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Global Biodiversity Assessment

V.H. Heywood, Executive Editor **R.T. Watson**, Chair

UNEP

Published for the United Nations Environment Programme

CAMBRIDGE
UNIVERSITY PRESS

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Human Influences on Biodiversity

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EXECUTIVE SUMMARY

Humans depend on biological resources for food, energy, construction, medicine, inspiration, and much else besides. Indeed, biodiversity and humans have had a close and mutually supportive relationship for tens of thousands of years. The biological resources upon which people depend have the critical character of being renewable, at least when they are managed well; but biological resources that are abused can also become extinct. The way societies have managed their resources determines how much diversity survives and the way that societies manage biological diversity determines the productivity of important resources and ecological services.

Human activities have helped to create substantial genetic and species diversity, and have increased the diversity of biological communities in particular regions through resource management practices and through the domestication of plants and animals.

A number of traditional resource management practices have supported the maintenance of species and genetic diversity. Systems of shifting cultivation in Southeast Asia, for example, often left some portions of the land permanently out of the rotation as sacred groves. And within the cultivation rotation itself, high levels of species diversity have been maintained, because the fallow fields offer productive feeding grounds for many species of wildlife. Shifting cultivation systems that once covered much of the land surface of the Earth (except Australia) have had a profound influence on biodiversity, often leading to increases in those species that were of greatest interest to people.

Low-input agricultural systems have long been important sources and custodians of biodiversity. Farmers frequently grow mixtures of different crops adapted to different localities in order to reduce the risk of loss to pests or extreme weather. Farmers have also traditionally engaged in active breeding of local cultivars and livestock, building most of the genetic base of our modern intensive agricultural systems. These traditional biological technologies have now been supplemented by modern breeding techniques and the new 'biotechnologies' including tissue culture and genetic engineering. These techniques rearrange genetic diversity and create new plant and animal varieties.

Within any given region, the introduction of alien species may increase the species diversity in that region. However, species introductions can be a major cause of extinction of native species and the global effect of increased rates of species introduction is overwhelmingly a net loss of global species diversity. Species are introduced for many reasons, most of which relate to the human interest in providing species that are especially helpful to people, such as agricultural species; but humans also accidentally introduce species, such as rats on oceanic islands and zebra mussels in the North American Great Lakes. Nevertheless, within a given region, species introductions can increase diversity. For example, the diversity of domesticated species in temperate cities may exceed the natural species diversity in the region, and many islands, such as those of New Zealand, now contain more alien plant species than native species. Similarly, the mammalian fauna of Britain has been increased through the introduction of new mammal species, even as it was earlier reduced by human-induced extinctions.

Biotic impoverishment – the loss of the characteristic diversity of species, genes and biological communities in a region – is an almost inevitable consequence of the ways in which the human species has used and misused the environment in the course of its rise to dominance; the factors that have led to the expanding ecological niche of humans are indirect causes of the loss of biodiversity. One study suggests that humans today annually mobilize approximately 40% of the total primary production on land, a massive and pervasive co-option of resources that inevitably leads to significant impoverishment of the biota.

The underlying causes of loss of biodiversity stem from changes in attitudes toward nature; growth in human population and natural resource consumption; the impact of global trade; economic systems that fail to value the environment and its resources; and inequity in the ownership, management, and flow of benefits from both the use and conservation of biological resources.

Human impacts on all levels of biodiversity are closely interrelated. An introduction of a new gene into a population, for example, could change the competitive dominance of that species, causing the extinction of a competitor and changing the composition and processes in the biological community. Recognizing that these impacts cannot be fully separated it is still useful to assess the impacts humans are having or could have on each general level of biodiversity

Humans have been a cause of species extinction for thousands of years especially when they migrated into new habitats. Hunting of large mammals in the Americas and Australia is thought to have contributed to substantial extinctions of large mammals between 50 000 and 15 000 years ago, as humans first moved into these continents. During the past 400 years, some 486 animal and 654 plant species are recorded as having gone extinct.

Despite the long history of human impact, human activities are placing significantly more species at risk of extinction today than at any time in the past as a result of environmental changes affecting current population sizes, environmental carrying capacity, population density, the mean and variance in population growth rates, the genetic structure of populations and the size, number and distances of suitable habitat patches and local populations.

The current dominance of intensive agricultural production in much of the world, which relies on lower levels of varietal diversity, has led to a significant reduction in the genetic diversity of crops and livestock under active management. For example, some 27% of the over 1400 recorded breeds of animals are threatened with extinction.

Declines in indigenous breeds and varieties and their replacement by a few varieties has been less extensive in developing countries but is now accelerating. In India, for example, an estimated 50 000 local varieties of rice existed until recently. Today, a small number of varieties is grown on over 70% of the rice land and on 90% of land allocated to wheat. In one district, an estimated 95% of traditional rice varieties have been lost.

The introduction of any new crop crop variety or micro-organism can have significant impacts on the genetic make-up of other species in the region, and potentially on the composition of surrounding biological communities. The nature of these potential impacts is independent of the technology used to produce the variety: gene flow from a traditionally bred crop variety could represent as great a threat as gene flow from a genetically engineered variety.

Human impacts on biological communities take two main forms: conversion from one type of community to another; and modification of the conditions within a biological community. Worldwide, forest and woodland communities have decreased by about 15% in area since pre-agricultural times. Temperate forests are currently relatively stable in area, while tropical forests are rapidly decreasing in area; but even in the temperate forests, the increasing area of plantations means that much biodiversity is being lost even if the forest area remains relatively constant.

Since 1700, cropland has increased five-fold and since 1800, irrigated cropland has increased 24-fold. The area in grassland has remained roughly constant over the past 300 years, with loss through conversion to cropland being balanced by gain through deforestation. The area of grassland has decreased significantly in Europe, North America and Southeast Asia, but this has been compensated by increases in Latin America and tropical Africa.

Commercial agriculture has led to considerable marginalization of the landscape. Surface irrigation schemes, for example, transform the complex mosaic of micro-habitats into a uniform agricultural mosaic, favouring a few crop species and varieties while displacing numerous micro-habitats such as hedgerows, fallow fields tree groves, riparian vegetation, and so forth.

The introduction of alien species is often responsible for the modification of conditions within a biological community. Introductions influence the genetic diversity of native species and may alter species composition by causing the extinction of other species, influencing the interactions between other species, and altering ecological processes such as water chemistry, nutrient cycling and soil structure.

The perception that biodiversity management is primarily an issue of isolating biodiversity from humanity is a very recent phenomenon and is scientifically unfounded. Traditionally, biodiversity has been conserved and utilized as an integral part of resource management. While active protection of biodiversity by governments has played and should continue to play an important role in biodiversity management, even more important will be steps to reintroduce or restore local and regional management practices that successfully integrate sound management of biological resources.

11.0 Introduction: conceptual framework

Humans depend on biological resources for food, energy, construction materials, medicine, inspiration, and much else besides. Further, biological resources have the critical character of being renewable, so with proper management they can be used sustainably. However, when the levels of human use of biological resources exceed their capacity for renewal, the diversity and productivity of the system in which they occur may be reduced. Ultimately, the way that societies manage their resources determines how much diversity survives. Societies vary in the extent to which they use external inputs in resource management, with some societies living at a very basic stage and others almost totally dependent on external inputs (especially of energy). This section reviews the history of human impacts on biodiversity, assesses the factors that govern the way human societies influence biodiversity, identifies gaps in knowledge, and speculates about future human impacts.

The history of human civilization is intricately associated with the evolution of artefacts – objects constructed by people from natural resources. Centuries of effort have resulted in an endless procession of technological innovations which transformed many terrestrial and aquatic ecosystems, leading in turn to profound – but usually unquantified – impacts on biological diversity.

As indicated by historical evidence, traditional activities related to agriculture, fishing and livestock husbandry sometimes had the quality of sustainability, but many traditional systems also carried with them the seeds of their own destruction. Over time, selection may have led to sustainable systems that were in the self-interest of the people involved, at least at their current level of population and technology. However, with recent technological advances, changing demographic profiles and the quest for a 'better' quality of life, biological resources became easy targets for over-exploitation, and at an unprecedented rate.

Modern tools and technologies, with their roots in the Industrial Revolution and their flowering after 1945, changed the relationship between people and resources in at least two fundamental ways: scale and intensity. In terms of impacts on ecosystems, a large number of technologies aimed at short-term gains have also had long-term effects which may not have been foreseen. While many of these technologies are more efficient than the earlier practices (in the sense of being able to support more people), their pattern, scale and intensity of use have led to profound and unpredicted consequences for biodiversity. For example, mechanized fishing trawlers, with satellite back-up and on-board processing units, have led to depletion of many fish stocks. Intensive agriculture with multiple cropping by artificial manipulation of the soil system and high input of chemicals has resulted in increased wastelands and waterlogged areas in many parts of the world. New technologies intensify open-cast mining resulting in large-scale loss of cropland and subsoil water. Taken together, the full range of heavy industries, chemicals, fertilizers and power plants has had significant impacts on surface water, groundwater quality and biological resources. However, the last few decades have also been marked by the development of technological innovations that appear to be 'biodiversity friendly', ranging from bio-composters and wetland options for waste-water treatment to national systems of protected areas.

Many of the issues involving human impacts on biodiversity can be illuminated by considering energy flows – especially in the form of carbon – between systems and regions. Once humans began to use sources of energy from outside their own bodies, their relationship with biodiversity underwent a fundamental transformation. The use of fire gave people the potential to change environments in fundamental ways, including converting forests to grasslands. The much later use of fossil fuels – formed from once-living organisms – has led to further changes, including international trade which has the effect of enabling local resources to be harvested to feed a global market that has little information on the impact of its harvest.

While the benefits to humanity of the use of fossil fuels such as oil and gas have been enormous, their use has also entailed costs to biodiversity. Fossil fuels have enabled the world to become a global marketplace, so that local feedback is no longer a mediating force in over-exploitation of local ecosystems. Fossil fuels have also played a dominant role in the Industrial Revolution, which has led to greatly increased levels of consumption and an additional range of costs and benefits for biodiversity. And fossil fuels have led to various forms of pollution, again with a range of impacts on biodiversity. Since fossil fuels are non-renewable, at least at time-spans of interest to humans, they will not form a permanent part of human cultures. It is therefore important that their impacts on biological resources be minimized so that the renewable resources remain available to support human welfare.

Among the most significant human impacts on biodiversity has been the domestication of plants and animals, which began thousands of years ago. The controlled breeding of plants and animals procured a more reliable and expandable resource base than subsistence hunting and gathering, allowing humans to reduce substantially the space required for sustaining each individual. This, is turn, provided a secure basis for cultural advancement, from the establishment of the first major settlements to entire civilizations. In terms of biodiversity, the selective breeding of species, whether conscious or unconscious, also expanded the range of human impact from habitats and species to genes. The 40 or so species of animals that have been domesticated have often greatly increased their genetic diversity, range and populations due

Table 11.1-1: Human forces driving changes in biological diversity (modified after di Castri 1989)

Before 1500

1. Fire.
2. Hunting and gathering
3. Domestication of plants and animals
4. Intensification of agriculture.
5. Trade.
6. Intensification of agriculture by ploughing.
7. Offshore traffic and trade.
8. Building up of large empires (e.g. Persian, Roman, Mongol) with considerable expansion of communication and transportation systems.
9. Long-ranging wars and military expansion
10. Large-scale invasions of people, long-distance shipping trade.
11. Establishment of 'market economies' (e.g. Venice).

1500 to 1800

12. Exploration, discovery and colonization by Europeans of other territories and continents (e.g. the 'Colombian exchange')
13. Establishment of new market economies and crossroad places (e.g. Amsterdam, London) favouring the globalization of trade exchange
14. 'Revolution' in food customs (e.g. increased use of tea, coffee, chocolate, rice, sugar, potatoes, maize, beef and lamb).
15. Increased demand for products such as cotton, tobacco, wool, etc.
16. International introductions of exotic species through activities of acclimatization societies, botanical gardens and zoos, and for agricultural, forestry, fishery or ornamental purposes.
17. Large-scale emigrations.

Since 1800

18. Rapid improvement of transportation systems (roads, railways, navigation canals)
19. Large-scale industrial production and emergence of multinational companies
20. Large engineering works for irrigation and hydropower
21. High input, chemicalized agriculture.
22. Mechanized fisheries and forestry.
23. World wars and displacement of human populations.
24. Tropical deforestation and resettlement schemes.
25. Afforestation of arid lands with exotic species.
26. Increased urbanization and creation of habitats characterized by cosmopolitan species
27. International interdependence of markets.
28. Release of genetically engineered organisms.

Mastery over tools and fire permitted hominids greatly to expand the range of plants and animals they could harvest and eat or put to a variety of other uses. It also facilitated their dispersal out of the original homeland of savannahs of East and South Africa. By one million years ago, *Homo erectus* populations had migrated out of Africa and reached the very different habitats of Europe, Java and China, undoubtedly learning to harvest a whole new range of biological resources. Fewer than 2000 individuals are known of fossils that can be applied to the human family. With such a relatively spotty fossil record, considerable controversy surrounds their taxonomy – estimates of the number of species involved range from five up to 20 or so. At any rate, it is generally agreed among anthropologists that the first fully modern humans appeared about 90 000–100 000 years ago. They seem to have expanded rapidly over the Earth. By 50 000 years ago they had reached Australia, and undoubtedly covered most of

Africa, or economic extinction of successive species of whales. As it became evident that these resources were not really limitless, a body of theory was developed on how to harvest them sustainably. Sustainable yield has, however, remained a myth given the very limited understanding of functioning of natural ecosystems and the lack of reliable data on the dynamics of natural populations (Ludwig *et al.* 1993). Thus even today there are two widely varying estimates of the number of minke whales: those who favour whaling estimate the target population at 80 000, while those who are opposed to it estimate it at 4000. Given these kinds of uncertainties it is evidently difficult to arrive at workable prescriptions for sustainable harvests. As commercial pressures are continually pushing for ever higher harvests it is no wonder that there are indeed continued trends of sequential exhaustion of forests and fisheries all over the Earth – whether it be Siberia and the Baltic Sea, or Brazil and the Pacific Ocean.

11.1.3 The farming phase

By about 15 000 to 10 000 years before present, *Homo sapiens* had colonized all the continents, other than Antarctica, and many islands as well. The last ice age had just withdrawn, bringing climate changes that induced shifts in vegetation zones, drastically changing levels of plant and animal populations on which humans depended. Thus, the withdrawal of glaciers resulted in a warmer, moister climate, leading to a switch from grasslands to forests and from dry to wet forests. This may have reduced the availability of large mammalian prey for humans, a species that is generally agreed to have originated on and was best adapted to the grasslands and savannahs, and may then have rendered the habitat less suitable for human occupation, resulting in a change in resource availability in many parts of the world, especially in the tropics and subtropics (Flannery 1973; Rindos 1984). It has been speculated that these changes may have prompted some people in southwestern Asia, southeastern Asia and middle America to bring plants and animals under domestication where they were selectively bred to bring advantages to people. The domesticated forms were, in turn, fed by people and protected from other predators.

Another possible explanation is that farming began in a haphazard way at a time when the climate was especially favourable for hunting and gathering (Boyden 1992). An abundance of food may have permitted a more sedentary lifestyle and, under these circumstances, some may have experimented with propagating plants and improving the farming of animals. Initially, these domesticated sources of food would have formed only a small part of the diet.

The earliest evidence of agriculture based on the cultivation of seeds, notably wheat and barley, and the domestication of goats, sheep and cattle, is found in a broad area known today as the Fertile Crescent, extending from Greece to a region about 2400 kilometres to the east and to the south of the Caspian Sea, as well as in the uplands flanking the valleys of the Tigris and Euphrates rivers (Baker 1970; Heiser 1973; Reed 1977). In southern Egypt people were collecting and grinding grain from barley nearly 18 000 years ago. Their tools included grinding stones, some mortars and pestles, and blades of sickles, presumably used for reaping barley and perhaps other grasses (Ucko *et al.* 1969; Boyden 1992). The first signs of seed agriculture with millet and pig-raising in northern China date from 7000–8000 BP. In the Americas, it seems likely that maize had been domesticated by 7000–8000 BP in the region of southern Mexico, Guatemala and Honduras. Squash, beans, avocados, gourds, pumpkins and chillies were also cultivated by 5000 BP. However, until about 5000 BP hunting and gathering remained the main source of food. In the coastal areas of Peru, squash, beans, chillies, peppers and cotton were grown by 7000 BP although fish was also an important sources of nutrition in these parts. In the lowlands to the east of the Andes, manioc, sweet potato and arrowroot were farmed, and on the Andean plateaux the potato became established as the main crop around 3000 BP (Salaman 1949).

The development of domestication marked the beginning of an entirely new era in the interplay between human society and biological systems. As a consequence, human populations no longer fitted into their ecosystems in much the same way as other large omnivorous species. This transition to domestication has allowed humans deliberately and systematically to manipulate biological systems, landscapes and waterscapes for their own perceived advantage using a small sample of the world's biodiversity.

The domesticated species consist of a tiny subset of all known living organisms. A few thousand of the 250 000 described species of flowering plants are today under cultivation, while a few tens of the 4000 species of mammals, 9672 species of birds, 24 000 species of fish and 40 000 species of crustaceans, and about 20 out of 70 000 species of molluscs, five out of millions of species of insects and a few out of thousands of species of bacteria, are domesticated by humans (see Box 11.1-1). That is equivalent to about 1 in 10 000 living species. Moreover, this is a very biased sample, with most domesticated species coming from tropical and subtropical biomes, especially from the more disturbed, successional habitats. In addition, traditional and indigenous communities have domesticated many species that are not counted here (Frankel and Soulé 1981; Turner *et al.* 1990).

The change in subsistence behaviour also resulted in higher food yields from a given area of land than had been the case in hunter–gatherer systems. Thus, farming systems until then used lightly by Australian aborigines for hunting and gathering. Since then, half the country has come to be grazed by domestic livestock (Holmes 1976). This expansion has caused ringbarking of trees and elimination of tree cover in New South Wales, Victoria and South Australia. In the drier tracts it has led to conversion of salt bush to grassland. In the process, a small proportion (less than 0.2%) of the plant species seem to have gone extinct (Wilson 1990). However, the process has caused an overall reduction in plant and bird diversity and lowering of population sizes of medium-sized marsupials (Friedel *et al* 1990). Similar impacts have been felt in North America beginning around 1850 and in South America beginning around the turn of the century.

Humans have endeavoured, rather successfully, to acquire their growing biomass needs from intensifying the productivity of a small number of domesticated species. Populations of the favoured species have then reached high densities in limited areas manipulated as farmlands, pastures, fish ponds or plantations. Substantial quantities of biomass are exported from these limited areas, involving removal of large quantities of minerals from soil or waters. To sustain productivity, these minerals must be replenished, through a long fallow period when only a small proportion of land and waters are under intensive use, or through addition of manure or fertilizers. Fallowing was the technique originally followed in most places, and it remains a component of the shifting cultivation systems in many parts of Asia, Africa and Latin America today (Grigg 1974). Such a system of cultivating a plot of land for a few years and leaving it under fallow for a much longer period creates a mosaic of vegetation under different successional stages. Furthermore, part of the land was often left out of cultivation. Thus in northeast Indian states such as Manipur, as much as 10 to 30% of the land was permanently maintained under natural climax vegetation in the form of sacred groves (Hemam pers. comm.). Historically, this would have ensured the persistence of almost all the natural elements of biodiversity, coupled with stimulation of overall productivity by favouring faster growing early successional species in the patchwork of successional stages covering 70% to 90% of the land. Selection for adaptation to highly heterogeneous local environments accompanied by genetic drift would also have promoted considerable genetic variation in the cultivated species (Frankel and Soulé 1981).

It is now recognized that shifting cultivation systems also actively encouraged diversity in other ways. Recent work in the Amazon Basin has concentrated on longer-term changes in the forest structure, and has discovered practices that result in the creation, for example, of forest islands, or *apete*, by the Kayapo Indians of Brazil who live at the southern limit of the rain forest (Posey 1985). *Apete* begin as small mounds of vegetation about 2 m in diameter (*apete-nu*). As planted crop and tree seedlings grow and the planted area expands, the taller vegetation in the centre of the mound is cut to allow in light. A full-grown *apete* has an architecture that creates zones that vary in shade and moisture. The species mix includes medicinal species, palms, and vines that produce drinking water. Of a total of 120 species found in ten *apete*, Posey (1985) estimated that 75% may have been planted.

New *apete* fields peak in crop production in 2–3 years, but some species continue to be productive for a longer period: sweet potatoes for 4–5 years, yams and taro for 5–6 years, papaya and banana for 5 years or more. Contrary to common belief, old fields (*ape-ti*) are not abandoned when the primary crop species disappear; they keep producing a range of useful products. They become forest patches in the savannah-like open *cerrado*, managed for fruit and nut trees, and 'game farms' which attract wildlife. This behaviour promotes patchiness and heterogeneity in the landscape through a number of devices. Posey first became aware that these isolated forest patches were human-made in the seventh year of his field research (Taylor 1988), but the local people were of course well aware of the dynamics involved.

Working in the Ecuadorian portion of the Amazon forest, Irvine (1989) has reported that Runa Indian swiddens resemble agroforestry systems rather than the slash-and-burn that merely results in temporary clearings in the forest canopy. Compared with unmanaged fallows, he found that management actually increased species diversity in 5-year-old fallows. Between 14 and 35% of this enhanced species diversity was attributed to direct planting and production of secondary species. Irvine (1989) characterized Runa agroforestry as a low-intensity succession management system which alters forest composition and structure in the long term.

Among the most diverse of agricultural systems known are the 'home' gardens in the humid tropics, the result of long historical development of technology designed to meet the needs of local agricultural communities. In West Java, the typical home garden appears as a crowded assemblage of trees, shrubs, climbers, herbs and creeping plants that are used for fruit, vegetables, starchy food crops, spices, ornamentals, medicines, fodder, fuel and building material, and involve over a hundred species. Even in the more arid regions, such as the Gondar area of northwestern Ethiopia, farmers plant together six or more crops, including maize, faba bean, sweet sorghum, cabbage, tomato, potato, pumpkin and bottle gourd. In northern Ethiopia, especially in the drought-prone areas, wheat and barley are grown in specific mixtures. In favourable years both wheat and barley give good yields, but in poor years barley still gives some returns.

In Vietnam, multiple varieties of early-maturing rice, *Oryza sativa* var. *indica*, are cultivated with multiple varieties of other *indica* and *japonica* rice with up to 20

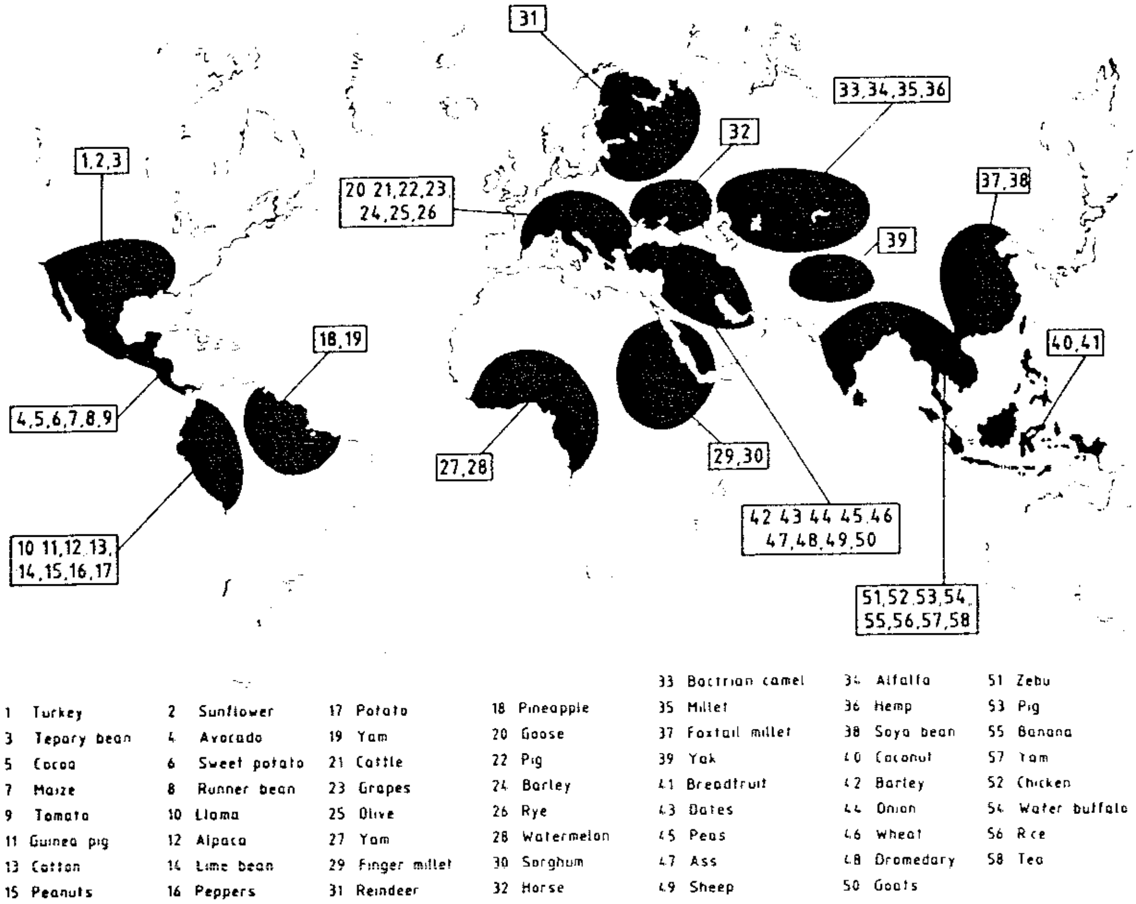

Figure 11.1-1: Regions of origin of domesticated plants and animals (from Boyden 1992)

forests that had covered much of the continent were displaced by Danubian farmers around 7000 BP. Until relatively recently many plant species used in farming systems, which had been domesticated at least 4000 years ago, were confined to their sources of origin (see Figure 11.1-1). In this context, the colonization of America by Europeans was especially important since not only were maize, potato, squash, gourds, pumpkins, peppers, chillies and the turkey introduced into Europe, but European cereal and vegetable crops, cattle, sheep and pigs were also introduced into the American continent. Eventually all the main European food sources were introduced to New Zealand and Australia. Just as new plants and animals were introduced into farming ecosystems, so were local native ones displaced.

The requirement of land for food production was not the only cause of deforestation. Eventually, the demands for timber for use as fuel and for various other purposes became increasingly important motives for felling trees. For example, although dense forest covered most of central and western Europe during Roman times, a significant increase in human population in the region is speculated to have caused 'the great age of land clearance' in the early part of the second millennium. Paradoxically, it has been suggested that deforestation was also an important contributing factor in the decline of the Roman and Greek civilizations (Boyden 1992).

In another region, the Indian epic Mahabharata, probably based on events that took place at the junction of the Indus and Gangetic plains 3000 years ago, narrates the story of the destruction of the great Khandava forest on the banks of the river Yamuna near Delhi. Krishna and Arjuna, the two great warrior heroes of the pastorals, supposedly burned the entire forest driving back into the fire any creature attempting to flee the conflagration. Historical evidence suggests that the destruction of the Gangetic plains forest continued over the next five centuries and was nearly completed by the time of Buddha, 2500 years ago (Gadgil and Guha 1992).

Pastoralism has also led to significant changes in vegetation. The most significant of the domesticated animals (sheep, cattle, buffalo, horse and camel) feed primarily on grass and their maintenance has catalysed the conversion of much natural vegetation into grasslands all over the world (Stewart 1956). Fire has enhanced this conversion, and has promoted the spread of a small number

Americas, Madagascar and the Pacific were discussed above. A more recent great and demographically significant movement consisted of the spread and expansion of Europeans to all corners of the globe. This began with the exploits of the navigational adventurers from Portugal, Spain, Britain, France and Holland in the late fifteenth and early sixteenth centuries and, in particular, with the European discovery of the American continent and two centuries later, of Australia and New Zealand. Europeans began to settle in North America in the sixteenth century and in South America early in the seventeenth century. In Australia and New Zealand European settlement began in 1788 and 1790 respectively. In southern Africa the Dutch started to settle in 1632, and the English in 1788 (Crosby 1986).

In North America and Australia, Europeans largely displaced the local native populations. Their biological advantage was partly due to their technology and weaponry, but it was also the consequence of the fact that they introduced into the local populations a series of devastating infectious diseases – diseases to which they themselves were, for historical reasons, relatively resistant. In Mexico, for instance, smallpox wiped out at least half the local population in the first few years after initial European contact.

Associated with the voluntary migration of Europeans to the Americas was the involuntary migration of Africans to the same region as slaves. It has been estimated that between 1451 and 1870 about 11 million slaves were taken from Africa, of which 9.6 million were still alive when they reached the American coast. In 1850 about 11% of the population of the USA was of African origin.

Between 1850 and 1960 – the great period of voluntary European migration – 60 million people left the continent to settle in faraway lands. This figure represents about a fifth of the population of Europe at the beginning of this period.

Largely as a consequence of these developments, the Caucasian population of the world increased 5.4 times between the years 1750 and 1930, while in the same period the Asian population increased 2.3 times and the African population less than twice. By 1930 the proportion of Caucasians who did not live in Europe was one-third; and in 1970 it was more than half. At present more than one-fifth of Africans live outside Africa.

Migrations have always resulted in a redistribution and mixing of both genetic and cultural traits, including an exchange of technologies for resource use, and these have had a variety of different impacts on biodiversity.

Migration and trade calls for means of transport. Historically, transport was by ships on sea and trains of camels, horses, bullocks and humans on land. Transport over water is the least expensive, and ships have been the dominant means of transport for millennia. By 6000 BP it was important in the Mediterranean and it has been speculated that the early city-builders of Mesopotamia, the Sumerians, had migrated to the region by sea between 5500 and 5000 BP.

For most of human history, boats and ships have been constructed of wood, and wood for shipbuilding was a major demand on forest résources, especially in medieval Europe (Thirgood 1981). Oak was the favoured raw material, and this demand caused extensive denudation of the oak forests of Europe. Extensive deforestation began around 1100 and continued until the fourteenth century, when it declined after the spread of the bubonic plague. Deforestation began again around 1500 and almost all the oak forest of Britain had disappeared by the sixteenth century. British interest in India's teak forests, to secure an alternative supply of timber for their merchant ships and navy, was a major motivation behind imperial ambitions. The teak plantations raised after the conquest of India were a significant cause of erosion of biodiversity over large forested tracts of peninsular India. So too was the demand for railway sleepers for the extensive network of railway lines built to facilitate transport of raw materials such as tea, jute, indigo and cotton out of India in exchange for manufactured goods from Britain, which were desired by Indian consumers (Rawat 1991).

Large-scale movements of material and people have also led to deliberate as well as accidental movements of living organisms. Such movements, for instance, led to the spread of tropical rat species as human commensals with the crusaders going back to Europe, and later to the outbreak of plague (Zinsser 1934). During their colonization of the world Europeans carried with them not only wheat, cattle and goats, but also many other European species which eliminated native biota over continental areas, such as American prairies, and on islands such as New Zealand (Crosby 1986). More recent times have witnessed the invasion of American weedy plants such as *Parthenium* and *Eupatorium*, all over the tropical world, leading to erosion of diversity of the native biota (di Castri *et al.* 1989; see 11.2.2.4 for a further discussion of the impact of introduced species).

Although the earliest settled communities most probably defended themselves against other human groups, the establishment of settled societies undoubtedly increased the reasons and potential for warfare by instituting clear ownership of resources and defined territories. The continually growing human demands for a variety of natural resources inevitably led to conflicts over access, and being a highly social species, humans have sometimes turned such conflicts into warfare. Other conflicts have arisen from attempts to keep aliens out of circumscribed group territory. Areas close to the boundaries of two contiguous group territories can be especially dangerous; these have often served as refugia for natural diversity in is very different. For example, in the 1970s, one farm worker would produce sufficient food for 50 people, and currently in Australia, one farmer produces enough for 85 people (two-thirds of whom live outside Australia)

Intensification of agriculture and livestock production has permitted the gradual differentiation of human populations into those directly dependent on biological resources produced with their own labour, and those dependent on the surplus production of the countryside. In the modern high-energy phase of society, the great majority of human beings do not participate in direct subsistence activity and so are far removed from the realities and consequences of food acquisition and production.

Dasmann (1988) distinguishes these two categories of people as 'ecosystem people' and 'biosphere people'. Ecosystem people are the farmers, herders, fishers and hunters who depend largely on natural resources gathered or produced from their own immediate surroundings: they experience at first hand the consequences of their patterns of resource use. Biosphere people are dependent on much larger systems, and typically are well insulated from the environmental consequences of their use of resources. If their consumption leads to over-exploitation, they can easily move on to other systems through the market-place. Early 'biosphere people' included the warriors, priests, bureaucrats, merchants, and artisans of the agrarian societies, while later biosphere people include those engaged in organized services and industries in modern societies who have access to the resources of the entire biosphere through global markets.

As agriculture and livestock production have become a part of modern industrial enterprise, farmers too are moving into the category of biosphere people. But over much of the historical period farmers have been ecosystem people, and to a large extent they remain so in parts of the developing world. The division into ecosystem and biosphere people is a great simplification, and different groups can be located at different places along a continuum of dependence on locally available resources. However, Dasmann's classification is a useful conceptual tool for understanding different relationships between people and biodiversity.

Subsistence farmers largely producing for domestic consumption or local level exchange – behaving as ecosystem people – have been motivated to cultivate a variety of plant species to fulfil their own manifold demands for food, fibre, fuel and medicine. They have also attempted to minimize the risks of large losses of plant production due to unfavourable weather events or outbreaks of pests. They would therefore tend to nurture a diversity of species, as well as a variety of landraces of many of these species. As farmers became linked to outside markets, they no longer had to produce locally a whole range of food, fibre and medicinal plants; indeed markets could bring to them a much greater diversity of plant products from many different regions than could be produced locally. But farmers also required cash to buy these products from the markets, and hence their interest gradually shifted to managing on-farm production to maximize its market value, rather then generating a variety of products for local consumption, or to ensure buffering against risks.

The new methods are extraordinarily dependent on continual external inputs – especially energy-costly artificial fertilizers and pesticides, and considerable input of energy.

The development of the steam engine ushered in a new kind of technology of overwhelming ecological significance, powered by the combustion of fossil fuels. Another set of scientific advances relating to the use of energy that has had an enormous influence on human affairs involved the discovery of electricity and electromagnetic phenomena.

Fossil fuel driven generators are the largest source of electricity, with a usual energy efficiency of about 30%. Hydroelectric plants contribute to around 6% of the world's overall electricity budget. Over 350 000 PJ of extrasomatic energy per year is currently being used by humankind, which is a 10 000-fold increase in the past 400 generations. For example, the average North American uses 100 times more extrasomatic energy than the average hunter–gatherer.

Ecologically important distinctions exist between the direct or indirect forms of non-fossil fuel derived energy (solar power, hydroelectric power and wind power) and fossil fuels and nuclear power. No incidental chemical by-products are released into the environment in the case of the former. Fossil fuels result in the liberation of carbon dioxide, carbon monoxide, hydrocarbons, and sulphur and nitrogen oxides; and nuclear power produces highly radioactive substances. Furthermore, the use of solar power does not release additional heat to the environment beyond that which would in any case be given off as a consequence of the solar radiation of the Earth.

Recent decades have also seen the growth of the production of synthetic materials used for a wide range of purposes, including the manufacture of clothing, utensils and countless other commodities. This industry dates back to the middle of the last century, when a hard flexible transparent substance known as celluloid was made by mixing nitrocellulose and camphor. The environmental impacts of plastics are under considerable criticism. On the one hand, it is argued that they are 'biosphere friendly', because it takes less energy to produce a plastic product than a comparable one made from glass or aluminium. On the negative side, the lack of degradability of plastics represents hazards for sea birds, marine mammals and other creatures. In some cases the processing and manufacture of plastics also results in the release of toxic chemicals.

motivations, while others declared as promoting conservation may in reality achieve something very different. Accepting that this may be so, it is still of considerable interest to review the variety of cultural practices that (a) apparently serve to conserve or enhance biological diversity – whether or not that is their declared purpose, and (b) expressly purport to conserve or enhance biological diversity – whether or not that is the actual result or the genuine underlying motivation.

Historically, people colonizing new environments or undergoing rapid economic development have not been concerned, at least in the initial phases, with conservation of biodiversity. But once an area is settled or developed, humans begin to accumulate experience of the impact of their resource management practices. They are able to see the resource depletions that follow non-sustainable harvesting pressures, and the recoveries that sometimes follow when, for some reason, harvesting pressures are reduced. Furthermore, when living in a given locality generation after generation, they might perceive self-interest in moderating harvesting efforts so that harvests are improved in the long term. This would be particularly so if they depend largely on harvests from a circumscribed area, and are using technologies that are not continually leading to higher and higher levels of harvesting efficiencies. Many small-scale, autonomous hunter–gatherer or agrarian societies have settled in regions where they control well-defined territories from which most resources garnered were likely to fulfil these conditions. Such people may then have had the knowledge base, the motivation, and the capability of moderating resource harvests so as to serve long-term, group interests in sustainable use and conservation of natural diversity (Gadgil and Berkes 1991).

A variety of such practices of moderating harvesting efforts are known historically from various parts of the world. Refugia immune from harvests may take the form of sacred groves, or ponds, or pools along river courses, or lagoons of coral islands where entire living communities are protected from human interference. Sacred groves may conserve species that have disappeared elsewhere; for example, the Botanical Survey of India discovered a new species of leguminous climber, *Kunstleria keralensis*, in a sacred grove on the densely populated coast of the state of Kerala. In Pakistan representatives of original tree species still persist in old Moslem graveyards, because of a taboo against cutting these trees. Khan (1994) used these tree stands to reconstruct the past distribution of the thorn forest in Punjab. In China, royal gardens, royal cemeteries, ancestor temples and Buddhist temples have long maintained examples of natural vegetation in excellent condition, although many of these are now disturbed. And the only surviving population of a freshwater turtle, *Trionyx nigricans*, survives in a sacred pond dedicated to a Moslem saint in Bangladesh (Gadgil *et al.* 1993).

The restraints on harvesting may involve giving protection to keystone species that may support the persistence of a range of other species. Thus, fig trees belonging to the genus *Ficus* are recognized as important sources of fleshy fruits available in seasons when no other tropical forest species are producing fleshy fruits. *Ficus* trees thereby promote persistence of a number of insect, bird, bat, squirrel and primate species for which they serve as a critical resource in a period of fruit shortage. All species of *Ficus* are even today to an extent protected as sacred trees through much of tropical Asia and Africa, where the local communities are aware of this ecological role.

Harvesting restraints also include the protection of critical stages in the life histories of species that are especially vulnerable to overharvesting. Thus a nomadic hunting tribe of Western India has the tradition of releasing any pregnant does or fawns of antelope or deer caught in their snares; and egrets, storks, herons, pelicans, ibises and cormorants at their colonial nesting colonies are given immunity from hunting over most of India, although these birds are hunted in the non-breeding season. Finally, in many Asian villages fruit bats are not hunted at their daytime roosts, but may be killed at a distance from the roost during the night (Gadgil *et al.* 1993).

A rich literature of such traditional conservation practices indicates that they have been a common feature of many cultures over many years (see, for example Suzuki and Knudtson 1992; Maybury-Lewis 1992; Western and Wright 1994). This literature indicates that such practices serve the group interests of communities and that they remain viable only so long as (a) local communities continue substantial levels of dependence on resources garnered from their immediate vicinity, (b) they have full control over the local resource base, and (c) they retain a sufficiently high level of internal cohesion. These conditions are no longer fulfilled when outside state or corporate bodies establish control over natural resources, when access to markets begins to bring in resources from outside and local resources become a source of cash income, and when local communities lose their traditional social organization (Ostrom 1990). In many parts of the world, therefore, hunter–gatherer–shifting cultivator communities are today involved in excessive harvests and depletion of natural biodiversity (Redford 1990, 1992).

Historically, the more advanced agrarian societies seem to abandon most of the conservation practices of technologically less advanced communities. Such societies do, however, provide an example of a new type of conservation practice. With domestication of livestock, meat became available in abundance without having to resort to hunting. However, hunting remained a pleasurable pastime, and provided training for warfare. So the elite established hunting preserves in which resource harvests were severely restricted; and hunting the larger birds and village community-based forest management was officially reinstated in a small number of villages, including Kallabbe. A survey in the 1980s revealed that the Kallabbe village forest was among the most biodiversity-rich tracts in the district (Chandran and Gadgil 1993).

However, not all colonies were the same. A few recognized the negative impacts of settlement and sought to correct them. On Mauritius, the French colonial government passed an ordinance in 1769 which stipulated that 25% of all land-holdings were to be kept as forest, particularly on steep mountain slopes, to prevent soil erosion; all denuded areas were to be reforested; and all forests within 200 metres of water were to be protected. In 1803, clearing of forest was forbidden higher than one-third of the way up a mountain side (Grove 1992).

In some parts of Europe, the community control of common property remained strong through the period of rampant deforestation of Europe. By the mid-nineteenth century Switzerland retained only about 4% of its land under forest cover, leading to serious problems of landslides and siltation. The communities then rolled back the tide of forest loss, and successfully built back the forest cover to the present 25% (WRI 1994). As of today these secondary forests remain under the control of powerful local community-based governments. But such examples of effective community control, whether of ecosystem people as in Kallabbe or of biosphere people as in Switzerland, are exceptions. Over much of the world, biodiversity-rich common lands and waters are largely under control of the state, and have often been permitted to lose much of their biodiversity.

Key messages

- Humans have endeavoured, rather successfully, to acquire their growing biomass needs from intensifying the productivity of a small number of domesticated species. Populations of the favoured species have then reached high densities in limited areas manipulated as farmlands, pastures, fish ponds or plantations.
- Humans have been engaged over historical times in steadily improving technology and expanding the range of biological resources useful to people. This has inevitably been accompanied by a retreat of the natural world; and an erosion of biodiversity.
- As natural forests and fish stocks have declined, the historical trend is to devote greater effort to plantations and aquaculture. These replace large tracts of natural diverse ecosystems with species-poor systems supported by high levels of technological inputs; they also promote extensive use of pesticides and other poisonous substances resulting in more widespread negative impacts on biodiversity.
- As human technological capacities have increased, so have inequities within and between societies. The powerful social segments within nations have access to natural resources from wide catchments, suffering few of the negative consequences of environmental degradation and erosion of biodiversity. Rather, they have a strong vested interest in continued growth of the artificial at the cost of the natural, often in another country. This disrupted link between maintenance of biodiversity and the quality of life of those who ultimately decide the course of economic activity is at the base of the growing pace of erosion of global biodiversity (Shiva *et al.* 1991).