1 Introduction – humans, nature and human nature

The history of the human species as global caretaker has not been good. As *Homo sapiens* subspecies *exploitabilis* we have polluted air, land and water, destroyed large areas of almost all kinds of natural habitat, overexploited living resources, transported organisms around the world with negative consequences for native ecosystems, and driven a multitude of species close to extinction. Our 'evolution' to subspecies *sustainabilis* needs to involve some significant behavior changes underpinned by ecological knowledge.

Chapter contents

Key concepts

In this chapter you will

note that *Homo sapiens* is not the only species to destroy habitat, overexploit resources or pollute the environment

recognize that human population density coupled with technology underlie our unique impact on nature

understand the scale of current and future impacts on biodiversity from habitat loss, introduced invader species, overexploitation, habitat degradation and global climate change

see the link between biodiversity loss and the provision of ecosystem services of importance to human well-being

grasp that a sustainable society is one able to meet current needs without compromising the ability of future generations to provide for themselves

appreciate that a sustainable future has three dimensions – ecological, economic and sociopolitical

1.1 *Homo* not-so-*sapiens*?

Homo sapiens, the name of the most recent in a line of hominids, might well be considered a misnomer. Just how sapient (wise) has *Homo sapiens* been? We have certainly been clever – inventing an amazing array of tools and technologies from the wheel to the nuclear power station. But how much of the natural world has been disrupted or destroyed during this technological 'progress'? And is our way of life actually sustainable? A crunch question is whether your descendants will be able to enjoy the same opportunities as you. If not, perhaps they will judge their ancestors to have been far from wise.

Humans destroy natural ecosystems to make way for urban and industrial development and to establish production ecosystems such as forestry and agriculture. We also exploit the natural world for nonrenewable resources (mining) as well as renewable ones (fisheries and forests). Mining destroys habitat directly, and fishery techniques such as bottom trawling can physically disrupt habitat. The natural ecosystems that remain are also affected by human activities. Our harvesting of species from the wild (whether trees, antelopes or fish) has often led to their decline through overexploitation. Our transport systems allow species from one part of the world to hitch a ride to another where, as 'invaders', their impacts on native biota can be profound. And every human activity, including defecation, transport, industry and agriculture, produces 'pollutants' that can adversely affect the biota locally or globally.

You might imagine there would be consensus about what constitutes reasonable behavior in our interactions with the natural world. But people take a variety of standpoints and there are a host of contradictions. Farmers usually consider weeds that reduce the productivity of their crops to be a very bad thing. But conservationists bemoan the farmers' attack on weeds because these species often help fuel the activities of butterflies and birds. The Nile perch (*Lates nilotica*) was introduced to Africa's Lake Victoria to provide a fishery in an economically depressed region, but it has driven most of the lake's 350 endemic fish species towards extinction (Kaufman, 1992). So gains at our dinner tables can equate to a loss of biological diversity.

Then again, our knowledge of plant physiology allows agricultural ecosystems to be managed intensively for maximum food production. But heavy use of fertilizers means that excess plant nutrients, particularly nitrate and phosphate, end up in rivers and lakes. Here ecosystem processes can be severely disrupted, with blooms of microscopic algae shading out waterweeds and, when the algae die and decompose, reducing oxygen and killing animals. And even in the oceans, large areas around river mouths can be so badly impacted that fisheries are lost. The farmers' gain is the fishers' loss.

Pesticides, too, are applied to land but find their way to places they were not intended to be. Some pass up food chains and adversely affect local birds of prey. Others move via ocean currents and through marine food chains, damaging predators at the ends of the earth (such as polar bears and the Inuit people of the Arctic). And hundreds of kilometers downwind of large population centers, acid rain (caused by emission of oxides of nitrogen and sulfur from power generation) kills trees and drives lake fish to extinction. Ironically, in other parts of the world a new ecology is imposed in previously fishless lakes because of the introduction of fish favored by anglers.

So *Homo sapiens* has a diversity of views and a wide variety of impacts. But are we really so different from other species?

Feces, urine and dead bodies of animals are sometimes sources of pollution in their environments. Thus, cattle avoid grass near their waste for several weeks, burrow-dwelling animals defecate outside their burrows, sometimes in special latrine sites, and many birds carry away the fecal sacs of their nestlings. Humans are not unique, either, in regarding corpses as pollutants to be removed. The 'undertaker' caste of honeybee, for example, recognizes dead bodies and removes them from the hive.

And just like humans, many species make profound physical changes to their habitats. These 'ecological engineers' include beavers that build dams (changing a stream into a pond), prairie dogs that build underground towns and freshwater crayfish that clear sediment from the bed. In each case other species in the community are affected. The impact may be positive (for pond dwellers in the beaver ponds, for species that share the prairie dog town, for insects whose gills are sensitive to clogging by sediment) or negative (stream species, plants displaced by burrowing, insects that feed on sediment).

Overexploitation, where individuals of a population are consumed faster than they can replenish themselves, is also a common feature in natural ecosystems. Sometimes overexploitation is subtle, with preferred prey species less common in the presence of their consumers – as compared to their less tasty or harder-to-catch counterparts. But overexploitation may be more dramatically demonstrated when the disappearance of top predators (such as wolves) allows herbivores (such as moose) to multiply to such an extent that the vegetation is virtually destroyed. And the appalling loss of fish species in Lake Victoria after the arrival of the 'invader' Nile perch provides a graphic example of overexploitation by one fish of others.

Invaders have always been a fact of nature, when by chance some individuals breach a dispersal barrier such as a mountain range or a stretch of ocean. But some species that migrate or disperse over large distances can carry their own invaders with them – just as humans do along transport routes. Examples include diseases carried by dispersing fruits and seeds and migrating mammals and birds. The animals may also have parasites and small hitchhikers in their fur and feathers.

Finally, there are species that, like farmers, increase plant nutrient concentrations in their habitats, and even some that produce 'pesticides'. Leguminous plants have root nodules containing symbiotic bacteria that fix atmospheric nitrogen into a form readily available to plants. The soil in their vicinity, and the water draining into neighboring streams, are both likely to contain higher concentrations of nitrate. And certain plants produce chemicals (allelochemicals) whose function appears to be the inhibition of growth of neighboring plants, giving the producer a competitive advantage.

So humans are hardly unique in their ecological impacts. When population density was low, and before the advent of our ability to harness nonfood energy, human populations probably had no greater impact than many other species that shared our habitats. But now the scale of human effects is proportional to our huge numbers and the advanced technologies we employ.

1.1.2 *Human population density and technology underlie environmental impact*

The expanding human population (Figure 1.1) is the primary cause of a wide variety of environmental problems. Someone has calculated that the total mass of humans is now about 100 million tonnes, in comparison to a paltry 10 million tonnes for all

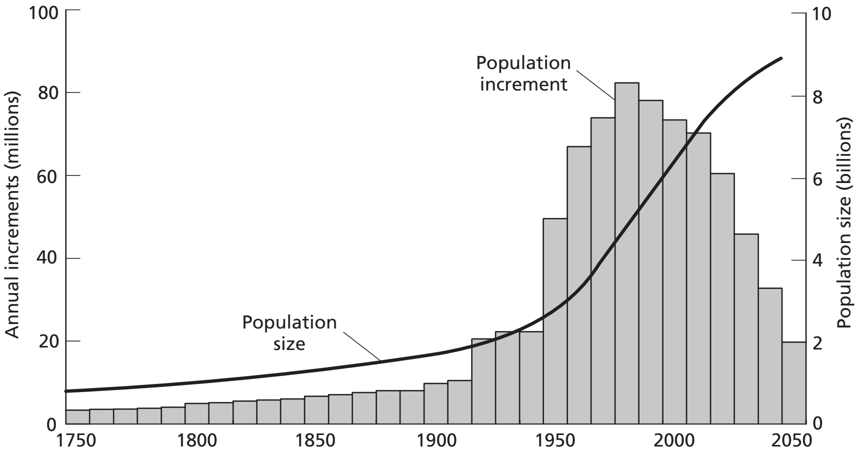


Fig. 1.1 Growth of the world's human population since 1750 and predicted growth until 2050 (solid line). The histograms represent population increments for each decade. The decadal increments are predicted to get smaller, but the overall population continues to grow. (After United Nations, 1999.)

wild mammals combined. We are not unique in destroying habitat and contaminating the environment. But we are distinctive in using fossil fuels, water and wind power, and nuclear fission to provide energy for our activities. These technologies have provided the power to transform much of the face of the planet through urbanization, industrial development, mining, and highly intensive agriculture, forestry and fishing. The loss of habitats and the degradation of what remains are responsible for driving a multitude of species to the verge of extinction. Beavers, prairie dogs and crayfish may fundamentally alter the habitats in which they live, but the burgeoning population of *Homo sapiens*, with attendant technologies, has spread to every continent. The consequences are both intense and widespread, leaving few hiding places for pristine nature to thrive.

Many environmental effects are caused locally, although the same patterns are repeated across the globe (pollution by fertilizers and pesticides, the spread of invaders, and so on). In one very important case, however, the scale of the problem is itself global – climate change resulting from an increase in atmospheric carbon dioxide (produced by burning fossil fuels) together with other 'greenhouse' gases. You will discover that this global pollution problem has implications for every other environmental management issue.

The remainder of this chapter focuses on the scale of human impacts on biological diversity (and the consequences for human welfare – Section 1.2), as well as the knowledge that needs to be harnessed for a sustainable future (Section 1.3). This will form the backdrop to the remainder of the book where, chapter by chapter and topic by topic, I explore how ecological knowledge can be applied to remedy the problems we have caused.

1.2 A biodiversity crisis

It is important to be clear about the meaning of *biodiversity*, and its relationship to *species richness*. Species richness is the total number of species present in a defined area. At its simplest, biodiversity is synonymous with species richness – and this is generally how I will use it. Biodiversity, though, can also be viewed at scales smaller

Box 1.1 Classification of extinction risk

The *IUCN Red List of Threatened Species* (produced by the World Conservation Union – previously the International Union for the Conservation of Nature, IUCN) highlights species at greatest risk of extinction in each taxonomic group in every part of the world. Overseen by expert specialist teams, plants and animals are defined according to criteria related mainly to population size, distributional range, and whether the population is currently declining. Figure 1.2 illustrates the 'decision tree' used to categorize species status. Of course, not all have been evaluated – most species remain to be identified and named! In some cases an evaluation has been attempted but the data are currently insufficient to classify threat (*Data Deficient*). Some are already considered to be *Extinct* or *Extinct in the Wild* (where individuals remain only in cultivation or captivity).

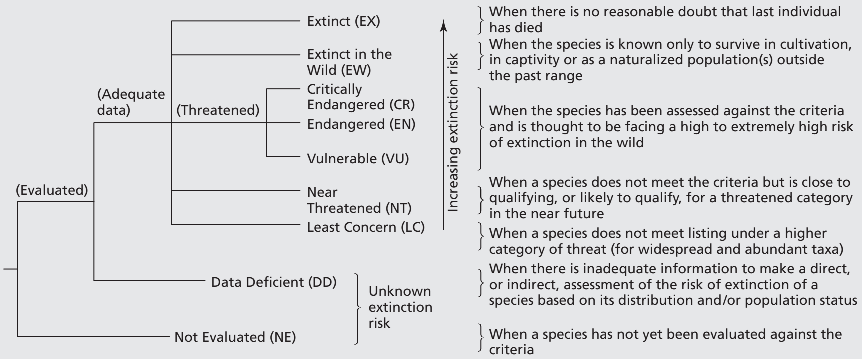


Fig. 1.2 A 'decision tree' showing the nine IUCN Red List categories in order of increasing extinction risk. (From Rodrigues et al., 2006.)

Species considered to be under threat of extinction are listed as *Critically Endangered* (more than a 50% probability of extinction in 10 years or three generations, whichever is longer), *Endangered* (more than a 20% chance of extinction in 20 years or five generations) or *Vulnerable* (greater than a 10% chance of extinction in 100 years). A further category is *Near Threatened* – species close to qualifying for a threat category or judged likely to qualify in the near future. Species that do not meet any of the threat categories are assessed as of *Least Concern*.

An estimated 12% of bird species, 25% of mammals and 30% or more of amphibians are threatened with extinction. The threat classifications help conservation managers prioritize their actions. In addition, conservation plans are supported by the wealth of data collected in the IUCN assessments (Rodrigues et al., 2006).

(genetic diversity within species) and larger than the species (the variety of ecosystem types present – e.g. streams, lakes, grassy glades, mature forest patches).

Human impacts are responsible for driving a multitude of species to such low numbers that much of the world's biodiversity is under threat. In this section I consider just how big this problem is (Section 1.2.1) before discussing the consequences of reduced biodiversity for the way that whole ecosystems function – and for the free 'services' that natural ecosystems provide us (1.2.2). A variety of processes are responsible for species extinctions (1.2.3) and the scale of each of these will be considered in turn: habitat loss (1.2.4), invaders (1.2.5), overexploitation (1.2.6), habitat degradation (1.2.7) and global climate change (1.2.8).

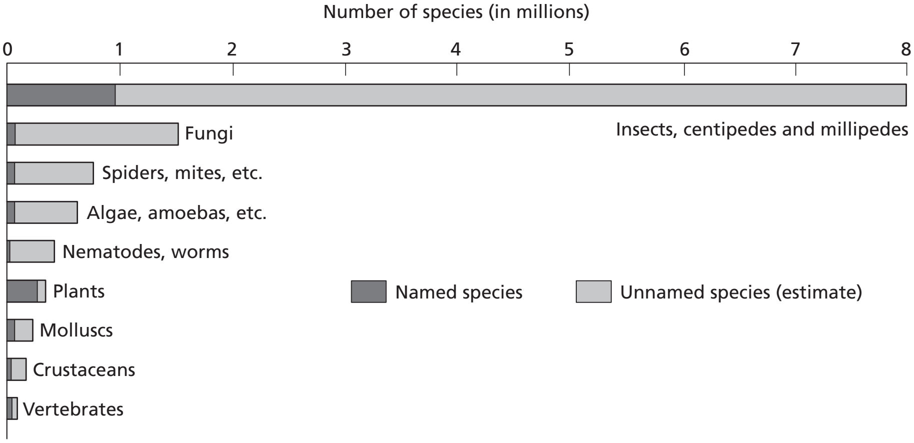


Fig. 1.3 Numbers of species identified and named (dark histograms) and estimates of unnamed species that exist (light histograms). (Modified from Millennium Ecosystem Assessment, 2005a.)

1.2.1 *The scale of the biodiversity problem*

To judge the scale of the problem facing environmental managers it would be useful to know the total number of species that exist, the rate at which these are going extinct and how this rate compares with pre-human times. Not surprisingly, there are considerable uncertainties in our estimates of all these things. For example, only about 1.8 million species have so far been named, but the real number lies between 3 and 30 million. Most biodiversity specialists think it is around 10 million (Figure 1.3).

Palaeontologists estimate that species exist, on average, for between 1 and 10 million years. If we accept this assumption, and taking the total number of species on earth to be 10 million, we can predict that each century between 100 (if species last 10 million years) and 1000 species will go extinct (if species last 1 million years). This represents a 'natural' extinction rate of between 0.001% and 0.01% of species per century. The current estimate of extinction of birds and mammals, the groups for which we have the best information, is about 1% per century. In other words, the current rate may be as much as 100 to 1000 times the 'natural' background rate. And when we bear in mind the number of species believed to be under threat (Box 1.1), the future rate of extinction may be more than ten times higher again (Millennium Ecosystem Assessment, 2005a).

Estimates of extinction rates are beset with difficulties and most extinctions pass unnoticed. Another way to gauge the problem is to focus on long-term assessments of the population sizes of species that have not yet gone extinct. In the case of British birds it is clear that woodland species and, more particularly, farmland species have been in decline for many years (Figure 1.4a). Worldwide, amphibians (Figure 1.4b) and marine and freshwater vertebrates (Figure 1.4c) also show clear signs of widespread population declines.

Consider how instructive it would be to carry out a massive experiment in which a region is allowed to completely fulfill its economic potential while simultaneously documenting the consequences for biodiversity. This decidedly 'unethical' experiment would give us a glimpse of what the world could be like if unlimited population growth and development continue indefinitely everywhere. In fact the 'experiment'

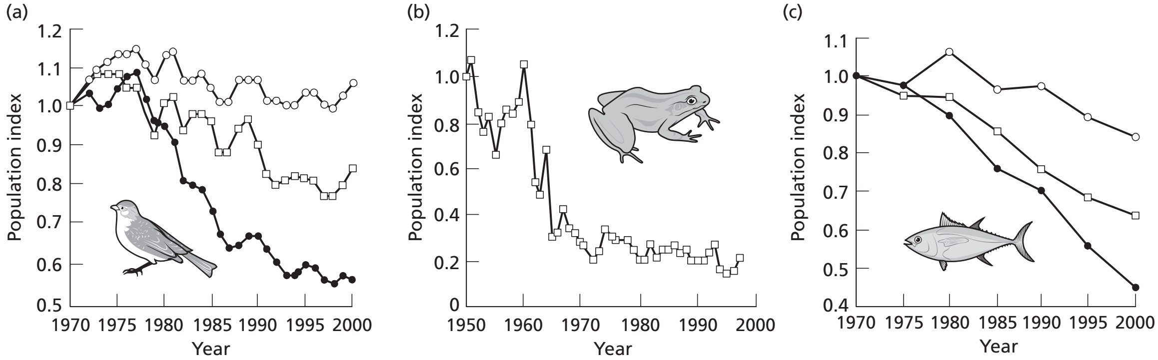


Fig. 1.4 Combined indexes of change in population size for various animal groups for which long-term data are available. In each case the index is standardized at 1.0 for the first year of the dataset. (a) Mean population sizes of British bird species from 1970 to 2000: open circles – all species (105 species), squares – woodland species (33 species), closed circles – farmland species (19 species). (b) Index of change in amphibian populations worldwide from 1950 to 1997, based on accumulated annual changes in 936 populations of 157 species. (c) Index of change in vertebrate populations worldwide: open circles – forest vertebrates (282 populations), closed circles – freshwater vertebrates (195 populations), squares – marine vertebrates (217 populations). (After Balmford et al., 2003, where original references can be found.)

has been done and, moreover, in one of the world's biodiversity hotspots in the East Asian tropics.

The island of Singapore has experienced exponential population growth, from 150 villagers in the early 1800s to more than four million people as it developed into a prosperous metropolis. During this period 95% of Singapore's forest was lost, initially to make way for crops and more recently for urbanization and industrialization. Many extinctions have been documented since 1800 (Figure 1.5 – green histograms). In addition, species lists from nearby Malaysia can be used to infer the likely pristine biodiversity in Singapore and provide an estimate of the number of extinctions that have gone unrecorded (Figure 1.5 – blue histograms). It seems that the majority of the island's species from a wide range of animal and plant groups are now extinct, an unfortunate consequence of the economic 'success story' of modern Singapore. Of course, Singapore is not unique and a similar exercise would produce an equally uncomfortable result for most of the world's cities and nations.

No matter how uncertain the data may be and however imprecise our knowledge of the history of Singapore, or anywhere else in the world, there is no room for complacency – population declines and increased extinction risks need to be confronted.

1.2.2 *Biodiversity, ecosystem function and ecosystem services*

Most people regret any extinction and value species in their own right. But a reduction in biodiversity can also have consequences at a higher level of ecological organization – that of the ecosystem. The *ecosystem* consists of all the species that coexist in an area, together with their physicochemical environment. Ecosystem ecologists pay particular attention to the way solar energy and chemical elements are harnessed by plants in photosynthesis and subsequently pass between living ecosystem compartments (herbivores, carnivores, decomposer organisms) and non-living compartments (dead organic matter in soil or water). Ecosystem processes that might respond to changes in biodiversity include the rate at which plants

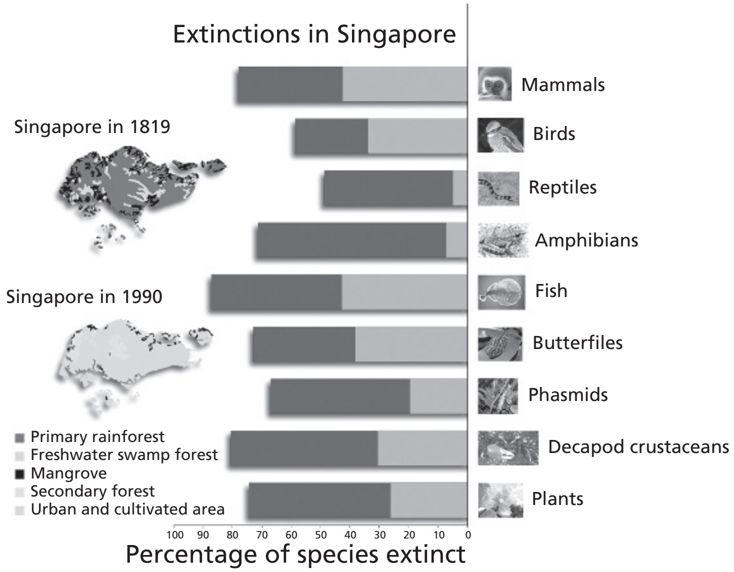


Fig. 1.5 Extinctions in Singapore since the early 1800s – green (light) and blue (dark) bars represent recorded and inferred extinctions, respectively. (After Sodhi et al., 2004.) (This figure also reproduced as color plate 1.5.)

produce new biomass (primary productivity), the rate at which dead organic matter decomposes, and the extent to which nutrients are recycled from dead organic matter back to living organisms. These processes are so fundamental that a substantial change in any one will ramify throughout the food web.

Note, first, that ecosystem properties are not invariably sensitive to a reduction in biodiversity. It may be, for example, that different species carry out similar functional roles and can 'cover for each other' should some be lost. In addition, some species only contribute a little to productivity (or decomposition or nutrient cycling) so their loss would barely register. Other species, however, contribute more than their fair share – the extinction of one of these would be strongly felt (Hooper et al., 2005).

Of most significance is the question of whether species are 'complementary' in the way they operate. If they are, then higher biodiversity will generally equate to higher productivity (or decomposition rate, or nutrient recycling). Take, for example, a set of grassland experiments carried out in Europe (Figure 1.6a). Plant biomass at the end of the growing season was higher when each of three different functional groups was represented (grasses, forbs (nongrass herbs) and nitrogen-fixing legumes). Similarly, the rate of breakdown of tree leaves that fall into streams is higher when the richness of detritivorous insect species is higher (because they 'shred' and feed on the leaves in different ways) (Figure 1.6b). In these cases, then, loss of species is likely to have a detectable impact on the way an ecosystem functions. Managers need to beware loss of biodiversity, both for the sake of the species concerned but also because of consequent changes to ecosystem processes.

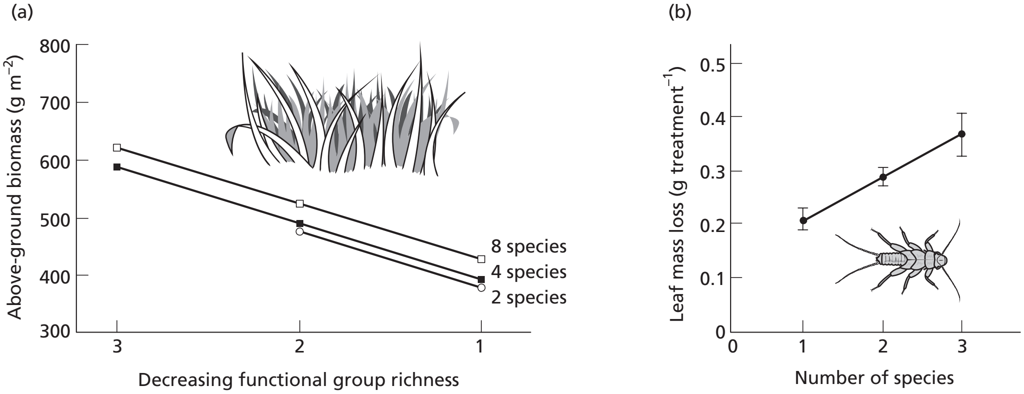


Fig. 1.6 (a) Primary productivity (expressed as above-ground biomass at the end of the growing season) of European grasslands composed of two, four or eight species – note that productivity is somewhat higher when there are more species. However, in cases where all three functional plant groups are represented (grasses, forbs and nitrogen-fixing legumes) productivity is substantially higher than where only two or one of the functional groups are represented. The functional groups differ in the way they garner and convert radiant energy, water and plant nutrients into biomass. (After Hector et al., 1999.) (b) Rate of decomposition of tree leaves that fall into a stream is greater when larvae of three species of stream-shredding stoneflies are present, in comparison to just two or one species. The same total number of stonefly individuals is present in all cases. (After Jonsson & Malmqvist, 2000.)

Beyond the academic quest to understand biodiversity and its role in ecosystems, a utilitarian view of nature focuses on the services that ecosystems provide for people to use and enjoy. *Provisioning services* include wild foods such as fish from the ocean and bushmeat and berries from the forest, medicinal herbs, wood and fiber products, fuel and drinking water. Then there are *cultural services* that nature contributes to human well-being by providing spiritual or aesthetic fulfillment and educational and recreational opportunities. *Regulating services* include the ecosystem's ability to deal with pollutants, the moderation by forest and wetland of disturbances such as floods, the ecosystem's ability to reduce pests and disease risk, and even the regulation of climate (via the capture or 'sequestration' by plants of the greenhouse gas carbon dioxide). Finally, there are *supporting services* that underlie all the other services, such as primary production (by plants), the nutrient cycling upon which productivity is based, and soil formation.

Different ecosystems, both relatively pristine and human-engineered, provide their particular blends of ecosystem services (Figure 1.7). In the case of three 'provisioning' services – production of crops, livestock and aquaculture – human activities have had a positive effect. And in recent times, because of increased tree planting in some parts of the world, there has been an improvement in the sequestration of carbon by trees (a 'regulating' ecosystem service).

But humans have degraded most of the other services. There have been adverse effects on 'provisioning' services in capture fisheries, timber production and water supply (because forest ecosystems moderate river flow, so forest loss increases flow during flooding and decreases it during dry times). We have also seen reductions in many 'regulating' services, including the soil's capacity to detoxify manmade

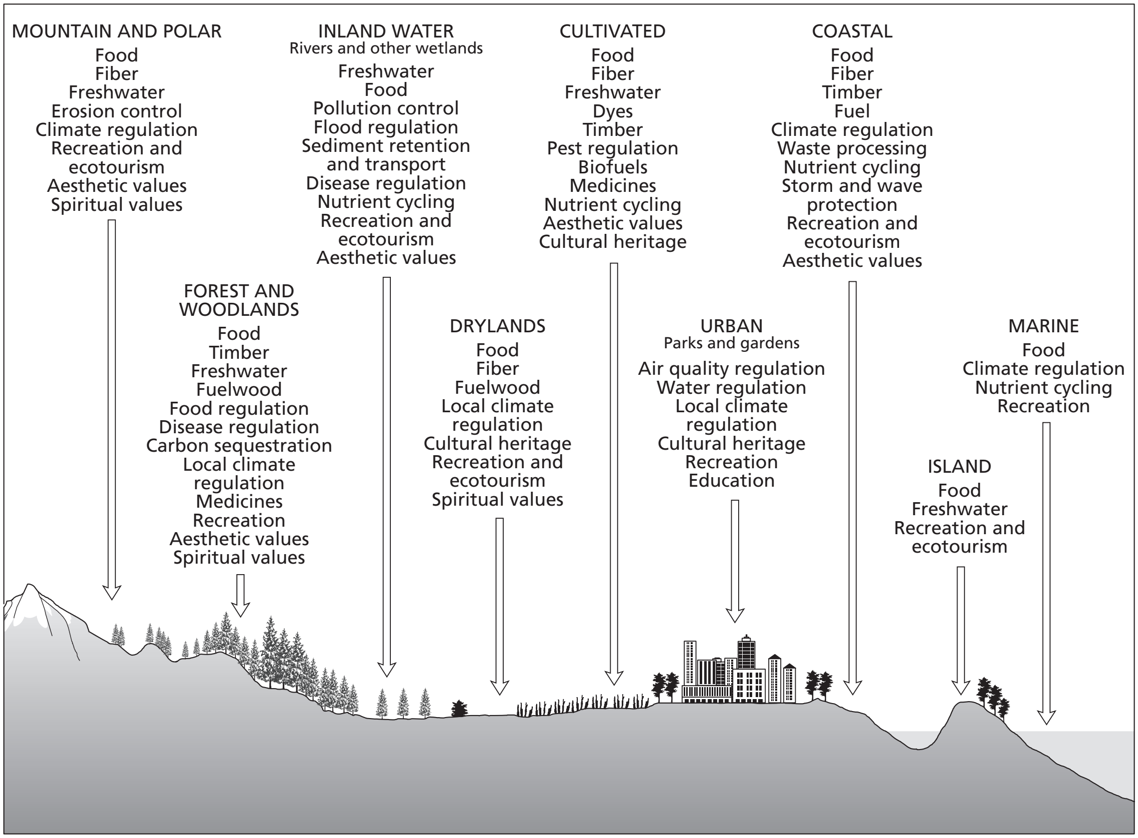


Fig. 1.7 A range of ecosystems, both natural and human engineered, extending from the mountains to the sea. Each ecosystem type provides its own particular set of ecosystem services. (From Millennium Ecosystem Assessment, 2005b.)

chemicals and the ecosystem's capacity to decompose organic waste. Similarly, the loss of riverside vegetation (which can filter nutrient loads) has allowed pollutant levels to increase in aquatic ecosystems. Declines have also occurred in natural hazard protection (loss of natural flood regulation), regulation of air quality and climate, regulation of soil erosion and in many 'cultural' services (Millennium Ecosystem Assessment, 2005b). It is worth noting that ecosystem modification to enhance one service (e.g. intensification of agriculture to produce more crop per hectare – 'provisioning') generally comes at a cost to other services that the ecosystem previously provided (loss of 'regulating' services such as nutrient uptake so pollutant runoff to streams is increased; loss of 'cultural' services such as sites sacred to particular people, streamside walks and valued biodiversity).

All ecosystem services depend directly on elements of biodiversity or on the ecosystem processes supported by biodiversity. Loss of biodiversity, therefore, will often reduce the range of services available to people. There are, in other words, strong economic reasons to manage and conserve nature. This is a point I return to in Section 1.3.2.

1.2.3 *Drivers of biodiversity loss – the extinction vortex*

Extinction may be caused by one of a number of 'drivers', including habitat loss (Section 1.2.4), invasive species (Section 1.2.5), overexploitation (Section 1.2.6) and habitat degradation (including pollution and intensification of agriculture – Section 1.2.7). The relative importance of different drivers for global bird biodiversity is illustrated in Figure 1.8. During the past 500 years bird extinctions can be attributed, in roughly equal measure, to the effects of invasive species, overexploitation by hunters and habitat loss. But now habitat loss is the biggest problem facing threatened species (whether they are classed as critically endangered, endangered or vulnerable). And in the case of 'near threatened' bird species, the ones that managers will increasingly need to attend to in future, habitat loss to agriculture is overwhelmingly the most important driver.

In reality, it seems likely that more than one driver will have played a role in the extinction of any given animal or plant. Thus, a species may be driven to a very small population size by habitat loss/degradation and/or the effect of an invader and/or overexploitation. Then, when numbers become very small there is an increased chance of matings among relatives that produce deleterious effects due to inbreeding depression, causing the population to become smaller still – the so-called extinction vortex (for more detail see Chapter 5, Box 5.1). And a further driver now needs to be added to the list – the global climate change that is predicted to occur over the next century (Section 1.2.8).

Changes to the relative importance of different drivers for all species in various ecosystem types are illustrated in Figure 1.9. Climate change and pollution are predicted to become progressively more important causes of biodiversity loss across all ecosystem types. Habitat change is also set to increase in importance, except in temperate forest, desert, island and mountain ecosystems. Invaders are expected to

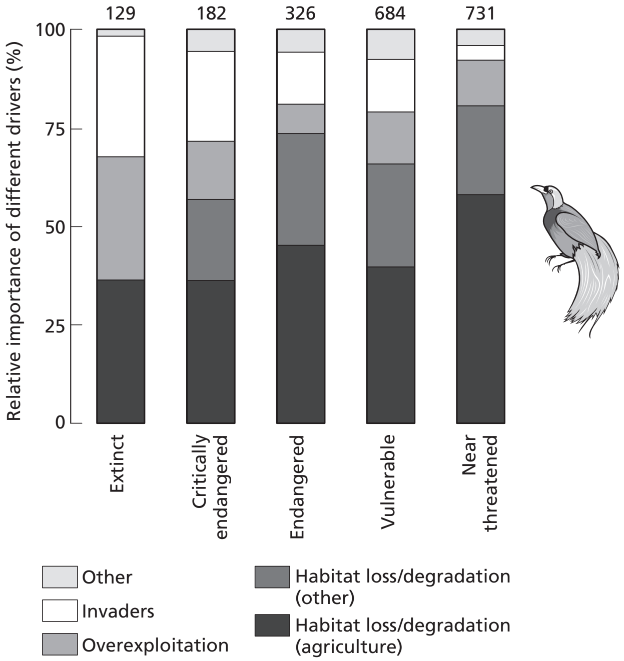


Fig. 1.8 Relative importance of different 'drivers' responsible for the loss or endangerment of bird biodiversity. Patterns are shown for five categories of extinction threat (refer to Box 1.1). The values above each histogram are the numbers of species in each threat category globally. In comparison to the past, habitat loss/degradation poses a much bigger risk now (compare histogram for *extinct* birds with histograms for *endangered* and *vulnerable* categories) and this is set to increase in future, in particular via agricultural expansion (histogram for *near threatened* species). (Modified from Balmford & Bond, 2005, where further references can be found.)

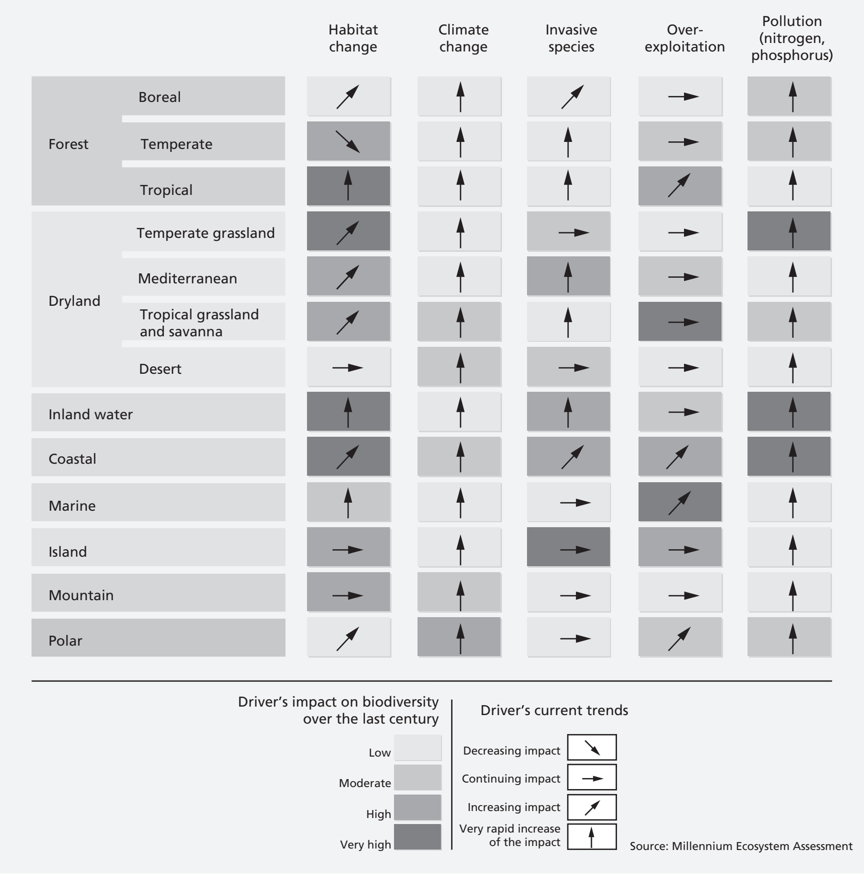


Fig. 1.9 Principal ‘drivers’ of biodiversity change in various terrestrial and aquatic ecosystems. The cell shade expresses expert panel opinion on the impact of each driver on biodiversity over the last century. The arrows indicate the predicted future trend in each driver’s impact. (From Millennium Ecosystem Assessment, 2005b.)

		Habitat change	Climate change	Invasive species	Over-exploitation	Pollution (nitrogen, phosphorus)
Forest	Boreal	↗	↑	↗	→	↑
	Temperate	↘	↑	↑	→	↑
	Tropical	↑	↑	↑	↗	↑
Dryland	Temperate grassland	↗	↑	→	→	↑
	Mediterranean	↗	↑	↑	→	↑
	Tropical grassland and savanna	↗	↑	↑	→	↑
	Desert	→	↑	→	→	↑
Inland water		↑	↑	↑	→	↑
Coastal		↗	↑	↗	↗	↑
Marine		↑	↑	→	↗	↑
Island		→	↑	→	→	↑
Mountain		→	↑	→	→	↑
Polar		↗	↑	→	↗	↑

Source: Millennium Ecosystem Assessment

pose a particular risk in forest and dryland habitats (other than desert) and in inland and coastal waters, whereas overexploitation may not figure quite so dramatically in future (except in aquatic environments, polar regions and tropical forests). These scenarios must underpin the plans and priorities of ecosystem managers around the globe.

1.2.4 *Habitat loss – driven from house and home*

Trends in extinction threat reflect, in large measure, the continuing escalation of the most powerful of human influences – the loss of between 0.5 and 1.5% of wild habitat each year (Balmford et al., 2003). To date, approximately one quarter of the earth’s surface has been transformed for agriculture. And in total, well over half of temperate broadleaf and Mediterranean forests have been lost together with 40–50% of tropical and subtropical forests and grasslands (Millennium Ecosystem Assessment, 2005b). Moreover, since 1980 about 35% of mangroves and 20% of tropical coral reefs have gone. In addition to the actual loss of habitat, what remains is almost invariably highly fragmented in its distribution and supports fewer species as a result. Because they are less hospitable to humans, the world’s deserts, mountains, boreal forests and tundra have fared less badly.

One obvious management response to habitat loss is to protect as much as possible of what remains, and to include in a network of reserves examples of the variety of natural habitats that exist. In fact, protected areas of various kinds (national parks, nature reserves, sites of special scientific interest, etc.) grew both in number and area during the twentieth century. But only about 7.9% of the world's land area is protected (and 0.5% of sea area – Balmford et al., 2002) and, moreover, there is the disturbing fact that most large reserves are on land that no one else wanted (Figure 1.10).

Protection of wilderness is important and, in one sense, 'relatively' easy to achieve. This is because wilderness is inhospitable to humans and therefore difficult to exploit. (But threats emerge if valuable minerals are discovered in such pristine settings.) However, distributions of endangered plant and animal species sometimes overlap with human population centers. To conserve maximum diversity, it follows that greater focus must be placed in future on areas of higher human value. A global trend toward reduced government subsidies for agriculture and the lowering of international trade barriers may have fortunate consequences for the protection of biodiversity. Thus, in Europe, North America and elsewhere, 'marginal' agricultural land is becoming increasingly uneconomic to farm. Mass-membership organizations, such as the Wilderness Foundation and the Royal Society for the Protection of Birds, have been responding to the opportunity by purchasing some of this land for 're-wilding'. The restoration of biodiverse grasslands and woodlands will add somewhat to the total area of the world that is protected for biodiversity.

1.2.5 *Invaders – unwanted biodiversity*

Travel has boomed, the world has shrunk and, just like people, plant and animal species have become globetrotters, sometimes transported to a new region on purpose but often as accidental tourists. Only about 10% of invaders become established and perhaps 10% of these spread and have significant consequences but, when they do, the effects can be dramatic. Take, for example, the huge loss of native fish biodiversity in Lake Victoria after the introduction of Nile perch. A more 'subtle' example concerns the arrival in South Africa of the *Varroa* mite, a species that parasitizes the larvae of honeybees in hives and wild nests. Commercial operators can use pesticides to keep the mite in check but 'natural' bee colonies are likely to be wiped out. This will put plant biodiversity at risk because 50–80% of South Africa's native flowers are pollinated by bees (Enserink, 1999).

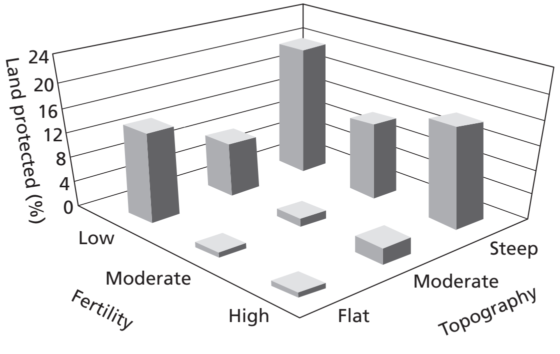


Fig. 1.10 Most national parks and nature reserves in southwest Australia are situated in unproductive areas (low soil fertility) in inaccessible terrain (steep topography). These areas have never been in demand for agriculture or urban development. This pattern is repeated around the world. (After Pressey, 1995; Bibby, 1998.)

A far-reaching consequence of global transport and the spread of human colonists around the world has been 'homogenization' of the biota. The same set of human camp followers now occur in widely separate regions – sparrows, cockroaches, rats and mice, salmonid fishes and game animals, domestic animals and crop plants (with their associated pests and diseases). Native species often do poorly in the face of this set of invaders so that many parts of North America and the Southern Hemisphere now reflect a European legacy more closely than their native heritage. A graphic example of biotic homogenization (involving fish, molluscs and crustaceans) is provided at either end of a trade link between the Great Lakes of North America and the Baltic Sea. Often spread in the ballast water of the ships that ply their trade along this route, a third of the 170 invaders in the Great Lakes come from the Baltic Sea and a third of the 100 invaders in the Baltic Sea come from the Great Lakes (Millennium Ecosystem Assessment, 2005b).

If native species, endemic to a region, are lost at the expense of a common set of invaders, local biodiversity can remain high but global biodiversity is diminished. And invaders can have far-reaching economic as well as ecological consequences. Table 1.1 breaks down the tens of thousands of exotic invaders in the USA into a variety of taxonomic groups. Among these, the red fire ant (*Solenopsis invicta*) from South America kills lizards, snakes, ground-nesting birds and poultry; in Texas alone, its estimated damage to wildlife, livestock and public health is $300 million per year with a further $200 million spent on control. Large populations of zebra mussel (*Dreissena polymorpha*) from the Caspian Sea threaten native mussels and other animals by reducing food and oxygen availability and by physically smothering them. The mussels also invade and clog water intake pipes, and millions of dollars need to be spent clearing them from water filtration and hydroelectric generating plants. The yellow star thistle (*Centaurea solstitialis*) from the Mediterranean area is a crop weed that now dominates more than 4 million hectares in California, resulting in the total loss of once productive grassland. Rats destroy $19 billion of stored grains nationwide per year, cause fires (by gnawing electric wires), pollute foodstuffs, spread diseases and prey on native species. Overall, pests of crop plants, including weeds, insects and pathogens, are the most costly. Imported human disease organisms, particularly HIV and influenza viruses, are also very expensive to treat and result in 40,000 deaths per year (see Pimentel et al., 2000, for further details). Ecological knowledge is needed to enable us to predict future invasions that are likely to have damaging consequences, so that we can confront the 'invaders', preferably before they arrive (via biosecurity precautions at national borders).

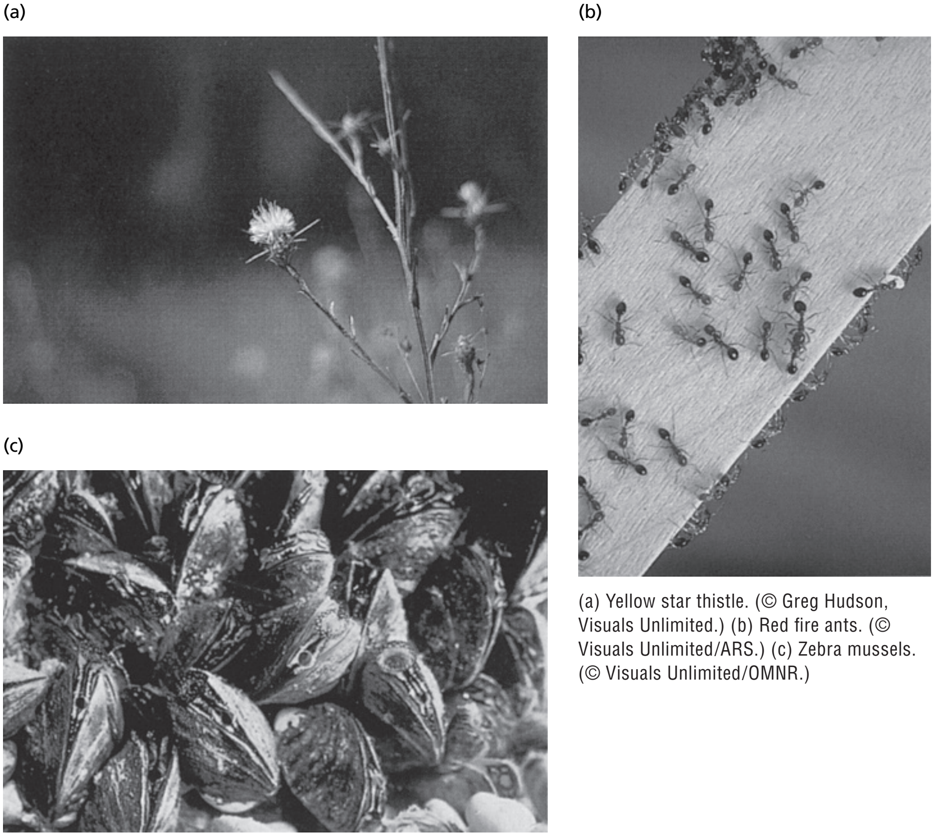
1.2.6
Overexploitation – too much of a good thing

The world once had many more large animals (*megafauna*). Toward the end of the last ice age, for example, Australia was home to giant marsupials, North America had its mammoths and giant ground sloths, and New Zealand and Madagascar were home to giant flightless birds – the moas (Dinornithidae) and elephant birds (Aepyornithidae), respectively. Much of this megafaunal biodiversity disappeared during recent millennia (Figure 1.11a), but at different times in different places (Figure 1.11b). The extinctions seem to mirror patterns of human migration – the arrival in Australia of ancestral aborigines some 50,000 years ago, the appearance of abundant stone spear points in North America about 12,000 years ago, and the arrival of humans around 1000 years ago in New Zealand and Madagascar. The demise of the megafauna may have involved the effects of habitat transformation, particularly by

Table 1.1 Estimated annual costs (billions of US dollars) associated with invaders in the USA. In each case, the cost is made up of loss and damage caused plus dollars spent to control the pests. Taxonomic groups are ordered in terms of the total costs associated with them. (After Pimentel et al., 2000.)

Type of organism	Number of invaders	Major culprits	Loss and damage	Control costs	Total costs
Microbes (pathogens)	>20,000	Crop pathogens	32.1	9.1	41.2
Mammals	20	Rats and cats	37.2	NA	37.2
Plants	5,000	Crop weeds	24.4	9.7	34.1
Arthropods	4,500	Crop pests	17.6	2.4	20.0
Birds	97	Pigeons	1.9	NA	1.9
Molluscs	88	Asian clams, zebra mussels	1.2	0.1	1.3
Fishes	138	Grass carp, etc.	1.0	NA	1.0
Reptiles, amphibians	53	Brown tree snake	0.001	0.005	0.006

NA, data not available.



(a) Yellow star thistle. (© Greg Hudson, Visuals Unlimited.) (b) Red fire ants. (© Visuals Unlimited/ARS.) (c) Zebra mussels. (© Visuals Unlimited/OMNR.)

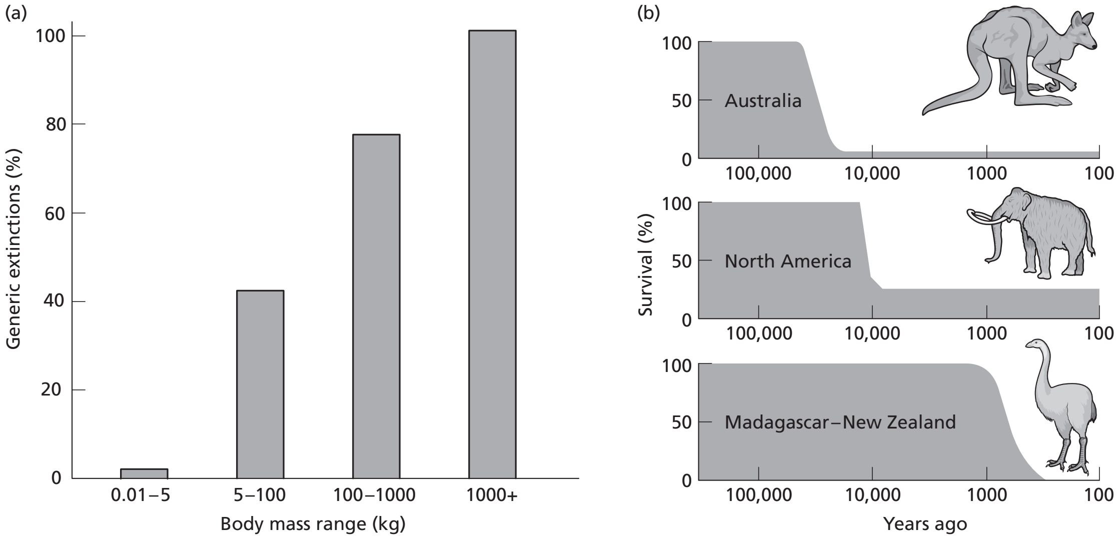


Fig. 1.11 (a) The percentage of genera of large mammalian herbivores that became extinct in the last 130,000 years is strongly related to size (data for North and South America, Europe and Australia combined. (After Owen-Smith, 1987.) (b) Percentage survival of large animals on two continents and two islands (New Zealand and Madagascar) during the past 100,000 years or so. Significant declines in numbers of large animals (mammals, reptiles, birds) occurred at different times in different places, mirroring historical evidence about the arrival of efficient human hunters. (After Martin, 1984.)

fire, and of diseases introduced by humans and their camp followers. But it seems likely that the prime cause was the arrival of efficient human hunters who targeted the largest and most highly profitable prey. Big animals tend to reproduce at a slow rate, making them particularly vulnerable to overexploitation and a downward spiral to extinction.

Prehistoric megafaunal extinctions were particularly dramatic, but in modern times a host of less conspicuous species have been driven by harvesters to the brink of extinction or, at least, to such low numbers that it is no longer profitable to hunt them. The most commonly overexploited species are marine fish and invertebrates (e.g. lobsters and shellfish) as well as trees and terrestrial animals hunted for meat.

Three quarters of the world's industrial fisheries are considered to be fully (50%) or overexploited (25%) (Millennium Ecosystem Assessment, 1995b). And there is a parallel here with the prehistoric extinctions – because species with lower reproductive rates are the most susceptible. Thus, overexploitation of large tuna species is a recognized problem, whereas smaller fish continue to thrive. One consequence of the size–vulnerability relationship, repeatedly observed around the world, is that the mean size of fish taken for human consumption has been declining. Note that it is not just harvesting for food that causes problems – overexploitation may involve plants that provide timber or medicinal products, or live animals and plants collected for the pet and garden trades. The effective regulation of harvesting effort is a difficult business, depending both on a thorough ecological understanding of the dynamics of exploited populations and an ability to regulate the behavior of harvesters.

The impacts of overexploitation are sometimes coupled to harvesting techniques that destroy habitat. A stark example is provided by the dynamiting of coral reef to stun and collect fish. The effects of bottom trawling are less visible but may sometimes be equally destructive. Take the cold-water coral reefs that occur down to depths of 3 km in the offshore waters of at least 41 nations. The technology to study these in close-up recently became available, only to find, for example, that heavy trawling gear has already destroyed up to 40% of the reef off the west coast of Ireland. Managers face the double task of developing harvesting policies that respond to the risk of overexploitation and the threat of physical damage to habitat.

1.2.7 *Habitat degradation – laying waste*

Like the other drivers of biodiversity loss, degradation of habitat by human pollutants continues to show an alarming increase. The chemicals that we release into the atmosphere return to Earth as gases, particles or dissolved in rain, snow and fog. But in the process the pollutants may be carried in the wind for hundreds or thousands of kilometers. Sulfur dioxide (SO_2) and oxides of nitrogen (NO_X) (associated with the burning of fossil fuels) interact with water and oxygen in the atmosphere to produce sulfuric and nitric acids, creating atmospheric pollution which falls as 'acid rain'. Rainwater has a pH of about 5.6, but pollutants lower it to below 5.0 and values as low as 2.1 have been recorded in various industrial areas of the world. Acid rain acidifies the water in lakes and streams, and many species of algae, invertebrates and fish cannot tolerate the extreme conditions. Forest trees can be affected just as badly. Other atmospheric pollutants, including the carbon dioxide produced by the burning of fossil fuels, are now known to cause disturbingly far-reaching climatic effects, with expected changes to global patterns of temperature and precipitation. This will be dealt with in Section 1.2.8.

Our dependence on fossil fuels has other consequences too. More than 4 million tonnes of oil find their way into waterways every year, some seeping naturally from the ocean floor, some from industry, and a large proportion from oil wells and oil tankers. Oil prevents light from reaching aquatic plants and reduces aeration of the water, with adverse effects for seaweeds and invertebrates such as molluscs and crustaceans. Feathers of seabirds become choked with oil and fish gills cease to function. The infamous incident in 1989, when the oil tanker *Exxon Valdez* ran aground in Alaska, spread oil along the coast for a thousand kilometers, contaminating the shores of state parks and other protected areas, and killing an estimated 300 harbor seals, 2800 sea otters and 250,000 birds.

Among the various categories of habitat degradation, agricultural development is set to pose the greatest problems in future. Between 3 and 6% of natural ecosystems around the world have been converted to agriculture since 1950, and this has consequences both for natural habitat loss and for the pollution and degradation of what remains. The scale of the problem is not uniform. As our use of habitat becomes ever more intensive (from protected land, through light grazing of natural grasslands, to cultivation and urban development), biodiversity loss increases for all animal and plant groups (Figure 1.12).

Increasing agricultural intensity is associated with increases in soil erosion, salinization (loss of productive capacity because of salt intrusion) and desertification, and with increased removal of surface and ground water for irrigation. River flow has been reduced so dramatically that, for example, the Nile in Africa, the Yellow River in China and the Colorado River in North America, for parts of the year dry

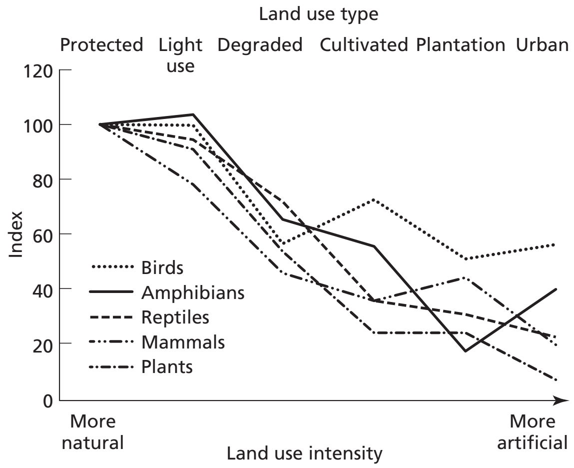


Fig. 1.12 Estimated average remaining population sizes of various animal and plant taxa in relation to intensity of land use. The index commences at 100 for all taxa in the most natural 'protected' situation, and represents the situation 300 years ago. There is a more-or-less progressive decline in all cases. The surprising increase in amphibian densities associated with urban land use occurs because urban areas in semiarid landscapes of southern Africa provide artificial water-filled habitats needed by frogs and their relatives. (From the Millennium Ecosystem Assessment, 2005b.)

up before they reach the ocean. In addition, excess plant nutrients find their way into waterways, and chemical pesticides affect nontarget species. All these agricultural problems look set to increase over the next 50 years as more land is converted (Figure 1.13). And because greater human population growth is expected in species-rich tropical areas, increased agricultural activity will place biodiversity at high risk. The challenge for managers is to keep land conversion to a minimum (needed to support the human population) and to promote agricultural 'best practices' that minimize ecological fallout.

1.2.8 *Global climate change – life in the greenhouse*

The most far-reaching consequence of our use of fossil fuels has been an increase in the concentration of carbon dioxide in the atmosphere. The level in 1750 (i.e. before the Industrial Revolution), measured in gas trapped in ice cores, was about 280 ppm (parts per million), but this rose to 320 ppm by 1965 and stands at about 380 ppm today (Figure 1.14). It is projected to increase to 700 ppm by the year 2100.

The Earth's atmosphere behaves rather like a greenhouse. Solar radiation warms up the Earth's surface, which reradiates energy outward, principally as infrared radiation. Carbon dioxide – together with other gases whose concentrations have increased as a result of human activity (nitrous oxide, methane, ozone, chlorofluorocarbons) – absorbs infrared radiation. Like the glass of a greenhouse, these gases (and water vapor) prevent some of the radiation from escaping and keep the temperature high. The air temperature at the land surface is now 0.6 ± 0.2°C warmer than in pre-industrial times. Note, however, that temperature change has not been uniform over the surface of the Earth. Up to 1997, for example, Alaska and parts of Asia experienced rises of 1.5–2°C, while the New York area experienced little change, and temperatures actually fell in Greenland and the northern Pacific Ocean. Given the expected further rises in greenhouse gases, temperatures are predicted to continue to rise by a global average of between 1.8°C and 4.0°C by 2100 (IPCC, 2007; Millennium Ecosystem Assessment, 2005b), but to different extents in different places. Such changes will lead to a melting of glaciers and icecaps, a consequent rise

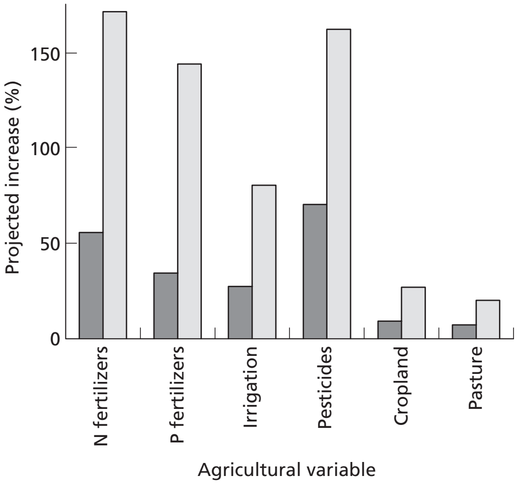


Fig. 1.13 Predicted increases in nitrogen (N) and phosphorus (P) fertilizers, irrigated land, pesticide use and global areas under crops and pasture by 2020 (dark bars) and 2050 (light bars). (From Laurance, 2001, based on data in Tilman et al., 2001a.)

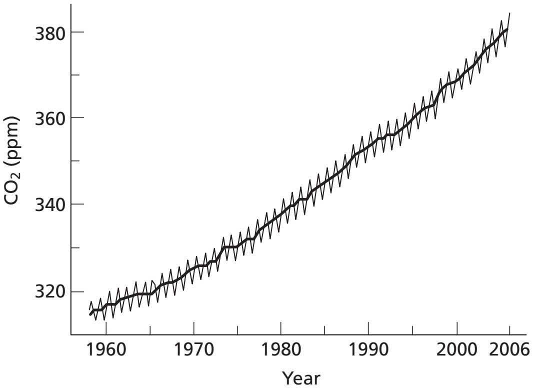


Fig. 1.14 The concentration of atmospheric CO_2 measured at the Mauna Loa Observatory, Hawaii showing the seasonal cycle (peaking each northern summer when photosynthetic rates are maximal in the Northern Hemisphere) and, more significantly, the long-term increase that is due largely to the burning of fossil fuels. (Courtesy of the Climate Monitoring and Diagnostics Laboratory (CMDL) of the National Oceanic and Atmospheric Administration (NOAA).)

in sea level, and large changes to global patterns of precipitation, winds, ocean currents and the timing and scale of storm events.

The principal cause of increased greenhouse gases has been the combustion of fossil fuels, but other factors also come into play. Adding the carbon dioxide released when limestone is kilned to produce cement (about 0.1 Pg of carbon per year) to fossil fuel use (5.6 Pg per year), a net increase of 5.7 (±0.5) Pg C per year was added to the atmosphere during the period 1980–1995 (1 petagram = 10^{15} g) (Houghton, 2000). Landuse change is believed to have pumped a further 1.9 (±0.2) Pg C into the atmosphere each year. In particular, the exploitation of tropical forest causes a significant release of carbon dioxide, particularly if the forest is cleared and burnt to make way for agriculture. Much of the carbon goes up in smoke, followed by further carbon dioxide release as vast stores of soil organic matter decompose.

Where does the extra 7.6 Pg C per year of carbon end up? The observed increase in atmospheric carbon dioxide accounts for 3.2 (±1.0) Pg C (i.e. 42% of the human inputs), while much of the rest, 2.1 (±0.6) Pg C, dissolves in the oceans. This leaves 2.3 Pg C per year, which is generally attributed to a terrestrial 'sink' – probably

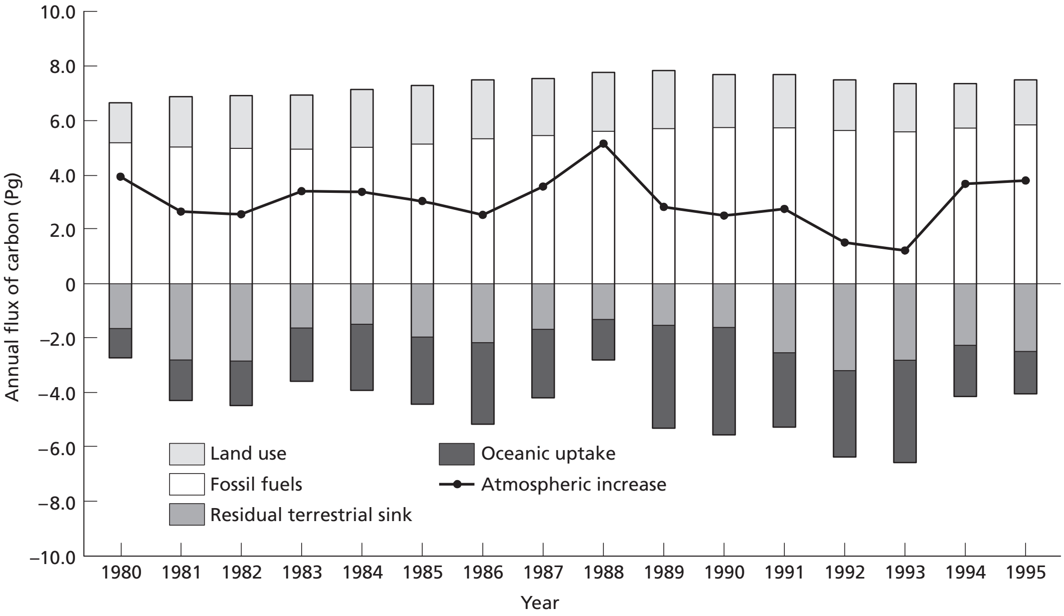


Fig. 1.15 Annual variations from 1980 to 1995 in the global atmospheric increase in carbon dioxide (circles and black line) and in carbon released (histograms above the midline) or accumulated (histograms below the midline) by changes to the burning of fossil fuels, land use, oceanic uptake and an uncertain terrestrial sink (probably related to increased plant productivity). (From Begon et al., 2006, after Houghton, 2000.)

involving carbon dioxide uptake associated with increased terrestrial productivity in northern mid-latitude regions (Houghton, 2000).

There is considerable year-to-year variation in the estimates of carbon sources and sinks, and of increases in the atmosphere (Figure 1.15). Declines in the rate of increase between 1981 and 1982 followed sharp rises in oil prices, while declines in 1992 and 1993 followed the collapse of the Soviet Union. In 1997–8 (not shown in Figure 1.15 but evident, if you look carefully, in Figure 1.14), massive forest fires in a small part of the globe (Indonesia) doubled the growth rate of CO_2 in the atmosphere. The accurate prediction of future changes in carbon emissions is difficult because so many variables play a role (climatic, political and sociological). And predictions of consequences for patterns in global temperature and precipitation are no less straightforward. However, the matter is pressing because we can be sure that climate change will further complicate all the other environmental issues so far discussed.

1.3 Toward a sustainable future?

Can there really be people (exploiters) interested only in short-term financial gain and with absolutely no thought for adverse environmental consequences? And can others (preservationists) be so naive as to argue that nature should be protected always and everywhere? Human nature is such that we tend to identify more with one pole than the other, and then to assume that those at the other end are extremists. Of course there are some fundamentalists, but the vast majority are not so polarized. Those who take the middle ground appreciate the necessity to produce food and industrial goods, to harvest natural resources and to control pests. But they also value nature and recognize the need to protect biodiversity. These nonextremists, of course, also have a variety of views – some are closer to the preservationist end of the spectrum (happy to have a lower standard of living for the sake of the natural world) and others are more exploitationist in their view (requiring that only a small portion of the natural world be protected – to be enjoyed as a recreational walker, an ecotourist or in a natural history film). Reconciling these views remains a challenge. But given the accumulating evidence of adverse effects of our activities, where many impacts only become apparent in the long term, we need to rise to the challenge.

Is it possible to take a completely objective approach to determine just how far we can push the drive to exploit – or, conversely, to decide how much of the natural world should be maintained in a completely pristine state, or be protected at some level? This is not easy, to say the least, but we can get close by pursuing a particular aim – that of sustainability. To call an activity 'sustainable' means that it can be continued or repeated in future. If people wish to have tuna to eat in future, they cannot continue to harvest them from the sea faster than the population can replace those that are lost. Nor can farmers continue to use fertilizers indiscriminately if people want to retain the ecosystem services provided by rivers, lakes and oceans that are impacted by the agricultural excess. And on the largest scale of all, our present reliance on fossil fuels puts at risk, through global climate change, the sustainability of all our activities, whether exploitative or protective. In essence, a sustainable society is one able to meet current needs without compromising the ability of future generations to provide for themselves. Sustainable behavior, in other words, provides the best outcomes for both human and natural systems – now and in future.

One of the problems with the idea of sustainability is that it can only be defined on the basis of what is known now. But what about the many factors that are unknown or unpredictable? Things might take a turn for the worse – when locally adverse oceanographic conditions damage a fishery already suffering from overexploitation, or global climate change increases flood risk in a region already prone to flooding because of deforestation. On the other hand, some people tend to downplay the risk – because *Homo sapiens* is so smart. Thus, they believe that technological advances will allow activities to be sustained that previously seemed unsustainable – the invention of processes to remove pollutants from the outflows of power stations and industry, or of a pesticide more precisely targeted on the pest and without harm to innocent bystanders. But it would be risky indeed to have faith that there will always be a technological 'fix' to solve current environmental problems. *Homo sapiens* needs to become truly wise, factoring in all conceivable risks to sustainability scenarios.

The recognition of the importance of sustainability as a unifying idea can be said to have come of age in 1991. This was the year that the Ecological Society of America published *The sustainable biosphere initiative: an ecological research agenda* (Lubchenco et al., 1991), and the World Conservation Union, the United Nations Environment Programme and the World Wide Fund for Nature jointly published *Caring for the Earth: a strategy for sustainable living* (IUCN/UNEP/WWF, 1991).

The emphasis shifted more recently from a purely ecological perspective to one that incorporates economic and social conditions that influence sustainability

(Milner-Gulland & Mace, 1998), a theme that has gathered pace in the new millennium. In 2002, for example, 190 countries committed themselves ‘to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth’ (UNEP, 2002). The Millennium Ecosystem Assessment, launched in 2001, is also based on contributions from a large number of natural and social scientists (Millennium Ecosystem Assessment, 2005b). Its aim is to provide both the general public and decision makers with ‘a scientific evaluation of the consequences of current and projected changes in ecosystems for ecosystem services and human well-being’ (Balmford & Bond 2005). In the remaining sections of this chapter, I introduce the ecological (Section 1.3.1), economic (1.3.2) and sociopolitical (1.3.3) dimensions of sustainability.

1.3.1 *Ecological applications – to conserve, restore and sustain biodiversity*

The body of ecological theory is organized in a hierarchical way. My focus in this book will be on ecological applications, but these will be presented in a sequence that mirrors the underlying theory.

At the lowest level is the ecology of *individual organisms* – their niche requirements (resource needs and tolerance of physicochemical conditions – Chapter 2), their life-history characteristics (Chapter 3) and their dispersal/migratory behavior (Chapter 4). Knowledge at this level is crucial when reintroducing species that have become locally extinct, restoring natural grassland and forest, or predicting invaders likely to pose a major problem. See Box 1.2 for ecological tidbits from each chapter.

Next comes the *population* level of ecological organization. The population comprises all the individuals of a single species in a particular place, and the focus is on factors that determine the density and genetic diversity of populations. Population theory is central to the management of endangered species (Chapter 5), pests (Chapter 6) and harvests (Chapter 7).

Moving up another step in the ecological layer cake, *community* ecology concerns itself with all the species that coexist. Two areas of community ecology of particular importance for environmental management are succession (the predictable temporal pattern in species composition after a disturbance such as a storm or fire – Chapter 8) and patterns in the feeding interactions of food webs. When the spotlight is turned on the community in relation to its physicochemical environment, and specifically the flux of energy and matter through the food web, we talk of the *ecosystem* level of organization (Chapter 9). Ecological theory associated with communities and ecosystems helps managers devise plans to conserve and restore natural communities, counteract invasions, increase the range of harvestable products and make agroecosystems sustainable. And of course, ecosystem theory underpins the whole idea of ecosystem services and their contribution to human well-being.

The last part of the book combines examples from all levels in the ecological hierarchy but shifts emphasis to a larger spatial scale, dealing with landscape ecology (the patchwork of habitats in the landscape as a whole – Chapter 10) and finally with the global environment, where global climate change becomes the focus (Chapter 11). Landscape ecology is crucial when designing networks of nature reserves, but often also when planning conservation, restoration, harvests and pest control. And global climate change has implications for everything else – whether at the level of individuals, populations, communities, ecosystems or landscape

Box 1.2 Ecological tidbits

This book, about how ecological theory can be harnessed to protect biodiversity and ecosystem services, is divided into sections that relate to four areas of ecological theory (see chapter grouping in the main contents list). Here are some morsels from the four chapter groupings to tempt your appetite – one per chapter.

1 Ecological applications at the level of individual organisms

Niche theory and the translocation of New Zealand's takahe

Source: Ross Armstrong/Alamy.

One of the few remaining representatives of a guild of large, flightless birds, the takahe declined almost to extinction because of human hunting and the effects of invaders that compete with them (deer) or prey upon them (stoats). The surviving individuals were restricted to a remote and climatically extreme mountain area. A conservation plan called for captive breeding and release of birds in suitable habitat elsewhere. Selecting the correct release sites, a crucial step, depends on understanding the bird's niche requirements – but was their mountain distribution a reflection of ideal conditions or simply their last outpost? Managers used evidence of fossil remains to map the takahe's historical distribution and throw light on its optimal niche requirements. Translocation of individuals to lowland areas on offshore islands has proved successful (Section 2.3.2).

Species traits can predict invasive trees and threatened natives

Photo: M.P. Frankis.

Of a hundred pine species that have been introduced to the USA, a small proportion have caused problems by spreading into native habitats. Their 'success' turns out to depend on certain traits, including small seed size, a short interval between successive large seed crops and rapid maturity to reproductive adult. Conversely, native pine species that are particularly prone to extinction, such as *Pinus maximartinezii*, have precisely the opposite traits. Such patterns give managers something to work on when it comes to predicting problematic invaders or identifying natives that are most likely to need protection (Section 3.3.1).

Migratory behavior and the design of nature reserves for giant pandas

Source: blickwinkel/Alamy.

Giant pandas depend for food on just a few species of bamboo. From June to September in China's Qinling Province, home to 20% of the world's remaining animals, the pandas eat *Fargesia spathacea*, which grows from 1900 to 3000 m. But as colder weather sets in, they move to lower elevations and between October and May feed primarily on *Bashania fargesii*, a bamboo that grows from 1000 to 2100 m. Existing reserves did not cater for the needs of pandas at both ends of this seasonal migration, putting the population at risk. But now, with a fuller knowledge of migratory behavior and the distribution of bamboo species, a network of connected reserves has been established (Section 4.2.2).

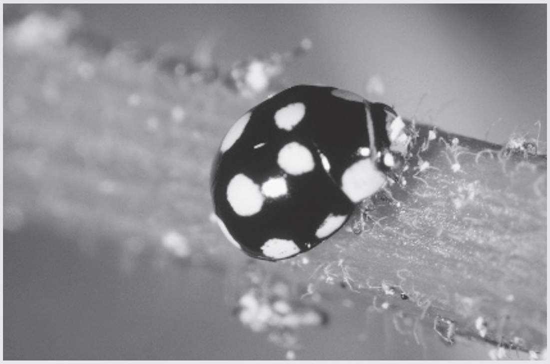
2 Applications at the level of populations

Countering the threat of extinction – genetic rescue of the Florida panther

Source: Mark J. Barrett/Alamy.

The last remaining population of the Florida panther (a subspecies of *Puma concolor*) became so small that genetic variation was remarkably low and deleterious forms of genes occurred at high frequency, causing features such as undescended testes, kinked tails and the poorest semen quality of any cat species. Managers decided to translocate individuals from another subspecies, the Texas cougar, in an attempt to eliminate deleterious variants and restore more normal levels of genetic variation. Now panthers with some cougar ancestry show dramatic reversals in the frequency of undesirable features and the signs are good that the probability of extinction has been reduced (Section 5.5.1).

Pest control on the island of St Helena – a ladybird beetle saves the day



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An invasive scale insect had put at risk the national tree of a small South Atlantic island. Only 2500 St Helena gumwoods were left when, in 1991, the South American scale insect *Orthezia insignis* was found to be mounting an attack on the trees, killing more than 100 of them by 1993 and expected to wipe them out by 1995. A known predator of the scale insect, the ladybird *Hyperaspis pantherina*, was cultured and released on the island in 1993 and as its numbers increased the scale insects quickly declined. Since 1995 no scale insect outbreak has been reported and culturing of the ladybirds has been discontinued because the population is maintaining itself at low density in the wild – as good biological control agents should (Section 6.3.1).

Harvest management – counteracting evolution towards small size

© D.P. Wilson/FLPA.

Harvesting is often size-selective, whether for bighorn sheep with the largest horns or for the biggest fish to sell at market. In an unharvested population, a few small individuals may mature earlier than the rest. If the population is then harvested in a way that takes mainly large individuals, the few small but mature animals are likely to provide a disproportionate number of offspring to the next generation and future generations become dominated by smaller animals. A graphic example is provided in the north Atlantic where the size at which cod mature has suffered a dramatic decline as a result of heavy fishing pressure. The consequences for harvest yields can be profound and managers need to devise harvesting rules that counteract this evolutionary trend (Section 7.4).

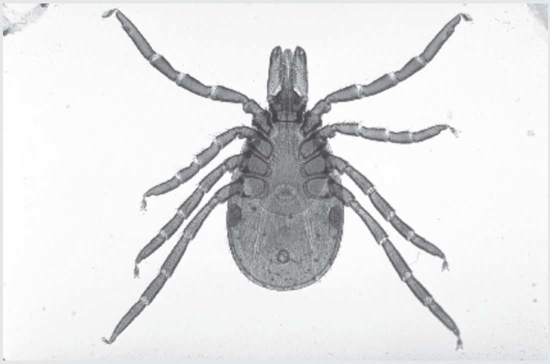
3 Applications at the level of communities and ecosystems

Succession theory – nursing a community back to health

Source: Kalpana Kartik/Alamy.

After a disturbance, such as a hurricane, volcanic eruption or forest clearance for agriculture, the community proceeds through a predictable successional species sequence until mature forest is regained. A dilemma for managers wishing to restore Mediterranean forest was whether to remove *or* encourage the pioneer shrubs in the succession. By-passing the early species might speed up the transition to forest, but not if the shrubs *facilitate* the success of later species in this hot, dry region. In fact, experiments showed that the pioneer shrubs act as ‘nurse’ plants for the vulnerable tree seedlings, shading and protecting them from the scorching Mediterranean sun. When pioneer species are facilitators of successional change the management prescription must be to leave them in place (Section 8.2.5).

Food web theory – minimizing human disease risk



Source: PHOTOTAKE Inc./Alamy.

If left untreated, Lyme disease can damage heart and nervous system and lead to a type of arthritis. The illness is caused by the bacterium *Borrelia burgdorferi*, which is carried by ticks in the genus *Ixodes* and transmitted when the tick feeds, first on small animals such as the white-footed mouse, and later on large mammals, including people wandering through the forest. In unusual years of massive acorn production by oak trees, the mouse population thrives and the parasite–host dynamics are such that two years later the risk of Lyme disease is considerably increased. This knowledge helps forest managers to provide a timely warning to hikers. Many small animal species are hosts to the ticks, but most are much less efficient than the mice at passing on the bacterium. This means that disease risk to humans is lower where the biodiversity of squirrels, birds and lizards is high – providing a compelling reason to conserve biodiversity (Section 9.2).

4 Applications at the regional and global scales

A marine zoning plan for sustainability

Source: Chad Ehlers/Alamy.

Maori, recreational and commercial fishers, tourism operators, marine scientists and environmentalists got over their differences, learnt from each other and produced a comprehensive ecosystem management plan for the large Fiordland region of New Zealand. A significant feature of the proposal was the concept of *gifts* and *gains* by the various groups. Thus the plan called for new fishing behavior: a reduction in bag limits for recreational fishers, the withdrawal of commercial fishers from the inner fiords and a voluntary suspension of certain customary fishing rights by Maori. In addition, a number of marine reserves and protected areas were identified to protect representative ecosystems and *china shops* – areas with outstanding but vulnerable natural values. These gains in sustainability and conservation were balanced by the gift from environmentalists to refrain from pursuing their original goal of a much more extensive marine reserve program. The New Zealand government agreed to implement the plan in its entirety and has passed the new legislation necessary (Section 10.7.2).

Global climate change – predicting future invasions

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The Argentine ant is now established on every continent except Antarctica. It can achieve extremely high densities, with adverse effects on biodiversity and unpleasant consequences for domestic life – the ants tend to swarm over human foodstuffs and even sleeping babies. A niche model was developed for the ant, according to current distributions in its native and invaded ranges. Then, based on expected global changes to temperature and precipitation, the likely future distribution of the ant was predicted. The species is set to contract its range in tropical areas but expand into temperate areas. Ironically, therefore, the Argentine ant looks set to do less well in Argentina and South America but become a major pest in North America and Europe. Efforts to eradicate Argentine ants have rarely been successful. The management response is therefore to increase biosecurity precautions in regions expected to become progressively more invadable as climate change takes hold (Section 11.2.2).

ecology, and whether concerned with conservation, restoration, harvest management, pest control, biosecurity or sustainable agroecosystems.

1.3.2 *From an economic perspective – putting a value on nature*

There is an economic side to every resource management argument. Sometimes this is obvious to everyone and 'relatively' straightforward to quantify. A decision to become a player in a fishery will take into account the costs of buying and maintaining fishing boats, crew, gear and shore facilities in relation to the value of the sustainable catch. The decision of a farmer to invest in pest control also depends on weighing up the dollars spent killing pests in comparison to the gains to be made in extra product at the farm gate. And the economic value of what is put at risk by the arrival of invaders can be set against the costs of biosecurity border operations to keep them out.

It can also be relatively easy to work out the cost of saving a species from extinction – in terms of purchasing a reserve, predator control, and so on. But how can managers determine the value of the species so they can decide whether the cost is justified? Then again, you have seen that many economic activities put ecosystem services at risk (Section 1.2.2). How do we determine the value of lost services so these can be set against the economic gains associated with the activity? Even the 'straightforward' economics of fishing and farming turn out to be fraught with difficulty. This is because traditional economics have not taken into account the associated environmental costs that are borne by society in general. Take, for example, the destruction of cold-water coral reefs while trawling, or the reduction in river water quality resulting from a farmer's indiscriminate application of fertilizer.

Economic valuation of nature is inherently a human preoccupation, being based on the contributions that biodiversity makes to our well-being. There are also 'deeper' reasons for conserving biodiversity – species may be considered of value in their own right, a value that would be the same if people were not around to exploit or appreciate it. But, to be effective, it seems inevitable that conservation arguments must ultimately be framed in cost–benefit terms. This is because governments decide policies against a background of the priorities accepted by their electorates, and the money they have to spend. The importance of the concept of ecosystem services, which is relatively new, lies in its focus on how biodiversity provides for human well-being. Now, economic value can be ascribed to biodiversity in a way that can be understood by everyone.

A range of techniques are available to put a value on nature. Goods and services for which there is a market are the most straightforward – values can quite readily be ascribed to clean water for drinking or irrigation, to fish from the sea and medicinal herbs from the forest. In other cases, a more imaginative approach is required.

For example, *travel cost* paid by people to access a natural area provides a minimum value of this recreational service. *Contingent valuation* may be determined in a survey of people's *willingness to pay* for each of a set of hypothetical landuse scenarios (perhaps in terms of a hypothetical 'nature tax'). *Replacement cost* is an estimate of how much would need to be spent to replace an ecosystem service with a manmade alternative – such as substituting the natural waste disposal capacity of a wetland by building a treatment works. *Avoided cost* is an estimate of the cost that would have occurred had a service not been available – such as flood damage if a protective off-shore reef were not present.

And when an ecosystem service has already been lost, the real costs – in loss of property, livelihoods, health and so on – can be determined. Take, for example, the collapse through overexploitation of the Newfoundland cod fishery in the early 1990s – this cost at least $2 billion in income support and retraining for the thousands of people who lost their jobs. Another graphic example is provided by the largely deliberate burning of 50,000 km^2 of Indonesian vegetation in 1997 – the economic cost comprised $4.5 billion in lost forest products and agriculture, increased greenhouse gas emissions, reductions in income from tourism, and healthcare expenditure on 12 million people affected by the smoke (Balmford & Bond, 2005).

Viewed from the broadest perspective of all, the total value of the world's ecosystem services has been roughly estimated at $38 trillion ($10^{12}$) – more than the gross domestic product of all nations combined (Costanza et al., 1997). The 'new economics' provides persuasive reasons for taking great care of biodiversity. You can dip into this book's smorgasbord of examples where economic arguments are prominent in Sections 2.4.3, 4.4, 4.5.3, 4.5.4, 5.6, 7.5, 7.6, 8.3 and 10.5.3.

1.3.3 *The sociopolitical dimension*

Many ecologists feel outside their comfort zone when asked to confront economic realities. But the situation is more complex still, because environmental issues almost always have a sociopolitical angle too. Sociologists can help managers identify the best approaches to reconcile the desires of all interested parties, from farmers and harvesters to tourism operators and conservationists. And political scientists help address the twin problems of whether sustainable management should be fostered by penalties or inducements, and be set in law or encouraged by education. Moreover, there are both sociological and political dimensions to the question of how the needs and perspectives of indigenous people can be taken into account. Sustainable environmental management clearly has a *triple bottom line* – ecological, economic and sociopolitical.

At the local level, the knowledge and ideals of the community can be of great value in improving sustainable behavior. So-called *social capital* is a measure of connectedness in a community, reflecting relationships of trust, willingness to share information, and to develop common rules about biodiversity protection and the sustainable use of nature (Pretty & Smith, 2004). By getting together, rural people, for example, can improve their understanding of the relationship between agriculture and nature and find ways to deal with adverse effects – by fencing waterways, replanting riparian (stream-side) vegetation buffer strips, and implementing more careful use of plough, fertilizer and pesticide. This process of social learning increases 'social capital' and helps new ideas to spread more rapidly through the community and to other places. Community groups reach a zenith of achievement when diverse interest sectors, which previously failed to engage with each other, come together to confront a sustainability issue. Once the barriers are down (aided by a skilled facilitator if necessary), people as diverse as commercial fishers and environmentalists can learn from each other and identify the real sustainability problems (see, for example, the marine zoning plan in Box 1.2). When people are well connected in groups and networks, and when their knowledge is sought and incorporated during environmental management planning, it seems they are more likely to retain a care-taking role in the long term (Pretty & Smith, 2004). At one end of the scale of community participation, government agencies merely keep people informed of plans, or consult by asking questions, but fail to concede to the community a share in decision-making. At the other end of the scale, and better by far, is full participation by the community in analysis, planning, implementing and policing a management strategy for which they take ownership.

If an environmental problem occurs at too large a scale for local communities and governments to solve, the sociopolitical machinations need to occur globally. Estimates of future greenhouse gas emissions, the concentrations to be expected in the atmosphere, and the resulting changes to global temperature vary considerably. Some of this variation reflects uncertainties in climate science. But the predicted patterns of increase, and in some cases eventual decreases, depend on how fast the human population continues to grow, where the population will peak, changing attitudes to the use of energy sources, the technological advances that come to pass and attitudes to the importance of ecosystem services. There is a profound sociopolitical dimension to all these things.

An analysis of four quite detailed sociopolitical scenarios in Table 1.2 explores likely trends in climate change, pollution problems and the state of ecosystem services. If there is little change in our sociopolitical outlook, the *order from strength* scenario may be our fate, with poor economic growth, degradation of all ecosystem services and a large increase in global temperature. A more globally connected society (*global orchestration*) could produce the highest economic growth and strongest improvement for the poorest people, but at the cost of many ecosystem services and with the largest predicted temperature increase. The global outcome of a world driven by local communities focusing on sound environmental management (*adapting mosaic*) will lead to the smallest economic growth, improvements to all ecosystem services and an intermediate rise in global temperature. Finally, the *technogarden* scenario, with its environmentally sound but highly managed ecosystems, and crucially with a climate change policy (stabilizing CO_2 at 550 ppm), leads to the smallest rise in temperature, reduces nutrient pollution of waterways and improves ecosystem services – except cultural ones, because so many ecosystems are managed and relatively unnatural. Which of these, or other, scenarios comes to pass depends on a wide range of sociopolitical factors.

Anyone wishing to make a difference to the fate of biodiversity will need to take on board the diversity of perspectives in their community and internationally. To encourage this broad perspective, and foster an approach that values the environmental knowledge existing in all sectors of society, I use a particular device at the beginning of each remaining chapter. Here you will encounter a viewpoint on an environmental issue that may be alien to your own or, at least, that engenders a more circumspect approach to the issue at hand. You may not agree with what the ‘focal person’ says, but what can you learn from them and how could you engage

Table 1.2 Four scenarios that explore plausible futures for ecosystems and human well-being based on different assumptions about sociopolitical forces of change and their interactions. Greenhouse gas emissions (carbon dioxide, methane, nitrous oxide and 'other') are expressed as gigatons of carbon-equivalents (a gigaton is one thousand million tons). (Based on Millennium Ecosystem Assessment, 2005b.)

	Greenhouse gas emissions to 2050 and predicted temperature rise	Land use and nitrogen transport in rivers	Ecosystem services
Global Orchestration – a globally connected society focused on global trade and economic liberalization. Assumes a reactive approach to ecosystem problems. Takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education. Economic growth is the highest of the four scenarios, while population in 2050 is lowest (8.1 billion)	CO_2: 20.1 GtC-eq CH_4: 3.7 GtC-eq N_2O: 1.1 GtC-eq Other: 0.7 GtC-eq 2050 +2.0°C 2100 +3.5°C	Slow forest decline to 2025, 10% more arable land Increased nitrogen in rivers	Provisioning services improved, regulating and cultural services degraded
Order from Strength – a regionalized and fragmented world, concerned with security and protection, emphasizing primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems. Economic growth rate is the lowest (particularly in developing countries) while population growth is the highest of the scenarios (9.6 billion in 2050)	CO_2: 15.4 GtC-eq CH_4: 3.3 GtC-eq N_2O: 1.1 GtC-eq Other: 0.5 GtC-eq 2050 +1.7°C 2100 +3.3°C	Rapid forest decline to 2025, 20% more arable land Increased nitrogen in rivers	All ecosystem services heavily degraded
Adapting Mosaic – river catchment-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common, with a strongly proactive (and learning) approach. Economic growth is low initially but increases with time. Population in 2050 is high (9.5 billion)	CO_2: 13.3 GtC-eq CH_4: 3.2 GtC-eq N_2O: 0.9 GtC-eq Other: 0.6 GtC-eq 2050 +1.9°C 2100 +2.8°C	Slow forest decline to 2025, 10% more arable land Increased nitrogen in rivers	All ecosystem services improved
TechnoGarden – a globally connected world relying on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to ecosystem management. Economic growth is relatively high and accelerating, while the 2050 population is midrange (8.8 billion). This is the only scenario to assume a climate policy (stabililizing CO_2 at 550 ppm)	CO_2: 4.7 GtC-eq CH_4: 1.6 GtC-eq N_2O: 0.6 GtC-eq Other: 0.2 GtC-eq 2050 +1.5°C 2100 +1.9°C	Forest increase to 2025, 9% more arable land Decreased nitrogen in rivers	Provisioning and regulating services improved, cultural services degraded

them in an effective dialogue? These are points to bear in mind as you move from chapter to chapter. You can get a taste of the sociopolitical dimension of sustainability by dipping into the first section of each chapter and also in Sections 2.3.1, 4.4, 5.6, 6.4, 7.3, 7.6, 8.3, 9.8, 10.5, 10.7 and 11.4.

Summary

Homo sapiens – *not just another species*

Humans destroy natural ecosystems to make way for urban and industrial development and to establish production ecosystems such as forestry and agriculture. Moreover, the natural ecosystems that remain are also affected by our activities – via overexploitation of harvested species, the spread of invaders, local pollution and global climate change. In one sense, we are not so different from many other species in our effects on other animals and plants. But human impacts are very much more profound because of the size of our population and the technologies we use.

The biodiversity crisis

To judge the scale of the human threat to biodiversity we need to know the total number of species that exist, the rate at which these are going extinct and how this compares with pre-human times. Roughly speaking, the current rate may be as much as 100–1000 times the historical rate. Bearing in mind the number of species believed to be under threat, the future rate of extinction may be more than ten times higher again.

A reduction in biodiversity can have consequences for the ecosystem as a whole. Species vary in the contribution they make to overall productivity, nutrient cycling or decomposition rates in an ecosystem – the loss of some will barely register. Of particular significance are situations where species are ‘complementary’ in the way they contribute to ecosystem function. Where this is the case, lower biodiversity will generally equate to impaired ecosystem functioning and losses to *ecosystem services* – whether *provisioning* (e.g. fish from the sea), *cultural* (e.g. recreational opportunities), *regulating* (e.g. flood control) or *supporting* (e.g. soil formation).

Causes of biodiversity loss

Extinction may be caused by one or a combination of *drivers* that include habitat loss, invasive species, overexploitation and habitat degradation (pollution and agricultural intensification). Historically, habitat loss, habitat degradation and overexploitation have been of most significance. In future, climate change and the pollution associated with agricultural intensification are predicted to become progressively more important causes of biodiversity loss across all ecosystem types.

Increasing agricultural intensity is associated with increases to soil erosion, desertification and removal of water for irrigation (so that some major rivers no longer reach the sea). In addition, excess plant nutrients find their way into waterways, and chemical pesticides affect nontarget species, often long after they are first applied. Because greater human population growth is expected in species-rich tropical areas, increased agricultural activity will place biodiversity at high risk.

The most far-reaching consequence of our use of fossil fuels has been an increase in the atmospheric concentration of carbon dioxide, a greenhouse gas. As a result, air temperature at the land surface is now 0.6 ± 0.2°C warmer than in pre-industrial times, and is predicted to continue to rise by a global average of between 2.0°C and 5.5°C by 2100. Such changes will lead to a melting of glaciers and icecaps, sea-level rise, and large changes to global patterns of precipitation, winds, ocean currents and the timing and scale of storm events. The ecological consequences for biodiversity and ecosystem services will be profound.

Toward a sustainable future

An activity is ‘sustainable’ if it can be continued into the future. If we want to eat tuna in future, we cannot continue to harvest them faster than the population can replace those that are lost. Nor can farmers continue to use fertilizers indiscriminately if people want to retain the ecosystem services provided by rivers, lakes and oceans that are impacted by the agricultural excess. The recognition of the importance of sustainability as a unifying idea came of age in the early 1990s. Since then the focus has shifted from a purely ecological perspective to one that incorporates the economic and social conditions that influence sustainability. Thus, sustainability has ecological, economic and sociopolitical dimensions.

The ecological dimension

From the ecological point of view, sustainability topics can be organized according to the underlying structure of ecology theory. At the lowest level is the ecology of individuals – niche requirements, life-history traits and dispersal/migratory behavior. Knowledge at this level is crucial when reintroducing species that have gone locally extinct, restoring natural grassland and forest, or predicting the arrival of damaging invaders. Next comes the population level – all individuals of a single species in a particular place. Population theory is central to the management of endangered species, pests and harvests. Then there is community (species composition) and ecosystem (energy and nutrient flux) ecology. Theory at this level helps managers devise plans to restore natural communities, counteract invasions, increase the range of harvestable products and make agroecosystems sustainable. Finally, at the largest scales, landscape ecology is crucial when designing networks of nature reserves, and global climate change has implications for just about everything else.

The economic dimension

There is an economic side to every resource management argument. Sometimes the costs and benefits are relatively straightforward to compute. But imaginative approaches are needed to determine the value of a species or an ecosystem service (e.g. *travel cost* paid by people to access a natural area provides a minimum value of this recreational service). Viewed from the broadest perspective of all, the total value of the world’s ecosystem services has been roughly estimated at $38 trillion – more than the gross domestic product of all nations combined. The ‘new economics’ provides persuasive reasons for taking great care of biodiversity.

The sociopolitical dimension

Environmental issues almost always have a sociopolitical angle too. Sociologists can help managers reconcile the desires of all interested parties. And political scientists help determine whether sustainable management should be fostered by penalties or inducements, or be set in law or encouraged by education. At the local level, when people are well connected in groups and networks, and when their knowledge is sought and incorporated during environmental management planning, they are more likely to retain a care-taking role in the long term. If an environmental problem occurs at too large a scale for local solutions, the sociopolitical machinations need to occur globally. Estimates of future greenhouse gas emissions and the resulting changes to global temperature vary according to sociopolitical factors – our predictions need to be based on models that take these things into account.

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