Cambridge University Press
0521532019 - Invertebrate Conservation and Agricultural Ecosystems
T. R. New
Excerpt
More information

1 · *Introduction: agricultural ecosystems and conservation*

Development of agriculture has had profound effects on natural communities and has involved changes in land-use patterns over much of the world. In general, the changes have involved replacement of complex natural communities by much simpler and less diverse systems, and loss or reduced abundance of numerous species of the fauna (of which invertebrates are predominant components) and flora previously present. Intensification of agriculture has escalated these changes and led to the development of so-called 'agroecosystems' as substantial and highly managed terrestrial ecosystems, in which commodity production (rather than conservation) is the major aim and outcome. Agroecosystems are an important arena in which to enhance conservation, including that of invertebrates, for major benefits to biodiversity.

Introduction

Agriculture has been defined as 'the art, practice, or science of crop and livestock production on organised farm units' (Pesek, 1993) and is the world's most extensive industry, one upon which humankind depends. Indeed, the future of human populations is linked fundamentally with sustaining agricultural production. Agriculture is thus the single largest component of global land use, with some 36% of the world's land surface devoted to providing the primary produce needed to sustain people (Gerard, 1995). Clearing of natural vegetation to increase this proportion is continuing in many parts of the world. Agriculture is also amongst the most varied suite of activities that may compromise the integrity of natural environments, and the variety of scales and activities associated with a very broad range of products renders generalisations about its wider effects difficult. However, agricultural activity, and its enhancement to cater for the needs of growing human populations, has led to remodelling of natural landscapes in many countries, to the extent that agricultural landscapes encompassing pasture and crops are often regarded as largely 'natural', particularly in parts of the northern hemisphere, where centuries of change have occurred. In parts of Europe, the transformation of natural ecosystems has rendered it impossible to find existing woodland habitats that can be considered realistic analogues of forests characteristic of the climatic climax vegetation of only some 5000–7000 years ago (Mannion, 1995). In much of the tropics and the southern hemisphere, such massive changes have occurred over a shorter period – in Australia, for example, only over about the past 200 years – and can be considered realistically in relation to the properties of the more pristine parental environments that they have replaced.

The history of agricultural development, though, shows parallels in many places, with changes to increase productivity, efficiency and economic wellbeing imposing the need to oppose factors (such as pests that attack crops and livestock) that may compromise those aims. These trends have also been associated with changing scales of operation. Agriculture requires environmental modification, but the extent of this varies and is reflected in the enormous variety of global agricultural systems. At one end of the spectrum of effects, practices such as nomadic pastoralism may necessitate little change, other than for transitory or seasonal effects, and the host ecosystems may remain largely unaltered. At the other extreme, intensive crop production involves massive changes, with severe implications for environmental wellbeing, and that may be regarded as 'permanent'. In principle, systems such as nomadic pastoralism and small-scale shifting agriculture reflect the 'low-input' end of the technological gradients (see below) and represent the beginnings from which more intensive systems have been developed. Neither practice involves use of fossil fuels, or other than very minimal chemical inputs, and both involve temporary use of land areas. Shifting agriculture is generally limited by availability of nutrients and commonly involves clearing of natural vegetation that is collected, dried and burned before cultivation of crops. Most occurs in the tropics, and the major variants in practice reflect local cultural practices and environmental conditions.

More permanent 'settled agriculture' is based largely on arable systems, i.e. those that historically require ploughing, tillage or other ground preparation before crop cultivation and that comprise the most diverse category of agricultural production systems. Croplands occupy some 11% of land area, not including the somewhat special case of agroforestry (see p. 296). In contrast, settled pastoral systems (extended to include the world's rangelands) occupy more land (with estimates of up to 50% of land area) (Mannion, 1995) but lesser variety, reflecting the regimes in which the relatively few species of domestic livestock are produced. Both these major categories have diversified in relation to (1) what is grown and (2) how it is grown, and the purposes for which the commodities are intended. Both occur in all except the most inhospitable parts of the world, in which productivity is limited by climate extremes such as lack of rainfall (although irrigation may, in places, counter this) and nutrient/food availability. Mixed farming systems involve integrating livestock and crop production, in many cases involving fodder crops for the livestock and human commodity crops. Collectively, these practices have affected all major terrestrial ecosystems directly, and aquatic systems more indirectly, with Hart *et al*. (1994) claiming that around 75% of Earth's habitable land has been disturbed to some extent by agriculture-related activities.

These activities thus range from local, largely subsistence agriculture to intensive operations over large land areas to satisfy export needs as major components of national economies. Very broadly, this variety allows agricultural activities and systems to be divided into three major categories, representing points in a cultural and economic continuum as progressive increases in complexity and ecological impact:

1 No-input agriculture. This is the simplest form of agriculture, involving very few inputs for management, and is involved predominantly with controlling amounts taken from a system and thereby leaving it sustainable. Such harvest-only systems are exemplified by gathering wild crops (rather than planting crops under 'improved' conditions) and grazing stock on open rangelands rather than on improved pasture.
2 Low-input agriculture. This level includes more intensive management than the above and is exemplified by many kinds of subsistence agriculture in which desirable crop species are planted and protected by removal of competitors, such as weeds and pests, to assure and increase yields.
3 High-input agriculture. This is the most intensive category of agriculture, involving substantial human management of production systems, and is typified by development of many forms of agroecosystem (see p. 7). Substantial amounts of energy and chemicals may be needed to maintain, promote and protect species cultivated in large areas of monoculture, and intensive management is usually a necessary cost in the production system. This category therefore typifies much agricultural production in industrialised countries and may have severe effects on local environments and biota (Gerard, 1995).

Agricultural intensification increases in the above sequence. Intensification has three major axes, each associated with changes of farming practice and each affecting the parental environment and the biota of surrounding areas. Intensification reflects, amongst other things, that (1) land available is finite, so better use must be made of land already in production, and (2) even if further land is available, concerns over continued intrusion into natural ecosystems through additional land conversion for agriculture commonly render this undesirable or controversial. These axes are:

1 Space. Spatial intensification involves a greater proportion of available land being used intensively. Increased clearing of natural vegetation may eventuate, sometimes to create larger cultivable units. Loss of native biota may be relevant to producers through loss of refuges or habitat for natural enemies of crop pests, and the major obvious (visual) environmental effect is loss of remaining natural habitat fragments or other residual vegetation such as that around field margins.
2 Time. Temporal intensification involves higher land use made possible by practices such as irrigation, increased fertiliser inputs, and development of fast-growing plant varieties. Increased inputs of fertilisers and pesticides for crop promotion and protection have, in some cases, obviated the need for fallow periods or crop rotations, as losses of soil quality and continuity of pest populations in the area are countered by these other means.
3 Technology. Technological intensification, touched on above, is reflected in the reliance on massive amounts of chemical use as a staple way to maintain and improve crop yields. This has led, amongst other things, to needs for intensive management, for example for resistance to insecticides, and innovative measures such as genetically modified plants to increase uniformity, predictability of yield and protection against pests.

In each of these aspects, intensification practices modify the characteristics of the system. Spatial intensification is associated directly with declines in native species that previously could be sustained in the mosaic of habitats in the landscape. Temporal intensification may omit rotation of recuperative crops in favour of further sequences of profitable extractive crops, so that maintenance of soil quality depends increasingly on greater use of fertilisers. Technological intensification leads to reduced variability in the systems, facilitating efficient pest management, harvesting procedures and predictability of phenology and production. Very broadly, each may reduce independent sustainability of the systems, and greater levels of intensification demand progressively greater levels of external management to assure productivity.

With this realisation that continued high-input intensification is associated with increasing levels of non-sustainability, considerable emphasis is now being placed on modification of agricultural practices to increase and assure sustainable agriculture. Broadly, the term 'sustainable' implies regenerative processes that preferentially use locally available resources and natural processes, such as nutrient recycling, and limit the use of external inputs of agrochemicals and non-renewable energy. 'Regenerative agriculture' requires that any such external inputs are used efficiently, so that by-products can be recycled and absorbed. The term 'sustainable agriculture' first appeared in the literature in 1978 (Kogan, 1998). However, the more than 80 proposed definitions of 'sustainability' advanced in the past decade or so emphasise a considerable variety of different values, goals and postulates. It may imply, for example, persistence and capacity to continue; or it may primarily imply not damaging or losing natural resources. In addition, it has wider connotations of environmental conservation and product safety. The pragmatic aims thereby converge with environmentalists' ideals in encompassing benefits allied with 'ecologically clean', 'low input', 'organic', 'alternative' and the like in emphasising reduced technological and chemical inputs to the agricultural systems.

The major trends in management (after NRC, 1989) are:

1 Diversification rather than continuous planting of fields to single or few annual crops.
2 Biological and other pest controls or management, including integrated pest management (IPM) (Chapter 4); measures that reduce pesticide applications.
3 Disease prevention in livestock, rather than routine prophylactic antibiotic doses.
4 Genetic improvements in crops for purposes such as (1) pest and disease resistance, (2) drought tolerance and (3) increased efficiency of nutrient use.

These principles have been enunciated in various, overlapping ways. Thus, Oades & Walters (1994) noted that sustainable agriculture should:

1 maintain or improve the production of 'clean' foods;
2 maintain or improve the quality of landscapes, which include soils, water, biota and aesthetic attributes;

Table 1.1. *Objectives of sustainable agriculture (after Pretty, 1998)*

1. Incorporation of natural processes, such as nutrient recycling, nitrogen fixation and pest–predator relationships into agricultural production processes, so ensuring profitable and efficient food production.
2. Reduction in use of those external and non-renewable inputs with greatest potential to damage the environment or harm health of farmers and consumers. More targeted use of remaining inputs, with a view to minimising costs.
3. Full participation of farmers and rural people in all processes of problem analyses, technology development, adaptation and extension.
4. More equitable access to productive resources and opportunities, and progress towards more socially just forms of agriculture.
5. Greater productive use of local knowledge and practices, including innovative processes.
6. Increase in self-reliance amongst farmers and local people.
7. Improved matching between cropping patterns and productive potential and environmental constraints of the climate and landscape to ensure long-term sustainability of current production levels.

3 have minimal impacts on the wider environment;
4 be economically viable.
5 be acceptable to society.

Pretty (1998) considered a wider range of farming objectives (Table 1.1), recognising the philosophical viewpoint that 'sustainable agriculture seeks the integrated use of a wide range of pest, nutrient, and soil and water technologies' with community level involvement to facilitate increasing substitution of natural processes for external inputs 'so the impact on the environment is reduced'.

Management of agricultural systems when the emphasis is on enhancing basic biological systems differs greatly from that based on continued, accelerated use of external inputs. Much of this book draws on one major context of massive relevance in sustainability – that of pest management in agricultural systems and the accompanying concerns for the most diverse components of animal diversity, the non-target invertebrates. The milieux of concern are so-called 'agroecosystems', a term that can be applied either to areas used primarily for cultivation or (on much larger scales) to areas such as natural catchments in which the effects of agricultural practices may ramify.

Table 1.2. *Structural and functional differences between natural ecosystems and agroecosystems (from Gliessman, 1997, after Odum, 1969)*

	Natural ecosystems	Agroecosystems
Net productivity	Medium	High
Trophic interactions	Complex, webs	Simple, linear
Species diversity	High	Low
Genetic diversity	High	Low
Nutrient cycles	Closed	Open
Resilience	High	Low
Duration/permanence	Long	Short
Habitat heterogeneity	Complex	Simple
Human control	Independent	Dependent

Agroecosystems and agroecology

The development of the concept of 'agroecosystems' has helped ecologists to focus on the peculiar features of agricultural systems and the many ways in which they may differ from natural ecosystems. The field of agroecology has grown in parallel to reflect those differences (Gliessman, 1990, 1997).

Most fundamentally, an agroecosystem is an agricultural production unit (such as a farm, field or orchard) understood as an ecosystem (Gliessman, 1997) and thus conventionally has imposed physical boundaries. However, changes within those boundaries transcend them to penetrate much of the surrounding area. Agroecosystems differ from natural ecosystems in some important ways (Table 1.2), with the extent of differences reflecting the intensity of agricultural practice. They are subject to a similar variety of constraints and ecological rules.

Their major features (after Pedigo, 1996) are:

- Agroecosystems often have very limited duration because the life of crops can be very short. Each crop may be removed completely (many field crops, in particular) at harvest, so any equivalent to long-term successional change is then absent.
- Agroecosystems commonly undergo massive changes from external management, such as tilling, ploughing, chemical applications, and changes in microclimate and soil quality.

- Agroecosystems commonly are dominated by exotic species. If native species are used, then these may have been modified substantially from their ancestral forms through long histories of artificial selection or imposed genetic uniformity.
- Most agroecosystems are assumed to have very low species diversity (see p. 12); many are monocultures, areas of a single plant species or variety with little intraspecific variability and with measures taken to prevent increase of diversity during crop life.
- Many agroecosystems also consist of plants of imposed uniform age and size, so development from germination to harvest is uniform, with phases such as flowering or seeding occurring simultaneously in all individuals. Density of the plants may be much higher than in natural communities.
- Agroecosystems are commonly 'enriched' by addition of fertilisers, rendering the plants nutritious and attractive to many herbivores. Rapid growth may prolong the presence of tender, palatable tissues.

To a large extent, agroecosystems are 'purpose-built', and the maintenance of natural ecosystem functions has been regarded as low-priority, in relation to increased efficiency of production. Much of this trend has been driven by simple economic need; for example, labour costs in Germany rose by 300% between 1950 and 1970, whereas prices for agricultural products rose by only 25% during this period. Survival of farmers necessitated increased efficiency and productivity, obtained through increased specialisation, reduced machinery requirements, concentration on a few cash crops, and increasing fertiliser and pesticide inputs (Kuhbauch, 1998). This example is paralleled in many other places and indicates a major driver for intensification and accelerated ecological change associated largely with decreased agricultural diversity (Table 1.3).

Each of these changes links with perceived decline of biodiversity. Thus, for example, the larger the number of crop species, the larger the overall pool of resident species of animals and plants is likely to be, because each crop provides different resources and different environmental conditions for coexisting species. Each crop species may have its characteristic complement of plant weeds as well as its own consumers and their predators and parasitoids (see p. 142). Many of these taxa are the direct targets for pesticide use or other management, so that higher diversity of crops may be accompanied by more varied pesticide applications.

Table 1.3. *Indicators of diversity in agriculture (Kuhbauch, 1998)*

1. Number of crop species used in single farms or regions.
2. Subdividing arable fields into individual smaller fields.
3. Size of individual fields.
4. Percentage area and distribution of land not used by crops (i.e. with hedges, trees, etc.).
5. Intensity and frequency of farm-management inputs (fertilisation, pesticide applications, harvesting, etc.).
6. Number and species used in animal husbandry, per farm, per area unit, per region.
7. Diversity of non-agricultural vegetation, including weeds.
8. Diversity of companion plants.
9. Number of individual farms in region.

Accompanying organisms of no interest to agriculturists are likely to be displaced by management.

Establishment and maintenance of agroecosystems thereby encompasses several levels of change. The initial establishment may entail removal of long-lived native vegetation and its replacement by a few transient exotic species, so that loss of natural habitats is the major initial perturbation. This is followed by persistent attempts to block any natural tendency for diversity to increase again, and the large areas treated are associated with landscape-level effects such as fragmentation and progressive isolation of remaining natural habitats. Indeed, in some places, patches of natural habitat remaining in largely agricultural landscapes are mostly fortuitous. The Western Australian 'wheat belt', for example, has been almost wholly cleared, other than for small patches that were too rocky or too steep for easy cultivation. Many such patches are now valued as remnant habitats for endemic biota largely extirpated from the otherwise altered landscape.

The pattern painted for Europe (Kuhbauch, 1998) is of much wider relevance. Four likely regimes resulting from agricultural intensification were perceived there, namely:

- areas with intensive agricultural production and low biodiversity;
- nearly bare regions, some of them reforested, with medium biodiversity;
- a small proportion of areas and farms in which sustainable farming methods lead to relatively high biodiversity;
- some uncultivated 'islands' of natural resources with oligotrophic soils that preserve high biodiversity.

Agroecosystems and natural ecosystems

The axes of change from natural ecosystems to agroecosystems encompass the most significant ecological concerns for conservationists, many of them centering on diversity, stability (van Emden & Williams, 1974) and levels of disturbance, each reflected in the resilience of the systems – that is, their ability to buffer internally against imposed changes. 'Diversity' is often interpreted simply as species richness, i.e. the number of species present. However, ecological diversity may be assessed also at the genetic level (this approach is relatively rare in practice) or at various structural levels, such as the number of horizontal layers (more complicated 'architecture') within the vegetation present, or patchiness of distribution within an area, in addition to functional complexity (such as analysis of food webs to indicate the complexity of interactions between the species present). High diversity is characteristic of many natural ecosystems and is seen widely as being correlated with resilience or stability. Diversity increases with time, particularly with time since disturbance, so that the later stages in an ecological succession typically support more species, more complex interactions and more structural complexity than earlier successional stages. Agroecosystems only rarely proceed far along successional gradients, and the regular and intensive disturbance is linked not only with loss of biodiversity but also with the inability of the systems to accumulate diversity – which, in any case, is often undesirable to growers as constituting pests (herbivores on crops) or competitors (plant weeds competing within the same nutrient pool as the crop). When an ecosystem is disturbed, structural changes may be apparent as loss of species and of architecture, but these accompany functional simplification, with their extent often reflecting the intensity and frequency of disturbance. In essence, such changes stop succession and cause it to recommence from the new beginning imposed. 'Secondary succession' is succession on disturbed sites, in contrast to 'primary succession' on previously uninhabited sites, such as volcanic ash and lava flows.

Disturbance to ecosystems varies in (1) scale – the spatial extent; (2) intensity – the extent of change by loss of biomass or species; and (3) frequency – with lower frequency implying longer recovery intervals between successive disturbances. These are not always easy to distinguish clearly. Recovery involves invasion and establishment of species, leading to re-establishment of ecological function. The initial species present, the pioneer species or '*r*-selected species', tend to be characterised by their ability to exploit low-diversity environments. They are typically good