Biological Conservation 170 (2014) 232–245

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Agriculture and nature: Trouble and strife?

Frédéric Baudron [a,*], Ken E. Giller [b,c]

[a] CIMMYT-Ethiopia, ILRI Shola Campus, P.O. Box 5689, Addis Ababa, Ethiopia
[b] Plant Production Systems, Wageningen University, P.O. Box 430, 6700 AK, Wageningen, The Netherlands
[c] Senior Fellow, UNEP World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge CB3 ODL, UK

ARTICLE INFO

Article history:
Received 23 June 2013
Received in revised form 27 November 2013
Accepted 3 December 2013

Keywords:
Biodiversity
Land sparing
Land sharing
Low external input agriculture
Intensification

ABSTRACT

Global demand for agricultural products is expected to double in the next decades, putting tremendous pressure on agriculture to produce more. The bulk of this increase will come from developing countries, which host most biodiversity-rich areas of the planet. Whilst most biodiversity is found in production landscapes shared with people, where agriculture represents an increasing threat, international conservation organisations continue to focus on the maintenance and expansion of the network of protected areas. When conservation organisations partner with agricultural programmes, they promote low input, extensive agriculture. Combined with the focus on protected areas, this may exacerbate rather than mitigate conflicts between biodiversity conservation and agricultural production. Two models have been proposed to increase agricultural production whilst minimising the negative consequences for biodiversity: 'land sparing' and 'land sharing'. Although often polarized in debates, both are realistic solutions, depending on the local circumstances. We propose a number of criteria that could guide the choice towards one or the other. We conclude that general principles to be considered in both land sparing and land sharing are: managing spillover effects, maintaining resilience and ecosystem services, accounting for landscape structure, reducing losses and wastes, improving access to agricultural products in developing countries and changing consumption patterns in developed countries, and developing supportive markets and policies.

1. Introduction

In Cockney rhyming slang 'trouble and strife' means wife. Is the relationship between agriculture and nature always an unhappy marriage? Or, in the end, should nature conservation seek synergies with agricultural development?

Agriculture faces tremendous pressure to supply the world with more food, fibre and fuel as the global population is projected to increase by 3 billion people from now to 2050, in parallel with an increase in global wealth and per capita consumption (Godfray et al., 2010; UNPD, 2011). The number of undernourished people risen in the past decade, even before the recent food and economic crises, and now exceeds one billion (FAO, 2009). Although food security may best be addressed by improving food access (Chappell and La Valle, 2011), the production of food and other agricultural commodities must nonetheless increase. The recent sustained rise in the cost of basic food has stimulated individual countries to reduce their dependency on food imports and their exposure to international food price volatility (Headey and Fan, 2008). This is not only a matter of 'food sovereignty' (Rosset, 2008) but is perceived as necessary to maintain political stability and prevent repeat of the violent protests experienced in North Africa and the Middle East in 2011 (Lagi et al., 2011). Considering population growth and wealth improvement, global demand for agricultural products is expected to double in 2050 from its 2005 value (Tilman et al., 2011).

The challenge of increased production will be met mainly by developing countries (Balmford et al., 2005). Whereas cropland area shrank in the developed world between 1961 and 1999, the total area of cropland increased by more than 20% in the developing world and this trend is likely to continue to 2050 (Green et al., 2005; Balmford et al., 2005; Gibbs et al., 2010; Phalan et al., 2013). Developing countries host most biodiversity-rich areas on the planet (Myers et al., 2000; Gibbs et al., 2010). As our understanding improves of the role of biodiversity in maintaining ecosystem processes (Chapin and Matson, 2011), the urgency to reduce current rates of deforestation becomes more evident (Pimm et al., 1995). Thus, finding ways to increase agricultural production in the developing world with minimum negative consequences for biodiversity should be a priority for nature conservation. But is this the case?

In this article, we argue that organisations concerned with nature conservation should partner strongly with those agencies concerned with the agricultural sector, as investing in agriculture could provide the highest returns on investment in terms of conservation benefits. We also examine how this investment could be made under various circumstances, based on a review of existing literature.

* Corresponding author. Tel.: +251 116 462324; fax: +251 116 464645.
E-mail address: f.baudron@cgiar.org (F. Baudron).

0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.12.009

2. Why conserving biodiversity outside of protected areas?

The 'wilderness conservation' approach – also referred to as 'fortress conservation', or 'fences and fines' – isolates designated areas and species from human impact (Swallow et al., 2009). Protected areas are its foundation, and undoubtedly an essential means to conserve biodiversity *in situ* (CBD, 1992). However, three issues undermine the approach: (i) most biodiversity is found outside of protected areas, in 'production landscapes' shared with people, (ii) the efficiency of current protected areas to conserve biodiversity is declining due to under-funding and (iii) climate change may further reduce their efficiency.

Protected areas designated explicitly to protect biodiversity – i.e. IUCN categories I–IV (IUCN, 1994) – cover only 5.1% of all terrestrial land (Hoekstra et al., 2005). As a result, numerous species – so-called 'gap species' – are not represented in the global network of protected areas (Rodrigues et al., 2004; Hoekstra et al., 2005). Most biodiversity actually coexists with humans, as about half of Earth's land surface has been transformed for settlement, grazing or cultivation (Vitousek et al., 1997; MEA, 2005). 'Wildlands' without evidence of human occupation or human use represent only 22% of Earth's ice-free land, most of which is located in the least productive regions (Ellis and Ramankutty, 2008). Recent studies have demonstrated that even rainforests thought to be virgin were extensively used by prehistoric humans (Willis et al., 2004). In fact, human population tends to be concentrated in areas rich in biodiversity, as illustrated by Balmford et al. (2001) for sub-Saharan Africa. In these areas, protected areas impose significant costs on local (often poor) communities (Andersson et al., 2013), whilst benefits of nature-based tourism accrue largely at national and international levels (Balmford and Whitten, 2003). These costs lead to acute conflicts between parks and surrounding communities: almost all the 93 tropical parks analysed by Bruner et al. (2001) sustained significant human pressures from clearing, grazing, fire, hunting and logging. Therefore, expanding the wilderness conservation approach is morally questionable.

In addition, the cost of the current network of protected areas is unmet by the present degree of funding, even when opportunity costs are not accounted for. This shortfall is expected to increase, as populations grow and costs of enforcement rise (Balmford and Whitten, 2003). The annual funding shortfall of protected areas in developing countries – excluding opportunity costs – is around US$1.4 billion, or two thirds of their needs (James et al., 2001). For developing countries, these opportunity costs could be more than US$5 billion each year (Balmford and Whitten, 2003). To expand protected areas for effective conservation of biodiversity, including opportunity costs, annual conservation spending globally must increase from US$6 to 27 billion (James et al., 2001). Therefore, expanding the global network of protected areas is unrealistic, given current investment.

Finally, evidence suggests that climate change is driving shifts in species ranges that may render the current spatial distribution of protected areas less effective in conserving biodiversity (Parmesan and Yohe, 2003). For example, the future range of the average European bird species is predicted to shift by nearly 550 km northeast by the end of this century, and to overlap only 40% with the current range (Huntley et al., 2007). Migrating to more suitable regions has been an important mechanism of adaptation during previous episodes of climate change (Dawson et al., 2011), but becomes increasingly difficult as habitats shrink and fragment.

Thus, if the wilderness approach is suited to the conservation of areas with the most endemic biodiversity – the so called 'biodiversity hotspots' (Myers et al., 2000) – the development of alternative approaches is urgently needed outside of these areas i.e. in production landscapes where agriculture is often the primary land use. How compatible is agriculture with biodiversity conservation?

3. Negative consequences of agriculture on biodiversity

When natural ecosystems are converted for agriculture, biodiversity is modified purposefully to increase benefits to humans (Fig. 1). The modifications are both direct and indirect. Direct modifications are biotic additions (of domestic, often exotic species; Ehrlich and Mooney, 1983) and biotic removals (e.g. of competitors, predators, pests, and parasites of domestic species). Indirect biodiversity changes result from the modification of biogeochemical cycles (e.g. addition of nutrients such as nitrogen and phosphorus), hydrological cycles (e.g. irrigation, drainage of wetlands, changes in land cover and impacts on infiltration and runoff), and species habitats (e.g. tree removal). In turn, changes in biodiversity alter ecosystem processes (e.g. decomposition, nutrient cycling) through changes in species traits (Fig. 1; Webb et al., 2010). For example, changes in species traits may modify the availability of limiting resources, disturbance regimes or micro-climate (Chapin et al., 2000). The interconnectedness of organisms that depend obligately on one another – including parasites with their hosts, predators with their preys and specialist herbivores with their host plants – leads to co-extinction of species (Koh et al., 2004). Extinctions in trophic chains are particularly important if 'keystone species' are lost, that is species whose contribution to ecosystem functioning is disproportionally large relative to their abundance (Mills et al., 1993; Pace et al., 1999). Cascades of extinction may take long to be fully manifested, and the initial ecosystem disturbance may represent a future 'extinction debt' (Cowlishaw, 1999). As an extreme example, a number of plant species display 'anachronistic attributes', as they have not adjusted to the loss of ecological and evolutionary interactions such as frugivory and herbivory since the extinction of dozens of large herbivores in the Americas 10,000 years ago (Janzen and Martin, 1982).

In addition to the negative consequences for *in situ* biodiversity, alteration of ecosystem processes also impact regional or even global biodiversity (Vitousek et al., 1997; Chapin et al., 2000; Tilman et al., 2001). The biodiversity of adjacent landscapes is often affected by habitat fragmentation and fragment isolation (Pimm et al., 1995; Fischer and Lindenmayer, 2007). A cascade of ecological changes often arises at the boundaries of patches of native vegetation, through a range of abiotic (e.g. microclimate) and biotic changes (e.g. increased abundance of species adapted to disturbance), the so-called 'edge effects' (Fischer et al., 2006). Moreover, the alteration of hydrological and biogeochemical cycles may have far-reaching consequences on distant biodiversity. For instance, runoff and erosion from farmland may cause siltation of distant streams, lakes, estuaries and coral reefs (Farella et al., 2001). Similarly, mobile nutrients such as nitrate and pesticides may contaminate regions downstream or downwind, leading to changes in species composition of distant ecosystems (Pimentel, 1995; Almasri and Kaluarachchi, 2004). Depending on their volatility and persistence, pesticides may disperse globally and accumulate in food chains (Tilman et al., 2001). The conversion of natural ecosystems to cultivation releases large amounts of CO_2 from the standing biomass and soil which contribute to global climate change and affect global biodiversity (Vitousek et al., 1997). Agriculture is also a major source of greenhouse gases such as methane from paddy rice cultivation and nitrous oxide from intensification of the N cycle (Tilman et al., 2001).

4. What is the current strategy of the largest conservation organisations?

4.1. A focus on protected areas

Although they acknowledge the threats from agriculture, the largest conservation organisations in the world focus on the