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Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes

Sara J. Scherr[1] and Jeffrey A. McNeely[2,*]

[1]*Ecoagriculture Partners, Washington, DC 20001, USA*
[2]*World Conservation Union—IUCN, 1196 Gland, Switzerland*

The dominant late twentieth century model of land use segregated agricultural production from areas managed for biodiversity conservation. This module is no longer adequate in much of the world. The Millennium Ecosystem Assessment confirmed that agriculture has dramatically increased its ecological footprint. Rural communities depend on key components of biodiversity and ecosystem services that are found in non-domestic habitats. Fortunately, agricultural landscapes can be designed and managed to host wild biodiversity of many types, with neutral or even positive effects on agricultural production and livelihoods. Innovative practitioners, scientists and indigenous land managers are adapting, designing and managing diverse types of 'ecoagriculture' landscapes to generate positive co-benefits for production, biodiversity and local people. We assess the potentials and limitations for successful conservation of biodiversity in productive agricultural landscapes, the feasibility of making such approaches financially viable, and the organizational, governance and policy frameworks needed to enable ecoagriculture planning and implementation at a globally significant scale. We conclude that effectively conserving wild biodiversity in agricultural landscapes will require increased research, policy coordination and strategic support to agricultural communities and conservationists.

Keywords: ecoagriculture; landscape; biodiversity conservation; agricultural production; rural livelihoods

1. INTRODUCTION

The Millennium Ecosystem Assessment (MA) documented the dominant impacts of agriculture on terrestrial land and freshwater use, and the critical importance of agricultural landscapes in providing products for human sustenance, supporting wild species biodiversity and maintaining ecosystem services (MA 2005). Yet global demand for associated agricultural products is projected to rise at least 50% over the next two decades (UN Millennium Project 2005). The need to reconcile agricultural production and production-dependent rural livelihoods with healthy ecosystems has prompted widespread innovation to coordinate landscape and policy action (Breckwoldt 1983; Jackson & Jackson 2002; McNeely & Scherr 2003; Acharya 2006). However, the dominant national and global institutions—for policy, business, conservation, agriculture and research—have been shaped largely by 'mental models' that assume and require segregated approaches.

This paper will discuss a new paradigm, 'ecoagriculture': integrated conservation–agriculture landscapes in which biodiversity conservation is an explicit objective of agriculture and rural development, and the latter are explicitly considered in shaping conservation strategies. Sections 2 and 3 present the rationale for scaled-up action to promote ecoagriculture landscapes, and define the approach. Section 4 assesses the current state of ecoagriculture knowledge and practice, in relation to agricultural technology, landscape management, financial viability, and supportive policies and investments. Section 5 outlines strategic actions required to mobilize ecoagriculture initiatives on a scale that would have a meaningful impact on global challenges for agricultural production and ecosystem management.

2. THE CHALLENGE OF MANAGING AGRICULTURAL LANDSCAPES IN THE TWENTY-FIRST CENTURY

Current trends suggest that, during the twenty-first century, a continuing and growing demand for agricultural and wild products and ecosystem services will require farmers, agricultural planners and conservationists to reconsider the relationship between production agriculture and conservation of biodiversity.

(a) *The current ecological footprint of agriculture*

Nearly one-third of terrestrial lands have agricultural crops or planted pastures as a dominant land use (accounting for at least 30% of total area), thus having a profound ecological effect on the whole landscape. Another 10–20% of land is under extensive livestock grazing; and approximately 1–5% of food is produced in natural forests (Wood *et al.* 2000). The 'human footprint' analysis of Sanderson *et al.* (2002) estimated

* Author for correspondence (jam@iucn.org).

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that 80–90% of lands habitable by humans is affected by some form of productive activity. More than 1.1 billion people, most agriculture-dependent, now live within the world's 25 biodiversity 'hot spots', areas described by ecologists as the most threatened species-rich regions on Earth (Cincotta & Engelman 2000; Myers *et al.* 2002).

Both extensive lower-yield and intensive higher-yield agricultural systems have profound ecological effects. Millions of hectares of forests and natural vegetation have been cleared for agricultural use and for harvesting timber and wood fuels, and empirical evidence suggests that intensification rarely results in saving 'land for nature'(Angelsen & Kaimowitz 2001). Half the world's wetlands have already been converted; California alone has lost 91% of its wetlands (WWF 2005). Overuse and mismanagement of pesticides poison water and soil, while nitrogen and phosphorus inputs and livestock wastes have become major pollutants of surface water, aquifers, and coastal wetlands and outlets. Between 1890 and 1990, the total amount of biologically available nitrogen created by human activities increased ninefold, and human activity now produces more nitrogen than all natural processes combined (MA 2005). Agrochemical nutrient pollution from the US farm belt is the principal cause of the biological 'dead zone' in the Gulf of Mexico 1500 km away (Rabalais *et al.* 2002), and similar impacts are felt in the Baltic Sea and along the coasts of China and India. Environmental impacts of livestock are extensive (Steinfeld *et al.* 2006).

Some introduced agricultural crops, livestock, trees and fishes have become invasive species, spreading beyond their planned range and displacing native species (Matthews & Brand 2004; Mooney *et al.* 2005). Concerns about genetically modified crop varieties include their potential to become invasive species or to hybridize with wild relatives, leading to the loss of biodiversity (NAS 2002; Oksman-Caldentey & Barz 2002; Omamo & von Grebmer 2005). Agriculture fragments the landscape, breaking formerly contiguous wild species populations into smaller units that are more vulnerable to extirpation. Farmers generally have sought to eliminate wild species from their lands in order to reduce the negative effects of pests, predators and weeds. However, these practices often harm beneficial wild species like pollinators (Buchmann & Nabhan 1996), insect-eating birds and other species that prey on agricultural pests.

These threats posed by agriculture to conservation have been a key motivator for conservationists to develop protected areas where agricultural activity is officially excluded or seriously circumscribed. Nonetheless, the MA (Hassan *et al.* 2005) calculated that more than 45% of 100 000 protected areas (PAs) had more than 30% of their land area under crops. In light of political and economic realities, many recently designated PAs in several African countries explicitly permit biodiversity-friendly agriculture, usually in areas considered category V or VI in the IUCN system (IUCN 1994).

(b) *Meeting increased demand for agricultural products in ecologically sensitive areas*

Human population is expected to grow from a little over 6 billion today to over 8 billion by 2030, an increase of approximately one-third, with another 2–4 billion added in the subsequent 50 years (Cohen 2003). But food demand is expected to grow even faster, as a result of growing urbanization and rising incomes, and if hunger is reduced among 800 million people currently undernourished (UN Millennium Project 2005). More land will surely be required to grow crops, even more so if biofuels become a greater contributor to energy needs. In Africa alone, land in cereal production is expected to increase from 102.9 Mha in 1997 to 135.3 Mha in 2025 (Rosegrant *et al.* 2005). Global consumption of livestock products is predicted to rise from 303 million metric tonnes in 1993 to 654 million tonnes in 2020 (Delgado *et al.* 1999).

Tilman *et al.* (2001) predict that feeding a population of 9 billion using current methods could result in converting another 1 billion hectares of natural habitat to agricultural production, primarily in the developing world, together with a doubling or tripling of nitrogen and phosphorous inputs, a twofold increase in water consumption and a threefold increase in pesticide use. A serious limiting factor is expected to be water, as 70% of the freshwater used by people is already devoted to agriculture (Rosegrant *et al.* 2002). Scenarios prepared by the MA thus suggest that agricultural production in the future will have to focus more explicitly on ecologically sensitive management systems (Carpenter *et al.* 2005).

Below are four major reasons why meeting increased demand for agricultural products will often require ecoagriculture systems.

(i) *Most of the increased food production will be grown domestically and increasingly in more 'marginal' or 'fragile' lands*

An estimated 90% of food products consumed in most countries will be produced by those countries. Total export levels increased sharply between 1961 and 2000, but agricultural exports still accounted for only approximately 10% of production (McCalla 2000). This pattern seems unlikely to change over the next few decades, even though continuing globalization of agriculture will influence product mix and prices. A reduction in developed world subsidies could further spur export agriculture in the developing world (Runge *et al.* 2003). Changes will depend not only on productivity and quality, but also on shifts in relative transport costs for international shipping and internal overland transport, and the distances between major population centres, ports and agricultural regions. Large and growing interior populations in large countries will continue to be fed mainly by local and national producers.

The declining rate of growth in yields in places like Punjab in India, the US Midwest and the Mekong Delta indicates that most new production may not come from the areas of highest current grain productivity, and some areas are already experiencing declining yields or productivity of inputs (Rosegrant & Clein 2003). While yields may increase somewhat in these places, through greater input use, plant breeding, biotechnology and improved irrigation efficiency (Runge *et al.* 2003), marginal costs are likely to be high, as are the environmental costs.

Moreover, lower-productivity lands (drylands, hillsides and rainforests) now account for more than two-thirds of total agricultural land in developing countries (Nelson *et al*. 1997). Because current yields are relatively low, technologies already existing can double or even triple yields, with adequate investment, market developments and attention to good ecosystem husbandry (UN Millennium Project 2005). Extensive grain monocultures are not likely to be sustainable in such areas, calling for more diversified land use approaches. Though the bulk of new production will come mainly from existing croplands, the most promising areas with significant new land for agriculture are in places like the forest and savannah zones of Brazil and Mozambique, which are the main remaining large reservoirs of natural habitat. These habitats will be seriously damaged by highly simplified, high external-input production systems, but an ecoagriculture approach could significantly reduce the damage.

(ii) *Wild products continue to be important for local food supply and livelihoods*

People in low-income developing countries and subregions will continue to rely on harvesting wild species. Wild greens, spices and flavourings enhance local diets, and many tree fruits and root crops serve to assuage 'pre-harvest hunger' or provide 'famine foods' when crops or the economy fails. Frogs, rodents, snails, edible insects and other small creatures have long been an important part of the rural diet in virtually all parts of the world (Paoletti 2005). Bushmeat is the principal source of animal protein in humid West Africa and other forest regions, and efforts to replace these with domestic livestock have been disappointing. Fisheries are the main animal protein source of the poor worldwide. In Africa and many parts of Asia, more than 80% of medicines still come from wild sources. Gathered wood fuel remains the main fuel for hundreds of millions of people, while forests and savannahs provide critical inputs for farming in the form of fodder, soil nutrients, fencing, etc. (McNeely & Scherr 2003). Achieving food security therefore will require the conservation of the ecosystems providing these foods and other products.

(iii) *Agricultural systems will need to diversify to adapt to climate change*

Strategic planning for agricultural development has begun to focus on adaptation of systems to climate change, anticipating rising temperatures and more extreme weather events. The US Department of Agriculture and the International Rice Research Institute have both concluded that with each 1°C increase in temperature during the growing season, the yields of rice, wheat and maize drop by 10% (Tan & Shibasaki 2003; Brown 2004). Cash crops such as coffee and tea, requiring cooler environments, will also be affected, forcing farmers of these crops to move higher up the hills, clearing new lands as they climb. Montane forests important for biodiversity are likely to come under increasing threat. Effective responses to climate change will require changing varieties and modified management of soils and water, and new strategies for pest management as species of wild pests, their natural predators, and their life cycles change in response to climates. Increasing landscape and farm-scale diversity are likely to be an important response for risk reduction (Jackson *et al.* 2005).

(iv) *Agricultural sustainability will require investment in ecosystem management*

Meeting food needs and economic demand for agricultural products will be constrained by widespread resource degradation that is already either reducing supply or increasing costs of production. Up to 50% of the globe's agricultural land and 60% of ecosystem services are now affected by some degree of degradation, with agricultural land use the chief cause of land degradation (MA 2005; Bossio *et al*. 2004). Half the world's rivers are seriously depleted and polluted and 60% of the world's 227 largest rivers have been significantly fragmented by large dams, many built to supply irrigation water. Estimates are that 20% of irrigated land suffers from secondary salinization and waterlogging, induced by the build-up of salts in irrigation water (Wood *et al*. 2000). The food system will also have to address, or adapt to, the collapse in harvests of wild game and wild fisheries in many regions around the world, due to overexploitation and habitat loss or pollution (Hassan *et al*. 2005). Considerable investments will be required to rehabilitate degraded resources and ecosystems upon which food supplies, particularly of the rural poor, depend (UN Millennium Project 2005).

(c) *Meeting increased demand for ecosystem services*

Conservation of wild biodiversity (genes, species and ecosystems) is considered by many to be an ethical imperative. At the same time, conservation also supports 'ecosystem services'—ecological processes and functions that sustain and improve human well-being (Daily 1997). Ecosystem services can be divided into four categories: (i) *provisioning services*, or ecosystems that provide food, timber, medicines and other useful products, (ii) *regulating services* such as flood control and climate stabilization, (iii) *supporting services* such as pollination, soil formation and water purification, and (iv) *cultural services*, which are aesthetic, spiritual or recreational assets that provide both intangible benefits and tangible ones such as ecotourism attractions (Kremen & Ostfeld 2005). 'Provisioning' historically has been seen as the highest priority service provided by agricultural landscapes. But it is now recognized that even the 'bread baskets' and 'rice bowls' of the world also provide other ecosystem services, such as water supply and quality, or pest and disease control, that are also important (Wood *et al*. 2000).

The conservation community is moving towards an 'ecosystem approach' to conserving biodiversity, in light of the dependence of protected areas on a supportive matrix of land and water use, and creation of biological corridors (Convention on Biological Diversity 2000). The international community has set a goal of having at least 10% of every habitat type under effective protection by 2015 (The Nature Conservancy 2004). This strategy, if successful, will protect many species and ecological communities. But some estimates suggest that more than half of all species exist principally outside PAs, mostly in agricultural landscapes (Blann 2006). For example, conservation of wetlands within agricultural landscapes is critical for wild bird populations (Heimlich *et al*. 1998). Such species will be conserved only through initiatives by and with farmers. The concept of agriculture as ecological 'sacrifice' areas is no longer valid in many regions, because agricultural lands both perform many ecosystem services and provide essential habitat to many species.

(i) *Agricultural landscapes provide critical watershed functions*

Many of the world's most important watersheds are densely populated and under predominantly agricultural use, and most of the rest are in agricultural land use mosaics where crop, livestock and forest production influence hydrological systems (Wood *et al*. 2000). In such regions, agriculture can be managed to maintain critical watershed functions, such as maintaining water quality, regulating water flow, recharging underground aquifers, mitigating flood risks, moderating sediment flows, and sustaining freshwater species and ecosystems. This has led to the concept of 'green water': that terrestrial land, soil and vegetation management have critical roles in the hydrological cycle (de Vries *et al*. 2003). Effective management of green water encompasses the choice of water-conserving crop mixtures, soil and water management (including irrigation), maintenance of soils to facilitate rainfall infiltration, vegetation barriers to slow movement of water downslopes, year-round soil vegetative cover and maintenance of natural vegetation in riparian areas, wetlands and other strategic areas of the watershed. Well-managed agricultural landscapes can also provide protection against extreme natural events. With increased water scarcity and more frequent extreme weather events predicted in coming decades, the capacity of agricultural systems to sustain watershed functions is likely to be a priority consideration in agricultural investment and management.

(ii) *Agricultural landscapes maintain 'green space', recreational opportunities, healthy habitats and aesthetic beauty in human settlements*

With accelerating urbanization worldwide, the loss of natural habitats and natural features has become a central concern for planners and residents, as well as farmers operating in peri-urban areas. Agriculture can protect green spaces for aesthetic and recreation values, and help to finance the maintenance of green space for wildlife habitat and ecosystem services. Overall positive outcomes for human habitat and aesthetics require adequate management of crop and livestock wastes, air pollution (smoke, dust and odours) and polluting run-off.

3. ECOAGRICULTURE: INTEGRATING PRODUCTION AND CONSERVATION AT A LANDSCAPE SCALE

The challenges described earlier are unlikely to be met by the solutions of industrial agriculture, the original green revolution, sustainable agriculture and natural resource management (with its primary focus on sustaining the resources underpinning production), or even the ecotechnology approach of Swaminathan (1994) with its focus on the farmer's field, although all of these have major elements to contribute. Approaches to biodiversity conservation also need to move beyond the wild biodiversity focus of strictly protected areas and the modest goals of integrated conservation and development projects. We argue that ecoagriculture—a fully integrated approach to agriculture, conservation and rural livelihoods, within a landscape or ecosystem context—is needed in many regions.

(a) *Ecoagriculture landscapes*

Ecoagriculture explicitly recognizes the economic and ecological relationships and mutual interdependence among agriculture, biodiversity and ecosystem services (figure 1). Ecoagriculture landscapes are mosaics of areas in natural/native habitat and areas under agricultural production. Effective ecoagriculture systems rely on maximizing the ecological, economic and social synergies among them, and minimizing the conflicts.

The term 'landscape' itself is functionally defined, depending upon the spatial units needed or actually managed by the group of stakeholders working together to achieve biodiversity, production and livelihood goals. Ecoagriculture landscapes are land use mosaics with:

- 'natural' areas (with high habitat quality and niches to ensure critical elements for habitat or ecosystem services that cannot be provided in areas under production), which are also managed to benefit agricultural livelihoods either through positive synergies with production or other livelihood benefits,
- agricultural production areas (productive, profitable and meeting food security, market and livelihood needs), which are also configured and managed to provide a 'matrix' with benign or positive ecological qualities for wild biodiversity and ecosystem services, and
- institutional mechanisms to coordinate initiatives to achieve production, conservation and livelihood objectives at landscape, farm and community scales, by exploiting synergies and managing trade-offs among them.

The concept of ecoagriculture further recognizes that agriculture-dependent rural communities are critical (and sometimes the principal) stewards of biodiversity and ecosystem services. While protected natural areas are essential in ecoagriculture landscapes to ensure critical habitat for vulnerable species, maintain water sources and provide cultural resource, these resources often may be owned or managed by local communities and farmers.

(b) *Biodiversity and ecosystem services in ecoagriculture landscapes*

Conservation of biodiversity in ecoagriculture landscapes embraces all three elements of agricultural biodiversity defined by the Convention on Biological

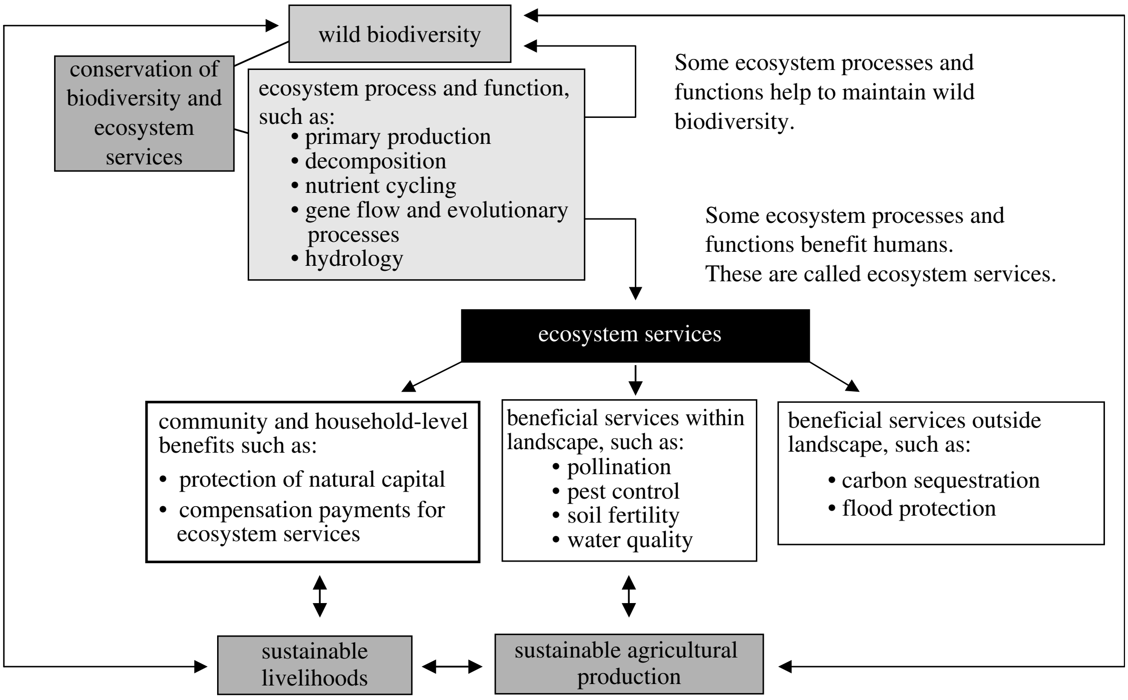

Figure 1. Ecosystem services are a key to the synergies between conservation, sustainable agricultural production and sustainable livelihoods (after Buck *et al.* 2004).

Diversity: genetic diversity of domesticated crops, animals, fish and trees; diversity of wild species on which agricultural production depends (such as wild pollinators, soil micro-organisms and predators of agricultural pests); and diversity of wild species and ecological communities that use agricultural landscapes as their habitat (Convention on Biological Diversity 2002).

Although wild biodiversity and ecosystem services are closely linked, they are not synonymous. A landscape with relatively intact wild biodiversity is likely to provide a full complement of ecosystem services. However, many ecosystem services can also be provided by non-native species, or by combinations of native and non-native species in heavily managed settings such as permanent farms. The implication is that even where wild biodiversity has been significantly reduced to make way for food and fibre production, high levels of ecosystem services can often still be provided through intentional land management practices. On the other hand, managing an ecoagriculture landscape for ecosystem services does not automatically ensure that wild biodiversity will be protected adequately. Thus, wild biodiversity and ecosystem services both require explicit consideration in ecoagriculture systems.

(c) *Ecoagriculture approaches*

Broadly, ecoagriculture landscapes rely on six basic strategies of resource management, three focused on the agricultural part of the landscape and three on the surrounding matrix.

In production areas, farmers sustainably increase agricultural output and reduce costs in ways that enhance the habitat quality and ecosystem services:

— minimize agricultural wastes and pollution,
— manage resources in ways that conserve water, soils, and wild flora and fauna, and
— use crop, grass and tree combinations to mimic the ecological structure and function of natural habitats.

Farmers or other conservation managers protect and expand natural areas in ways that also provide benefits for adjacent farmers and communities:

— minimize or reverse conversion of natural areas,
— protect and expand larger patches of high-quality natural habitat, and
— develop effective ecological networks and corridors (McNeely & Scherr 2003).

The relative area and spatial configuration of agricultural and natural components (and other elements, such as physical infrastructure and human settlements) are key landscape design issues (Forman 1995). The conservation of wild species that are highly sensitive to habitat disturbance—as are some of those most endangered or rare globally—requires large well-connected patches of natural habitat. But many wild species, including many that are threatened and endangered, can coexist in compatibly managed agricultural landscapes, even in high-yielding systems.

Numerous approaches to agriculture, conservation and rural development contribute components, management practices and planning frameworks that can be applied in ecoagriculture landscapes. The outcomes of planning and negotiations among the multiple stakeholders in any particular landscape will take diverse forms depending on the context of local cultures and philosophies of land management.

Ecoagriculture landscapes with documented joint benefits for agricultural production, biodiversity conservation and rural livelihoods include these three examples.

(i) *Kalinga Province, The Philippines*
For centuries, the Kalinga indigenous people of The Philippines have supported local livelihoods and conserved mountain biodiversity through integrated landscape management. Communities manage their watersheds to ensure a continual supply of water to communal irrigation systems, and in recent years over 150 ha of integrated rice terraces (including fish and vegetable production) have been rehabilitated. Indigenous forests are managed for sustainable harvest of wild animals for protein, leading to an 81% rate of intact forest in Kalinga Province (Gillis & Southey 2005).

(ii) *Transboundary co-management in Costa Rica and Panama*
The Gandoca–Manzanillo National Wildlife Refuge on Costa Rica's Caribbean coast connects with Panama's San Pondsak National Wildlife Refuge. This 10 000 ha refuge is co-managed by local communities, non-governmental organizations (NGOs) and government agencies. Small farm agro-ecosystems are integral to regional biodiversity conservation. Over 300 farmers hold secure land titles in the refuge's buffer zone. A regional small farmers' cooperative (Smallholder Association of Talamanca, APPTA) supports over 1500 small farmers to become Central America's largest volume organic producer and exporter, generating 15–60% increases in small-farmer revenue. Conservation-based carbon offset schemes are being developed to provide additional revenue for stewardship-focused farming.

(iii) *Community dryland restoration in Rajasthan, India*
For most of the past century, drought and environmental degradation severely impaired the livelihood security of local communities within Rajasthan's Arvari Basin. Twenty years ago, the Tarun Bharat Sangh, a voluntary organization based in Jaipur, India, initiated a community-led watershed restoration programme. The programme reinstated 'johads', a traditional indigenous technology for water harvesting. Johads are simple concave mud barriers, built across small, uphill river tributaries to collect water. As the water drains through the catchment area, johads encourage groundwater recharge and improve hillside forest growth, while providing water for irrigation, wildlife, livestock and domestic use. Over 5000 johads now serve over 1000 villages in the region, and are coordinated by village councils. Landscape changes include restoration of the Avari River, which had not flowed since the 1940s, and the return of native bird populations (Narain *et al.* 2005).

(d) *Where ecoagriculture approaches are needed*

Ecoagriculture approaches may be relevant to some extent in all agricultural landscapes, in light of their focus on improving landscape performance vis-á-vis three goals (agricultural production, biodiversity conservation and livelihoods). Synergies may be most apparent, and trade-offs least difficult, in areas with less productive agricultural lands (so that the opportunity costs of protecting or restoring habitats are lower), and in heterogeneous areas where farms are already interspersed with hills, forests and abandoned farms (Jackson & Jackson 2002). Nonetheless, the need to reconcile increased agricultural productivity and livelihoods with effective conservation of biodiversity and ecosystem services may be most critical in agriculture-dominated landscapes. Ecoagriculture approaches offer opportunities for integrated action, at a lower overall cost, to achieve Millennium Development Goals for poverty, hunger, water, and sanitation and environmental sustainability (Scherr & Rhodes 2005). Ecoagriculture also provides a strategy for implementing national commitments to multilateral environmental conventions, including the Convention on Biological Diversity (CBD), the Framework Convention on Climate Change, Ramsar and the Convention to Combat Desertification.

But it is important to consider the situations under which integrated versus segregated land use is likely to be especially advantageous, and the scale at which integration is desirable (Balmford *et al.* 2001; Green *et al.* 2005). For example, where most biodiversity is likely to be lost in the transition from pristine to extensive systems or if key species are very sensitive to fragmentation, then segregated systems might be indicated at a coarser grain. But where the transition from extensive to intensive agriculture will result in greater biodiversity loss, then integrated low-intensity agriculture finely interspersed with natural areas may be most desirable.

Real costs are associated with the cross-sectoral planning and coordination and technical innovations needed to achieve impacts at a landscape scale. These must be considered in prioritizing private, public and civic ecoagriculture investments. Top priorities would be:

(i) agricultural landscapes located in or around critical habitat areas for wild species of local, national or international importance (e.g. landscapes in the highly threatened habitats of the Atlantic Forest of Brazil, now dominated by farming),
(ii) degraded agricultural landscapes where restored ecosystem services will be essential to achieve both agricultural and biodiversity benefits (such as the dryland farming and pastoral regions of West Africa),
(iii) agricultural landscapes that must also function to provide critical ecosystem services (such as the densely populated landscapes of Europe and Java), and
(iv) peri-urban agricultural systems, where careful management is required to protect ecological, wildlife and human health.

No assessment has been done of the geographical scale and location of such priority areas for ecoagriculture development strategies (as distinct from agriculture- or conservation-led development), but undertaking such analyses is a critical step to guide policy action.

4. THE STATE OF ECOAGRICULTURE KNOWLEDGE AND PRACTICE

Little effort has been devoted to explicitly pursuing agricultural development and biodiversity conservation objectives jointly at a landscape scale, so experience is poorly documented and the science is immature and poorly synthesized across disciplines. Removing major barriers to the widespread development of ecoagriculture landscapes requires answering questions like the following.

- How can agricultural production systems contribute to conserving biodiversity while maintaining or increasing productivity?
- How can agricultural and natural areas be jointly managed to produce adequate ecosystem services, including wildlife habitat, at a landscape scale?
- How can ecoagriculture approaches become more financially viable for farmers and other stakeholders?
- How can communities, institutions and governments mobilize and develop the institutions and policies needed for ecoagriculture landscapes?

The current state of knowledge on these four questions is considered below.

(a) *Production systems that support biologically diverse ecoagriculture landscapes*

Since the 1960s, the 'improved seed–fertilizer–pesticide (irrigation)' paradigm has characterized both industrial agriculture in developed countries and the original green revolution in developing countries. This production model involved short-term, plot-level production of a small number of crops, generally in monoculture stands (to increase efficiency in use of external inputs and mechanization, maximize the flow of natural resources to harvestable products). Wild flora and fauna were considered direct competitors for resources or harvested products, and thus eliminated, while water was diverted from wetlands and natural habitats for irrigation.

More ecologically benign production systems were retained in many traditional systems that for ecological, cultural or economic reasons were not effectively incorporated into the industrial model. Such systems sought to build on, rather than replace, natural ecosystems. Different modern approaches have focused on different aspects of ecological synergy, arising from differences in discipline, philosophy, problem focus or geographical conditions. Agroecology, permaculture (Mollison 1990), conservation agriculture (FAO 2001), agroforestry (Huxley 1999), organic agriculture (IFOAM 2000) and sustainable agriculture (Pretty 1999) have focused principally on maintaining the resource base for production, through managing nutrient cycles, protecting pollinators and beneficial micro-organisms, maintaining healthy soils and conserving water. They sought to reduce the ecological 'footprint' of farmed areas and the damage to wild species from toxics, soil disturbance and water pollution, but most focused on farm-scale action, rather than coordinating efforts among farmers and others to achieve demonstrable biodiversity benefits at a landscape scale.

To protect wild fauna and flora, ecoagriculture landscapes must provide protection of nesting areas from disturbance, diverse perennial cover for protection from predators, adequate access to clean water throughout the year, territorial access between dispersed population groups to ensure provide minimum viable populations genetically and demographically, all-season access to food from diverse sources, viable populations of predators and prey, healthy populations of other species with which they are interdependent (such as their pollinators), and biologically active soils. Many of these functions can be provided by healthy patches and networks of natural habitat (discussed in §5), but production areas also play a critical role. To achieve these attributes in production areas, agricultural and conservation innovators are pursuing strategies such as minimizing agricultural pollution of natural habitats, managing conventional cropping systems in ways that enhance habitat quality, and designing farming systems to mimic the structure and function of natural ecosystems. A key challenge for farmers is to do so in ways that also maintain or increase agricultural output, reduce overall production costs or enhance the market value of their products in order to meet their broader livelihood needs while conserving biodiversity.

(i) *Minimizing agricultural pollution of natural habitats*

Reducing agrochemical use and livestock wastes in high-input production systems can greatly benefit wildlife. For example, high-nutrient or toxic run-off into waterways (a problem for both natural and synthetic forms of nitrogen) can dramatically reduce aquatic biodiversity. Major advances have been made in methods to reduce and improve the efficiency of fertilizer use, through better timing and methods of application.

Agricultural pesticides may also kill non-target insects and weeds that constitute the food base for insect- and grain-eating species. Integrated pest management systems have effectively used varietal crop mixes, pest monitoring and management practices to reduce the need for pesticides (Kogan 1998). Cellular and molecular biology have been used to tailor pesticides to affect only specific pests. New ecological and biochemical research techniques are revealing an unexpected sophistication of host–pest relations that could revolutionize agricultural pest control in the future (Wittenberg & Cock 2001).

Pretty's (2005) meta-review of farmer experience found gains in both productivity and biodiversity from reduced chemical use in developing counties. For example, the System of Rice Intensification mobilizes biological interactions in plant–soil systems, rather than external inputs, to raise yields significantly while reducing costs (Uphoff *et al.* 2006). Meanwhile, new whole-farm planning approaches minimize run-off of agrochemical and livestock waste into aquatic systems by improving storage systems, managing fields to improve infiltration and reduce run-off, and establishing buffer zones to filter pollutants before they enter streams (Coombe 1996).

(ii) *Managing production systems to enhance habitat quality*

Farmers and conservationists have modified management of soil, water, fire and vegetation to transform crop fields into useful habitat for species, or to enhance their value as 'corridors' connecting natural habitat areas in the landscape (McNeely & Scherr 2003; Clay 2004). Buck *et al.* (2006) reviewed 79 studies where investigators quantified biodiversity (usually species richness) associated with 18 specific agricultural practices. The strategy most often correlated with the conservation of wild biodiversity was the maintenance of adjacent hedgerows, windbreaks or woodlots; 18 studies documented positive correlations with eight taxa. Organic agriculture was correlated with an increase in seven taxa in eight studies (Peach *et al.* 2001; Klein & Sutherland 2003; Kleijn *et al.* 2006). Shaded tropical crop production (especially coffee and cacao) had higher species richness of three higher taxa by eight different studies (Buck *et al.* 2007).

Research has also found that many of these practices provide additional benefits to farmers, such as useful by-products, reduced risk of crop loss during droughts, diversified food and income sources and reduced vulnerability to environmental risks. For example, following the October 1998 Hurricane Mitch (the worst natural disaster to strike Central America in 200 years), researchers found that farms using agroecological practices suffered 58% less damage in Honduras, 70% less in Nicaragua and 99% less in Guatemala than those using conventional farming methods (Bunch 2000).

Impacts of conservation practices may be species specific. For example, cotton is an inhospitable habitat for many songbirds, particularly due to very high levels of pesticide use in conventional systems. But approaches such as conservation tillage and strip cover cropping reduce the ecological impact of cotton fields. Cederbaum *et al.* (2004) examined the effects of clover strip cover cropping with conservation tillage versus conventionally grown cotton with either conventional or conservation tillage on avian and arthropod species composition and field use in Georgia, USA. Strip cover fields had higher bird densities and biomass and higher relative abundance of arthropods than either conservation tillage or conventional fields. During migration and breeding periods, total bird densities on strip cover fields were 2–6 and 7–20 times greater than on conservation and conventional fields, respectively. Although the clover treatment attracted the highest avian and arthropod densities, conservation fields still provided more wildlife and agronomic benefits than conventional management. The reduction of inputs possible with the clover system allows farmers to reduce costs associated with conventional cotton production. Transgenic cotton has been developed to significantly reduce the need for pesticides, with observed benefits for biodiversity (Cattaneo *et al.* 2006).

The organic farming industry has only recently begun to develop standards that explicitly address conservation of wild biodiversity. But Hole *et al.* (2005) found that a wide range of taxa, including birds, mammals, invertebrates and arable flora can benefit from organic management through increases in abundance and/or species richness. Management practices, such as prohibition or reduced use of chemical pesticides and inorganic fertilizers, protection of non-cropped habitats, and preservation of mixed farming, are particularly beneficial for farmland wildlife. Though yields from organic systems are still often lower than those in conventional systems, the gap is narrowing and research is accumulating that shows how agricultural production systems primarily or exclusively dependent on organic inputs can produce superior agronomic and economic results (Uphoff *et al.* 2006).

Carefully targeted management practices applied to relatively small areas of cropped or non-cropped habitats within conventional agriculture may also provide valuable biodiversity benefits (Trewavas 2001). Weibull *et al.* (2003) found that wild species richness generally increased with landscape heterogeneity on a farm scale, and habitat type had a major effect on species richness for most groups, with most species found in pastures and leys (lands temporarily sown with grass). The level of motivation of the farmer to maintain biodiversity on the farmstead was more predictive of biodiversity outcomes than specific practices.

(iii) *Modifying farming systems to mimic natural ecosystems*

From a wild biodiversity conservation perspective, the ideal agricultural production systems for ecoagriculture landscapes mimic the structure and function of natural ecosystems (Leakey 1999; Lefroy *et al.* 1999; Jackson & Jackson 2002; Blann 2006). In humid and sub-humid forest ecosystems, farms would mimic forests, with productive tree crops, shade-loving understory crops and agroforestry mixtures; in grassland ecosystems, production systems would rely more on perennial grains and grasses, and economically useful shrubs and dryland tree species. Annual crops would be cultivated in such systems, but as intercrops, or monoculture plots interspersed in mosaics of perennial production and natural habitat areas. Domesticated crop and livestock species diversity would be encouraged at a landscape scale, and intra-species genetic diversity would be conserved *in situ* at least at an ecosystem scale, to ensure system resilience and ecological diversity.

Multi-story agroforest systems, tree fallows and complex home gardens are especially rich in wild biodiversity (Cairns & Garrity (1999); Schroth *et al.* 2004; Leakey & Tehoundjeu 2001). For example, Siebert (2002) found that canopy height, tree, epiphyte, liana and bird species diversity, vegetation structural complexity, per cent ground cover by leaf litter, and soil calcium, nitrate nitrogen and organic matter levels in topsoils were all significantly greater in shaded than in sun-grown farms, while air and soil temperatures, weed diversity and per cent ground cover by weeds were significantly greater in sun farms. Recent research in Central America has identified polyculture combinations and management systems that significantly improve the productivity of coffee, cocoa, banana, timber and other commercial tree products in these complex systems (e.g. Beer *et al.* 2000).

New and improved perennial crops can substitute for products now provided by annuals, such as fruits, leafy vegetables, spices and vegetable oils. Perennial crops can be more resilient and involve less soil and ecosystem disturbance than annual crops, and provide much greater habitat value, especially if grown in mixtures and mosaics (Jackson & Jackson 1999; Leakey & Tchoundjeu 2001). Breeding efforts are also underway to perennialize annual grains and to mimic ecosystem functions of natural grasslands; in some cases, yields are becoming competitive with conventional varieties (de Haan *et al.* 2007). This is a significant research opportunity. Increased demand for livestock products in turn raises demand for animal feed, including for higher-quality pastures, fodder or inputs for concentrates. While historically low grain prices have meant that corn and soy have been dominant feedstocks during the past few decades, alternatives abound, including perennial grass, shrub and tree species that can be grown more sustainably in marginal lands, as industrial processes adapt. Moreover, the future of industrial-type intensive, grain-fed livestock production is uncertain in the face of emerging zoonotic infectious diseases and associated pollution, opening more economic opportunity for substitutes from rotational grazing and even pastoral systems (Nierenberg 2005). Crops for biofuels are poised to become one of the fastest-growing segments of agricultural production, and although short-term investments have favoured annual crop sources in the developed world (as a way to absorb subsidy-driven surpluses), grasses, shrubs and tree sources may be more economic and sustainable options once the technical challenges of processing cellulosic sources are overcome (Ruark *et al.* 2006).

(iv) *Major gaps*

The development of agricultural practices and systems that explicitly support wild biodiversity is in its infancy. Buck *et al.* (2006) highlight numerous critical knowledge gaps, especially knowledge about the link between diversity and ecosystem function, and the relationships between below- and above-ground biodiversity. Methods being used to assess biodiversity impacts are inadequate, and generally fail to evaluate the impact on regional or global diversity, or to interpret the significance of an individual member of a species found at a particular site. Researchers still find it difficult to link plot-based analysis with landscape-scale impacts (Tomich *et al.* 2004).

Even where successful biodiversity and production outcomes are well documented, the underlying biological or ecological mechanisms may be poorly understood. The potential contributions and threats of genetically modified organisms to biodiversity in ecoagriculture landscapes have not been explored. Little of the existing crop breeding research in general has been considered within an ecoagriculture framework. Rather, most have focused on addressing problems at the 'end-of-pipe' to offset existing problems rather than rethinking the ecological management system, or even considering potential trade-offs of risks and benefits.

Redford & Richter (1999) propose that researchers much more systematically assess the impact of different resource management options on specific components of biodiversity (the function, structure and composition of communities/ecosystems, populations/species, genetic diversity and option space; Redford & Richter 1999; Swift *et al.* 2004). Then, where ecoagriculture systems are successful in increasing populations of wild species, new methods for managing them may be needed to minimize conflicts. The major gap is the miniscule level of international and national public investment in research documenting and evaluating existing ecoagriculture production systems, or in pursuing agricultural and conservation research to improve biodiversity-supporting and financially viable production systems.

(b) *Managing ecoagriculture landscapes for both production and conservation*

The ecoagriculture approach encompasses both biodiversity-friendly agricultural production systems and practices, and their management in mosaics with natural areas and other landscape features to meet conservation, livelihood and production goals. One premise of ecoagriculture is that ecosystem services can come from both production and conservation areas, especially if they are coordinated and managed for that purpose. Improved tools, greater demand for landscape-scale action and reassessment of long-sustained traditional agro-ecosystems, have led to substantial progress over the past two decades in laying out the basic parameters for biophysical management of ecoagriculture landscapes, if not location-specific guidance. Social and institutional aspects of landscape management are addressed in §4*d*.

(i) *New tools for landscape assessment*

Despite the importance of agricultural landscapes for biodiversity conservation, only a small fraction of published conservation biology studies has been undertaken in agricultural landscapes (Buck *et al.* 2004), so developing a baseline for assessing change is difficult. Most studies of the biodiversity impacts of particular agricultural practices and even the work of biodiversity-oriented groups like the Rainforest Alliance have focused on farm-level indicators. Meanwhile, a review of basic biodiversity research found very little empirical data on the contributions of wild species and natural ecosystem conditions to agricultural productivity (Jackson *et al.* 2005). Landscape ecology has provided us with the analytical language and tools to systematically examine the interactions between farmed and unfarmed areas (Forman 1995; Wojtkowski 2004). The science of 'countryside biogeography' has recently begun to work on biodiversity patterns in complex landscape mosaics, which shows how different land use elements and configurations support different wild species (Daily *et al.* 2000). Sophisticated landscape modelling and remote sensing tools are becoming available (e.g. Dushku *et al.* 2007; Scherr *et al.* 2007*a*).

(ii) *Maintaining natural habitats for terrestrial species in agricultural landscapes*

A common goal in ecoagriculture landscapes is to conserve a broad range of terrestrial species native to the area. This includes species that are relatively resilient to habitat fragmentation and agricultural land use, as well as species that are rare or locally or globally threatened, and those that require larger extensions of minimally disturbed habitat. The prospects for achieving this in agricultural landscapes depends on the degree of fragmentation and functional connectivity of natural areas, the habitat quality of those areas, the habitat quality of the productive matrix and the behaviour of farmers.

Efforts to maintain natural habitats in farming areas are longstanding, principally through diverse types of agricultural set-aside schemes (Kleijn & Baldi 2005). Based on a meta-analysis of 127 published studies, Van Buskirk & Willi (2005) found that land withdrawn from conventional production of crops unequivocally enhances biodiversity in North America and Europe. The number of species of birds, insects, spiders and plants is 1–1.5 standard deviation units higher on set-aside land, and population densities increase by 0.5–1 standard deviation units. Set-aside land may be especially beneficial for desirable taxa because North American bird species that have suffered population declines reacted most positively to set-aside agricultural land. Larger and older plots protect more species with higher densities, and set-aside land is more effective in countries with less-intensive agricultural practices and higher fractions of land removed from production. For many commercial crop monocultures, leaving field margins uncultivated for habitat protection does not reduce total yields, as inputs were applied more economically on the rest (Clay 2004).

However, landscape-scale interventions specifically designed to protect habitats for biodiversity (that include but coordinate and go beyond farm- and plot-specific interventions) are much more effective. A recent review of evidence from North America on how much habitat is 'enough' in agricultural landscapes (Blann 2006) concluded that strategies need to consider habitat needs within the landscape history and context. Adequate habitat patch size and connectivity must be maintained, but 'adequate' must be considered in relation to matrix influence and patch condition (sinks and ecological traps, patch location and configuration, edge effects and boundary zones). Smaller patches of natural habitat may be sufficient if adjacent agricultural patches are ecologically managed.

Based on studies from Central America, Harvey *et al*. (2005) conclude that landscape connectivity between large patches of forest can be effectively maintained through retention of tree cover on the farm, such as live fences, windbreaks, and hedges in grazing lands and agricultural fields. Sayer & Maginnis (2005) describe effective approaches for forest landscape restoration in mixed use mosaics.

(iii) *Protecting habitats for freshwater aquatic biodiversity*

Protection or establishment of native vegetation buffers along streams, rivers and riparian systems is critical for biodiversity conservation (Blann 2006). Data from the US suggest a minimum buffer width of 25 m to provide nutrient and pollutant removal, 30 m to provide temperature and microclimate regulation and sediment removal, a minimum of 50 m to provide detrital input and bank stabilization and over 100 m to provide for wildlife habitat functions. Wetlands should be protected, and the critical function zone of wetlands should be maintained in natural vegetation. The latest guideline in North America is that at least 10% of a watershed and 6% of any sub-watershed should comprise wetlands. Molden *et al*. (2005) and Blann (2006) emphasize the importance of re-establishing hydrological connectivity and natural patterns for aquatic ecosystems. Based on literature review and field experiments, van Noordwijk *et al*. (2007) conclude that watershed functions in agricultural landscapes can be effectively provided through strategic spatial configuration of perennial natural vegetation and planted vegetation, with maintenance of continuous soil cover enhancing infiltration.

Maintaining seasonal flood pulse dynamics in floodplains involves restoring floodplains and protecting them from developments that disconnect rivers through levees and water level management (Blann 2006). If floodplains must be used for agriculture, ecologists recommend using agroforestry and other approaches compatible with natural cycles rather than monocultures requiring annual ploughing and fertilization. Sendzimir & Flachner (2007) present an example of river floodplain polyculture in the Tisza River Basin in Hungary that exploits flooding as an engine of biodiversity. Natural floodplains, unconstrained by hydro-engineering infrastructure, sustained a diversity of habitats and the elevational structure in the landscape. They further maintained hydraulic connections that sustain nursery and migratory functions, stored water during times of drought, and distributed and mixed fallen fruit in novel combinations that stimulated agro-biodiversity and the cultivation of hundreds of varieties of fruits and nuts, as well as fisheries.

(iv) *Optimizing agriculture–natural habitat interactions in landscape mosaics*

Biologically diverse agricultural systems and landscapes can contribute to control of pests and diseases, provide new economic species, and buffer environmental changes and challenges (Jackson *et al*. 2005; Thompson *et al.* 2007). Ricketts (2004) investigated the role of tropical forest remnants as sources of pollinators for surrounding coffee crops in Costa Rica, observing bee activity and pollen deposition rates at coffee flowers, including 10 species of native bees and the introduced honeybee, *Apis mellifera*. Bee species richness, overall visitation rate and pollen deposition rate were all significantly higher in sites within approximately 100 m of forest fragments than in sites farther away. The vast majority of pollination in coffee plantations more than 100 m from a forest was by the introduced honeybee. Forest fragments near coffee plantations increased both the amount and stability of pollination services by reducing dependence on a single introduced species. Kremen *et al*. (2002) found similar results for pollinators of watermelon fields near and far from natural woodlands in California.

(v) *Major gaps*

The past two decades have revolutionized the potential for landscape-scale assessment and scientific understanding of the ecological functioning of diverse types of agricultural landscapes. A framework for considering key management guidelines and broad parameters is now in place, but empirical or even ecological modelling evidence needed for managing ecoagriculture landscapes (e.g. size and shape of natural areas required to sustain ecological functions, impacts on agricultural productivity of natural vegetation and species) is lacking. Agreed methods do not yet exist for integrated monitoring of livelihood, biodiversity and agricultural outcomes at a landscape scale, although this challenge is being taken up (Scherr & Meredith 2005; Buck *et al.* 2007). Rigorous understanding of the potential benefits and costs for agriculture of associated wild flora and fauna, and key ecosystem services, is lacking (Jackson *et al.* 2005).

Molden *et al.* (2007) highlights numerous practices to manage irrigation water in ways that also support biodiversity. But these are not widely implemented because they are not part of the institutions, incentive structures and education related to irrigation. Little of the new science has been shared with farmers or even with agronomists and other specialized agricultural scientists and technicians. The science is often missing that informs real-life innovations that local people can make to modify ecological impacts of management activities. Technical assistance services for farmers rarely address landscape management issues. Lack of rigorous data and analysis about ecoagriculture impacts and potentials is a key constraint to increased investment in and policy support for ecoagriculture. The complexity of ecoagriculture landscapes and management, multiple objectives and lack of information on interactions have made it difficult for project or community managers to document outcomes effectively or to compare results across sites. International collaborative research on tropical forest margins is rare (Palm *et al.* 2005).

(c) *Achieving financial viability of ecoagriculture landscapes*

Investing and engaging in ecoagriculture systems will require that all key elements—farm production, nature conservation and associated institutions for collective landscape management—be adequately financed. If ecoagriculture systems are to be widely adopted around the world, then incomes (defined to include not only cash but also other livelihood components) for farmers in those systems need to be at least as high, or higher, than in less biodiversity-friendly production systems, and other non-monetary benefits will be key. Market-based innovations could provide many opportunities for scaling up ecoagriculture.

(i) *Making ecoagriculture systems more profitable for farmers and investors*

Contrary to common assumptions, farmers and their communities often have strong economic and social rationales for supporting biodiversity conservation: to reduce production costs, raise or stabilize yields; improve product quality; protect their right to farm/herd/harvest wild products in and around protected areas; comply cost-effectively with environmental regulations; conserve biodiversity and ecosystem services critical to their own livelihoods; access product markets that require biodiversity-friendly production systems; earn payments for ecosystem services; or conserve species and landscapes of special cultural, spiritual or aesthetic significance to them.

Many ecoagriculture systems are, in fact, more profitable or less risky than alternatives. McNeely & Scherr (2003) present 28 examples that clearly demonstrated positive economic benefits, and another five cases had a neutral impact on incomes (despite major benefits for wild biodiversity). Farm incomes had doubled or tripled in ecoagriculture landscapes with irrigated rice in The Philippines, dairy systems in Brazil and the US, and improved fallow systems in Africa.

Investment needs to be targeted to produce the research and management breakthroughs that will enable farmers to raise output and/or reduce their costs while protecting and enhancing biodiversity. Community non-monetary benefits from use and non-use values of biodiversity, including inputs for farming and processing, medicines and cultural values are also important. Pearce (2005) documents financial and economic contributions of ecosystem services and biodiversity to poverty reduction and vice versa.

Communities are organizing themselves regionally to improve market linkages, reduce marketing costs and connect directly with buyers. Communities need to understand and meet the quality and time demands of interested buyers and to enter into and fully respect commercial contracts. They also need technical assistance to improve product quality and manage commercial contracts, and gain access to harvest finance and credit for post-harvest product processing and handling facilities/technologies. Development of innovations at all points in the marketing chain can reduce costs for trading, storage, transport, bulking, grading, etc. and thus improve returns from marketing products from polycultures and multi-product landscapes.

(ii) *Develop product markets that reward ecosystem stewardship*

New market niches are beginning to develop for agricultural products that are certified to be ‘green’. Producers or products are certified by independent third parties to have positive or neutral effects on biodiversity, based on criteria such as reduced agrochemical pollution, protection of natural areas, use of production practices that do not interfere with key natural processes or species lifecycles and participation in the development of landscape-scale wildlife corridors (Millard 2007). A 2005 review by Ecoagriculture Partners found more than 70 such green certification systems, ranging from ‘salmon-friendly’ certification of farms protecting critical stream habitats in the northwest United States to ‘conservation beef’ to Rainforest Alliance-certified commodities in Latin America (Y. Fukui 2005, unpublished data). The Sustainable Agriculture Initiative Platform and the Sustainable Food Lab are working with suppliers to enhance sustainability, including some elements of biodiversity.

New markets are also developing for products based on sustainable harvest of wild species, or on the domestication of wild species (such as extracts, spices, medicinals, construction materials and fruits; STCP 2005). The use of marketing labels for agricultural products coming from particular geographical regions, originally focused on quality, culture and taste, is being adopted for products labelled as supporting conservation of high-biodiversity-value landscapes. Demand is growing as the food industry becomes more sensitive to reputation issues around environment, and advocates promote new institutional procurement policies (Rainforest Alliance 2006), although consumers remain motivated more by human health-related issues. Concerns about bio-terrorism and health, combined with low-cost monitoring technologies, could enable farm-to-consumer farm product tracking to become more common in high- and middle-income countries, reducing the relative costs of managing value chains for eco-certified products.

(iii) *Reward farmers and farming communities for ecosystem services*

A major potential driver for ecoagriculture landscapes is payments to farmers or herders/ranchers and their communities for conserving biodiversity important to outsiders, and for conserving other ecosystem services using management practices that also conserve biodiversity. Such compensation currently takes various forms, including payments for access to species or habitats (e.g. research permits; hunting, fishing or gathering permits for wild species; or ecotourism); payments for biodiversity conservation management (e.g. conservation easements, land leases, conservation concessions or management contracts); tradable rights under 'cap-and-trade' regulations (e.g. wetland mitigation credits, tradable development rights and biodiversity offset credits) and support for biodiversity-conserving businesses (e.g. business investments or eco-labelling of green products; Scherr *et al.* 2007*a*).

An estimated $6000 million is spent worldwide on land trusts and conservation easements, a third in developing countries, with a large proportion in farm and ranchlands. Direct conservation and biodiversity payments for flora and fauna by governments amount to at least $3000 million, most in the US, Europe and China. Roughly, 20% of the farmland in the EU is under some form of agri-environment scheme to counteract the negative impacts of modern agriculture on the environment, at a cost of approximately US$1.5 billion (approx. 4% of the EU expenditure on the Common Agricultural Policy). In the US, approximately US$45 million is spent on regulatory offsets for biodiversity, including conservation banking, and such programmes have been initiated in Australia and France (Ecosystem Marketplace 2006). New models are emerging for payments by private sector companies, utilities and municipalities for ecosystem services essential to businesses, and to reduce ecological risks. For example, at least $20 million in voluntary biodiversity offsets have been documented, half in developing countries (Ecosystem Marketplace 2006).

Thus, the size of payments is already considerable, although their effectiveness in achieving biodiversity objectives and in supporting biodiversity-friendly production systems at landscape scale is quite mixed (Scherr *et al.* 2006). The potential future contribution of these new payments and markets to financing ecoagriculture landscapes will depend on the 'rules of the game' and institutions that are currently being developed (Scherr *et al.* 2007*b*).

(iv) *Major gaps*

New mechanisms have arisen over the past decade to reward and finance biodiversity conservation and biodiversity-friendly agriculture, but most of these are modest in scale or modestly effective at landscape scale. Little research has been done on the structures and institutions in product market chains that facilitate biologically diverse production. Nor has any systematic assessment been done of overall agricultural investment and finance and how it might be shaped to better support biodiversity. Certification processes for agricultural products (and wild products sustainably harvested) can be expanded, streamlined, designed for landscape-scale impact, enable low-income people to participate (IITA 2001; Molnar 2003). Still, most demand in developing countries is for domestic markets and seeking lowest-cost supply, so it is crucial to focus on reducing costs across the market value chain (not only at the level of the producer). More explicit attention is needed to mobilize payments for ecosystem services to support ecoagriculture landscapes. Finance through carbon emission offsets is the greatest unexploited opportunity, but further technical research is needed to lower costs of organizing landscape-scale action and monitoring performance. The trade-offs and synergies among different ecosystem services for different production and conservation strategies need to be more fully understood and addressed.

(d) *Mobilizing ecoagriculture: from community action to global impacts*

Ecoagriculture landscape innovators often identify their major constraint to be institutional barriers rather than technical or even financial ones (Bumacas *et al.* 2007). Key institutional challenges include inadequate community-level organizations for ecoagriculture action, landscape-scale planning, policies at various levels and mechanisms to achieve equitable outcomes in ecoagriculture landscapes.

(i) *Organization of communities for ecoagriculture*

A core feature of ecoagriculture landscapes is the role of resident local farming or pastoral communities as key stewards, decision makers and managers of biodiversity. Public agencies may operate forests and protected areas, but their viability and sustainability depend on the matrix of private land uses in the landscape. Economic and social incentives can motivate collective action of local communities. Hundreds of community-based organizations have been documented to mobilize or engage in landscape-scale ecoagriculture initiatives (e.g. Campbell 1994; Brookfield *et al.* 2002; Imhoff 2003; Isely & Scherr 2003; McNeely & Scherr 2003; Rhodes & Scherr 2005). The institutions leading these initiatives are 'hybrids' fusing conventional farmer cooperatives, rural development committees and community-based conservation organizations (Buck *et al.* 2004). In The Philippines, for example, local farmer-based Landcare groups are linked with conservation organizations, municipal governments and research organizations to revegetate hillsides, conserve biodiversity in populated PAs and improve water quality (Cramb & Culasero 2003). An important implication is the central role of communities in biodiversity conservation, especially outside PAs. Conservation organizations need to embrace and reorient their role explicitly to support local community stewardship in ways that respect and realistically address the central role of agriculture and livelihoods in planning and implementation methodologies (e.g. Bumacas *et al.* 2007).

(ii) *Landscape-scale planning and governance*

To achieve objectives at the landscape scale requires a process of collective action to support producers and coordinate action among key stakeholders in the landscape, often across sectors with a historical legacy of distrust. Development or adaptation of institutions for engagement, coordination and governance of ecoagriculture become the critical challenges. Scaling up and sustaining ecoagriculture landscapes that involve multiple stakeholders requires a process, and usually an institution, that will enable multi-stakeholder assessment, planning, implementation and monitoring for adaptive management. Currently, ecoagriculture initiatives take numerous forms, mobilized by community organizations, public agencies, NGOs or national/international projects. Methodologies that have been developed to assist the planning and governance process include landscape 'visioning' and 'scenario-building' processes, participatory landscape modelling, community biodiversity assessments and guidelines for 'adaptive collaborative management' (Buck *et al.* 2001; Edmunds & Wollenberg 2001). Multi-stakeholder trust-building processes and negotiation platforms are being adapted to the specific context of agriculture–biodiversity conflict situations (e.g. Hemmati 2007). Diversity of approaches is expected and desirable, but more systematic and comparative evaluation of effectiveness in achieving sustainable processes and outcomes is lacking.

(iii) *Policies that support ecoagriculture landscapes*

Ecoagriculture innovators around the world highlight the need for a more supportive policy environment for ecoagriculture, or simply the removal of major policy barriers (Mattison & Norris 2005; Rhodes & Scherr 2005; Robertson & Swinton 2005). Core policy needs, at local, national and international scales are: (i) compatibility and coordination of agricultural development and biodiversity conservation policies, (ii) environmental legislation that embraces the potentials and rights of farming communities as conservators of biodiversity, and (iii) the removal of public subsidies for agricultural systems and investments that harm biodiversity.

Consumers, policy makers and investors are beginning to focus on the link between agriculture and conservation, and responding with new demands on the agricultural system, through systems of voluntary certification, industry standards and government regulation (e.g. SCBD 2005, Decisions III/11, V/5 and VI/5). Ecosystem/landscape-scale programmes and projects are being initiated by government agencies and NGOs, often in multi-stakeholder partnerships, and financed through public budgets (e.g. in India and China) and international development loans (e.g. Fernandes 2004). Initiatives to achieve these policy objectives include the Central America Presidents' joint commitment to promote environmentally friendly agriculture, the removal of agricultural subsidies in Australia, and the recommendations from Communities to the Millennium Summit. New political coalitions are being formed to promote integrated cross-sectoral policies, bringing in voices and sectors not traditionally involved in either agricultural or conservation policy, such as municipal governments (in the context of political decentralization), urban consumer groups, international financial organizations concerned with screening investments for environmental sustainability, parts of the food industry, public health advocates and 'good governance' movements seeking to reduce wasteful spending on subsidies.

At the international policy level, ecoagriculture strategies are being integrated into the work programmes of the relevant international conventions. For example, the CBD has adopted a new biodiversity goal of 30% of agricultural areas under biodiversity-friendly management by 2010 (CBD 2006), and will focus on agriculture in meetings during 2008, as will the Commission on Sustainable Development. Rules developing under the World Trade Organization will need to be carefully scrutinized to ensure that they do not disadvantage producers in ecoagriculture landscapes.

Some countries, notably Australia, Brazil and India, have adopted legislation that explicitly recognizes the rights of indigenous and other local communities to manage and conserve forests and natural habitats (Ellsworth 2004; Molnar *et al.* 2004). The Convention on Biological Diversity and other international bodies are beginning to focus on opportunities for community-led conservation, although many elements of the conservation community are still uncomfortable directly addressing and supporting agricultural development.

Policy changes can enhance the financial viability of ecoagriculture by removing government subsidies and fiscal incentives for biodiversity-harming production systems, in particular subsidies for agrochemical inputs and water, rules for commodity payment support that limit crop rotations, subsidies that favour annual crops over perennials, and intensive livestock production systems over grazing systems, and tax incentives for vegetation clearing.

(iv) *Achieving social equity*

Efforts to maintain or promote ecoagriculture landscapes are often instigated, complicated or impeded by the serious social inequities characterizing rural regions in many parts of the world. Indigenous communities are documenting their effective ecoagriculture systems in their efforts to reclaim land rights from the state. Corporate agribusinesses are seeking to promote ecoagriculture to ensure their 'social license to operate'. Ecoagriculture strategies that coordinate the use and management of landscape resources can help resolve resource disputes between farmers and pastoralists. Community groups and advocates for the poor are promoting ecoagriculture policies as a way to protect and restore biodiversity and ecosystem services important to the poor.

Ecoagriculture approaches can create more 'space' for equitable outcomes by identifying synergies between local livelihood benefits and benefits for agricultural economies and biodiversity, and by justifying stronger rights for poor producers over natural resources. But ecoagriculture systems are both context specific and the result of negotiations among diverse actors. To achieve equitable outcomes will require that poor and disenfranchised groups within the landscape organize themselves for political strength, that they join coalitions with other stakeholders, and that they be supported strategically in their negotiations with more powerful groups.

(v) *Major gaps*

While this survey of ecoagriculture innovators reports numerous promising institutional models—at community, landscape and policy levels—the conditions under which such innovations are most likely to emerge, or can be successfully applied, are poorly understood. Effective cross-sectoral political coalitions have seldom arisen to advocate for reconciling conflicting agriculture and environmental policies. Ecoagriculture strategies are not well integrated into public investment plans, including the Poverty Reduction Strategies of low-income countries and donor strategies designed to support the MDGs. Rural farming communities are largely unrepresented at most international environmental policy forums, and environmental interests generally are absent from farming organizations. Local organizations find it difficult to access the specialized knowledge generated by others and are poorly integrated into ecosystem or watershed planning and policy processes at local, national or international levels. Few conservation organizations have staff with agricultural expertise. Most international and national policy and legal frameworks separate action on agricultural productivity, ecosystem management and rural livelihoods, and policy-making institutions reflect this separation. Most policy makers are unfamiliar with the opportunities for ecoagriculture, or of alternative policies and laws that would enable ecoagriculture activities and outcomes. Mainstreaming ecoagriculture will require that strategically important institutions—responsible for policy, research, and markets—modify how they do business to embrace ecoagriculture vision and strategies.

5. ACHIEVING ECOAGRICULTURE AT A GLOBALLY MEANINGFUL SCALE

This review found many examples of apparently successful approaches linking biodiversity conservation with sustainable agriculture. On the other hand, the current knowledge base and institutional arrangements are clearly inadequate to meet the objectives noted above across diverse ecosystems and production systems. To enable ecoagriculture landscape approaches to expand to a globally significant scale will require at least three elements: new knowledge, institutional capacity, and an enabling policy and market environment.

(a) *Produce and share knowledge for ecoagriculture*

The challenge of shaping agricultural landscapes to meet joint production, conservation and livelihood goals will require a dramatic scaling up and refocusing of research, in national research systems, the center supported by the Consultative Group for International Agricultural Research, centres of conservation science, national academies of science, and universities. Priorities are to understand the interaction and dynamics of conservation and production areas; to develop production systems (including improved varieties of more diverse domesticated species) that explicitly meet biodiversity objectives and mimic natural ecosystems; and to make more elements of farming systems ecologically sustainable, including industrial processing, packaging, transport, etc. Ecoagriculture systems that appear to be successful need to be fully documented, both in terms of landscape-scale outcomes and specific interventions. Mapping of spatial overlays between important agricultural areas (in terms of national product supply or local livelihoods) and important biodiversity will be essential.

(b) *Build capacity for ecoagriculture*

Knowledge innovation systems need to be reshaped to provide services to rural resource stewards, and to accelerate exchange of practical knowledge among them and across sectors. Rural communities must be acknowledged as key stewards of biodiversity conservation, and professional conservation organizations, public agencies and others need to reorient their activities to reflect this reality and provide services to community-based organizations, as well as to other stakeholder groups. Conservation organizations need to fully embrace farming partners, develop agricultural expertise and aggressively advocate for sustainable agriculture investment in coordination with conservation strategies.

(c) *Promote markets and policies that support ecoagriculture*

Technical and local organizational opportunities and initiatives for ecoagriculture are unlikely to be successful unless major policy barriers are removed, and supportive policies developed. To advocate for this agenda, beneficiaries of ecosystem services provided by agricultural landscapes, new economic actors in the product value chain and advocates for reinvigorated rural development need to form new political coalitions. In North America, Europe, Japan, Australia and many developing countries, shifting of government funds from agricultural commodity subsidies to payments for ecosystem services (including carbon emission offsets) in ecoagriculture landscapes could provide initial funding to build institutions and farmer capacity for ecoagriculture. Ecoagriculture offers cost-effective approaches for national investment strategies to achieve the Millennium Development Goals.

Strategic changes in the food industry, institutional procurement, eco-certification of agricultural products and financial investors' oversight of agricultural investments can be mobilized to shift financial incentives towards ecoagriculture. At the international policy level, opportunities exist to integrate ecoagriculture strategies into the work programmes of the international environmental conventions, and to ensure that rules of the World Trade Organization support ecoagriculture landscapes.

6. CONCLUSION

The transformation of agricultural production from one of the greatest threats to global biodiversity and ecosystem services to a major contributor to ecosystem integrity is unquestionably a key challenge of the twenty-first century. Many elements of ecoagriculture landscapes could also help to achieve the critical goals of agricultural sustainability, resilience of food systems and adaptation to climate change. To realize these potentials, the agricultural and conservation research and policy communities will need to re-evaluate and coordinate their priorities and strategies.

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