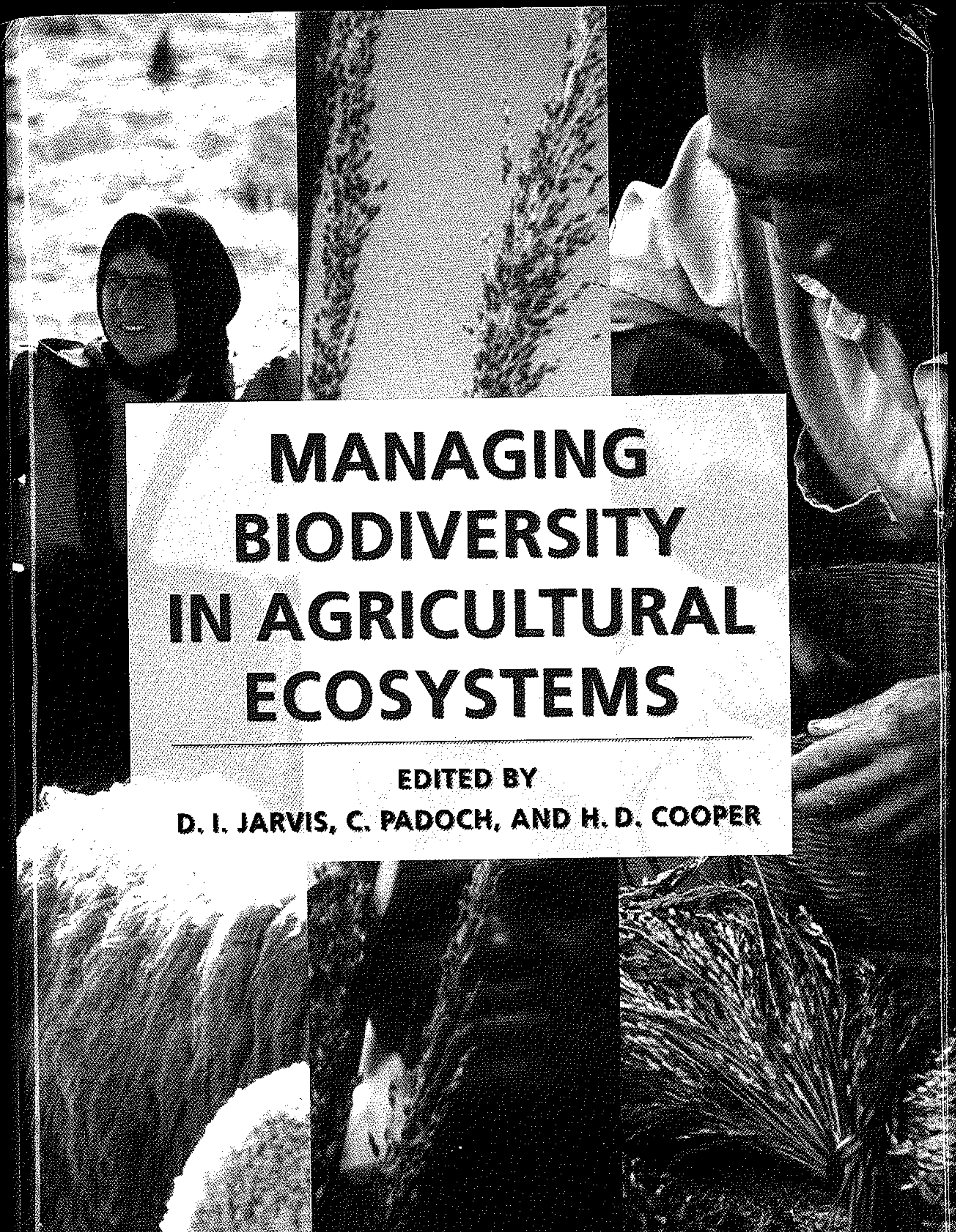

MANAGING BIODIVERSITY IN AGRICULTURAL ECOSYSTEMS

EDITED BY

D. I. JARVIS, C. PADOCH, AND H. D. COOPER

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MANAGING BIODIVERSITY IN AGRICULTURAL ECOSYSTEMS

"Assembling the efforts and expertise of a diverse and well-qualified set of authors, this book addresses a wide range of topics, yet the essays clearly cohere. The perspective is global, which will make the book the single most authoritative source to date on issues of agrobiodiversity."

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1 Biodiversity, Agriculture, and Ecosystem Services

D. I. JARVIS, C. PADOCH, AND H. D. COOPER

Biodiversity in agricultural ecosystems provides our food and the means to produce it. The variety of plants and animals that constitute the food we eat are obvious parts of agricultural biodiversity. Less visible—but equally important—are the myriad of soil organisms, pollinators, and natural enemies of pests and diseases that provide essential regulating services that support agricultural production. Every day, farmers are managing these and other aspects of biological diversity in agricultural ecosystems in order to produce food and other products and to sustain their livelihoods. Biodiversity in agricultural ecosystems also contributes to generating other ecosystem services such as watershed protection and carbon sequestration. Besides having this functional significance, maintenance of biodiversity in agricultural ecosystems may be considered important in its own right. Indeed, the extent of agriculture is now so large, any strategy for biodiversity conservation must address biodiversity in these largely anthropogenic systems. Moreover, biodiversity in agricultural landscapes has powerful cultural significance, partly because of the interplay with historic landscapes associated with agriculture, and partly because many people come into contact with wild biodiversity in and around farmland.

This book examines these various aspects of agricultural biodiversity. A number of chapters examine crop genetic resources (chapters 1, 2, 3, 10, 11, and 16) and livestock genetic resources (chapters 4, 5, and 17). Other chapters examine aquatic biodiversity (chapter 6), pollinator diversity (chapter 7), and soil biodiversity (chapter 8). Three chapters (9, 10, and 11) examine various aspects of the relationship between diversity and the management of pests and diseases. Chapters 12 and 13 explore farmer management of diversity in the wider context of spatial complexity and environmental and economic change. Chapter 14 looks at the contribution of diversity to diet, nutrition, and human health. Chapters 15 through 17 explore the value of genetic resources and of the ecosystem services provided by biodiversity in agricultural ecosystems.

This introductory chapter sets the scene for the subsequent chapters. After reviewing recent efforts to address agricultural biodiversity in the academic community and international policy fora, the multiple dimensions of biodiversity in agricultural ecosystems are surveyed. Subsequent sections examine the value of ecosystems services provided by biodiversity, the functions of biodiversity, and how these are influenced by management. The chapter concludes with a brief consideration of the future of biodiversity in agricultural ecosystems.

Recent and Current Initiatives to Address Agricultural Biodiversity

The importance to agriculture of crop, livestock, and aquatic genetic resources has long been recognized, but only in the last decade or so has the global community acknowledged the significance of the full range of agricultural biodiversity in the functioning of agricultural ecosystems. In the international policy arena, agricultural biodiversity was addressed for the first time in a comprehensive manner by the Conference of the Parties of the Convention on Biological Diversity (CBD) in 1996. The CBD program of work on agricultural biodiversity, which was subsequently developed and adopted in 2000, recognizes the multiple dimensions of agricultural biodiversity and the range of goods and services provided. In adopting the program of work, the Conference of the Parties recognized the contribution of farmers and indigenous and local communities to the conservation and sustainable use of agricultural biodiversity and the importance of agricultural biodiversity to their livelihoods. Within the framework of the convention's program of work on agricultural biodiversity, specific initiatives on pollinators, soil biodiversity, and biodiversity for food and nutrition have been launched.

This new spotlight on agricultural biodiversity is a response to a broad consensus that global rates of agricultural biodiversity loss are increasing. Estimates from the World Watch List of Domestic Animal Diversity note that 35% of mammalian breeds and 63% of avian breeds are at risk of extinction and that one breed is lost every week. The *State of the World's Plant*

Genetic Resources for Food and Agriculture (PGRFA) describes as "substantial" the loss in diversity of plant genetic resources for food and agriculture, including the disappearance of species, plant varieties, and gene complexes (FAO 1998). Every continent except Antarctica has reports of pollinator declines in at least one region or country. Numbers of honeybee colonies have plummeted in Europe and North America, and the related Himalayan cliff bee (*Apis laboriosa*) has experienced significant declines (Ingram et al. 1996). Other pollinator taxa are also the focus of monitoring concerns, with strong evidence of declines in mammalian and bird pollinators. Globally, at least 45 species of bats, 36 species of nonflying mammals, 26 species of hummingbirds, 7 species of sunbirds, and 70 species of passerine birds are considered threatened or extinct (Kearns et al. 1998).

The broad consensus on amplified rates of biodiversity loss in agricultural systems, with the need to have better quantification of these rates of change, has spurred an increasing number of international, national, and local actions on agricultural biodiversity management over the last few years. The International Plant Genetic Resources Institute (IPGRI) global on-farm conservation project (Jarvis and Hodgkin 2000; Jarvis et al. 2000); the People, Land Management and Environmental Change (PLEC) Project (Brookfield 2001; Brookfield et al. 2002); the Community Biodiversity Development and Conservation (CBDC) Programme; the Centro Internacional de Agricultura Tropical (CIAT), Tropical Soil Biology and Fertility Institute (TSBF), and Global Environmental Facility Below Ground Biodiversity (BGBD) Project; the Global Pollinator Project supported by FAO; and Operational Programme on Agricultural Biodiversity and projects supported under the Global Environment Facility (GEF) are a few prominent examples. Many case studies carried out under these and other initiatives were reviewed at the international symposium "Managing Biodiversity in Agricultural Ecosystems," held in 2001 in Montreal on the margins of the meeting of the Scientific Subsidiary Body to the CBD.

This book builds on case studies presented at the Montreal symposium. Whereas conventional approaches to agricultural biodiversity focus on its components as static things, many of the chapters in this book emphasize instead the dynamic aspects of agricultural biodiversity and the interactions between its components. Researchers with backgrounds and interests in the social and environmental sciences have also brought new perspectives and approaches to the field. They seek to understand the processes and linkages, the dynamism and practices that are essential to the way biodiversity has long been and continues to be managed in farming systems, agricultural communities, and the broader societies.

Multiple Dimensions of Agricultural Biodiversity

Agricultural biodiversity includes all components of biological diversity relevant to the production of goods in agricultural systems: the variety and variability of plants, animals, and microorganisms at genetic, species, and ecosystem levels that are necessary to sustain key functions, structures, and processes in the agroecosystem. Thus it includes crops, trees, and other associated plants, fish and livestock, and interacting species of pollinators, symbionts, pests, parasites, predators, and competitors.

Cultivated systems contain *planned biodiversity*, that is, the diversity of plants sown as crops and animals raised as livestock. Together with crop wild relatives, this diversity comprises the genetic resources of food agriculture. However, *agricultural biodiversity* is a broader term that also encompasses the associated biodiversity that supports agricultural production through nutrient cycling, pest control, and pollination (Wood and Lenne 1999) and through multiple products. Biodiversity that provides broader ecosystem services such as watershed protection may also be considered part of agricultural biodiversity (Aarnink et al. 1999; CBD 2000; Cromwell et al. 2001).

This volume takes a broad and inclusive approach and attempts to point to emerging issues in research on biodiversity in agricultural ecosystems. Chapters 2 to 7 focus primarily on diversity among crops, livestock, and fish that constitute much of the planned biodiversity in agricultural systems. In addition to domesticated crops and livestock, *managed* and *wild* biodiversity provides a diverse range of useful plant and animal species, including leafy vegetables, fruits and nuts, fungi, wild game insects and other arthropods, and fish (including mollusks and crustaceans as well as finfish) (Pimbert 1999; Koziell and Saunders 2001; also see Halwart and Bartley, chapter 7). These sources of food remain particularly important for the poor and landless (Ahkter in box 13.2, chapter 13) and are especially important during times of famine and insecurity or conflict where normal food supplies are disrupted and local or displaced populations have limited access to other forms of nutrition (Scoones et al. 1992; Johns, chapter 15). Even at normal times such associated biodiversity—including "weeds"—often is important in complementing staple foods to provide a balanced diet.

Some indigenous and traditional communities use 200 or more species for food (Kuhnlein et al. 2001; Johns and Sthapit 2004; Johns, chapter 15).

Diversity at species and genetic levels comprises the total variation present in a population or species in any given location. Genetic diversity can be manifested in different phenotypes and their different uses. It can be characterized by three different facets: the number of different entities (e.g., the number of varieties used per crop and the number of alleles at a given locus), the evenness of the distribution of these entities, and the extent of the difference between the entities. Crop genetic diversity can be measured at varying scales as well (from countries or large agroecosystems to local communities, farms, and plots), and indicators of genetic diversity are scale dependent. These issues are examined for crops by Brown and Hodgkin (chapter 2) and Sadiki et al. (chapter 3), for livestock by Gibson et al. (chapter 5), and for aquatic diversity in rice ecosystems by Halwart and Bartley (chapter 7). These chapters are complemented by case studies that illustrate how farmers name and manage units of diversity in their agricultural systems for crops (Sadiki et al., chapter 3; Hodgkin et al., chapter 4), animals (Hoffmann, chapter 6), and aquatic resources (Halwart and Bartley, chapter 7).

Chapters 8 to 10 focus on the essential role of *associated biodiversity* in supporting crop production (see also Swift et al. 1996; Pimbert 1999; Cromwell et al. 2001). Earthworms and other soil fauna and microorganisms, together with the roots of plants and trees, maintain soil structure and ensure nutrient cycling (Brown et al., chapter 9). Pests and diseases are kept in check by parasites, predators, and disease-control organisms and by genetic resistances in crop plants themselves (Wilby and Thomas, chapter 10; Jarvis et al., chapter 11; Zhu et al., chapter 12), and insect pollinators contribute to the cross-fertilization of outcrossing crop plants (Kevan and Wojcik, chapter 8). It is not only the organisms that directly provide services supporting agricultural production but also other components of food webs, such as alternative forage plants for pollinators (including those in small patches of uncultivated lands within agricultural landscapes) and alternative prey for natural enemies of agricultural pests. This has been shown in Javanese rice fields, where complex food webs ensure that the natural enemies of crop pests such as insects, spiders, and other arthropods have alternative food sources when pest populations are low, providing stability to this natural pest management system (Settle et al. 1996).

The multiple dimensions of biodiversity in cultivated systems make it difficult to categorize production systems as a whole into high or low biodiversity, especially when spatial and temporal scales are also included. In chapter 11, Jarvis et al. discuss whether crop genetic diversity is a benefit in reducing disease in time or whether it could be a hazard, given the potential emergence of pathogen super-races. They present case studies of resistant local genotypes used by farmers, use of resistance in intraspecific variety mixtures, and breeding programs that have selected for and used genotypes resistant to pests and pathogens to reduce crop vulnerability. The authors note the challenge of developing criteria that determine when and where genetic diversity can play or is playing a role in managing pest and disease.

Although academic research on agricultural biodiversity typically has focused on specific components (e.g., crops, pests, livestock), farmers manage whole systems as well as their separate parts. Built on long histories of adaptation, innovation and change, and rich bases of knowledge and practice, biodiversity management is not easily bounded or described. In chapter 7, Halwart and Bartley explain how farmers integrate the management of fish into their agricultural systems. In chapter 13, Brookfield and Padoch discuss approaches to understanding management of agricultural biodiversity by farmers over larger and more complex spatial and temporal scales. They argue that farmers often manage biodiversity in heterogeneous landscapes using a range of technologies. The authors use the term *agrodiversity* to describe the integration of biodiversity with the technological and institutional diversity typical of small-scale production. The concept of agrodiversity is also the core of chapter 14. In this chapter Rerkasem and Pinedo-Vasquez discuss a set of examples of how small-scale farmers manage biodiversity to solve emerging problems. Emphasizing the complexity, dynamism, and *hybrid* nature of their examples, the authors revise and update conventional views of traditional knowledge and practice to better reflect the realities of smallholder production.

Ecosystem Services and Their Value

Biodiversity in agricultural ecosystems underpins the provision of a range of goods and services from these ecosystems (Millenium Ecosystem Assessment 2000). The value of biodiversity can be expressed in economic terms because people and societies derive benefit (or utility) from the use of the ecosystem services it provides. The concept of total economic value, which includes current use value, option value (insurance value plus exploration value), and existence value or human preference for the existence of the resource unrelated to any use, is widely used by economists to identify various types of value from biodiversity (Orians et al. 1990; Pearce and Moran 1994, Swanson 1996). In addition, biodiversity goods and services often have either public or mixed private and public properties. The economic value of such goods is not well captured by market prices because they are not traded (Brown 1990). For example, the combinations of seed types grown by farmers produce a harvest from which they derive private benefits through food consumption, sales, or other utility. When they are considered as genotypes, however, the pattern of seed types across an agricultural landscape contributes to the crop genetic diversity from which not only these farmers but also people residing elsewhere and in the future may derive public benefit (Smale 2005). Because farmers' decisions on the use and management of crop varieties in their fields can result in loss of potentially valuable alleles, their choices have intergenerational and interregional consequences. Economic theory predicts that as long as agricultural biodiversity is a good, farmers as a group will underproduce it relative to the social optimum, and institutional interventions are necessary to close the gap (Sandler 1999).

In chapter 15, Johns gives empirical evidence of the value of agricultural biodiversity to dietary diversity, nutrition, and health. Gauchan and Smale (chapter 16) and Drucker (chapter 17) describe case studies that illustrate crop and animal diversity (variation within and between crops and breeds, respectively) values to farmers in ways not captured in analysis of market prices. Indeed, much of the value of crop and livestock variation is related to the potential for future adaptation or crop improvement and to ecosystem services such as erosion prevention and disease control. As discussed in chapters 16 and 17, different sectors of society perceive these values in different ways (see also Smale 2005). Chapter 16 compares geneticists' and farmers' values, identifying the factors that influence whether farmers will continue to grow (i.e., find valuable) the rice landraces that plant breeders and conservationists consider to be important for future adaptation or crop improvement. Chapter 17 discusses how declines in indigenous breeds may reflect the lack of availability of indigenous breeding stock rather than farmer net returns.

Although the worth of biodiversity in providing food is most widely appreciated, other values derived from biodiversity can be highly significant (Ceroni et al., chapter 18). The value of biodiversity and related ecosystems usually is calculated at the margin, that is, for assessing the value of changes in ecosystem services resulting from management decisions or other human actions or for assessing the value of the biodiversity of or service provided by an area that is small compared with the total area. Despite the existence of various valuation methods to estimate the different values of biodiversity, only ecosystem goods (or *provisioning ecosystem services*) are routinely valued (Ceroni et al., chapter 18). Most supporting and regulating services are not valued at all because they bear the characteristics of public goods and are not traded in markets.

Interactions Between Components of Biodiversity and Management by Farmers

Although our understanding of the relationship between biodiversity and ecosystem functioning is incomplete, several points can be stated with a high degree of certainty. First, species composition may be more important than absolute numbers of species. A high diversity of functional guilds is more important from a functional perspective than species richness itself (Brown et al., chapter 9). For example the range of functional guilds of predators of pests is key to effective natural pest control (Wilby and Thomas, chapter 10). Second, genetic diversity within populations is important for continued adaptation to changing conditions and farmers' needs through evolution and, ultimately, for the continued provision of ecosystem goods and services (see Brown and Hodgkin, chapter 2; Sadiki et al., chapter 3; Hodgkin et al., chapter 4; Hoffmann, chapter 6; Halwart and Bartley, chapter 7; Jarvis et al., chapter 11). And third, diversity within and between habitats and at the landscape level is also important in multiple ways (Brookfield and Padoch, chapter 13; Rerkasem and Pinedo-Vasquez, chapter 14). Diversity at the landscape level may include the diversity of plants needed to provide crop pollinators with alternative forage sources and nesting sites or to provide the alternative food sources for the natural enemies of crop pests (Kevan and Wojcik, chapter 8; Wilby and Thomas, chapter 10).

Many of the case studies of small-scale management described throughout the book feature exploitation of what are conventionally viewed as environments unsuited or marginal for agricultural production. It is in such environments (steep, infertile, flood-prone, dry, or distant) that many small farmers and much agricultural biodiversity continue to be found. In these circumstances, management of high levels of diversity can become a central part of the livelihood management strategies of farmers and pastoralists and survival of their communities (Brookfield and Padoch, chapter 13; Rerkasem and Pinedo-Vasquez, chapter 14). Agricultural biodiversity helps guarantee some level of resilience, with the capacity to absorb shocks while maintaining function. Smallholder farmers and the social and ecological environments in which they operate are continually exposed to many changes. When sudden change occurs, those most resilient have the capacity to renew, reorganize, and even prosper (Folke et al. 2002). In a system that has lost its resilience, adaptation to change is difficult at best, and therefore even small changes are potentially disastrous. Inability to cope with risks, stresses, and shocks, be they political, economic, or environmental, undermines and threatens the livelihoods of small-scale farmers.

Future of Agricultural Biodiversity

It is commonly said that globalization and the drive to higher agricultural productivity are the enemies of agricultural biodiversity. The spread of Green Revolution hybrid seeds and technologies, new diets, and laws on intellectual property, and seed and variety release, registration and certification, as well as access restrictions worldwide have all had negative impacts on diversity. The effects of these modernization and globalization trends have been neither simple nor linear, however. New opportunities to manage agricultural biodiversity and threats are provided by modern technologies and the globalization of markets. In some cases these tend to favor further specialization and uniformity in agricultural systems; some services provided by on-farm agricultural biodiversity are replaced in part by external inputs such as fertilizers, pesticides, and improved varieties. Inappropriate or excessive use of some inputs often reduces biodiversity in agricultural ecosystems (thus compromising future productivity) and in other ecosystems. As many of the chapters of this book suggest, alternative approaches that make use of agricultural biodiversity to provide these services can result in benefits for both productivity and biodiversity conservation. In order to identify management practices, technologies, and policies that promote the positive and mitigate the negative impacts of agriculture on biodiversity, enhance productivity, and increase the capacity to sustain livelihoods, we will need an improved understanding of the links, interactions, and associations between different components of agricultural biodiversity and the ways in which they can contribute to stability, resilience, and productivity in different kinds of production systems. As the creators and custodians of most of the world's agricultural biodiversity, farmers must be fully engaged in these efforts.

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13 Managing Biodiversity in Spatially and Temporally Complex Agricultural Landscapes

H. BROOKFIELD AND C. PADOCH

Farmers manage biodiversity. At one extreme, they may minimize it by planting thousands of hectares to a chemically enhanced and protected single crop or, at the other, create a diverse landscape of patches under multiple crops and trees interspersed with edges and woodlots. This chapter departs significantly from the subject matter of the preceding chapters. It is about biodiversity management at the scale of whole farms and farming regions, including not only agrobiodiversity but also natural and other managed biodiversity.

This chapter also views biodiversity in agricultural landscapes at a somewhat broader temporal scale. By rotating crops and modifying and managing natural regrowth after cropping, farmers ensure continued production of crops. Farmers take advantage of seasonal changes in water and soil conditions to introduce or encourage plant complexes that can survive and flourish in different seasons. Some cope with problems such as soil degradation, salinity, and waterlogging by changing management practices to compensate and thereby create mosaics of land use better adapted to environmental dynamics. All these modifications affect biodiversity at the landscape scale. The purpose of this chapter is to evaluate these wider changes and discuss some of the scientific efforts made to understand and measure them.

Agricultural Landscape

Much recent work on biodiversity has focused on small plots and detailed analyses. On the other hand, reconnaissance work for conservation purposes has often been carried out in large areas that are thought to be of special value and over which protective regimes have been proposed or applied. In the more specialized study of agricultural biodiversity (agrobiodiversity), farmer selection, deliberate or inadvertent, is an important element. Thus farms and their fields, orchards, gardens, fallows, and pastures become significant units for sampling and investigation. Farmers, too, are a diverse group of people.

Biodiversity comes together in patches, fields come together in farms, and farms come together in rural communities. If we are concerned with the maintenance of biodiversity on farm, we need to look at areas within which metapopulations, interconnected by gene flow and subject to change and replacement, have meaning. Everything comes together, then, at a level somewhere between the patch, or field, and the large region. This is where the structure of diversity is expressed, where its generating processes operate, and where interrelations can be observed and understood. This is the landscape, but we need to try to define this in more positive terms before we can begin.

As a scientific entity, as opposed to its qualitative meaning of a view as seen from a particular viewpoint, *landscape* is not easily defined. It came into Anglophone science from German geography of the late 19th century, in which the *Naturlandschaft* and *Kulturlandschaft* of specific regions were analyzed, sometimes in an integrated manner. Analysis depended on maps, and nowadays on remote sensing, but the definition remains linked to what is visible at ground level, and thus the units of landscape are defined within the topographic range of scales. These have become significant in ecology since the 1970s through the evolution of the notion of patches and mosaics of patches, and Forman (1995:13) has usefully defined landscapes as areas in which a mix of local ecosystems and land uses is repeated in similar form over a wide area. By the empirical evidence of writings about ecology and land cover, landscape areas may range from a few square kilometers to several hundreds, even more in sparsely peopled areas with poorly described landscape history. Even the smaller areas contain micro-environmental diversity, often dynamic. Various systems of management, adapted to this diversity, create the pattern of land uses.

Pure science apart, the most common purpose of biodiversity analysis at landscape level is to measure or estimate change resulting from human use and change in the conditions of that use. This has become of particular importance because of the great changes that have taken place since the 19th century and especially since 1950. Population growth has been a basic driving force of change, with global totals increasing from 1.25 billion to more than 6 billion since 1850. Huge changes in agricultural technology have taken place since 1950 alone, with great success in terms of production but with serious ecological consequences. It is common wisdom that a great loss of species and genetic diversity has taken place, in areas both with and without modern agricultural technology.

It took less than 30 years of what is already called conventional agricultural technology before consequences in terms of pollution, soil loss and deterioration, deforestation and landscape homogenization, genetic erosion, and the impoverishment of areas unsuited to mechanization and chemicalization became matters of serious concern among policymakers and among a minority of farmers. In the regions most changed by the new technologies, these concerns have overtaken the earlier and still widespread concerns simply because of intensification of human use.

In Europe, where only about 3% of the landscape carries what can still be described as a natural vegetation and where 44% is managed in farms, land degradation and other changes became matters of public concern as early as 1980. By the 1990s, these concerns had led to initiation of what are now becoming major changes in the common agricultural policy of the European Union. These involve new basic standards of environmental management, which will be applied to all farms receiving subsidies, and specifically funded agro-environmental programs, which are now in use in all member countries, though with very different levels of participation (Piorr 2003). About one farm in seven is involved, and 17% of farmland in the pre-2004 European Union is subject to some type of agro-environmental program (Bureau 2003). With almost the entire European area subject to anthropogenic land use, solutions must be found through land use management. Whereas some agro-environmental programs involve no more than reducing livestock densities, others are more constructive, and some seek to create or recreate hedgerows and copses to link remaining areas of woody species and break up the wholly cleared areas that have been greatly enlarged since 1950. The aim is to restore a measure of diversity in a mosaic of suitable habitat patches at landscape level.

Characterizing Landscape-Level Biodiversity: Europe and the Developing Countries

Although the fact that diversity is disappearing is rarely disputed, monitoring change precisely continues to challenge researchers. Europeans are prepared to have part of their taxes spent on restoring their agricultural environment, and farmers participating in agro-environmental programs are paid to do so. This creates a need for monitoring, and for several years there has been a rising effort to find ways to characterize and monitor changes in biodiversity at landscape level. Although Europe is very different from the developing countries that are the main focus of this volume, the fairly intricate mosaic of land uses that still characterizes a large part of the continent makes it more similar to the latter than are the wide landscapes of, for example, North America. It is therefore worthwhile to examine some of this work, most of it in Germany.

A range of methods has been explored. Some have concentrated on inventories of the plant biodiversity on land that has come to be used in different ways; one such study in an area where farming has been given up in stages since the 1950s found, unsurprisingly, that biodiversity increased with the number of years since cultivation ceased (Waldhardt and Otte 2003). In order to avoid the large input of time and money that such standard inventories entail, a large amount of effort has been put into the search for indicator species that can be readily identified and used to monitor change. There has been particular focus on insect fauna, such as beetles, that can be trapped quickly (Duelli 1997; Büchs 2003). Sampling is major problem, and some approaches have focused specifically on the subclassification of landscape into habitat type areas. Landscape structure, involving the nature and scale of the mosaic, can itself be a valuable surrogate indicator, taking account of the influence of the matrix surrounding managed sites on species richness (Dauber et al. 2003).

One study used a combination of Landsat imagery and a detailed biotope mapping, carried out some years earlier, to develop a stratified sample (Osinski 2003). An ecological area sampling project used satellite-generated land cover data to develop an initial classification of 28 land classes for Germany, within which samples of $1 km^2$ were drawn (of agricultural land only) for detailed analysis of their biotope content (Hoffmann-Kroll et al. 2003). This work was carried out in the mid-1990s, at about the same time as the large-scale British countryside survey, which used a similar approach to the search for country-wide information based on representative sites (Haines-Young et al. 2000). Opperman (2003) proposed an even more indirect but thoroughly participatory method, evaluating the ecological management of specific farms by presence of a few indicator species—both flora and fauna—but principally by physical characteristics of the farm space and its management.

In a comparative review of recent work mainly in Germany and Switzerland, Waldhardt (2003) and Waldhardt et al. (2003) concentrate on the value of combining organismic and landscape indicators, which may well be the road forward. However, the search for indicators raises many problems, and the methods of sampling and assessment proposed all have high costs. Both the species groups and the reference areas considered in most of this work are small, and the search for indicator species that can be used widely to monitor progress in agroenvironmental work still has a long way to go. The whole European effort, despite its regionally dense level of scientific input, is still at an early stage, although an enormous amount of valuable information has been gathered. The long-term aim of developing a set of indicators for agricultural landscapes that have international validity, as proposed by the OECD (1997), remains almost as far from achievement as when it was first proposed.

Surrogate indicators can barely be envisaged in the developing countries in view of the great range of agricultural systems, climates, and biotic and abiotic conditions. Although habitat diversity and pattern are potentially important, their interpretation from remote sensing and ground-truthing demands skills and resources that are available in only a few of these countries. Sample area surveys on the ground still have to provide most of the information. Despite their limited power of explanation, the 50 or more quantitative measures of biodiversity to be found in the literature, most developed several years ago, remain the only tools available for classifying biological diversity, whether in agriculturally used or natural areas (Whittaker 1972; Magurran 1988).

The 12-country People, Land Management and Environmental Change (PLEC) project set out with the hypothesis that agricultural management using diversity strategies can sustain and even enhance biodiversity. This view has gained support in Europe, where 1,000 years of agriculture, until the development of modern technology in the 1950s, had the effect of creating a dynamic mosaic of habitat or ecotope patches that enhanced not only species diversity but also structural and functional diversity, and probably genetic diversity as well, among plants and animals (Waldhardt et al. 2003). For PLEC, which was mandated to prepare biodiversity inventories, it was necessary to record diversity in all its demonstration site areas, and a sampling scheme was set up to do this in 1999 (Zarin et al. 2002), followed by a database design (Coffey 2000) and detailed guidelines on calculation of the most relevant indices of α (and its area summation γ) and β diversity[1] (Coffey 2002). PLEC was concerned only with the diversity of vascular plants, not with fauna at any level.

Full stratified random sampling was, even more than in Europe, logistically infeasible, so our sampling procedure was more purposive than random. It went through three stages. In each of 12 countries, one to seven landscape areas (the demonstration site areas) were chosen to represent the territories of particular villages or groups of farmers with whom contact had been established and where the project was invited to work. They ranged from less than $10\,km^2$ to a notional maximum (never achieved) of $100\,km^2$ but often lay within transect bands in which reconnaissance work had been done before final selection. Within these landscapes, broad land use classes distinguished by a superficially common groundcover were first identified. Because we were working largely in areas where land rotational practices were or had recently been present, and to stress the impermanence of land cover, we called them land use stages. In 12 countries, 27 such stages were identified, reducible for comparative purposes into seven main categories, including edges (Pinedo-Vasquez et al. 2003a).

Within these larger classes, we sought characteristic types or assemblages of habitats or biotopes. Because of an emphasis on defining these by farmers' management practices, we called them field types, although they also included different stages of managed or unmanaged fallow and of forest. Actual sample areas were then selected within these field types, in a biased manner with emphasis on greatest apparent diversity or on the land worked by particular households on which other information was collected (Guo et al. 2002). Within these, sample quadrats were marked for enumeration of species. Details on management practices in the whole sampled field around the biodiversity enumeration quadrat were collected at the same time (Brookfield et al. 2002). Home gardens and edges between fields were separately sampled and treated in different ways (Zarin et al. 2002).

PLEC's biodiversity assessment was done on the ground, only sometimes with partial aid from air photographs and remote sensing images. The system was designed to make the best use of limited human and financial resources. PLEC's purpose was to study farmers' management and its effects. Such work has to be done in close collaboration with the farmers. In a small area of a few square kilometers on the upper slopes of Mt. Meru in Tanzania, Kaihura et al. (2002) found the order of detail that is summarized in box 13.1, noting that because planting takes place three times a year in this area, the crop composition of fields may change every few months. The crop composition was one important criterion for distinction of field types, and a great deal of other information was also recorded, including land ownership, age and wealth of the farmer, slope, fertility rating, evidence of nitrogen, phosphorus, and potassium deficiency, type of tillage and tillage tools used, livestock raised, methods used to control pests and weeds, and methods used to manage erosion, soil moisture, and drainage. Further inquiry on one farm, with 12 field types encountered in 1999, revealed 10 different food and cash crops, 6 types of trees, more than 10 medicinal plants used in curing more than 30 diseases, 17 types of nursery seedlings for propagation and sale, 6 vegetable crops, 18 fruit tree s, and 7 ornamental plants (Kaihura 2002:136). Thus does management diversity give context to agrobiodiversity.

Scale is an important consideration. Habitat types or field types can be hard to distinguish from land use stages when they are repeated over large areas. Though also distinguishable by different floristic composition, they are always determined by differences in farmers' management. Over much of southeast Asia the irrigated pond fields, alternately cultivated and fallowed dry fields, planted and managed agroforests or woodlots, and intensively managed home gardens constitute just four main classes of field type, each constituting a land use stage, but each can be subdivided in terms of crop content or management. Similarly, on the Fouta Djallon of Guinée, West Africa, all land except small areas of forest and uncultivable waste can be classified into three land use stages: the intensively cultivated infields that are cultivated all year and every year, the more extensive outfields and the associated fallow land, and small areas of planted and managed agroforest. At the level of a single Fouta Djallon village, these could be subdivided into a larger number of field types, together with the edges between them. Both levels of classification are valid, and both relate to the whole landscape. Which is chosen depends on the purposes of characterization.

Box 13.1 Description of Land Use Stages and Field Types in Olgilai/Ng'iresi, Arumeru, Tanzania

BOX TABLE 13.1.

Land Use Stage	Field Types	Field Type Description
Natural forest	Least disturbed	Upper foothills of Mount Meru; inaccessible because of steepness and deep incised valleys. Slopes from 85% to 50%; humid tropical climate; some wild animals; area gazetted.
	Slightly disturbed	Upper footslopes of Mount Meru; used for timber, firewood, and medicinal plants; distance from village and steepness limits use. Slopes from 15% to 35%; humid tropical climate with few wild animals; area gazetted.
	Highly disturbed	Cone-shaped hilltops some times used for recreation; used for timber, firewood, and medicinal plants. Treeharvesting controlled by village, butmost economic trees and shrubsalready harvested.
Planted forest	*Pinus* with temporary cropping	*Pinus* trees planted after clearing natural forest; maize and beans commonly in rotation with cabbage and potatoes; crop combinations and sequences differ between farmers and seasons. Slopes from 10% to 20%.
	Cypress with temporary cropping	Cypress trees planted; cropping system similar to *Pinus* plantations.
	Eucalyptus plantation	Natural forest cleared and planted with eucalyptus only.

Box 13.1 continues to next page

Box 13.1 continued

Land Use Stage	Field Types	Field Type Description
Agroforestry	Crops and trees	Complex mixes of crops and trees depending on farm size, season, and farmer preference; coffee, banana, and trees, with maize and beans most typical. Varying slopes.
	Maize and beans with trees	Maize and beans as intercrops, with trees as hedges on contours and boundaries; the most economic crops occupy the largest area.
	Potatoes in rotation with vegetables	Commercial potatoes in first season, followed by cabbage and fallow in the third season of the year.
	Maize	Maize planted as monocrop.
	Potatoes	Potatoes as a commercial monocrop.
	Farm boundaries	Boundary fences and partitioning structures with trees, shrubs, and climbers. Species have diverse uses, but most have thorns to limit trespass.
	Plot boundaries	Structures separating field types within farm, including crop residue and weed piles along boundaries, creepers, and shrubs of economic value. These may be destroyed and spread for soil fertility improvement.
	House gardens	Near the house with local and introduced vegetables. Mostly on flat areas or gentle slopes with irrigation.
Water source	Microcatchment	Delineated patches less than 30 m^2 protecting water seepage points; planted with perennial trees and bananas. No tree harvesting; trespass limited to fetching water; owned communally.

Box 13.1 continued

Land Use Stage	Field Types	Field Type Description
Fallows	Regenerating fallows	Communal or individual plots temporarily left uncultivated for fertility recovery. Steep to moderately steep slopes.
	Pastures, recreation, or fallows	Lands left fallow or family recreation places; goats may graze.
	Tethering and cut-and-carry fields	Pastures where cows are tethered for grazing or servicing (in case of bulls); grass may also be cut for fodder.

Source: Kaihura et al. (2002:155).

Farmers and Other Users of Biodiversity

Whether the landscape is a big region or the territory of only a single community, farms are the units through which most of its diversity is managed for production. Farmers rarely manage only one field type or even one land use stage; they often include areas of forest, planted woodland, and water bodies as well as arable and pasture land and the edges between these types. Fallow land may or may not be managed, and it very often provides resources that are harvested. The measurement and recording of diversity at landscape level must have not only the agreement of the landholder or user but also his or her active cooperation. Even on tracts of common property, there is much to be learned from those who use the resources.

In PLEC, we made extensive use of the concept of agrodiversity, first proposed by Brookfield and Padoch (1994), going beyond the natural versus cultural division of most landscape study to interrelate agrobiodiversity, management diversity, and biophysical diversity and put them into the context of a fourth dimension, which we called organizational diversity (Brookfield 2001; Brookfield et al. 2002). The latter term needs explanation. Whether or not it sets out to make money, a farm is a working enterprise with a distinctive set of relationships with parallel enterprises and the higher levels of the community, the authorities, and the regional, national, and global economies. Like any other enterprise, it is both a social and an economic system nested within larger social and economic systems. The operators of the farm are land managers in the sense used by Blaikie and Brookfield (1987). Even if they have to work within a system that determines what crops and livestock are produced, the farmers or farming households have to make the yearly, monthly, and daily rounds of decisions needed to obtain that production. Farms differ greatly from one another, and the resources and skills of farm operators also differ greatly.

This is a central part of diversity. It includes diversity in the manner in which farms are owned or rented and operated and in the use made of resource endowments and the farm workforce. Elements include labor, household size, the differing resource endowments of households, and reliance on off-farm employment. Also included are age group and gender relations in farm work, dependence on the farm rather than external sources of support, the spatial distribution of the farm, the amount of mutual aid that is practiced between farms, and differences between farmers in access to land. Tenure of resources, the conditions of access to them, and what Leach et al. (1999) describe as environmental entitlements are fundamentally important. Organizational diversity is involved in all management of resources, including land, crops, labor, capital, and other inputs.

Whatever the conditions of tenure, the skills needed in simple organization of the workforce at periods of peak demand are much undervalued in the general literature on agricultural development. The shift from single to double or even triple cropping made possible by Green Revolution innovations was enormously demanding of these skills. Yet farmers received little guidance and instruction on how to manage their resources and workforces at such times. They learned this by themselves. Organizational diversity is highly dynamic. Farmers change their organization of labor and resources according to circumstances, sometimes in a very short time, and are quick to respond to signals that call for new ways of combining the factors of production.

The expert farmers who do this best are not often political or social leaders in their communities. PLEC in China found a remarkable example of an innovating expert, Mr. Li Dayi, a former shifting cultivator and hunter. In the 1980s he became interested in experimenting with domestication of a rare but valuable timber species found in the forest, *Phoebe puwenensis*. Although no botanically established means existed, he succeeded in two years in growing viable seedlings. He then converted 0.13 ha of maize-growing land allocated to him in the privatization of collective land that took place in 1983 into a mixed-tree plantation. With support from PLEC, he has extended his technology to 95 village farmers (Dao et al. 2003).

In the past few years farmers in a remote Papua New Guinea village have modified their subsistence farming system to incorporate cash crops. A number of them are planting cacao or coffee seedlings in the garden during the first and second year of yam cultivation. Until around 1990 the only cash crop in the area was robusta coffee, introduced by the extension service in the 1960s, and it was grown on small plots averaging 150 trees per plot, surrounded by secondary forest and shaded by *Leuceana*. Very little additional coffee was planted after the initial enthusiasm of the 1960s, when all families planted at least one plot and often two. However, between 1990 and 2001, more than 70,000 cacao trees were planted. In this case, the shifting cultivation system is being modified in response to new conditions. In the old final stage of a three-year cropping life, plots became dominated by weeds, but these have been controlled in modern times by the introduction of ground-mantling sweet potatoes. Fallow tree species and tall grasses now are weeded out, and *Gliricidia* is planted to shade the cacao. Thus the food garden is transformed into a cash crop garden. Farmers argue that in 20 years, they will clear the cacao and plant food again. They know that land cleared from cacao and *Gliricidia* or *Leuceana* grows food crops as well as a 20-year forest fallow. So the consequences of this practice will not be a reduction in food production. Rather it will be, over 20 years, a significant loss of natural successional fallow species, many of which have uses for the people who gather them. Farmers recognize this problem but believe the loss will not be serious because not every site cleared for food crops will be converted into cacao or coffee. They will not have the labor to harvest and process this amount of cacao or coffee (Sowei and Allen 2003).

Many other examples of this kind could be cited. The most famous case in modern history is the creation of a major export industry in southern Ghana, West Africa, by enterprising migrant farmers who established big areas of cacao among secondary forest in that country between 1890 and 1920 and developed new land tenure systems in order to facilitate their colonization of land purchased from others (Hill 1963). Later in this chapter we describe how farmers in the Brazilian Amazon

Box 13.2 Agricultural Biodiversity and the Livelihood Strategies of the Very Poor in Rural Bangladesh

The fact that the poor people depend on uncultivated foods for their survival and livelihoods is well known in the villages of rural Bangladesh. But what is the nature of this dependence? Our study explores the use by the very poor of the food and plants they collect from the lands, water bodies, and forests where they live. When we asked villagers, "Where are the poor?" the answer was "Chak," meaning in the cultivated fields of others or out on the roadsides. From the months of Bhadra to Kartik they are busy in the sugarcane fields harvesting for farmers. In the months of Agarhayan, Poush, and Magh they are busy harvesting potatoes and preparing seedlings for the paddy fields of farmers. They may receive some money for this labor, which they will use for oil, salt, school expenses, and debt repayment. But they will also take potatoes as partial payment and collect the straw that is no longer needed to cover the ground in the potato field and bring it home for fuel. They will pick the jute leaves in the farmers' field for food and collect the uncultivated leafy greens along the side of the rice field, some of which they will sell. They will sell eggs from their free-range chickens to buy rice and collect small fish in the water bodies for the daily meal. This is their livelihood.

What is an appropriate response to the challenges of ensuring their access to these food sources? Agricultural development based on a few crops cannot adequately compensate the very poor for the losses in access to uncultivated food sources caused by farming practices such as the extensive use of pesticides and monocropping. Nor can they compensate for the erosion of the common property regimes and social rules that enable people to use these food sources. Analysis of the contributions of uncultivated foods to food security in Bangladesh suggests that the appropriate level for enhancing access to these food sources is the community landscape, not the individual plant species, farm, or backyard. Simply by promoting biodiversity-based farming systems and protecting village lands from pesticides and enclosure of common lands, an enormous resource of uncultivated foods is also ensured. Such a strategy can be called cultivating the landscape, in contrast to more limited definitions of agriculture based on cultivated plants in cultivated fields. Improvements in agriculture should be pursued in the context of a broader strategy to increase the capacity of communities to create and maintain the conditions needed for biodiverse food systems. Ultimately, biodiversity is not cultivated but rather nurtured in biodiverse agroecosystems.

Source: Farida Ahkter, the Centre for Policy Research for Development Alternatives, Bangladesh.

are responding to price signals by converting a field crop system into an agroforestry system. Activities of this type transform the biodiversity of whole landscapes.

There are other users of biodiversity apart from farmers. Transhumant pastoralists may use different landscapes at different times of year, and some of them enter into contractual arrangements with farmers to pasture their livestock on fallow land. This is a widespread practice in the savanna regions of western Africa. Toulmin (1992) showed how the households of one Bambara village in northern Mali dug wells by hand in the 1970s and 1980s in order to attract migrating Fulani herders, whose livestock would then be corralled on the fields of the well owners to provide manure and thus permit expansion of their cropping. But the villagers make sure that the herders remain their clients and that if Fulani settle in the vicinity they do not acquire land on which they might dig their own wells. Maintaining this security of resource access takes a lot of organization among the Bambara.

Within any resident population, some have very little land or are landless. They may depend on the resources of common lands or almost anywhere in the landscape. The foods they use may not be cultivated at all. Box 13.2, derived from an abstract of a paper presented in Montreal by Farida Ahkter of the Centre for Policy Research for Development Alternatives in Bangladesh, describes graphically how the poorest of the poor depend on landscape diversity.

Temporal Dimension

Biodiversity, whether found in agroecosystems or outside them, is always in a state of flux. The seasonal variations of temperate zones, their orderly crop rotations, and short-term farm and fallow sequences may be familiar types of temporal variation in northern agriculture. But the temporal complexities of smallholder systems in the tropics often are unfamiliar, poorly understood by scientists, and often ignored or condemned by governments.

Among the most commonly studied smallholder patterns, which typically involve both complex temporal changes in management and high levels of biological diversity, are swidden or shifting cultivation systems. These pan-tropical—and perhaps near-global—forms of smallholder agriculture are highly varied, but they generally feature clearing of fields by cutting and burning and alternations of a brief intensive cropping phase with years of forest or bush fallowing. Until recently, the phase of swiddening systems characterized by less intensive management of crops—or the "fallow" phase—usually was understood to be a temporary abandonment. It was assumed that during this part of the cycle, when planting, weeding, and harvesting of most crops were done, all active management of plants and animals ceased, and direct economic benefits derived from the plot became negligible. Indeed, fields under "fallow" often appear to have reverted to completely natural vegetation.

Research carried out over the last several decades, particularly in South America and Southeast Asia, has shown otherwise. An increasing number of studies have demonstrated that many shifting cultivation systems are more accurately described as cyclic agroforestry and that although management of swiddens may change dramatically over time, many plots are never really abandoned. Even when a substantial part of the vegetation seems to be wild or spontaneous, active and skilled, though subtle, management may be going on, shaping the species and frequencies of plants and animals on the site. Which among the plants in a particular fallow plot has actually been cultivated or which has not often is difficult or impossible to determine. And although the species sampled may not change, the wild/cultivated ratio may shift as natural regeneration and volunteers join or replace cultivated plants over the months or years in which a fallow is subtly managed.

Economic pressures are rising and rural populations increasing throughout tropical Asia and in other parts of the world where swiddening has been a common way to make a living. The management of swidden–fallows is undergoing dramatic changes in response to these shifts. Management of all phases of the cycle is becoming more intensive and visible, with market-oriented species increasingly featured. The forms these intensified swidden–fallow systems are now taking remain varied, with agroforests often dominated by rubber, fruit, or fast-growing timbers. Other, more intensive—but still complex and cyclic systems—include fallows dominated by economically valued shrubs and even by herbaceous legumes (Cairns 2006).

How can we accurately measure the biodiversity in systems such as swidden–fallow agroforestry systems that change continuously? Taking the broader landscape as a unit of research and including fields and "fallows" of various management levels and ages helps the researcher capture a good amount of the richness and complexity of such agricultural patterns. Resampling over time is desirable to catch seasonal and other variations. The PLEC project found that in each region researchers must be flexible in their methods, varying them to suit local conditions. And they must understand the limitations of their data when long-term research and resampling are not possible.

Temporal complexity takes many forms and therefore presents many difficulties to the researcher. In the floodplain of the Amazon River, where PLEC has several research sites, plots of land annually pass through both terrestrial and aquatic phases. Farmers' plots disappear under river waters in the annual flood, normally about 10 meters high in the upper section of the river in Peru. The fields that appear after floodwaters recede several months later are changed not only in vegetative cover but often in size, soil type, and other qualities that determine both present and future agricultural uses. Complicating the issue for the researcher is the fact that while a plot is under water and its biodiversity changes drastically, it is often not unproductive but is merely passing through a different, aquatic phase. Many floodplain farmers in the PLEC site of Muyuy in Peru, for example, manage streamside and lakeside vegetation, including fruit-bearing trees, not only to produce fruits for human consumers in the terrestrial phase but also to attract fish during the flood season (Pinedo-Vasquez et al. 2003b). The multipurpose aquatic and terrestrial phase management developed by Amazonian farmers is difficult for agricultural researchers to see, much less appreciate; its biodiversity components are certainly difficult to measure.

Multifunctionality and simultaneous management of agricultural, agroforestry, and forestry resources in a single field are common to smallholder enterprises throughout the tropics. Despite their pervasiveness, these approaches are rarely mentioned in the literature and appear to be invisible to most researchers. Many farmers manage annual crops in their fields for harvest in a few months while also tending interspersed tree seedlings that will be cut in 30 years or so. The tree seedlings may be spontaneous volunteers or be deliberately planted or transplanted from neighboring forests or gardens. While the crops are planted, weeded, and harvested, the slower-growing trees may receive little more attention than a cursory cleaning and an occasional pruning. The continued nonmechanized nature of much smallholder farming in the tropics makes such diversity possible. The knowledge local farmers have of the growth characteristics of many organisms and their combinations, as well as of the specific capabilities and limitations of each corner of their fields, make such complex management profitable. Box 13.3 demonstrates the end result of such a process of management in the Amazon floodplain of Brazil, beginning in the swidden stage with planting or nuturing the seedlings of valued trees, continuing through the fallow stage to final incorporation in the developed forest.

Dynamism can be easy to misinterpret, particularly in systems that are rich in diversity and managed by farmers or communities that are politically marginal or culturally distinct. The work of anthropologists Fairhead and Leach (1996) in Guinea illustrates this point in what has now become a famous case. They describe a situation in which there is general agreement that the fields, forests, and grasslands of Kissidougou Province are now, and have long been, in flux. However, official and local understandings of the direction of those changes, and of the essential nature of human–forest interactions in Kissidougou, are at complete odds. If the local contention that most of the diverse and large forest islands that dot the landscape are largely human creations is accepted, measures of regional agrobiodiversity and notions of human manipulation of local landscapes are essentially opposite to those suggested if the competing scenario of advancing deforestation is affirmed. Making effective use of the modern evidence of air photography and remote sensing, as well as earlier descriptions, Fairhead and Leach confirmed the local interpretations.

In another part of the world, Yin (2001) has shown how the remaining swidden farmers in Yunnan, China, have greatly modified their systems, some of them recently, some a long time ago. Crops and cultivation methods have been changed, rotations have been shortened and means have been found to sustain fertility within these shortened rotations, cash crops have been introduced or cash-earning uses have been found for plants formerly used only for subsistence, and even terracing has been incorporated. Yet despite the highly skilled adaptations that have been made and continue to be made, many officials and some scientists continue to regard all that the swidden farmers do as primitive, to be replaced rapidly. Only with modern appreciation of the ecological advantages of agroforestry has a new understanding of traditional skills begun, belatedly, to arise.

Change in smallholder agroecosystems often occurs in incremental and seemingly disjointed steps (Doolittle 1984; Padoch et al. 1998) that again add a measure of complexity and ambiguity. Limitations in human

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Box 13.3 Biodiversity in the Forest Stage at Two Sites on the Lower Amazon in Brazil

In two sites we found that the forest areas that are part of the landholdings of smallholders are the results of successive management operations that began in the field stage and continued into the fallow and forest stages. Inventories conducted in a sample of 10 ha (5 ha in Mazagão and 5 ha in Ipixuna) show a great diversity of species (box table 13.3).

In both sites the forests contain high levels of species richness and evenness. However, the average number of species found in the Mazagão forests (51) is slightly higher than the average found in Ipixuna (36). In contrast, the sampled forests of Ipixuna have more trees (average 1,117) than the ones sampled in Mazagão (average 1,041). These results reflect the histories of management and resource extraction practiced by smallholders in both sites. In Mazagão people are more dedicated to forest activities, and they tend to continually enrich their forest with desirable timber, medicinal, and fruit species. Farmers in Ipixuna are more dedicated to agroforestry and the collection of fruits and medicinal products than to timber extraction.

Despite the differences in forest uses and management practiced by the inhabitants of Mazagão and Ipixuna, forests in both sites show very high diversity or Shannon's index. Based on the estimated diversity indices, forests in Mazagão have higher values (average $H'=2.59$) than forests in Ipixuna (average $H'=1.77$). These results are very similar to the reported estimated Shannon's index for forest areas in other regions of the estuarine *várzea* floodplain (Anderson and Ioris 1992).

Although forests in Mazagão are richer in species than those in Ipixuna, the two most commercially valued species (*Euterpe oleraceae* and *Calycophyllum spruceanum*) are some of most dominant and abundant species in both sites. This indicates that people are encouraging the establishment and growth of

BOX TABLE 13.3. Diversity in forest samples comparing the number of species, number of individuals, and Shannon index (H)

Mazagão				Ipixuna			
Sample Plot	Number of Species	Number of Individuals	H	Sample Plot	Number of Species	Number of Individuals	H
1	48	892	2.96	6	26	623	1.66
2	55	1,096	2.66	7	41	1,032	1.91
3	54	1,118	2.43	8	38	1,610	1.68
4	45	778	2.66	9	43	1,696	1.80
5	55	1,322	2.26	10	34	923	1.80

Box 13.3 continues to next page

Box 13.3 continued

these and other valuable species in their forests. Similarly, the presence of a high number of timber, fruit, and medicinal species suggests the intensity and frequency of management by local people in both sites. The inventory data also show that people maintain a low number of individuals of several noncommercial species. Among these species are some pioneer species, such as *Cecropia palmata* and *Croton* sp., that play an important role in attracting game animals.

The estimated importance value index shows that 8 of the 10 most important species found in the forests of Mazagão and Ipixuna produce commercial products. As in the case of managing fallows, people also are adapting and developing new management technologies that correspond to specific environmental and economic conditions. The abundance and dominance of economically important species are maintained by smallholders through the application of management operations that promote the regeneration of species under different light and environmental conditions. For instance, the majority of farmers conduct preharvest operations to avoid excessive damage to the forests, thus optimizing production. Among the most recent and innovative preharvest operations is broadcasting seeds or planting seedlings of valuable species before cutting timber. Most seedlings are collected from other parts of the forests; however, the seedlings of andiroba (*Carapa guianensis*) are produced mainly in home gardens.

Source: Pinedo-Vasquez et al. (2003c:69–71).

labor and other resources available to rural households to produce substantial environmental alterations make long-term, farm-as-you-go approaches necessary. In what are agriculturally marginal environments, the very creation of arable land may take years and many labor-intensive operations. For instance, the conversion of peat swamps to productive coconut orchards or rambutan gardens on the coasts of Indonesia's West Kalimantan Province takes years of ditch-digging, drainage, and creation and destruction of several forms of rice planting before a profitable orchard is established. A typical landscape in such a region may comprise a multitude of patches of varying use, management, and diversity. All of the components of this landscape mosaic are parts of a diverse, complex, and dynamic system of smallholder tree cropping.

Inland from Kalimantan's peat swamps, change from one system to another is taking place in what is also a discontinuous, incremental, and visually confusing process. Padoch and others have documented how Dayak villagers are switching from swidden farming of upland rice to irrigated rice cropping (Padoch et al. 1998). The process of change creates multiple intermediate stages, many of them diverse, and all of them differing in productivity and appearance. The study of agrobiodiversity in such dynamic systems poses challenges to scientists who would accurately represent their richness.

Conclusion

Biodiversity at landscape scale presents a number of challenges in both measurement and interpretation. Because comprehensive survey is logistically impossible at this scale, the nature of the sampling frame is centrally important, and it creates a number of difficulties, especially in the definition of the nested samples. A strong purposive element is almost always introduced. In PLEC, we selected fields within field types and comprehensively sampled quadrats within these, as well as entire home gardens. In the European work, efforts have been made to find indicators to overcome the scale problem of landscape-wide surveying, but none have been found that are universally applicable. Because the purpose is to evaluate the success of management improvements, a combination of selected biotic indicators with structural aspects of the farming matrix and even specific management characteristics seems a likely way to proceed. Modified, such an approach could be applicable in developing countries.

However difficult it may be to measure in a scientifically defensible manner, appreciating agricultural biodiversity at the landscape scale is necessary for understanding many of the strengths of smallholder farming, particularly in developing countries. A large part of the managed—if not directly planted—diversity of these systems is found in the margins of fields, along the paths, between the houses, and along the watercourses. These patches of vegetation are harvested regularly and their fruits are eaten, sold, and used to fill a hundred economic needs. When farmers are deprived of these invisible resources, their diets and incomes often decline, and their ability to deal with climatic or economic perturbations often is lost.

Larger questions are raised by the temporal element of biodiversity management by farmers. The alternation of aquatic and terrestrial phases in annually inundated floodplains has been discussed in some detail, but the larger issue is the purposive management of land at one land use stage to create a modified biodiversity in a later land use stage or, put another way, the different biodiversity that results from deliberate changes in land use. These sequences are central to the understanding of landscape-level management, and they reveal how large an effect management can have on biodiversity. This chapter has discussed the modification of biodiversity through management, both deliberately to affect biodiversity and indirectly through changes determined only by the needs of production. The constant flux of biodiversity emerges as a central conclusion, and it is one that questions all notions of conserving "static" conditions in plants, plant assemblages, and managed landscapes.

Note

1. Alpha diversity is the diversity within a site or quadrat (i.e., local diversity), beta diversity is the change in species composition from site to site (i.e., species turnover), and gamma diversity is the diversity of a landscape or of all sites combined (i.e., regional diversity).

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