Agriculture and biodiversity conservation: opportunity knocks

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Abstract

The fact that the expansion and intensification of agriculture has been the major driver of past biodiversity loss and ecosystem degradation globally is beyond dispute. It is highly likely that these trends will continue through the 21st century, unless action is taken to design effective management strategies for biodiversity in agricultural landscapes. To do this, we first need to recognize that some biodiversity is retained in farmland, and that it is the degree of biodiversity retention that we need to understand and effectively manage. We need to understand which biodiversity components are retained as a natural ecosystem is converted to agriculture and why; how community dynamics affect biodiversity retention; and how we can effectively manage biodiversity retention. These questions are being addressed, but much remains to be done; and we have to accept that progress will be contentious. Challenging as these questions are, conservationists cannot address them in isolation. Multifunctional ecosystem science and policy linked to human well-being is the ultimate goal. While the goal seems distant and daunting, integration between relevant research disciplines is happening, research funding is beginning to recognize the need for better integration and policy has to respond. Conservation science has a key role to play and must be ready to meet this challenge.

Introduction

The expansion and intensification of agriculture during the 20th century contributed to poverty alleviation and improved food security globally, but these benefits came at a cost to the environment (Tilman 1999). Natural ecosystems have been destroyed or damaged, and the ecosystem services they provide to man degraded or lost (MEA 2005). Not surprisingly, these ecosystem changes have been accompanied by losses of biodiversity locally and by an increased risk of extinction globally. According to IUCN data, agriculture is a major cause of global endangerment (Figure 1); and recent analyses have shown that endangerment is closely linked with agricultural land-use (Scharlemann *et al.* 2005). Even within regions, such as Europe, with a long history of agricultural land-use, intensification during the 20th century contributed to considerable biodiversity losses (Donald *et al.* 2001; Donald *et al.* 2006).

World food demand is expected to double from 20th century levels by 2050 (Tilman *et al.* 2002). Estimates suggest that agricultural land area in developing countries might need to increase considerably (e.g., by 25%) to meet this demand (Balmford *et al.* 2005), and it seems likely that this expansion will occur disproportionately within tropical and subtropical areas of high current biodiversity value (Scharlemann *et al.* 2004). In addition, the demand for crop lands to grow industrial raw materials, such as bioenergy, is increasing (Field *et al.* 2008); and certain crops such as oil palm and sugar cane provide poor-quality habitat for biodiversity in comparison with the natural habitats they often replace (Petit & Petit 2003; Aratrakorn *et al.* 2006). The detrimental impact of agriculture on ecosystems and their associated biodiversity is, therefore, set to continue through the 21st century.

The need for agroecosystems to play a major role in biodiversity conservation is becoming increasingly recognized (Fischer *et al.* 2006; Perrings *et al.* 2006). Addressing

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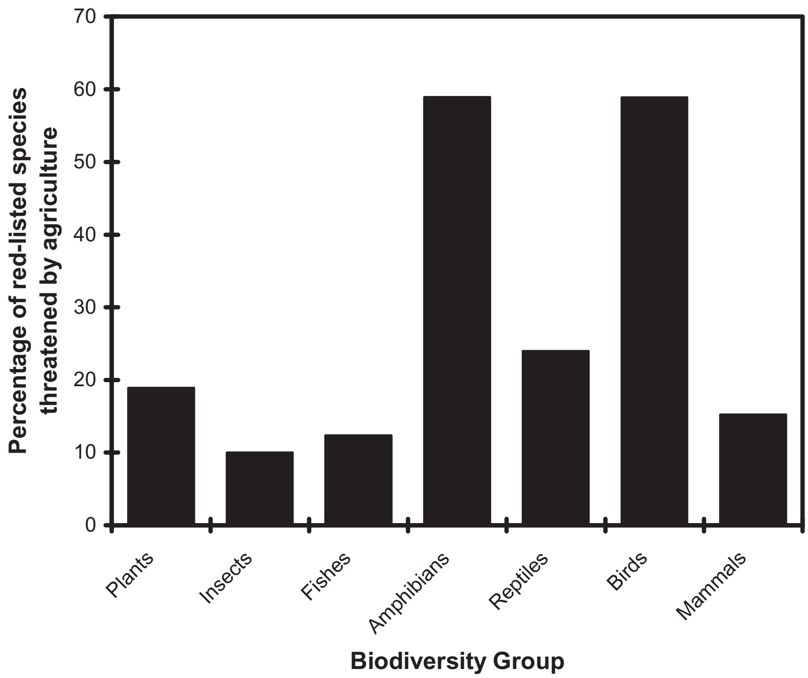

Figure 1 The percentage of red-listed species threatened by agriculture in a range of biodiversity groups. Data are from the World Conservation Union (IUCN) Red List database (http://www.iucnredlist.org/search/search-basic). Least concern (LC) species were excluded from the analysis. IUCN threat codes used to assess agricultural threats were 1.1, 6.2.1, 6.3.1, and 6.3.7.

this need is presenting conservation science with new challenges and opportunities. Knowledge gaps exist; ideas for land management strategies are emerging that require new data and further development; and biodiversity conservation is increasingly becoming part of a more holistic view of ecosystems and their value to man. This review aims to evaluate critically what we currently know, where gaps still exist, and highlight the need for better integration between conservation science and a range of other research disciplines to address agricultural landscapes as multifunctional ecosystems.

Agriculture and the retention of biodiversity

Conservationists are no strangers to evocative images of habitat destruction, in which remnant patches of natural habitat are left isolated amid an apparently inhospitable matrix. Given its impact on ecosystems and their biodiversity, it is tempting to view agriculture in the same stark way, and there are undoubtedly examples of landscapes in which this view of agriculture is ecologically justified. However, as a conceptual basis for understanding the impact of agriculture on biodiversity and its management, this image of agriculture is false for two main reasons. First, in landscapes with remnant patches of natural habitat the agricultural "matrix" is not a featureless area of unsuitable habitat, but a heterogeneous part of the landscape within which "suitability" is likely to vary between species. Studies are beginning to address how dispersal rates through an agricultural matrix affect species persistence in remnant patches of natural habitat (Lens *et al.* 2002), but we clearly need to understand better the ecology of agriculture as a "matrix" habitat, and the extent to which this affects the retention of biodiversity in agricultural landscapes (Wiens 2001; Donald & Evans 2006). Secondly, even if large blocks of remnant natural habitat are lacking or widely dispersed within an agricultural landscape, agricultural production systems vary in the biodiversity they retain, when compared with the natural habitats from which the land was originally derived. Agroforestry and silvo-pastoral systems in particular can retain significant fractions of original forest biodiversity; while others, such as oil palm and rubber plantations, and sugar cane, retain considerably less (Petit & Petit 2003; Donald 2004; Aratrakorn *et al.* 2006).

These observations suggest that it is the degree to which biodiversity is retained in agricultural landscapes that we need to understand and manage effectively (Scholes & Biggs 2005). To facilitate this understanding, we need to view agricultural landscapes as functional ecosystems consisting of natural/seminatural and managed (agricultural) components, rather than viewing either the natural or managed components in isolation (Fischer *et al.* 2006). We can then address key questions for biodiversity conservation: which biodiversity components are retained as agriculture expands and intensifies within landscapes and why; what community dynamics underpin these changes; and how can we effectively manage biodiversity retention?

Biodiversity retention, community dynamics, and management strategies

Describing and explaining patterns of biodiversity retention

The typical approach used by ecologists to study biodiversity retention is the agricultural intensification or agricultural land-use gradient, which in effect uses spatial variation in agricultural land-use as pseudoexperimental treatments to investigate biodiversity impacts. A classic example of this approach is the study of agroforestry systems cultivating coffee, in which the gradient is defined by increasing production intensity from native forest and traditional agroforestry systems, through more intensively managed shade systems, to cultivation without shade (Donald 2004) (Figure 2). A wide range of studies have described biodiversity changes along this gradient, or parts of this gradient, in different regions (Moguel & Toledo 1999; Perfecto *et al.* 2003; Gillison *et al.* 2004; Tejeda-Cruz & Sutherland 2004; Pineda *et al.* 2005). There are a plethora of studies that have used a comparable approach in a range of different agricultural systems, geographical areas, and biodiversity groups.

An extension of the idea of land-use gradients is to investigate the wider landscape context within which a particular production system occurs (Figure 2). For example, studies on coffee agroforestry systems have shown that pollinator diversity on farms is, at least in part, related to proximity to remnant forest patches, and coffee plants relatively close to remnant forest also have higher pollination rates (Klein *et al.* 2003b, a; De Marco & Coelho 2004; Ricketts 2004). Comparable patterns are evident in more intensively managed landscapes as well (see below). This approach takes a more holistic ecosystem view of agricultural landscapes, and neatly links natural habitats with biodiversity and ecosystem service delivery in the managed, agricultural component. Ideally, studies would be able to document biodiversity changes along intensification gradients, over a range of wider landscape contexts. In theory, it should then be possible to explore biodiversity retention across a range of landscape conditions. In practice, identifying suitable landscapes that cover a wide range of conditions is likely to be challenging, not least because intensively managed agricultural landscapes also tend to have relatively little remnant natural habitat.

While progress is being made describing biodiversity patterns in relation to agricultural land-use such as changes in species richness or the occurrence/abundance of particular guilds, we know less about the underlying mechanisms responsible for these patterns. There is a dearth of information on population densities and trends in relation to land-use gradients (Green *et al.* 2005), except for isolated cases for which long-term data are available (Gillings *et al.* 2005); and demographic data are also sparse (Komar 2006). Some studies have explored species traits that are related to persistence or loss along land-use gradients (Aratrakorn *et al.* 2006) or population trends in relation to increasing intensification over time (Butler *et al.* 2007). There is real potential to apply comparative methods more widely in this area, and so provide insights that might help manage the biodiversity impacts of agriculture in the future (Norris & Harper 2004). We need to synthesize existing studies to establish whether generalities exist both within and between biodiversity groups, and make better use of biodiversity pattern data to explore underlying mechanisms.

Community dynamics and biodiversity retention

While linking patterns of biodiversity change in relation to agricultural land-use with comparative analyses of traits that affect species' susceptibility to change would aid our understanding of biodiversity retention, these approaches inevitably address species interactions rather simplistically if at all (Butler *et al.* 2007). Theoretically, an agricultural change could directly affect the persistence of a particular species, which could in turn indirectly affect the persistence of a number of others by modifying the ecological interactions between them (Memmott *et al.* 2004). What is known about these cascades, and to what extent can they help explain biodiversity retention in agricultural landscapes?

The simple answer is that we know relatively little—with the majority of studies to date on biodiversity loss/retention tending to focus on describing biodiversity change rather than changes in species interactions (van der Putten *et al.* 2004). However, there is evidence consistent with the idea that land-use can modify species interactions and hence biodiversity, particularly for flowering plant-insect pollination systems and the delivery of pollination services to wild and crop plants (Kremen *et al.* 2002). Furthermore, the conservation of rare plant species might depend, at least to some extent, on conserving interactions between more widespread plants and pollinators (Gibson *et al.* 2006). Understanding how such interactions change is being addressed using quantitative food webs (Memmott 1999), and this approach has recently been applied to explore how food webs change along an agricultural land-use gradient (Tylianakis *et al.* 2007). Additional studies using this approach are needed in order to see whether generalizations begin to emerge.

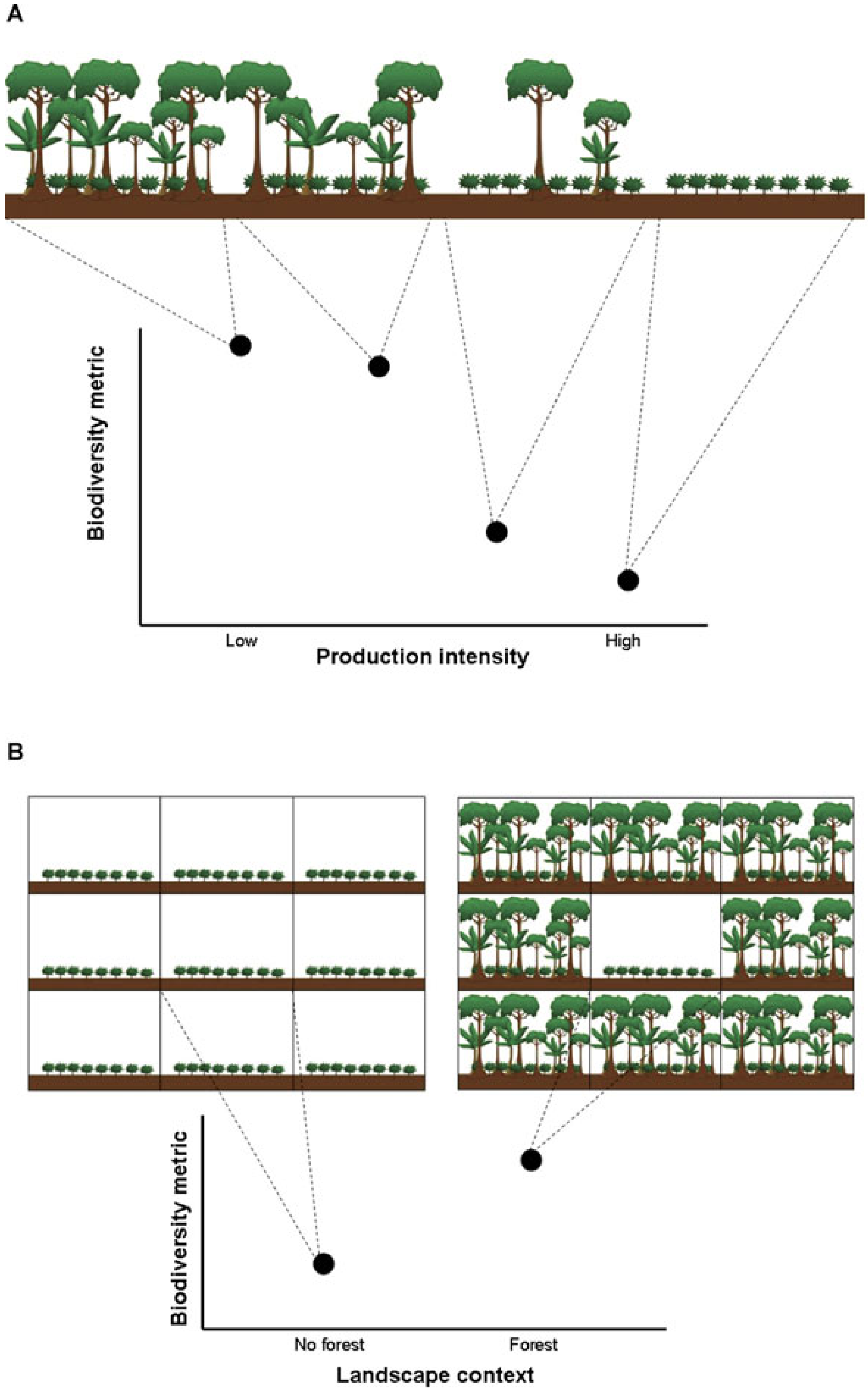

Figure 2 Describing the relationship between biodiversity and **(A)** the intensity of agricultural production, and **(B)** the landscape context of a specific agricultural land-use. The term "biodiversity metric" is used to describe any statistic that might be used to quantify biodiversity value, such as species richness. The land-use schematic in (A) illustrates an agroforestry production system (e.g., coffee) that ranges in intensity from (low intensity) traditional shade systems with relatively extensive tree cover, to (high intensity) full-sun systems devoid of shade. The land-use schematic in (B) illustrates a full-sun production system in contrasting landscape contexts—one in a landscape consisting of other full-sun farms (*no forest*), and the other in a landscape consisting of traditional shade farms with extensive tree cover (*forest*).

Quantitative food webs can also be used for making predictions about the impact of future environmental change (Memmott *et al.* 2007), but we still need to critically apply this approach to agricultural systems by validating predictions in the field.

Another approach that provides insights into community dynamics is the use of microcosm experiments (Benton *et al.* 2007). Agricultural grassland systems have been particularly productive in this respect, providing insights into biodiversity and ecosystem function (Tilman *et al.* 2001; Tilman *et al.* 2006), community assembly (Fukami *et al.* 2005), and a mechanistic understanding of the impact of management on biodiversity (Harpole & Tilman 2007). However, the extent to which microcosms can provide insights into large-scale issues facing biodiversity in agricultural landscapes remains debatable. Certain authors have argued that microcosms are irrelevant to these types of land-use change issue (Srivastava & Vellend 2005); whereas others have argued that microcosms should be seen as part of a more integrated theoretical, experimental, and field research agenda (Benton *et al.* 2007). This latter view is, in my opinion, rather optimistic given the complexities and scales associated with understanding biodiversity in agricultural landscapes. While studies in real landscapes frequently lack the experimental elegance of a microcosm, agricultural land-use gradients have the advantage that they provide a basis for observational, experimental, and theoretical studies at a range of scales and levels of ecological complexity typical of the "real world."

Managing biodiversity retention

If biodiversity losses are to be halted, agricultural landscapes must be managed more effectively to maximize biodiversity retention, while providing sufficient agricultural outputs to meet current and future demand. At first sight, this appears a diffuse problem because different regions of the world face different issues that are relevant to management. For example, in many parts of Central and South America, Africa, and South-East Asia agricultural expansion is causing the loss of natural habitats and more traditional low-intensity forms of agriculture; whereas in North-West Europe, for example, agricultural landscapes are already dominated by intensive agriculture, and little natural habitat remains. Human population growth is also very different in these contrasting regions. Nevertheless, in each of these regions we seem to be faced with a choice between wildlife-friendly farming, whereby on-farm practices are made as benign to wildlife as possible (at the potential cost of decreasing yields); and land sparing, in which farm yields are increased and pressure to convert land for agriculture thereby reduced (at the potential cost of decreasing wildlife populations on farmland) (Balmford *et al.* 2005; Green *et al.* 2005). How do we decide which option is likely to be most effective?

Theoretically, the best option depends upon the way population densities of individual animal or plant species change along an agricultural intensification (= yield) gradient (Green *et al.* 2005). If population density drops sharply when natural habitat is converted to low-intensity production (low yield), then land sparing is the most effective strategy for a species. In contrast, wildlife-friendly farming is the best option if population density only drops sharply under conditions of high-intensity production (high yield). However, data are currently lacking that would allow us to distinguish between these alternatives (Green *et al.* 2005).

The land-sparing idea is contentious, mainly because concerns have been expressed about whether intensification actually "spares" land for conservation (Morton *et al.* 2006; Dorrough *et al.* 2007). Application of this idea will also be problematic due to contrasting biodiversity responses to intensification (Perfecto *et al.* 2003). Even so, it is important that we build an evidence base upon which we can design effective landscape management strategies for biodiversity. We first need to collect the appropriate data to assess critically, which strategy is likely to be best "in principle" for biodiversity in a given landscape; and then undertake inter-disciplinary research to explore the feasibility of implementing the "best" strategy and the potential socioeconomic mechanisms that might need to be adopted to shape agricultural land-use in the desired way. In doing so, it may be pragmatic to consider both land sparing and wildlife-friendly farming as component parts of the solution, rather than as alternative outcomes (Fischer *et al.* 2008). However, simply because land sparing might seem difficult to implement in the current socioeconomic climate does not mean it has limited potential, especially as agriculture policy increasingly recognizes the need to improve environmental sustainability (Mattison & Norris 2005).

Interestingly, the policy drive to promote wildlife-friendly farming in Europe has taken place in the absence of evidence to show this is the most efficient mechanism to maximize biodiversity retention and agricultural output, despite calls in some countries to consider these issues more broadly (Sutherland 2002, 2004). It could be argued that this debate is peripheral in Europe because of the desire to reduce agricultural output, following years of overproduction. However, there are at least two reasons why considering land sparing as an option in Europe is important. First, farmers are reluctant to introduce management, within wildlife-friendly farming schemes, to the productive areas of fields, concentrating instead on measures to improve the biodiversity value of field margins and boundaries. Although this is likely to increase biodiversity value, it seems unlikely that this will be sufficient to meet biodiversity targets (Butler *et al.* 2007). Secondly, increasing demand for industrial raw materials derived from crops (e.g., bioenergy) and high current commodity prices reduce the economic incentives to take land out of production, or compromise production to manage farmland in a wildlife-friendly way.

Even if we accept that wildlife-friendly farming is the best option, there has been considerable debate in Europe about whether or not wildlife-friendly farming schemes work. Small-scale programs targeted at particular species do seem to work (Peach *et al.* 2001), but the impact of larger-scale national programs is equivocal (Kleijn *et al.* 2001; Kleijn & Sutherland 2003; Kleijn *et al.* 2004; Kleijn *et al.* 2006; Knop *et al.* 2006; Whittingham 2007). The debate has been fuelled by poorly defined program objectives for biodiversity and a lack of rigorous evaluation. Furthermore, the implementation of programs rarely considers the wider landscape context, even though studies of both small- and large-scale programs show this is important in terms of biodiversity impact (Peach *et al.* 2001; Bradbury *et al.* 2004).

Biodiversity conservation as part of a multifunctional landscape

Conservation science meets agricultural and social science

So far, the discussion has focused on biodiversity conservation in isolation. As data on biodiversity patterns grow and our understanding of the ecological processes driving these patterns improves, we will increasingly need to link the conservation science with studies of agricultural and land-use change (Mattison & Norris 2005; Tallis & Kareiva 2006). We need to build a two-way street between conservation science on the one hand; and agricultural and social science on the other (Perrings *et al.* 2006). This would allow us to understand how to effect desirable land-use changes for biodiversity benefits, while exploring the agricultural, social, and economic consequences; and to understand how agricultural, social and economic factors drive land-use change, while exploring the biodiversity consequences.

There are already examples of this type of integration, although there is clearly much more that needs to be done to develop a genuinely unified approach. The following examples illustrate the types of approach being used. Readily available data on the land areas and yields of agricultural commodities have been related to population trends to explore the relationship between agricultural outputs and biodiversity (Donald *et al.* 2001). Socioeconomic models of land-use change have been directly linked to ecological models to explore the potential impact of land-use change scenarios (Rounsevell *et al.* 2006). Social data have been used to explore drivers of land-use change, and these studies have been linked to an assessment of the impact of land-use change on biodiversity and ecosystem function (Steffan-Dewenter *et al.* 2007).

Ecosystem services and multiple environmental objectives

Wildlife-friendly farming in Europe is encouraged by Government payments to farmers (Kleijn & Sutherland 2003), and there are examples elsewhere of comparable schemes based on payments for the protection of ecosystem services (Chomitz *et al.* 1999). This illustrates a simple but important truth. If we want to retain biodiversity in agricultural landscapes we need to understand better the value (both social and economic) of biodiversity to man, and develop mechanisms to return this value to rural communities managing the land. This is true irrespective of whether we decide to spatially segregate (e.g., land sparing) or integrate the natural and managed components of agricultural landscapes.

Certain biodiversity groups have large economic value as a result of the ecosystem services they provide. For example, pollination and pest control services to agriculture were valued in excess of U.S. $240 billion p.a. at 1994 prices (Costanza *et al.* 1997). Recent work on insect pollinators has begun to understand the links between landscape structure and the diversity of service providers, and between the diversity of service providers and service provision (Klein *et al.* 2003a; Kremen *et al.* 2004; Klein *et al.* 2007); but clearly much more work is needed in this area (Tscharntke *et al.* 2005; Kremen *et al.* 2007). Furthermore, it is becoming increasingly apparent that maintaining an ecosystem service in the absence of biodiversity is problematic, as illustrated by the recent collapse in honey bee populations in the United States (Kearns *et al.* 1998; Kremen *et al.* 2002). This means that the conservation of natural habitats and their biodiversity to provide pollination services to agriculture can make good economic sense (Morandin & Winston 2006).

Not all biodiversity is so easy to value though. One way to overcome this difficulty is to embed biodiversity conservation within a more holistic understanding of a range of other ecosystem services within agricultural landscapes. The way agricultural land-use is being shaped by the climate change agenda provides an illustration of the possible opportunities and problems of a more holistic approach. Agriculture has important implications for the global carbon cycle (Lal 2004), and provides opportunities to sequester and store carbon. Agroforestry systems are particularly promising in this respect (Albrecht & Kandji 2003). There is an emerging market for carbon and at least one example of a payment system for landowners designed to protect forests, in part, for carbon storage (Chomitz *et al.* 1999). Evidence suggests that shaded agroforestry systems are of higher biodiversity value than more intensive, shade-free production systems (see above); so paying farmers to maintain forest cover for carbon storage could, at least in principle, also help to protect biodiversity.

Climate change is also generating interest in renewable energy sources based, in part, on bioenergy crops. While ameliorating climate change in this way might benefit biodiversity, there are also potentially negative impacts of land-use change associated with bioenergy crops (Field *et al.* 2008), such as forest clearance in SE Asia to cultivate oil palm. These climate change examples illustrate the need for a more integrated research agenda in which we explore the implications of land-use for multiple environmental objectives, including biodiversity.

Multifunctional ecosystem science

To address the future links between agriculture and biodiversity we need to increasingly embed this issue within a wider agenda based on multifunctional landscape science and policy linked to human well-being (Chan *et al.* 2006; Farber *et al.* 2006; Kareiva *et al.* 2007). We need to understand synergies and trade-offs between environmental objectives in relation to land-use (Kareiva *et al.* 2007), and in so doing take a more holistic view of the environmental impact of the drivers of land-use change, and the way these drivers can be influenced to manage change. Agriculture and biodiversity are important components of this vision because both influence a wide range ecosystem services linked to human well-being. How do we tackle the science, who is likely to fund it, and how do we engage with policy makers?

There are already ambitious, integrated projects taking place as part of the Natural Capital Project (http://www.naturalcapitalproject.org/tanzania_prim.html), and there are a number of examples above of more focused, integrated projects that bring together land-use and biodiversity with agricultural, social and natural sciences in various ways. These provide an excellent foundation for the development of new projects. There are signs that research funding agencies are responding to the need for integration. Within the UK, for example, Government funding for science is dispensed, in large part, through a series of Research Councils that support specific broad subject areas such as the physical, natural, biological, or social sciences. A number of cross-council initiatives have developed to support interdisciplinary research over recent years, such as the >£20M Rural Economy and Land-Use (RELU) programme (http://www.relu.ac.uk/) and the £30M Living with Environmental Change program (http://www.nerc.ac.uk/research/programmes/lwec/). This research activity needs to feed into policy development and implementation. This will be challenging (Lawton 2007), not least because it will require traditionally separate areas of policy to come together. However, if we approach the science in a more holistic way, we will have a better evidence-base upon which to argue for better-integrated policies.

Concluding remarks

Agriculture is a major driver of global biodiversity loss. If we want to halt these losses, then we need to learn from the past, and develop a more sustainable vision for the future. The issue of agriculture and biodiversity needs to be embedded in a more holistic view that considers the implications of land-use for a wide range of ecosystem services. Conservation science has an immensely important role to play if this opportunity is to be realized. We need a better understanding of biodiversity patterns in relation to land-use and of the underlying processes; we need data to help design management strategies in landscapes to retain biodiversity; we need further work on the role of biodiversity in ecosystem function and the delivery of ecosystem services; we need to describe the relationships between biodiversity and other ecosystem services mediated by land-use; and we need to bring all these areas of research together with the agricultural and social sciences. This multifunctional view of agricultural landscapes seems daunting, but we must meet the challenge. Our ability to feed people, alleviate poverty and protect the environment depends upon it.

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