intensification, but agroecological intensification is likely to enhance other ecosystem services, as will be discussed below.

4. Agroecological intensification sustains ecosystem services, while minimizing environmental costs and maintaining functional biodiversity

4.1. Wildlife-friendly farming sustains cultural ecosystem services

Last but not least, cultural ecosystem services need to be taken into account. Often, religious and ethical attitudes are important drivers of choosing agricultural practices (Sodhi and Ehrlich, 2010). In developed countries for example, people value traditional heterogeneity and complexity of their surroundings such as hedges, flowering field margins, fallows, and forest margins – all of which benefit biodiversity (Brodt et al., 2009; Soliva et al., 2010). In addition, people appreciate the biodiversity in agricultural landscapes allowing, for example, bird watching. This interest is also reflected in large numbers of publications dealing with the current decline of common farmland birds that is perceived as a severe problem in Europe (Whittingham, 2011). The public has to a large extent identified habitat destruction, increased use of agrochemicals, and landscape-wide structural simplification as unwanted. This desire for heterogeneous human-dominated landscapes needs to be an important part of concepts aiming to sustain multifunctionality of landscapes, integrating food production and conservation of both openland and forest species. The fact that 40% of terrestrial area is under agricultural management and just 12% is protected (Perfecto and Vandermeer, 2010) also means that, for example, endangered large carnivores (lynx, wolf, bear, etc.) cannot be conserved by a system of reserves, but need a highly connected matrix made up of semi-natural habitats, managed habitat and reserves (Linnell et al., 2005).

4.2. Conventional intensification causes often overlooked environmental costs

Environmental quality in agricultural landscapes dominated by smallholders is often overlooked in the land sparing vs sharing debate (Perrings et al., 2006). Conventional agricultural intensification often results in contamination by pesticides and fertilizers, which can affect human health and create non-target effects on wildlife and functional agrobiodiversity (Dutcher, 2007; Gibbs et al., 2009; Geiger et al., 2010; Meehan et al., 2011). Eco-efficient fertilization of poor soils is essential for sustainable agriculture (Tilman et al., 2001; Keating et al., 2010). Environmental costs of all N losses in Europe have recently been estimated at €70–€320 billion per year, which outweighs the direct economic benefits of N in agriculture (Sutton and van Grinsven, 2011). These high societal costs are due to losses in air quality, water quality and especially human health (Sutton and van Grinsven, 2011). At a global scale, sevenfold increase in N-fertilizer application in 1960–1995 resulted in doubling of cereal yields, but efficiency declined from 70 to 25 kg grain per kg N (Keating et al., 2010). Agriculture causes 30–35% of global greenhouse gas emissions, mainly due to tropical deforestation, methane emissions from livestock and rice fields, and nitrous oxide emissions from fertilized soils (Foley et al., 2011). Soil degradation has been estimated to affect 16–40% of terrestrial area (Chappell and LaValle, 2011) and even for Europe, meaningful soil losses causing reduced yields are predicted for the coming century (Banwart, 2011). However, little quantitative detail of costs and benefits of technical improvements is known, i.e. which changes in agroecological or conventional management regime (from crop rotation to agrochemical use) should be implemented to maximize productivity and to minimize negative externalities at the same time (see Fig. 1). Implementing agroecological principles in agriculture, i.e. adopting eco-efficient and environmentally friendly management with a focus on more diversified cropping systems (Letourneau et al., 2011; Ratnadass et al., in press), can greatly improve productivity and contribute to closing yield gaps (Foley et al., 2011) and to promoting agroecosystem resilience, i.e. the capacity to reorganize food production after disturbances or disasters (Tscharntke et al., 2011). Enhancing sustainable productivity of farmland needs a holistic, integrated strategy considering all resources (from e.g. labor, capital, energy, soil and water to biodiversity and climate) as well as external effects (environmental costs). Adoption of the most efficient techniques from the toolbox of sustainable land-use practices means, for example, enhanced fertilization and use of resource-efficient crop varieties in southern Africa, whereas current surplus fertilization in Europe needs to be sanctified.

4.3. The role of agrobiodiversity and associated ecosystem services

Agricultural production is highly dependent on ecosystem services such as pest control, pollination and soil fertility amongst others (Power, 2010). Both "planned" and "associated" biodiversity in farming systems and agricultural landscapes provide important ecosystem services. The concept of land-sparing, however, implicitly neglects the fact that biodiversity in agroecosystems can be of high short-term and long-term functional importance (Tscharntke et al., 2005; Jackson et al., 2009). So then, what are the benefits of 30% higher species richness and 50% higher density in organic farms (Bengtsson et al., 2005)? Consider, for example, the role of predators and pollinators in agroecosystems. A 1-hectare cereal

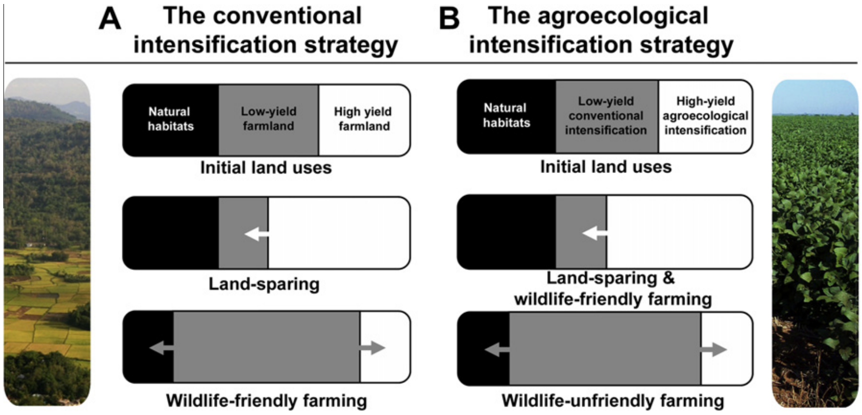

Fig. 2. Cartoon illustrating the possible combination of global food security with biodiversity conservation. The land sparing vs wildlife-friendly farming strategy (Phalan et al., 2011a,b) (A), which we here call "conventional intensification strategy", is contrasted with an agroecological intensification strategy based on the arguments presented in this paper (B). (A) Phalan et al. (2011a,b) introduce a region with equal areas of natural habitats, low-yield farmland and high-yield farmland (top). Land sparing (centre) involves increasing yields in the production landscape while protecting or restoring natural habitats. Wildlife-friendly farming (bottom) involves expanding the area of low-yield farmland at the expense of natural habitats. (B) In the same style of (A), three equal areas and natural habitats are shown, but conventional intensification (not wildlife friendly farming) is considered to be associated with low-yield farmland, while agroecological intensification (wildlife-friendly farming) is associated with high-yield farmland providing a multifunctional set of ecosystem services. The well-known inverse relationship between farm size and food productivity per unit of land (see text) means that increasing small-scale agroecological intensification (where the poor and hungry live) could combine wildlife-friendly farming with land sparing. More scientific effort needs to be invested to demonstrate and improve such agroecological strategies, combining high-quality matrix for wildlife and environmental quality with increased yields and land spared for undisturbed nature.

field (in Central Europe) hosts several 100,000 individuals and several 100's of species of predators (beetles, spiders, flies; Tischler, 1980). The experimental exclusion of predators results in dramatic increases in pest aphid density (Schmidt et al., 2003; Costamagna and Landis, 2006) across European countries (Thies et al., 2011), with relative importance of predators changing with region indicating an insurance value of functional redundancy (Thies et al., 2011). In coffee production, the complex interactions of multiple ecosystem players combine to effectively create an autonomous control of pests (Vandermeer et al., 2010) and in maize as well as in other crops, push–pull strategies for natural pest control are successful (Cook et al., 2007). A textbook example is the biological control of Indonesian rice pests by avoiding pesticide use and increasing habitat heterogeneity (Settle et al., 1996). In a recent meta-analysis, Letourneau et al. (2011) demonstrated that diverse agroecosystems have less pest damage, fewer herbivores and more natural enemies than less diverse cropping systems. Globally, 30–40% of potential crop yield is destroyed by pathogens and pests (Oerke, 2006).

Pollinators are required for reproduction of almost 90% of angiosperms and consequently are a limiting factor of most plant communities and vegetation types. Further, pollinators improve production of 70% of the globally most important crop species (124 crop species, based on data from 200 countries) and influence 35% of global human food supply (although staple crops such as cereals, corn and rice are predominantly self-pollinating) (Klein et al., 2007; see also Gallai et al., 2009; Garibaldi et al., 2011). A little known and underappreciated fact is that important commodities such as cocoa completely depend on insect-mediated pollination (e.g. Groeneveld et al., 2010). Pollinator-dependent crops include particularly vitamin-rich foods (Eilers et al., 2011). There is increasing evidence that a diverse assemblage of pollinators can maximize crop yields, compared to the abundance of just one pollinator species (usually the honeybee) (Klein et al., 2003; Hoehn et al., 2008; Winfree and Kremen, 2009).

Despite the need to protect functional biodiversity and its services, conventional agricultural practices increasingly rely on frequent pesticide application, resulting in negative effects on functional biodiversity, for example on bees (Brittain and Potts, 2011) or soil biota (Culman et al., 2010). Hence, the true value of functional biodiversity on the farm in mitigating potential pesticide impacts is often not adequately acknowledged and understood – even in major commodities such as coffee and cocoa.

In agricultural landscapes, natural habitat and habitat heterogeneity is known to enhance sufficient natural enemy density and diversity to reduce crop pest pressure (Thies and Tscharntke, 1999; Bianchi et al., 2006; Letourneau et al., 2011; Tscharntke et al., 2011). If human-dominated landscapes comprise a mix of land-use systems and forest remnants, re-colonization processes reduce extinction and allow for a combination of high functional biodiversity and efficient as well as sustainable food production (Tscharntke and Brandl, 2004; Steffan-Dewenter et al., 2007; Chazdon et al., 2009; Perfecto and Vandermeer, 2010; Clough et al., 2009, 2011; Tscharntke et al., 2011).

5. Conclusions

In conclusion, conventional ("industrial"; de Schutter, 2011) intensification of agriculture increasing yields in the developed world does not necessarily contribute to global hunger reduction. Food security and food sovereignty need to increase in areas where the hungry live, based on robust, eco-efficient approaches (Keating et al., 2010) and "agroecological intensification" (or "ecological engineering" increasing sustainable productivity), which incorporates natural biodiversity patterns and processes. We see three main problems with the land sharing vs sparing debate. First, yield and biodiversity are not necessarily negatively correlated where farms are efficiently managed. Second, increased yield does not necessarily spare land for nature; and third, conventional intensification tends to disrupt beneficial functions of biodiversity (e.g., natural pest control and pollination) and degrades environmental quality, threatening sustainability of food production. The high variability in yield-biodiversity relationships due to high variability of economically viable agricultural practices in both temperate and tropical regions illustrate that there are promising management options balancing human and ecological needs (Figs. 1 and 2). In any case, sensitive wildland ecosystems cannot be converted into agriculture and remaining natural habitat needs to be protected due to the high sensitivity of many species to anthropogenic disturbance (Kleijn et al., 2011). Linking agricultural intensification with biodiversity conservation and hunger reduction is a great challenge for the future. We do agree with Phalan et al. (2011a) that this requires well-informed regional and targeted solutions - but these are more complex than currently discussed in the "black-and-white" land sparing vs sharing debate.

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