Chapter 4

Biodiversity

'Still Flying' from the painting of a Wandering Albatross by Richard Weatherly.

Prepared by

Denis Saunders (Chair), CSIRO Division of Wildlife and Ecology

Andrew Beattie, Centre for Biodiversity and Bioresources, School of Biological Sciences, Macquarie University

Susannah Eliott (Research Assistant/Science Writer), Centre for Science Communication, University of Technology, Sydney

Marilyn Fox, School of Geography, University of New South Wales

Burke Hill, CSIRO Division of Fisheries

Bob Pressey, New South Wales National Parks and Wildlife Service

Duncan Veal, Centre for Biodiversity and Bioresources, School of Biological Sciences, Macquarie University

Jackie Venning, State of Environment Reporting, South Australian Department of Environment and Natural Resources

Mathew Maliel (State of the Environment Reporting Unit member), Department of the Environment, Sport and Territories (Facilitator)

Charlie Zammit (former State of the Environment Reporting Unit member), Department of the Environment, Sport and Territories (former Facilitator)

Contents

Boxes

Introduction

Australia has an immense number of unique and unusual plants, animals and micro-organisms. More than one million species (including micro-organisms) are thought to live in Australia, but less than 15 per cent have been formally described. Not only is this living resource part of our cultural identity, we depend on it for our survival and quality of life. Lack of knowledge about the diversity of life on this continent and the effect of our activities on this fundamental resource pose the most significant impediment to its conservation and management.

Biodiversity is the variety of all life forms — the different plants, animals and micro-organisms, the genes they contain and the ecosystems of which they form a part. Consequently, biodiversity is considered at three levels: ecosystem diversity, species diversity and genetic diversity.

Genetic diversity: These starfish belong to a single species (*Patiriella calcar*), but various colour patterns result from different genes.

Species diversity: A small area of reef can contain a wide range of species — fish, corals, feather stars and algae.

Ecosystem diversity: Coastal coral reefs, sandy shores, rainforest and grassland provide different ecosystems that support different plants and animals.

The species in a given area interact with each other, and with their environment, to form complex networks known as ecosystems. These differ from place to place, thus creating ecosystem diversity. Each ecosystem differs from all others because it contains a unique combination of species (and therefore genes) and because these species interact with each other and with each environment in distinctive ways.

Species diversity is the number of species and their relative abundance in a defined area.

Genetic diversity is the variety of genes contained in all the species in a given area. There are so many genes and different possible combinations of genes that, for most types of organisms, every individual, population and species is genetically distinct.

As a party to the 1992 international Convention on Biological Diversity, Australia is committed to the conservation of biodiversity, to the sustainable use of ecosystems, species and genetic resources and to the equitable sharing of any benefits arising from the utilisation of its genetic resources. The Australian Commonwealth, State, and Territory governments are responsible for managing human activities that threaten biodiversity. It is of real concern that species, including many that are as yet unrecorded, could become extinct due to human activities. For this reason, lack of scientific certainty regarding the impacts of human activities on biodiversity cannot be used to justify postponing measures to prevent environmental degradation.

Australia has evolved in relative isolation for at least the past 50 million years. This has resulted in a rich diversity of unique life forms. For example, 85 per cent of our flowering plants, 84 per cent of our mammals, 45 per cent of the birds, 89 per cent of the reptiles and 93 per cent of our frogs are found nowhere else (that is, they are endemic). Of the 600 inshore species of finfish in the southern temperate zone, about 85 per cent are found only in Australian waters.

While most of the large organisms, such as flowering plants and vertebrates, have been described and in some cases studied in detail, relatively little is known about the vast and less-visible world of invertebrates and micro-organisms. Australia has an invertebrate fauna estimated at around 225 000 species, of which only half have been described. Where limited data are available, however, some groups are known to be endemic. For example, 90 per cent of Australian springtails (Collembola) and 80 per cent of tiger beetles (Cincindelinae) are found nowhere else. The high level of endemism found in our plants and animals is also likely to be reflected among the micro-organisms. However, even less is known about micro-organisms, their ecology and their importance in ecosystems and the vast majority of them have yet to be identified.

Areas like the Great Barrier Reef, the species-rich rainforests of northern Queensland and the Southwest Botanical Province of Western Australia (with over one-third of Australia's plant species, of which 70 per cent are endemic) are internationally recognised major centres of biodiversity. Australia is the second-driest continent in the world (after Antarctica) and its inner arid core accounts for more than 70 per cent of the total land mass. Contrary to popular belief, this arid zone comprises many different kinds of communities and habitats, some with their own unique species and many that are highly sensitive to disturbance.

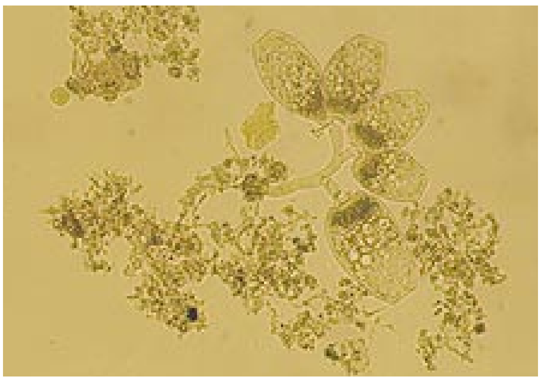
The four main reasons for preserving biodiversity relate to ecosystem processes, ethics, aesthetics and culture, and economics.

Biodiversity provides the critical processes that make life possible and that are often taken for granted. Healthy, functioning ecosystems are necessary to maintain the quality of the atmosphere, and to maintain and regulate the climate, fresh water, soil formation, cycling of nutrients and disposal of wastes (often referred to as ecosystem services). Biodiversity is essential for controlling pest plants, animals and diseases, for pollinating crops and for providing food, clothing and many kinds of raw materials.

Ethical values reflect the view that all species have an inherent right to exist. Biodiversity belongs to the future as well as the present and no species or generation has the right to sequester it for their exclusive use.

Biodiversity has intrinsic values, such as beauty, tranquility and isolation. Many Australians place high values on native plants and animals. This regard has contributed to our sense of cultural identity and is important for spiritual enrichment and recreation. Retaining biodiversity is also critical for maintaining the culture of Aboriginal and Torres Strait Islander peoples.

Some elements of biodiversity have economic value and can be used to create wealth. Australia's plants and animals attract tourists and provide food, medicines and other pharmaceutical products, energy and building materials. The commercial fishing industry, for example, produced catch worth 1.7 billion dollars in 1994–95 (ABARE, 1995). Tourists to six protected areas in 1991–92 spent more than two billion dollars (Driml, 1994). Ecotourism, which is a growing environmental business in Australia, has the potential to enhance the effect of other conservation activities, such as education and donations.



Micro-organisms in activated sewage sludge. Microbial biodiversity is essential for the many ecosystem services such as the breakdown of waste material and cycling of nutrients.

The Pilbara, Western Australia; Australia's arid zone contains unique ecosystems, plants and animals.

Another environmental business attracting attention is biodiversity prospecting. Sponges, for example, appear to be particularly rich in anti-cancer compounds. Other potentially valuable compounds include a sunscreen derived from a chemical that shallow-water corals use to protect themselves from ultraviolet rays.

Genetic resources from the wild

Natural compounds

Many chemical compounds produced in nature are used in medicine and technology. While an unknown number remain to be discovered, high levels of investment by the pharmaceutical industry suggest major future commercial prospects. Genetic resources are particularly abundant in species-rich habitats, such as rainforests and the ocean, but useful genes can be found in any type of environment.

Wild crop relatives

Crops usually have less genetic diversity than the wild populations from which they were derived because they have been intensively selected for many generations. Wild relatives often harbour extremely useful genes, like those that protect against disease or drought. Plant breeders can utilise the genetic diversity of wild crop relatives by hybridising domestic and wild varieties and choosing offspring with improved characteristics.

The soybean (*Glycine max*), for example, has a very narrow genetic base (Brown *et al*., 1985). Plants cultivated throughout the world are descended from a few founders from a single geographic area. However, the genus *Glycine* contains about 16 species of wild soybeans, many of which are native to tropical northern Australia. These wild species are an important resource for the improvement of domesticated varieties. Research is underway to transfer the genes for rust and mould resistance found in native Australian species into agricultural varieties.

Like soybean, cotton has native Australian relatives including Sturt's desert rose (*Gossypium sturtianum*), a popular garden plant. Wild Australian cotton species in the genus *Gossypium* are being studied for their potential for crop improvement. Cottonseed is used as a stock food, but must be processed to remove the naturally occurring insecticide that the plant manufactures for its own defence. Australian *Gossypium* spp. have low levels of this compound in their seeds but normal levels in the rest of the plant. Experiments are being conducted to transfer this genetic trait into cultivated cotton varieties.

Elabana Falls, Lamington National Park; biodiversity values include beauty, tranquility and also vital ecosystem services: natural vegetation acts as an effective filter for sediment in catchments. When the vegetation is removed, the run-off becomes discoloured with sediment and creeks silt up.

Biodiversity provides a vast library of genetic material for use now and in the future, for a variety of industries including agriculture, medicine and gene technology. A loss in genetic diversity would result in a loss of potential for these industries. Thus, the challenge for Australians is to balance the exploitation and preservation of biological resources to ensure that exploitation does not compromise the options for the future.

The rate at which development has occurred in Australia is almost unprecedented. For example, in less than 200 years, land use in the wheat and sheep zones of Australia has changed from one of predominantly hunter–gatherer to one of intensive and extensive harvesting, compared with more than 10 000 years for the same evolution in the Middle East (Hobbs and Hopkins, 1990). Since European settlement, Australia has lost an estimated 75 per cent of its rainforests (Winter *et al*., 1987) and about 40 per cent of its total forest area (AUSLIG, 1990). Nearly 70 per cent of all native vegetation has been removed or significantly modified by human activity since 1788 (see pages 6-8 and 6-9). The rate of land clearance has accelerated over time, with as much cleared during the last 50 years as in the 150 years before 1945.

While primary ecological processes are well understood, we know little about the ecological role of individual species. The maintenance of soil structure and fertility, for example, depends largely on the activity of groups of poorly understood organisms that constitute soil biodiversity. Loss of these organisms results in the disruption of processes essential to agriculture, such as water intake, nitrogen fixation and other types of nutrient cycling. Thus, by failing to take appropriate action to conserve biodiversity, Australia could be losing species vital to the sustainability of its rural industries.

State of the Environment reporting provides a framework to monitor and report on aspects of biodiversity essential to Australia's future, and to report on responses to changes in its condition. This chapter examines the pressures on biodiversity, as well as its current condition or state, and reports on responses to these pressures and states.

The vast majority of the organisms comprising soil biodiversity are small and generally unknown

Soil biodiversity

The highly diverse biota of the soil performs a wide range of important ecosystem services. They maintain soil health and fertility by cycling carbon, nitrogen, sulfur and phosphorus and by maintaining soil structure.

Human activities — such as cultivation, irrigation and the application of fertilisers and pesticides — alter both chemical and physical characteristics of the soil. Information on the effects of these impacts on soil biodiversity and key ecosystem services is fragmentary. However, it has become apparent that increasing acidification of soil in many parts of Australia is adversely affecting the nitrogen-fixing bacteria so important to the growth of many crop and native plants. Loss of the soil's biodiversity, as a consequence of cultivation, is associated with loss of its structure, making it subject to erosion. The destruction of its mycorrhizal fungi, which form a symbiotic association with many plants, can adversely affect the prospects of recolonisation of those plants.

While most soil biodiversity is yet to be discovered, it is clear that species of soil biota are tightly linked functionally to above-ground biota. Thus, preservation of familiar plant and animal biodiversity is dependent on a diverse soil biota.

Pressure

The ecosystem context

The major pressures on biodiversity today result directly and indirectly from the increasing human population and our lifestyles and expectations: our needs and desires for food, water, housing, energy, transportation, recreation and many other aspects of modern living.

The pressures develop because all human activities are carried out within, and thus form part of, some kind of ecosystem. This is most obvious in the country, where farms are established in grassland or woodland ecosystems, remnants of which survive between cultivated fields or in the corners of paddocks. Fishing is clearly an activity where species are removed from aquatic ecosystems. Towns, suburbs, industrial areas and cities also form part of ecosystems that existed long before development took place. Fragments of these original ecosystems persist even when the environment appears to be entirely one of human construction; one such remnant, for example, is the urban wildlife that colonises inner city suburbs or abandoned industrial sites.

Ecosystems are the result of long-term interactions between the physical environment and living species that produce characteristic processes and structural features. Well-established processes include, for example, food chains and soil formation, the development of particular groups of species called communities and, within each species, gene pools distributed among populations of different sizes. Evolution continuously modifies ecosystems, communities and species, making change a natural part of each of these entities. So too is disturbance; many species are unable to gain a foothold in established communities but flourish when dominant species are disturbed. The scale of disturbance may be as small as soil turnover at a wombat burrow or as large as a bushfire, but both can cause changes in the species present.

Human activities almost invariably affect the pace and alter the direction of change and the extent of disturbance, challenging the ability of ecosystems, communities and species to respond (Saunders *et al*., 1990). Responses are often far-reaching because of the interactions between species and between different species and their environment, and so human pressures cause a cascade of effects.

Cascading effects

The best-known examples result from the removal of vegetation for agriculture, forestry or urban development. Clearing is often so rapid and extensive that natural systems cannot recover. The removal of plant species results in the loss of food for herbivores and, consequently, carnivores further up the food chain. Removal of plant cover leads to the loss of soils through erosion, or of soil nutrients through leaching. Both processes reduce the vast complexes of minute species that comprise soil biodiversity. Urbanisation and pastoral and agricultural programs that suppress the regeneration of native vegetation make these changes and losses long-term, perhaps permanent. Loss of vegetation such as mangroves or seagrasses at coastal sites may have far-reaching effects because the juvenile nursery grounds of fish, crabs and prawns are destroyed.

The 'living dead'; many long-lived organisms such as some trees in agricultural landscapes do not regenerate due to changes resulting from human activities.

Clearing rarely involves entire landscapes, and much effort has been made to understand the biodiversity of remnant vegetation and other communities isolated, like islands, in 'oceans' of rural or urban development. This process, known as fragmentation, often conceals cascading effects that are subtle and hard to detect, but nevertheless highly threatening. For example, trees in vegetation remnants in city bushland or rural paddocks are often very long-lived and give the appearance of healthy greenery. However, many of these remnants have no seedlings or saplings. It could be that the insects that once pollinated the flowers have become locally extinct, so the trees do not produce seed, or that ecological conditions have changed so the species can no longer regenerate.

Table 4.1 Pressures on plant biodiversity: major causes of extinction and past and present threats to endangered plant species

Threat/cause	Number of species presumed extinct	Endangered species	
		Past threat	Present and future threat
Agriculture	44	112	50
Grazing	34	51	55
Low numbers	-	10	85
Weed competition	4	12	57
Roadworks	1	8	57
Industrial and urban development	3	20	21
Fire frequency	-	10	17
Forestry	-	10	10
Collecting	-	6	17
Mining	1	3	11

Note: Many species are affected by more than one threat. In some cases the past threat may have ceased and new ones arisen. Other threats include recreation, dieback, clearing, railway maintenance, salinity, insect attack, quarrying, trampling by pigs and buffalo, drainage and flooding.

Source: Leigh and Briggs, 1994.

Table 4.2 Sources of current threats to Australian birds, marsupials, rodents, reptiles and freshwater fish

Threatening process	Birds		Marsupials		Rodents		Reptiles	Freshwater fish	
	C	S	C	S	C	S	S	C	S
Habitat clearance and/or fragmentation	32	4	13	3	3	4	35		
Altered fire regimes	16	35	1	16		2	10		
Grazing and/or trampling	10	35	5		1	6	21		
Fishing		3							
Disease		3		1					
Pollution		7					7		
Erosion	1	1							
Environmental weeds	2	9					5		
Forestry operations	3	14	2	1		1	6		
Changed hydrological regimes	1	3						5	4
Climatic variations	2	7					5		
Shortage of nest hollows	3	20	1						
Predation	8	29	9	13	1	4	14		
Competition	3	20	1	11		1			
Direct exploitation	10	33	2					3	1
Cropping							21		
Urban development	4	3					14		
Pasture improvement							12		
Soil degradation							9		
Visitor disturbance							8		
Mining	2	4					6		
Rabbit grazing				11	1	2	6		
Habitat drainage							4		
Rock removal							4		
Geomorphic alteration								12	6
Water quality								4	1
Introduced exotic species			9		1	10		5	10
Introduced native species				14					3
Loss of genetic diversity			1	1					2
Road kills			1						
Unknown			4			3			

Note: **C** — confirmed **S** — speculative

The figures in each column are the number of species affected by each process. However, a species may be affected by more than one process.

Source: Garnett, 1992 (a & b); Cogger *et al.*, 1993; Wager and Jackson, 1993; Lee, 1995; and Kennedy, 1992.

Many micro-organisms are crucial for the decomposition of organic material. Fallen branches and logs in forests are broken down by the action of fungi whose reproductive structures are mushrooms, toadstools and bracket fungi.

Another reason for the absence of seeds can be loss of genetic diversity. As a population shrinks, so does its gene pool. Genes that help species to adapt to changing environments, to win competitive interactions with other species or to combat disease, disappear along with the individuals that carry them. These genes are then unavailable to the survivors. In small populations, the level of inbreeding increases, which further decreases the ability to adapt to current and future challenges. Many species become highly vulnerable when populations decline because they have strong mechanisms to prevent inbreeding and thus individuals have few suitable mates.

Biologists believe that many small populations enter an 'extinction vortex', which occurs when small numbers of individuals harbour such low levels of genetic variation that few offspring survive. This further reduces their genetic resources and the chances of finding a suitable mate. The process continues until a final generation has so few individuals and such reduced genetic diversity that reproduction is no longer possible. This may happen quickly in small, short-lived species such as butterflies, but may take a century or more for bigger, long-lived species such as large trees.

Cascading effects commonly follow the introduction of exotic plants, animals or micro-organisms. Introduced weeds have effects that start at the base of the food chain. They displace native species and even entire communities of native plants. The effects flow on to animals, such as insects and birds, that depend on them for food and shelter. Higher up the food chain, introduced predators feed on native animals, both diminishing their numbers and competing with native predators. Marine animals from other parts of the world, introduced into coastal waters from ships' ballast, enter and change native food chains and, like weeds, can dominate local communities. Introduced micro-organisms, such as dieback fungus (*Phytophthora cinnamomi*), invade plant communities, killing selected species, and disrupting ecosystem processes and food webs.

Ecosystem health

Assessing the health of ecosystems — that is, determining whether or not their structure and processes are intact and they contain the expected variety of species — has become an important research objective. In forestry, for example, the removal of trees for sawlogs and for chipping disrupts forest structure, function and floristics. Forest-dwelling species rely on the structure or architecture provided by trees, shrubs and other plants for food, nesting places and concealment. The vegetation also plays a major part in regulating nutrients in the forest. When it is removed, branches and fallen trees that normally rot on the forest floor and recycle nutrients back to the soil can no longer do so, while rainfall, which is normally scattered by the tree canopy, falls directly to earth, flushing soil nutrients and organic matter out of the ecosystem.

Human populations

Our increasing human population with its affluence and technology, has resulted in increasing demands for natural resources and, in turn, increasing pressures on biodiversity (see Fig. 4.1).

Since 1788 when Europeans colonised Australia, about eight generations have lived on the continent and wrought vast changes to the natural environment. Habitat modification, particularly removal of vegetation for agriculture, urban development and forestry, has been and still is the most significant cause of loss of biodiversity (see Tables 4.1 and 4.2). Tourism, altered fire regimes and the effects of introduced plants and animals also adversely affect Australia's biodiversity.

Urban development

Australia has a relatively small, highly urbanised population, with about 86 per cent of people living on the coastal fringe (RAC, 1993). About 66 per cent live in coastal towns and cities of more than 100 000 people, located on harbours and estuaries with considerable biodiversity and habitat richness (NPC, 1992). The concentration of people in these areas generates a range of pressures on biodiversity throughout the continent, caused by destruction of natural habitat, harvesting of plants and animals, the spread of exotic species and pollution (see pages 4-21 and 8-8).

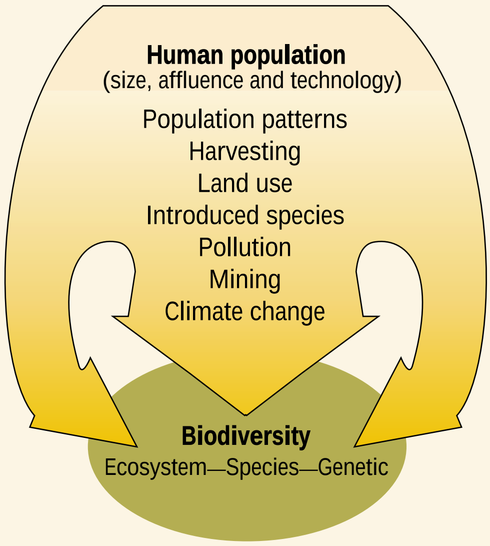
Huge parts of the continent are used for primary production to feed and clothe Australia's population as well as tens of millions of people living in other countries. The export of goods is a major factor in maintaining the high standard of living that most Australians enjoy. Some of the most intense pressures on biodiversity are therefore in agricultural and pastoral districts that are relatively sparsely populated.

Tourism and recreation

Little research has been carried out on the effects of tourism on biodiversity. The rapid growth of the tourist industry in Australia is a potential threat that requires continual monitoring and regulation. Since tourism focuses on areas of particular appeal that often have high biodiversity, the pressures it exerts can be disproportionately high and often result in the destruction of the qualities that initially attracted tourists to the area.

Recreational activities frequently affect biodiversity in ways that are not immediately obvious. For example, some popular beaches on the New South Wales coast have been protected from sharks since the late 1930s and some in Queensland since the early 1960s. In Queensland, more than 30 000 large sharks had been captured in shark nets or on lines by 1988 (Paterson, 1990). Catch rates for large sharks declined by 75 per cent over 25 years, suggesting a substantial fall in the shark population. Similar declines have been reported for whaler and white pointer sharks off New South Wales (Reid and Krogh, 1992). Large mesh shark nets also catch other large animals that are generally slow-growing with a low replacement rate. Records from shark nets off Newcastle show mean annual catches of 111 rays, seven dolphins, four turtles, 25 jewfish and four tuna.

Figure 4.1 Major pressures on biodiversity



Increasing population size with its attendant demands for natural resources places increasing pressure on biodiversity

Like other types of urban growth, tourist developments — such as resort hotels and golf courses in wetland areas — can have a large impact on biodiversity in the surrounding region. The developments often take place in sensitive ecosystems, such as at the edge of national parks, on floodplains or close to beaches, accentuating the effect. An example is the increase in numbers of silver gulls (*Larus novaehollandiae*) and other scavenging birds, due to the availability of food from urban waste dumps. Populations of silver gulls are increasing at a rate of 10 to 13 per cent per year (Blaber *et al*., in press). Waste dumps at tourist resorts on islands encourage gulls, which also prey on eggs of other seabirds, increasing

Changes in urban birds

The County of Cumberland (4273 sq km) surrounds and includes Sydney. It is the site of the first European settlement in Australia and represents the largest concentration of the human population, with 27.5 per cent of Australians living there (Cocks, 1992). Development of this area has had a major impact on the biota, as illustrated by changes to the bird community. At the time of European settlement 283 species of birds were believed to have occurred there (excluding seabirds and rare vagrants) (Hoskin *et al.*, 1991). Of these, 11 species (four per cent) are now locally extinct, 76 (27 per cent) have decreased in range and/or abundance and only 39 (14 per cent) have increased in range and/or abundance. As well, five Australian species have invaded the area because the changes imposed on the landscape suited them and 20 exotic species were deliberately released and have established viable populations.

pressure on other species. On Rottnest Island, for example, predation by silver gulls poses a serious threat to fairy terns (*Sterna nereis*), which breed there.

Pressures on biodiversity are synergistic, the impact of several activities compounding to produce a much greater impact than any one alone. The mallee woodland in Western Australia, for example, has already been severely reduced by clearing for agriculture. Demand in the tourist industry for didgeridoos made from mallee is an added pressure that on its own would be insignificant. Other impacts from tourism that can create cumulative effects are soil erosion caused by four-wheel drive vehicles, increases in the frequency of wildfires and localised nutrient-enrichment of the soil and water from food scraps and other wastes.

Seabed on the north-west shelf of Australia;. communities of sponges and large fish are found in several areas around Australia.

Prawn trawler bycatch: in addition to prawns, the trawl collects a variety of animals. Although these will be dumped back into the sea, most (except for hardy species such as bivalves and crabs) will not survive. Dolphins, seabirds and sharks feed on dead animals at the surface while fish and crabs eat them on the seabed (Hill and Wassenberg, 1990). They make up an important part of the diet of these scavengers and appear to have contributed to increases in populations of some, such as crested terns (*Sterna bergii*) in the Gulf of Carpentaria (Blaber *et al*., in press).

Harvesting resources and land use

A number of Australian industries are based on the exploitation of natural resources. They include fisheries, forestry and industries based on the use of wildlife and wildflowers. While harvesting natural resources is not necessarily detrimental to biodiversity, many harvesting practices are not sustainable. These can cause habitat loss, fragmentation and/or modification and reduced populations through overexploitation, or a combination of these pressures.

Fisheries

Australia exploits its marine biodiversity — with commercial harvesting of four species of crabs, four of lobster, 12 of prawn, three each of abalone and scallops and about 300 species of finfish. Under good management, the number of fish that commercial fishers take can be sustainable, especially if they use species that are present in large numbers and that have a high reproductive rate. However, high fishing pressure, especially on long-lived species, usually leads to over-exploitation. For example, catches of southern bluefin tuna (*Thunnus maccoyi*), which can live to over 20 years, peaked at 80 000 tonnes in 1961 but have since declined steadily (see Fig. 8.13). The breeding stock of this species is now estimated to be less than 10 per cent of the original (CSIRO Division of Fisheries, unpublished data). While the commercial catch of many species has been regulated and quantified, the recreational catch has been largely uncontrolled and for some popular angling species, such as snapper (*Pagrus auratus*), exceeds the commercial catch.

Heavy fishing pressure can be severe when populations are low due to adverse environmental factors. The gemfish (*Rexea solandri*) was once an abundant species off New South Wales but appears to have been depleted by a combination of adverse oceanographic conditions and heavy fishing (see Fig. 8.14).

Some forms of harvesting — trawling and dredging — are non-selective and kill large numbers of non-target species. The unwanted catch (bycatch) can be very large, as in the case of the prawn fishery in northern Australian waters, which catches and discards a total of about 38 000 tonnes of other species. This is four to six times the weight of prawns caught (Pender *et al*., 1992). Fisheries research has concentrated on the impact of fishing on commercially valuable species and the effects of bycatches on other species are poorly understood.

Trawling can cause long-lasting damage to the seabed, resulting in a loss of biodiversity in trawled regions. In some areas, the seabed has a complex community of sponges, soft and hard corals and other bottom-dwelling organisms as well as species of large edible fish. In the 1970s, foreign trawlers exploited the fish resource on the north-western coast of Australia and, in the process, damaged and removed some of the seabed structure. This resulted in loss of habitat and a dramatic decrease in the numbers of commercially valuable fish. Large areas were subsequently closed to trawling and alternative methods of fishing encouraged. The fishery and seabed fauna are now recovering (Sainsbury, 1988).

A minimum size limit — usually set at the size at which the animals first mature — protects many commercially and recreationally important species of fish and marine invertebrates. If the stocks are subjected to heavy fishing pressure, few individuals larger than the minimum legal size survive to spawn and so the successful spawners are those individuals that do so at a smaller size. This process acts as a selection pressure favouring individuals with genes associated with spawning at a smaller size. For example, it appears to be responsible for a downward shift in size at maturity of King George whiting (*Sillaginodes punctata*) in South Australia and could cause a reduction in genetic diversity with the loss from the population of genes for maturity at a larger or older stage (Hill, 1992).

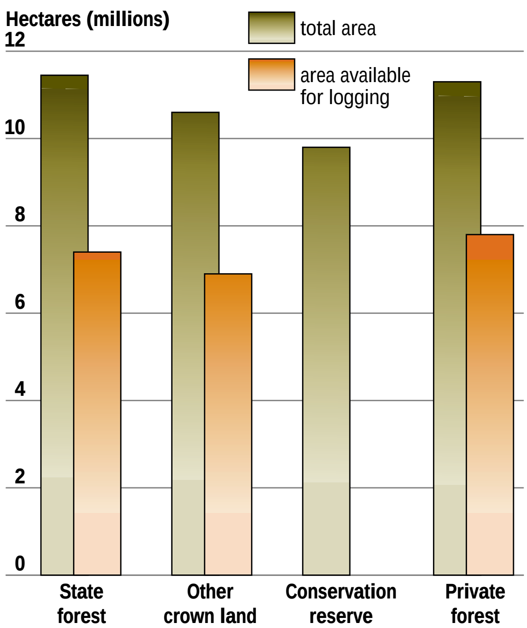
Forestry

Forests cover a small fraction of the continent (see pages 6-8 and 6-9 and Fig. 4.2). Logging operations, including the building of access roads, result in major structural changes in the vegetation and soil from which forests and their fauna may take a long time to recover. Recovery of biodiversity depends upon many factors, including the ages and species of the trees remaining, the extent of soil erosion and loss of nutrients and the areas left as sources for recolonisation by the forest flora, fauna and micro-organisms. Researchers have studied the recovery of biodiversity from previous logging operations in a range of Australian forest environments, but as yet they have identified few generic principles.

The fragmentation of previously continuous areas of forest can have destructive effects on the forest flora and fauna. Some species will become locally extinct when confined to small 'islands' or remnants of habitat that do not support viable populations (see page 4-13).

Other uses can compound the pressures associated with forestry operations. Grazing, for example, often destroys or alters the composition of the understorey and the species that depend upon it, and may result in soil erosion. Tourism and recreational activities such as hiking, camping, off-road driving, horse-riding, hunting and fishing all have some impact on biodiversity. Individually the effects may be localised, but together they can exert major pressures on forest biodiversity.

Figure 4.2 Australian forest area by tenure, 1990

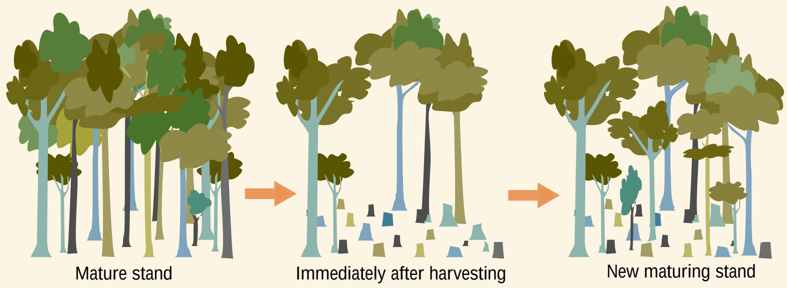


Source: Resource Assesment Commission, 1992.

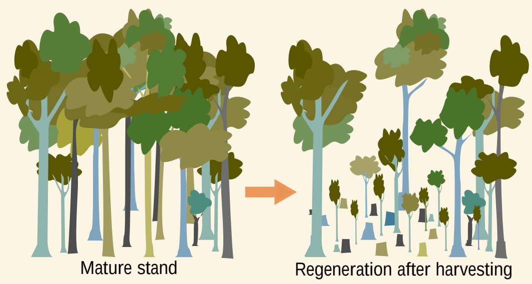
Figure 4.3 The effects of different logging methods on forest ecosystem structure

Clearfelling is the localised removal of most or all trees followed by burning of debris. The soil tends to be exposed to erosion, and regrowth is often less diverse, both in terms of species and the age of trees.

Modified clearfelling keeps some trees for conservation purposes such as mammal habitat and to allow further growth of immature trees. The resulting forest retains a greater diversity of species and age classes.



Shelterwood logging in highland forests minimises snow or frost damage to seedlings. Shelter trees are retained and then felled once some regrowth is established.



Selective logging removes individuals or patches of trees at relatively short intervals. There are many variations including focus on a particular species or thinning of small trees. The general aim is to retain diversity of species, sizes and ages.

Source: Resource Assessment Commission, 1992.

A fence-line separating grazed from ungrazed land illustrates how soil erosion and loss of vegetation can result from overgrazing.

Pastoralism

The pastoral industry covers an area of 5.4 million sq km, or about 70 per cent of the continent. In the arid zone, despite lower stock densities, the impact of grazing on biodiversity can be greater than it is in high rainfall zones because low productivity limits forage and stock compete with native animals for limited resources. Introduced livestock trample vegetation and degrade soil structure, leading to changes in native vegetation cover. In turn, this results in erosion and loss of species associated with native vegetation. The provision of water through bore holes, earth tanks and dams, where water was formerly limiting, together with introduced predators, feral herbivores and altered fire regimes, contribute to changes in arid zone biodiversity.

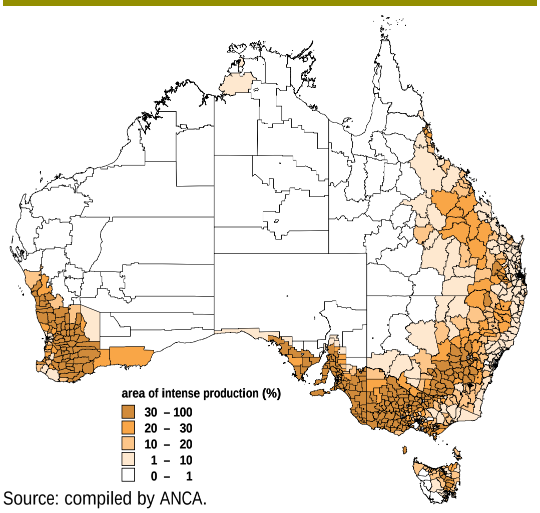
Overgrazing of native pastures has three main effects on the diversity of native animals. Firstly, as stock remove long grass, native animals' shelter sites are depleted and the animals become exposed to predation and weather. Secondly, stock compact the soil and alter the soil texture, destroying burrows and making burrowing difficult. Finally, stock compete with native herbivores for food and water, a situation which becomes critical in arid regions where such resources are scarce during drought. In some cases, the extra watering points associated with pastoralism have resulted in increases in the abundance of native species able to exploit the situation, like kangaroos (*Macropus* spp.) and emus (*Dromaius novaehollandiae*). This also increases grazing pressure on native vegetation.

Grazing in arid and semi-arid regions is thought to be partly responsible for the extinction of 34 plant species (41 per cent of the total number of plant species lost from Australia since European settlement) and continues to threaten a further 55 species in the rangelands or 24 per cent of plant species currently listed as endangered (Leigh and Briggs, 1992) (see Table 4.1).

Although the arid zone appears unchanged, about one-third of mammal species in the sandy and stony desert ecosystems are known to be regionally extinct (Burbidge *et al*., 1988; Burbidge and McKenzie, 1989). This is the highest regional extinction rate on the Australian mainland (Kennedy, 1992). Many birds are also in decline. For example, eight per cent of arid zone birds are classified as rare and threatened nationally and a further five per cent are uncommon species that have declined or are at risk in two or more arid regions (Reid and Fleming, 1992).

Research agencies and pastoralists have introduced, and continue to introduce, many exotic grasses in an attempt to make rangelands more profitable. Since 1947, 463 exotic plant species have been introduced as pasture. Only five per cent of these have proved useful as fodder, yet 13 per cent have become problem weeds. These include mission grass (*Pennisetum polystachion*), which invades native bushland, outcompeting native grasses and changing fire regimes, and para grass (*Brachiaria mutica*), which has spread into Kakadu National Park, reducing habitats for waterbirds. As exotic pasture species are still being introduced, pastoralism poses a continuing threat to biodiversity in rangeland environments.

Figure 4.4 Percentage of Statistical Local Areas used for intensive production



Source: compiled by ANCA.

Intensive production refers to sown pastures and all crops for which the Australian Bureau of Statistics collects data. Cropping, the main activity, is dominated by wheat production, but includes other products as diverse as sugarcane, cotton, bananas and soybeans. Much of the eastern and south-western parts of the continent are used to some extent for intensive production, but not the arid interior or the monsoonal north, which are widely used for grazing on native rangelands.

Agriculture

Agricultural practices adversely affect biodiversity in many ways. Following the initial destruction of native vegetation, soil tillage and burning of stubble lower the microbial biomass in the soil, affecting its structure and ecological processes such as decomposition rates and nutrient cycling. Soil micro-organisms help prevent erosion by binding soil particles together. Thus tillage can have a long-term impact on soil health, with adverse consequences for other soil organisms (see Chapter 6).

The long-term use of pesticides, herbicides and fertilisers has had direct and indirect effects on biodiversity. Pesticide residues enter the soil and aquatic ecosystems and may be ingested by organisms, with the harmful effects magnified up the food chain. Pesticides have been linked with the death of aquatic organisms in many areas such as the Namoi Valley in New South Wales and Maroochy River in Queensland. Their use is also

Vegetation clearance and fragmentation

Following European settlement, governments actively encouraged the clearing of native vegetation to make way for pastoralism and agriculture in the higher-rainfall areas. While it is difficult to get accurate estimates of changes in vegetation cover over the past 200 years, native vegetation (including regrowth) is still being cleared at a rate of over 600 000 hectares per year — about half the rate of clearing in the Brazilian Amazon in 1990–91. Most of this is taking place in Queensland and New South Wales (see page 6-40). Vegetation clearance and fragmentation are the major causes of loss of biodiversity (see Tables 4.1 and 4.2).

The situation in Kellerberrin, a shire in the central wheat belt of Western Australia about 200 km east of Perth, illustrates the effects on biological diversity of vegetation clearance and fragmentation (Hobbs and Saunders, 1993).

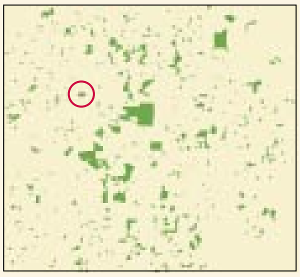
Clearing of native vegetation was not carried out randomly. The heavier soils on valley floors were cleared first and more extensively, as they were regarded as having most potential to support agriculture. In the landscape illustrated above, only five per cent of the valley floors (green and blue) are still covered with native vegetation compared with 63 per cent of the highest parts of the landscape (red).

In common with other intensively cleared regions in Australia, much of the remnant native vegetation is privately owned (more than 75 per cent in the diagram below) and is not regarded as part of the Crown conservation estate. Significant numbers of endangered or restricted species live on these privately owned remnants and so sympathetic management is required to ensure their survival.

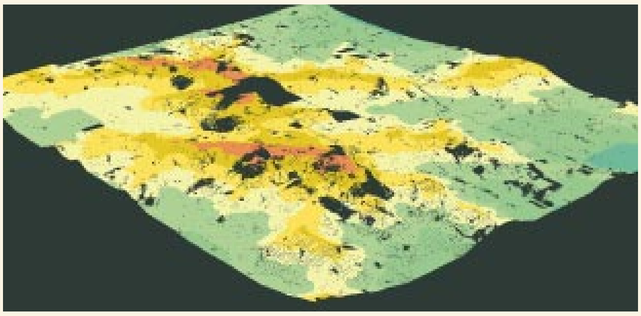
Changes in ecosystem processes

Clearing of native vegetation leads to changes in rainfall interception and evapotranspiration, with more water flowing across the landscape and infiltrating the water table. In this case, little or no run-off or groundwater recharge occurred before clearing. After crops and pasture replaced native vegetation, rainfall run-off measured 25 per cent and recharge of groundwater was seven per cent. This has caused saline groundwaters to rise by more than 20 metres in some areas since clearing began. Consequently, soil salinity has increased, with various effects on remnant vegetation depending on its position in the landscape. On valley floors, for example, which have an average of 13 500 tonnes of total soluble salts per hectare stored in the soils, vegetation is highly susceptible and fresh-water ecosystems are under threat.

Increases in soil erosion cause topsoil and nutrients to move down slopes and into watercourses. Clearing also results in changes in the microclimate; radiation at ground level increases and higher soil temperatures occur. Cleared areas are subject to a much greater range of extreme temperatures. Wind speed is higher closer to the ground in cleared areas, leading to more rapid loss of soil moisture.



Distribution of native vegetation in the Kellerberrin area pre-1920 and in 1984. East Yorkrakine Nature Reserve is circled. Source: CSIRO.



Digital elevation model of the Kellerberrin area; remnant vegetation is shown in black. Only five per cent of the valley floors (green and blue) are still covered with native vegetation compared with 63 per cent of the higher parts of the landscape (red). Source: CSIRO.

Changes in species distribution and abundance

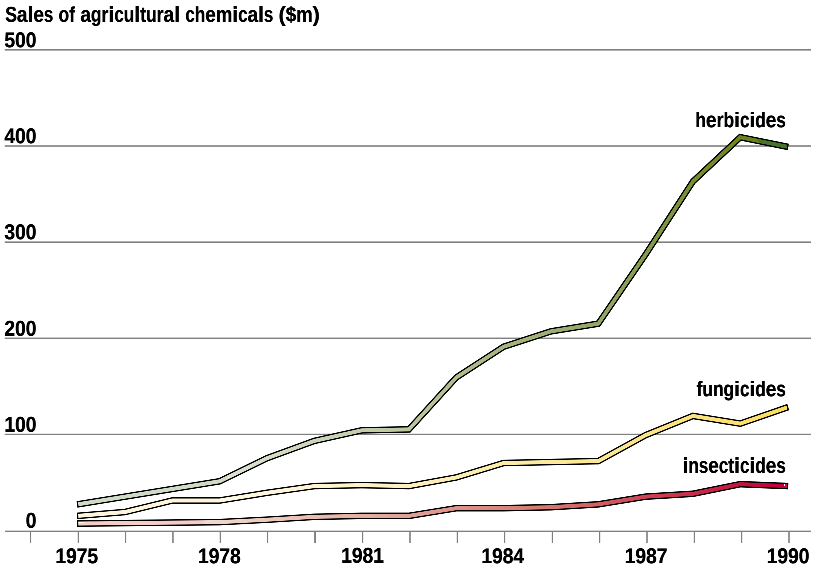
Clearing and fragmentation of native vegetation result in loss of species dependent on it and increases in species dependent on the cleared agricultural matrix. For example, of 131 bird species recorded in Kellerberrin, 38 have declined or have become locally extinct since it was cleared and 18 have increased. These include 11 species that were introduced or invaded the area when suitable habitat was created in the agricultural land. Only nine of the 15 recorded species of native mammal (excluding bats) are still found there.

Isolation of species dependent on remnant vegetation

When a remnant is isolated from other native vegetation, it will be carrying more species than it can carry over time and so some will be lost. This loss will be most rapid for: species that depend entirely on native vegetation, for example, the yellow-plumed honeyeater (*Lichenostomus ornatus*), which is dependent on eucalypt woodlands, was the most common honeyeater in the Kellerberrin area and is now extinct there; those that require large territories, for example, the mallee fowl (*Leipoa ocellata*); and those that exist at low densities, such as the broad-faced potoroo (*Potorous platyops*). Loss will be slowest for eucalypts and other species with long generation times, like the salmon gums (*Eucalyptus salmonophloia*). These still occur along road verges, in agricultural land and in some remnant patches, but few seedlings are growing.

East Yorkrakine Nature Reserve (see left) was isolated from surrounding native vegetation in the late 1920s. Since 1974, four species of bird dependent on undisturbed native vegetation have disappeared from the reserve and others will be lost in future because the populations are too small and too isolated (they will not cross open agricultural land) to persist over time. Remnant vegetation is degrading and species are being lost because of: the creation of edges and an increase in edge specialists; the invasion of weeds; nutrient enrichment from agricultural practices (fertilisers or livestock excrement); grazing by domestic livestock, which is eliminating understorey and litter layers; and changed disturbance regimes such as fire frequencies.

Figure 4.5 Australia's pesticide profile



Pesticides and herbicides are still widely used in Australia, as shown by the increasing sales trends. These chemicals kill native species as well as pests and so adversely impact on biodiversity.

Source: AVCA, cited in Short, 1994.

associated with eggshell thinning in several species of Australian birds, particularly birds of prey and pelicans (*Pelecanus conspicillatus*) (Olsen *et al*., 1993). Herbicides used to kill unwanted weed species also kill native plants.

Australia has large areas of low-nutrient soils so, to grow crops and improve pasture, farmers have made widespread and heavy use of fertiliser. The use of fertilisers over long periods has disturbed many soil and aquatic ecosystems by increasing their nutrient levels. Native vegetation is adapted to nutrient-poor soils and is resistant to invasion by exotic species unless soils are disturbed or enriched by nutrients. As this occurs, so does invasion by introduced weeds that are better-adapted to higher nutrient levels and to exploiting disturbed sites. Increasing nutrient levels in watercourses has led to algal blooms and an increase in other micro-organisms (see the box on page 4-15 and Fig. 4.6).

Vegetation clearance has caused major changes in the hydrological balance because native plants use more water by transpiration than most of the annual species that replaced them, and so more water flows across the landscape and enters the water table.

Water harvesting

Agricultural and urban development in Australia has dramatically altered the flow of many rivers and streams. These changes have been brought about because of our demand for water and a desire to mitigate floods. Many rivers, particularly in the south-east of the continent, have been severely affected by human demand for water. For example, 10 megalitres (one ML is a million litres) of an annual volume of 12.2 ML of water entering the Condamine–Ballone–Culgoa–Darling–Murray watercourse from the Murray–Darling basin is diverted for human use, thus significantly reducing the actual volume discharged (McComb and Lake, 1990). Many streams in the Mount Lofty Ranges of South Australia, which were permanent 50 years ago, no longer flow in summer. In fact, humans have significantly modified the flow of most rivers in south-eastern Australia.

Such changes have significant effects on biodiversity, which are most obvious when large fish such as Macquarie perch (*Macquaria ambigua*) or trout cod (*Maccullochella macquariensis*) become endangered. However, fish like these are near the top of complex food chains and it is important to realise that changes to the vertebrate fauna often reflect less obvious alterations in biodiversity. For example, the River Murray crayfish (*Euastacus armatus*) has declined in range and abundance and 13 of 14 native snails have disappeared from the banks of the Murray due to artificial changes in water level.

The threatening process responsible for loss of biodiversity in fresh-water ecosystems is habitat modification, which is caused by factors such as pollution, salinity, changes in water temperature or low oxygen. These conditions are often exacerbated by reduced flow rates connected with water harvesting.

Changes in the flow of a river may also affect the terrestrial biota surrounding a watercourse. For example, changing water levels in the Murray River due to flood control have been associated with the death of large numbers of trees and consequent loss of habitats. Water impoundments capture and store water that is subsequently redirected to other uses, such as irrigation schemes. These reduce the amount of channel submerged in water downstream resulting in a loss of aquatic habitat. Above the impoundment, they will have changed the environment from flowing water associated with periodically flooded wetlands to still water associated with a permanently flooded environment. Declines in wetland, riverine habitat and water quality are primary causes for the decline of several species of frog, aquatic tortoise and lizard. Some 32 species of frog have been recorded as being in decline, and only limited data are available for many other species. Such changes will have a significant impact on both the aquatic and surrounding terrestrial communities.

Changes in wetland habitats through alteration in water regimes, water quality and physical disturbance may all favour the spread of introduced or translocated aquatic plants. Infestations of many aquatic plants indicate that significant degradation has occurred or is occurring in infested rivers and wetlands.

In uncleared areas of arid and semi-arid regions of Australia, native flora and fauna utilise practically all water from rainfall or it evaporates and thus only rarely finds its way into the groundwater. This balance can easily be disrupted by clearing native vegetation (see the box on page 4-13) or by excessive irrigation. Irrigation involves drenching the soil with water, some of which will be discharged into the groundwater. Water deep in underground aquifers is usually saline (about 30 000 ppm) and thus a rise in water levels can result in salinisation of the soil and nearby rivers.

Pressures on aquatic biodiversity from land use

Estuaries and the sea

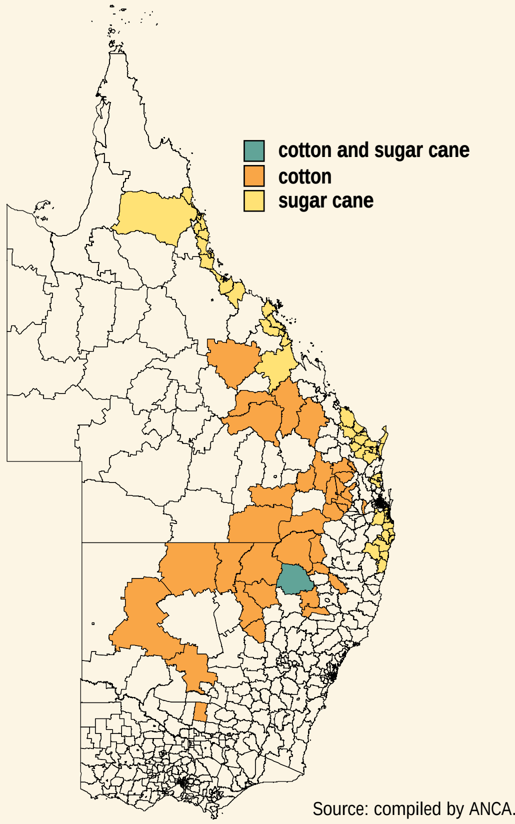
On many parts of the east coast of Australia, estuaries and floodplains of coastal rivers have been drained for a variety of agricultural and pastoral enterprises or for the establishment of townships and tourist facilities. This often results in the exposure of sediments containing iron pyrite. Oxidation of this mineral leads to the formation of highly acidic soils (acid sulfate soils) with highly acidic run-off, which can kill fish when flushed into rivers and estuaries (Callinan *et al*., 1993). The fish may die from high acidity and other chemical properties of the water such as high levels of dissolved aluminium. Natural exposure of the acid-producing sediment also causes fish deaths.

Flood mitigation structures have exacerbated these problems by exposing more sediment in drainage works and changing drainage patterns. Floodgates prevent the normal tidal flushes that would neutralise or dilute the run-off water.

In southern Queensland and northern New South Wales, observers have noted seasonal fish kills where fish show symptoms of a skin disease identified by characteristic red spots that become lethal ulcers. The organism responsible, an exotic fungus (*Aphanomyces* sp.), cannot invade the intact skin of healthy fish. However, skin damage resulting from exposure to run-off from acid sulfate soils may allow the fungus to invade. Scientists have established strong links in the temporal and spatial patterns of rainfall, drainage from acid sulfate soil areas and outbreaks of 'red spot' disease.

Fish deaths are the most obvious symptom of acid run-off, but less mobile organisms such as crabs, worms, molluscs and seagrass beds are also severely affected. All of these changes disrupt estuarine food chains and have economic impacts on fisheries.

Statistical Local Areas in which sugarcane (162 500 ha) and cotton (235 200 ha) are grown



Source: compiled by ANCA.

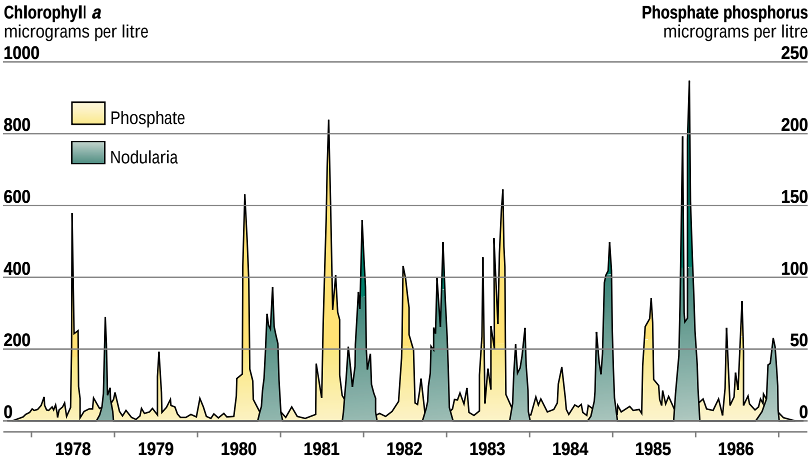
Rivers

Periodic outbreaks of blue-green algal 'blooms' in inland rivers are becoming predictable spring/summer events (see page 7-48). The timing of the blooms coincides with periods of low water levels and high temperatures. However, the main causal agents are the enrichment of river water with nutrients from farming land and effluents from rural cities and towns. The area sown to cotton has increased sharply over the past two decades (see the diagram above and Fig. 7.8). The nutrient load for the Darling Basin for an average year is 440 tonnes of phosphorus and 1890 tonnes of nitrogen.

A variety of organisms use the nutrients in the water, particularly fresh-water algae that, when they decay, use up the dissolved oxygen and create conditions unsuited to other aquatic organisms. Fish kills are one indication of deteriorating water conditions. As blue-green algae continue to grow, their toxic by-products increase in concentration and the water becomes poisonous to land animals. For example, waterfowl and stock may die from drinking the river water and towns can no longer rely on it for domestic purposes.

This green water taken from the Darling River indicates the presence of an algal bloom. High nutrient levels can cause algal blooms, sometimes resulting in fish kills.

Figure 4.6 Long-term pattern of cyanobacterial blooms (*Nodularia spumigena*) in the Peel–Harvey estuary, Western Australia and its relationship to phosphate discharge from agricultural fertilisers in the previous winter period



Source: Hillman *et al.*, 1990.

In many regions, water tables are rising and, in some cases, bringing subsurface salt to the topsoil. In parts of the wheat belt of south-western Australia, saline groundwater tables have been rising by between 0.1 and 1.0 metres per year since removal of native vegetation began. When these saline waters reach the root zone of plants they cause widespread death of remnant vegetation (see page 4-13).

Fragmentation of native vegetation disrupts activity patterns of mobile species, particularly those that will not move over open agricultural land. Some honeyeaters, for example, may now be restricted to patches of remnant vegetation (Saunders and de Rebeira, 1991) and this may prevent them from carrying out their role in important plant pollination processes.

Introduced species

Many species, for a number of reasons, now occur in areas they formerly did not. Introduced species can include exotic organisms, both those introduced for production purposes and introduced diseases, as well as genetically modified organisms and native species whose range and/or abundance have changed because of human activities. Examples occur in terrestrial and aquatic ecosystems.

Introduced species exert a major pressure on biodiversity. They consume native fauna and flora and compete with native species for habitat, often to the detriment of those species.

Vertebrates

At least 18 exotic mammals have established feral populations in Australia, including cats, dogs, foxes, pigs, water buffalo, donkeys, goats and horses. Many species, such as sparrows (*Passer* spp.), trout (*Trutta* spp.) and salmon (*Salmo trutta*), were introduced by acclimatisation societies in the 1800s in an attempt to make Australia more like Europe; others, like the black rat (*Rattus rattus*), brown rat (*R. norvegicus*) and house mouse (*Mus musculus*), were introduced accidentally. Many domesticated animals were introduced for production purposes (Fox and Adamson, 1986).

Cats and foxes prey on a wide range of native animals and have been implicated in the decline, if not the extinction, of a number of species. The role of foxes in the decline of native species is well established. However, much less information exists on the role of cats. Studies of the red-tailed black cockatoo (*Calyptohypchus magnificus*) in Western Australia showed that feral cats climbing into tree hollows and preying on nestlings, caused the failure of up to 17 per cent of nests (Saunders, 1991).

Early European settlers introduced rabbits, which reached plague proportions over much of Australia, affecting native vegetation cover and competing with native fauna for scarce resources. Rabbits also take over burrows from native mammals such as bandicoots and bilbies, seriously reducing the breeding of these species.

All States and Territories have populations of exotic fish. Most widespread of these are trout, mosquito fish (*Gambusia affinis*), goldfish (*Carassius auratus*), European carp (*Cyprinus carpio*), redfin perch (*Perca fluviatilis*), and tench (*Tenca tenca*). All have expanded their ranges since first introduction, most with human assistance. Tilapia (*Oreochromis mossambicus*), one of the most recent fish introductions, is now found in many coastal creeks and estuaries in Queensland. Its spread is expected to continue, since the species can survive in fresh and sea water, and is extremely adaptable and a prolific breeder. Trout have been stocked intensively since the late 1800s, although climatic conditions have largely limited their spread since the mid 1900s. Goldfish are the most widespread of the exotic fish species in Australia, being found in every major drainage system from the Fitzroy River in Queensland to south-western Australia and Tasmania.

Exotic fish have been implicated in the decline of nine endangered, eight vulnerable and five rare or common native fish species. Trout alone are assumed wholly or partially responsible for declines in the abundance and range of nine native fish species as well as for changes in species composition and abundance of stream invertebrates.

Endangerment categories

Presumed extinct

A species is presumed extinct at a particular time if it has not been located in nature during the preceding 50 years, or during the preceding 10 years if thorough searching has been undertaken during the period.

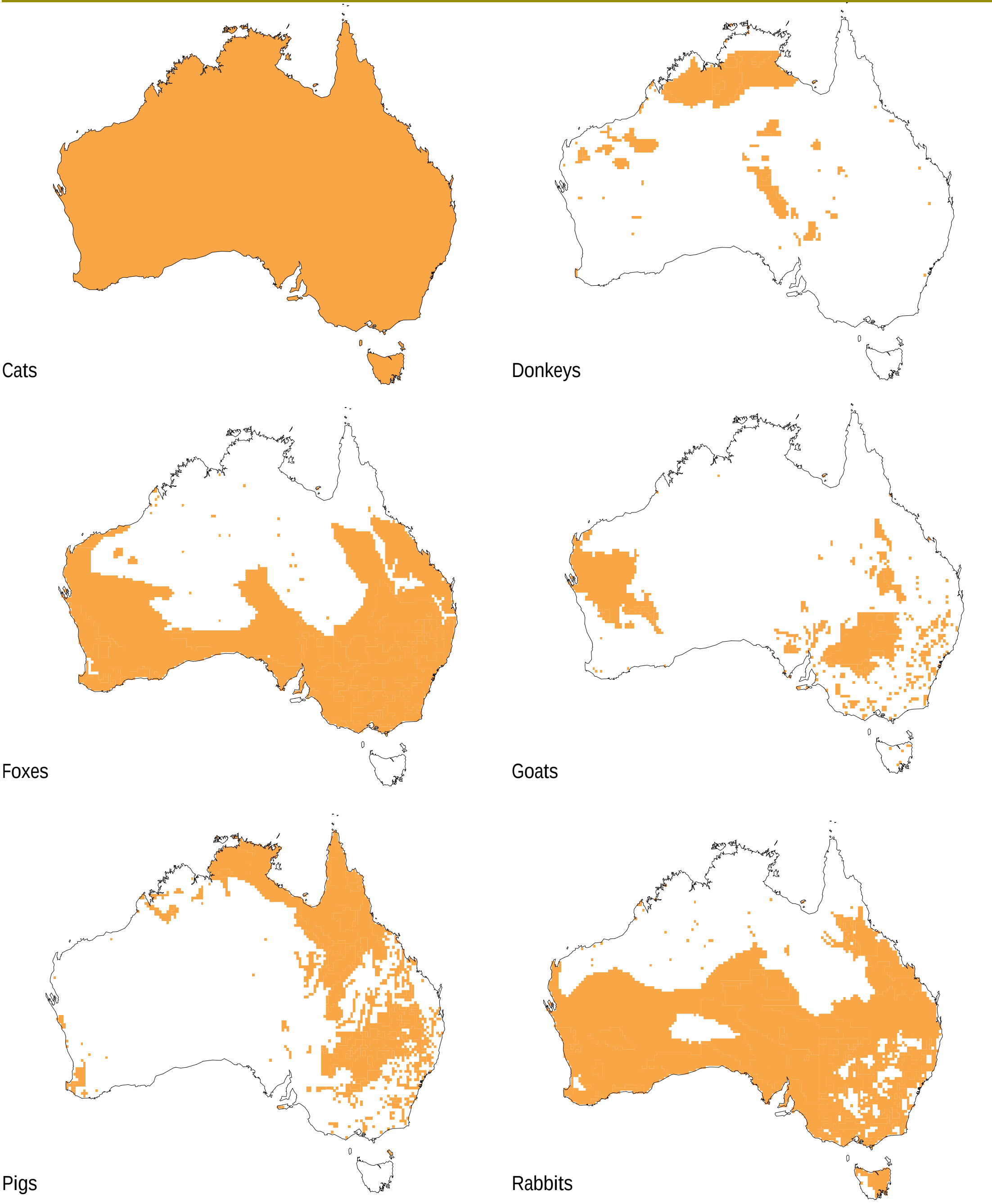
Endangered

Species in danger of extinction include those whose survival is unlikely if the causal factors (threats) continue operating. This also applies to species whose numbers have been reduced to such a critical level, or whose habitats have been so drastically reduced, that they are in immediate danger of extinction.

Vulnerable

These are species believed likely to move into the 'endangered' category in the next 25 years if the threats continue operating.

Figure 4.7 Occurrence of six species of introduced mammals



The entire continent is occupied by at least one of these feral species. Cats occur virtually everywhere, rabbits and foxes occur mainly in the south and not in the far north, pigs are found in the east, north and south-west, goats in the east and west and donkeys mainly in the north-west.

Grid cells (one degree of latitude by one degree of longitude).

Source: Compiled by ANCA.

Invertebrates

Many invertebrate species have been introduced from overseas, but most have attracted little attention because they are small and little is known about their effects on native species and ecosystems. However, some introductions are both obvious and destructive.

The European wasp (*Vespula germanica*) appears to have arrived in timber shipments. The nests were first seen in the Sydney area in 1978 and since then the wasp has not only spread widely, but its biology has changed significantly. In its native Northern Hemisphere, colonies are generally annual, the onset of winter killing all individuals except the fertilised queens, which have to start colonies from scratch the following year. In Australia, however, the relatively warm winters do not kill colonies, which consequently become perennial and grow large with enormous numbers of workers. They prey on native insects, including commercially important pollinators, and attack soft fruits.

Pacific oysters (*Crassostrea gigas*) were introduced into Australia between 1947 and 1970 to establish an oyster industry in the southern States. Native Sydney rock oysters (*Saccostrea commercialis*) are not suitable for culture in the cool waters of Tasmania and Victoria. Despite attempts to

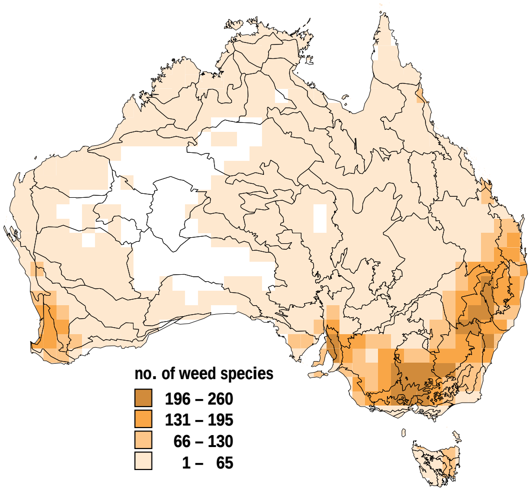
The Gouldian finch *(Erythura gouldiae)* has been affected by an introduced mite and has disappeared from large parts of its former range.

prevent the introduced oysters from invading New South Wales, they gradually spread up the coast where, because of their long breeding season, prolific production of spat and rapid growth, they are replacing the indigenous Sydney rock oysters by settling on and smothering them along with other rock fauna (Holliday and Nell, 1987).

The Gouldian finch (*Erythura gouldiae*), which now has a very patchy distribution in tropical northern Australia, has undergone a serious population decline over the past 20–30 years. Such has been the extent of its decline that large flocks are rarely encountered and the birds have disappeared altogether from parts of their former range. A study of possible causal factors (Tidemann *et al.*, 1992) demonstrated that finches in the wild suffered high incidences of infestation with an air-sac mite (*Sternostoma tracheacolum*). Aviary populations are susceptible to infection by the mite, which interferes with breathing. Affected birds may live for many months or die quickly depending on the severity of the infection. The mite was first described in aviary birds in South Africa and to date has not been widely reported in wild bird populations in the Southern Hemisphere.

Other introduced terrestrial invertebrates that have hit headlines are tiny springtails that displace native species (important in the decomposition of leaves), garden snails, the so-called Argentine ants, West Indian termites, a millipede and several varieties of cockroaches.

Figure 4.8 Number of weed species by area



Source: compiled by ANCA

The numbers refer to those species officially listed as noxious by the States and Territories and indicate the many problems with introduced plants considered to have serious adverse effects on biodiversity and production. The map does not necessarily indicate the extent to which ecosystems or native species are affected by weeds; some serious environmental weeds occur both in areas of high and low weed diversity.

Grid cells (one degree of latitude by one degree of longitude).

The boundaries indicate Interim Biogeographic Regions for Australia.

Introduced species also affect marine ecosystems. About 70 species are known to have been introduced into Australian waters. Many have come in as fouling organisms on the hulls of ships. Others have been introduced in ballast-water discharge. A total of 121 million tonnes of ballast water from overseas are released into our waters annually from international shipping and a further 34 million tonnes are translocated between Australian ports. This water carries many exotic marine organisms, including plants, animals and micro-organisms and at least 20 exotic species are believed to have been introduced into Australian waters this way. Many of these may have little effect, but several will impact on marine biodiversity.

Northern Pacific starfish (*Asterias amurensis*) were probably introduced into Tasmanian waters in ballast water from Japan. They can live in water temperatures of up to about 24°C and are thus capable of spreading to much of southern Australia. These are large starfish — adults can reach up to 40 cm across — and are prolific breeders, each individual producing up to 19 million eggs at a spawning. They can grow rapidly — reaching a size of 12 cm in less than a year. Tens of thousands have been removed from the Derwent estuary in Hobart, where they have reached densities of up to five per sq m. Pacific starfish have been found to eat many species that occur on the seabed, and thus the large numbers of starfish may have a devastating effect on populations of seabed organisms (see the box on page 8-17).

Plants

Introduced plants are an acute and insufficiently appreciated ecological problem. On a national scale, populations of the most invasive species are expanding. Plant species not native to Australia now account for about 15 per cent of our total flora. About half of them invade native vegetation and about one-quarter are regarded as serious environmental weeds or have the potential to be serious weeds (see Table 4.3). The largest proportion of environmental weeds are horticultural species that have escaped from cultivation. Almost all of Australia's native vegetation has been, or is likely to be, invaded by exotic species that could result in changes to the structure, species composition, fire frequency and abundance of native communities. Those species of greatest concern include rubber vine (*Cryptostegia grandiflora*), blue thunbergia (*Thunbergia grandiflora*), the semi-aquatic grasses hymenachne (*Hymenachne amplexicaulis*) and aleman grass (*Echinochloa polystachia*), para grass (*Brachiaria mutica*), giant sensitive plant (*Mimosa pigra*) and athel pine (*Tamarix aphylla*).

The rubber vine, which entangles trees and other vegetation and eventually smothers them, is spreading at an alarming rate through the river systems of southern Cape York and the Queensland part of the Gulf of Carpentaria and along the coast as far south as the Burnett River near Bundaberg, destroying the riverside vegetation in these regions.

Table 4.3 Australia's worst environmental weeds

Species	Key community/habitat affected	Nature of impact/threat
Prickly acacia *(Acacia nilotica)* small tree/shrub	Mitchell grasslands	Replaces perennial *Astrebla* spp. with annuals or bare soil and is a long-term threat to the Mitchell grass biome; converts grassland to shrubland
Para grass *(Brachiaria mutica)* semi-aquatic	Wetlands and streams in the wet-dry and wet tropics and sub tropics	Planted for ponded pasture but spreading into non-target areas destroying waterbird breeding habitats and choking tropical streams; replaces native vegetation
Buffel grass *(Cenchrus ciliaris)* groundcover	Moist 'refuges' and river banks in the arid zone	Threatening keystone habitats by displacing native vegetation and altering the fire regime; likely to reduce fauna resources
Bitou bush *(Chrysanthemoides monilifera rotundata)* **Boneseed** *(C.m. monilifera)* shrub	Range of coastal systems: foredune, heath, littoral rainforest; range of coastal and sub-coastal systems	Displaces native vegetation with unknown effects on fauna
Rubber vine *(Cryptostegia grandiflora)* shrub/vine	Gallery and other riparian communities in the wet-dry tropics; dry rainforest (vine thickets)	Smothers trees and shrubs and shades out the ground layer; destroys riparian vegetation including gallery forests threatening associated fauna; forms impenetrable thickets in Queensland's Gulf river systems
Water hyacinth *(Eichhornia crassipes)* aquatic	Standing surface waters especially where nutrient levels are high; occurs in all mainland States but particularly tropics and sub-tropics	Aggressively invades open water with potential for very rapid growth; still spreading in Australia despite extensive control measures; alters aquatic ecosystems
Aleman grass *(Echinochloa polystachia)* semi-aquatic	Wetlands in the wet-dry and wet tropics; grows in water up to 2 m	As for para grass; recent introduction and not yet widespread but larger than para grass with greater potential for damage
Reed sweetgrass *(Glyceria maxima)* semi-aquatic	Margins of creeks, rivers and ponded areas up to 1 m deep; temperate species eastern States	Used as a pasture or ornamental plant but is spreading to non-target areas; chokes the habitat
Hymenachne *(Hymenachne amplexicaulis)* semi-aquatic	As for para grass but can grow in water up to 2 m	Recently introduced as ponded pasture species, so not yet widespread, but has potential to modify tropical wetlands totally if not controlled
Giant sensitive plant *(Mimosa pigra)* small tree/shrub, semi-aquatic	Disturbed areas especially flood plains in the wet-dry tropics	Totally displaces native species leaving bare mud if removed; spreads by floods
Bridal creeper *(Myrsiphyllum asparagoides)* creeper	Spreading through wide range of habitats in southern Australia	Smothers ground and shrub layers
Parkinsonia *(Parkinsonia aculeata)* small tree/shrub	Ephemeral wetlands and riparian communities in the wet-dry tropics	Invades mesic habitats and seasonal wetlands threatening waterbird habitats of continental significance
Mission grass *(Pennisetum polystachion)* groundcover	Dry forests and woodlands of the wet-dry tropics	Displaces native sorghum changing the fire regime, which potentially reduces recruitment potential of woodland species of high conservation significance
Mesquite *(Prosopis spp.)* small tree/shrub	Semi-arid and arid riparian and other communities; Mitchell grasslands	Similar to prickly acacia but has a wider range of soil tolerances
Salvinia *(Salvinia molesta)* aquatic	Stationary and slow-moving water bodies, especially where nutrient levels are high; all mainland States and Territories	Aggressively invades open water with potential for very rapid growth; still spreading in Australia despite extensive control measures; alters aquatic ecosystems
Athel pine *(Tamarix aphylla)* small tree	Dryland river systems; currently small infestations	Displaces native trees; salinises soil; changes hydrology and geomorphology; reduces fauna resources
Blue thunbergia *(Thunbergia grandiflora)* vine	Tropical lowland rainforest in far north Queensland, especially along watercourses	Vigorous vine rapidly spreading and smothering native vegetation to the canopy; infestation in early stages
Japanese kelp *(Undaria pinnatifida)* marine kelp	Near-shore habitats along east coast of Tasmania	Spreading at rate of 10 km per year with potential to spread along southern coastline

Source: Humphries *et al.*, 1991

▲ This kelp *(Undaria)* was probably introduced from Japan in ballast water and is a conspicuous underwater plant on the Tasmanian coast.

Another species spreading along the river systems is the athel pine, which displaces native vegetation — usually river red gum (*Eucalyptus camaldulensis*) — and can change river flow and sedimentation regimes. It is considered a threat to all the watercourses of arid Australia. So far it has become established along several hundred kilometres of the Finke River, the largest river system in the arid zone.

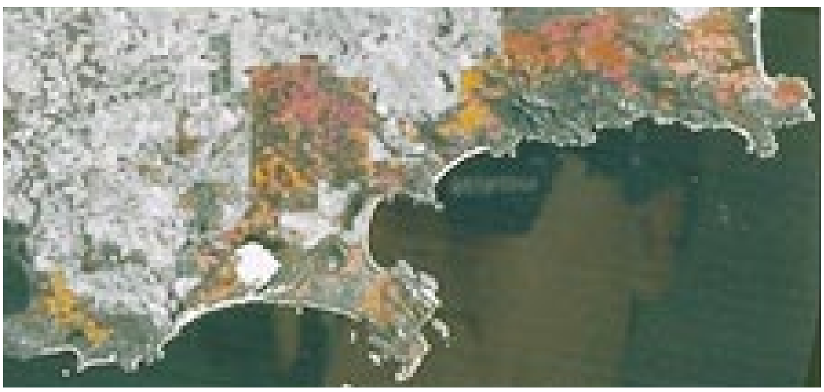
Some 65 species of aquatic plants have become weeds in Australian inland waters. About 15 of these are significant pests and 13 have the potential to become so. These species have been introduced either intentionally, for economic, aesthetic or management reasons, or accidentally through the aquarium and agricultural industries. One example of an introduced aquatic plant is the giant sensitive plant, which infests wetlands of the Northern Territory. It rapidly reduces the number of species of native plants and animals, and alters seasonal wetlands from predominantly native grassland to shrubland dominated by a single species.

Japanese kelp (*Undaria pinnatifida*) was probably introduced via ballast water discharge and is spreading widely in southern waters. This species is known to displace native seaweeds, changing seabed habitats and altering species composition.

Micro-organisms

Introduced species sometimes carry diseases that can infect native species. The introduced fungus *Phytophthora cinnamomi*, causes a disease, known as dieback, that is devastating many native communities in southern Australia and is now the most important threat to the biodiversity of Stirling Range National Park in Western Australia. By killing key species in those systems, the pathogen is threatening entire communities and ecosystems. In highly susceptible genera (such as *Banksia*, *Grevillea* and *Dryandra*), 80 to 100 per cent of infected individuals may die, exposing ground that is then invaded by weeds. The numbers of birds in affected areas in Two Peoples Bay Nature Reserve in Western Australia have been reduced significantly because of the effects of *Phytophthora* infection on the vegetation (Hart, in press).

Two Peoples Bay, Western Australia; red, purple, orange and light red represent dieback locations. The other colours represent dieback-free areas. Source: Behn and Campbell, 1992. ▼



The impact of other introduced micro-organisms on native animals is largely unknown, although an introduced fish virus (epizootic haematopoietic necrosis or EHN virus) may have been responsible for the decline of the Macquarie perch in Lake Eildon.

Native species out of place

Outside their natural range, native species may be as serious a threat to biodiversity as exotic ones. Many are spreading beyond their usual habitat or increasing in abundance due to human activities such as clearing, cropping, pastoralism, tree-planting on farms and in gardens and landscaping of roads and railways.

Much of the pastoral land in the central-western areas of New South Wales and Queensland has become densely infested with shrubs. These so-called woody weeds (including *Eremophilia mitchellii*, *E. sturtii* and *Cassia nemophila*) occur naturally in the pastoral regions but have spread at the expense of other native species due to overgrazing and changed fire regimes. Before European settlement, regular fires checked their spread. However, overgrazing, which removes the perennial grass cover, reduces the capacity of the land to carry fire. Longer periods between fires have allowed young plants to develop beyond their vulnerable stage, and once established they are able to survive fire. Dense thickets of these shrubs prevent pasture growth and impede mustering of stock.

The galah (*Cacatua roseicapilla)* was formerly associated with the river systems of the arid zone. However, development has created vast areas of suitable habitat (grasses, cereal crops and abundant water), encouraging the bird to colonise much of Australia. This expansion has brought the galah into contact with other species formerly outside its range. One of these is Carnaby's cockatoo (*Calyptorhynchus latirostris*), a black cockatoo of south-western Australia, which has disappeared from more than one-third of its range in the last 25 years due to loss of food and habitat. This cockatoo also suffers from competition with galahs over nest sites. In addition, galahs remove bark from the trunks of some of their nest trees, which in severe cases leads to the death of the trees and has become a significant cause of mortality in extensively cleared semi-arid woodlands with poor recruitment of trees.

Not only can introduced species reduce the numbers of indigenous organisms, they may hybridise with closely related endemic species, changing the genetic composition of the population. In some cases, hybrids resulting from interbreeding between endemic and closely related non-endemic species are more vigorous than the original stock. This can lead to reduction or eventual elimination of the indigenous species. The escape of rosemary grevillea (*Grevillea rosmarinifolia*) from gardens, for example, has resulted in hybridisation with a rarer endemic species, *G. glabella*. The resulting hybrids are more vigorous and may replace the parental *G. glabella*.

Galahs remove bark from some of their nest trees. In extreme cases this may lead to the death of the tree.

Pollution

The release of pollutants into the environment is an actual and potential threat to biodiversity, particularly in regions close to industrial sites and highly urbanised areas. Urban stormwater may contain high levels of contaminants such as faecal bacteria, nutrients, chromium, cadmium, lead, nickel, hydrocarbons and chlorinated hydrocarbons. In rural areas, irrigation run-off often contains insecticides, fertilisers and herbicides that have been applied to crops and may affect fresh-water and marine ecosystems. Nutrients from urban effluent and agricultural chemicals, for example, are polluting inshore reefs of the Great Barrier Reef, killing coral and encouraging the growth of sessile algae.

Pollutants can act in a synergistic way to cause uncertain long-term impacts. These impacts are compounded by the cyclic nature of ecosystem processes, which disperse pollutants widely from their sources and may affect biodiversity at considerable distances from the original source.

Potential effects of pollutants on ecosystems include changes in the abundance of species, interruption of energy and nutrient flows, modification of habitats, reductions in soil, water and air quality, and changes to the stability and resilience of ecosystems. As an example, industrial discharges into Cockburn Sound in Western Australia have been associated with massive loss of seagrasses and substantial levels of contamination of sediments and fish (see page 8-25).

Natural enrichment in the sea occurs mainly in upwelling areas where water rich in nutrients rises to the surface and is used by algae, chiefly diatoms. A variety of small animals, which form part of the extremely diverse marine plankton and which include larval stages of many fish and crustaceans, feed on these diatoms. More than 5000 species of diatoms are found in Australian waters. Effluents from sewage and from agricultural run-off are high in nitrogen and phosphorus, but are lacking in silica. Thus diatoms — which require silica — cannot make use of these nutrients and they are used by other species of algae — especially dinoflagellates — that do not require silica. This results in a major shift in species composition,

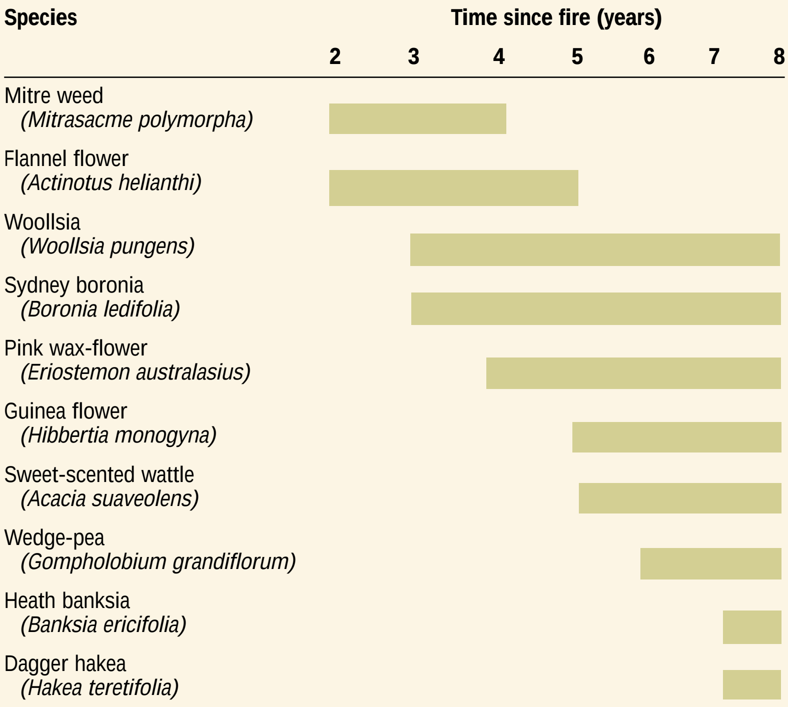
Fire and Australia's biodiversity

The January 1994 wildfires in eastern New South Wales provided a vivid reminder of how destructive some of the natural forces affecting our landscape can be. Fire is a natural disturbance and the Australian biota has evolved under its influence. However, its contemporary pattern differs from the one that occurred before the arrival of Europeans.

The pattern comprises the frequency (expected return-time) of fire. This in turn affects its intensity, since litter accumulates between outbreaks, and the longer the interval the greater the amount of litter or fuel that can accumulate. The third important part of the pattern is the season in which fire usually occurs. In much of Australia, some or all of these components of the fire regime have changed. This in turn affects the way that communities of plants, animals and micro-organisms respond to fire.

Most often, people, by their actions, bring about the changes in fire frequency (and intensity) or seasonality. Some areas are protected. Thus, fires may be suppressed in urban bushland close to houses, schools and commercial buildings to prevent destruction of property. Such practices will cause biological changes. More commonly, bushland areas are burnt more frequently than they were prior to European settlement. For some species of plants and animals, the time between fires may be insufficient to allow their natural reproduction. For example, in shrubland around Sydney the heath banksia (*Banksia ericifolia*) first flowers in the seventh year after a fire, and the fruit are not mature until at least the eighth year. This means that if bushland such as Royal National Park is burnt more frequently than every eight years, that species of banksia will become locally extinct.

Flowering times for selected plants from sandstone shrublands near Sydney



Source: Benson, 1985.

Mine sites such as this one at Queenstown, Tasmania can have a severe impact on biodiversity.

Table 4.4 Ten vertebrate species most threatened by climate change

Species	Vertebrate order	Loss of core climate area (%)
Kowari *(Dasyuroides byrnei)*	Mammal	99.6–100
Red-tailed phascogale *(Phascogale calura)*	Mammal	99.4–100
Central rock-rat *(Zyzomys pedunculatus)*	Mammal	94.0–100
Forty-spotted pardalote *(Pardalotus quadragintus)*	Bird	86.0–100
Swan galaxias *(Galaxias fontanus)*	Fish	81.8–100
Dusky hopping-mouse *(Notomys fuscus)*	Mammal	78.9–100
Heath rat *(Pseudomys shortridgei)*	Mammal	71.7–100
Broad-headed snake *(Hoplocephalus bungaroides)*	Reptile	65.1–98.9
Northern hairy-nosed wombat *(Lasiorhinus krefftii)*	Mammal	59.4–100
Carpentaria grass wren *(Amytornis dorotheae)*	Bird	51.6– 100

Climate change due to increasing greenhouse gases is a potential threatening process to Australia's biodiversity. Some vertebrate species may be driven to extinction due to loss of core habitat.

Source: Dexter *et al.*, 1995

from a plankton community dominated by diatoms to one dominated by dinoflagellate algae. Dinoflagellate blooms cause a range of serious problems from massive fish kills associated with red tides to paralytic shellfish poisoning in humans (see Chapter 8).

Mining

Mining affects the environment and associated biota through the removal of vegetation and topsoil, the displacement of fauna, the release of pollutants into the air and water and the production of mine overburden. When pyrite (iron disulfide) is brought to the surface during the mining of coal and metal ores it is oxidised to sulfuric acid, which in turn mobilises heavy metals. This acid mine waste can severely pollute rivers, causing loss of biodiversity. The Rum Jungle Mine in the Northern Territory, for example, released 130 tonnes of copper, 100 tonnes of manganese, 40 tonnes of zinc and 13 000 tonnes of sulfate into the Finnis River in one year. In submarine mining operations, equivalent disruptions occur in the immediate environs of the mine or drilling site. Whether terrestrial or marine, mining sites are numerous but generally of relatively small total area (see Fig. 6.3). Extensive mining operations, such as open-cut extraction of coal, bauxite and manganese, as well as sand mining in coastal heathlands, have caused long-term changes to biodiversity despite recent attempts at rehabilitation (Fox, 1990).

Climate change

The impact of climate change on biodiversity is difficult to assess since it depends largely on the rate of change and the compounding effects of other pressures such as habitat loss and fragmentation. While most scientists agree that the climate is changing, it is not yet possible to distinguish human-induced change from natural climatic variations.

As the global climate warms, the preferred climatic conditions for a species will shift to higher altitudes and latitudes. Survival will depend on its ability to relocate quickly enough and the availability of alternative habitats. Species most at risk are those with small population sizes that have slow growth rates with poor dispersal abilities and recruitment. The disruption of migration paths by human activities will also influence the ability of organisms to adjust geographically to climate change. Regions of urban development, agriculture and pastoralism will act as barriers, preventing the movement of many species from one remnant habitat to another.

A recent study into the impact of global warming on the distribution of vertebrates (Dexter *et al.*, 1995) found that the habitats of many of Australia's endangered vertebrates are likely to contract significantly in the advent of climate change (see Table 4.4). Under one scenario, 46 out of 57 endangered species examined would contract in range.

State

The state of ecosystem diversity

Biogeographic regionalisations for Australia

Ecosystems can be defined at many scales because there are many ways of representing them, depending on the purpose and the particular ecosystem components and processes that need to be emphasised. The main reason for developing the terrestrial regionalisations discussed here was to provide a framework for identifying gaps in the national system of protected areas and to assist in allocating priorities for funding to projects concerned with conservation of biodiversity (Thackway and Cresswell, 1995). The rationale for the marine regionalisation was similar. Quite different classifications of ecosystems could be appropriate for different purposes.

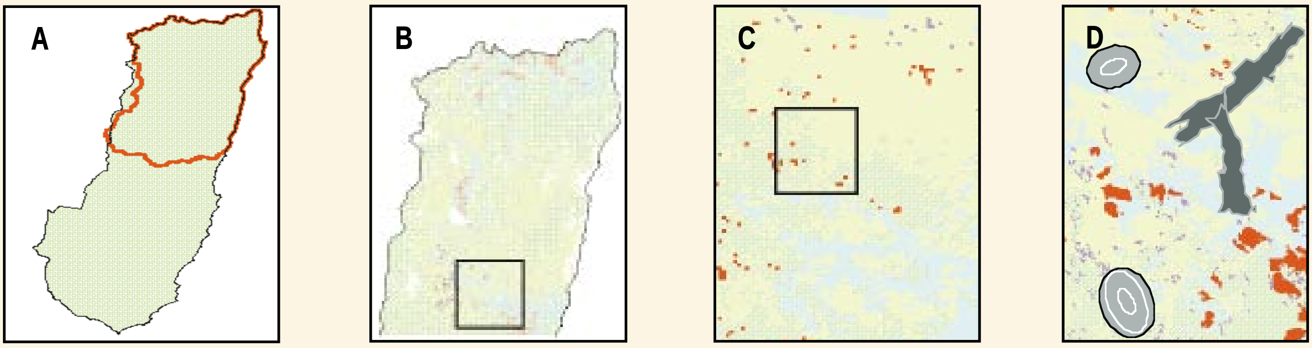
The terrestrial ecosystems discussed here are those outlined in the Interim Biogeographic Regionalisation for Australia (IBRA) (see Fig. 4.9), which divides the continent into 80 biogeographic regions representing major environmental units (Thackway and Cresswell, 1995). It is the only continent-wide regionalisation agreed to by all States and Territories and was initially developed in February 1994 by combining State and Territory land classifications at a scale appropriate for the whole continent. The system is still evolving as methods are developed to refine boundaries, make levels of classification consistent between parts of the country and reconcile differences in approach between jurisdictions.

The biogeographic regions vary in size from 2372 sq km (Furneaux, in Bass Strait) to 423 751 sq km (Great Victoria Desert). The smaller regions occur within 300 km of the coastline, have relatively high rainfall in the growing season and, in many cases, are mountainous. Of the largest regions, most are in arid or semi-arid areas with broad climatic gradients and little topographic relief. The regions can be progressively subdivided into smaller units based on, for example, major vegetation structural types, vegetation communities, local topographic variations in communities and, at extremely fine scales, water-filled tree hollows and small sections of the soil surface (see the box below). Any of these scales of ecosystems can be characterised in terms of distinctive biological and physical patterns and processes.

In 1986, the Australian Committee for IUCN proposed the classification used here for major marine regions (see Fig. 4.9), which is an interim one. The Department of the Environment, Sport and Territories (DEST) is reviewing the inshore classification with the States and the Northern Territory for waters under their jurisdiction — the marine areas within three nautical miles of the coast. DEST has also commissioned CSIRO to develop a new offshore regional classification that will integrate information on depth, type of substratum, water column characteristics, such as temperature, salinity, currents and eddies, and the distribution of more than 4000 species of fish (the best known group of marine organisms). Of the interim marine regions, 12 are predominantly coastal or near-coastal, defined arbitrarily within the 200-m-depth contour, which is relatively close to the coast in many areas but extends well offshore in Bass Strait and the Great Australian Bight and along the Great Barrier Reef and much of the northern coastline.

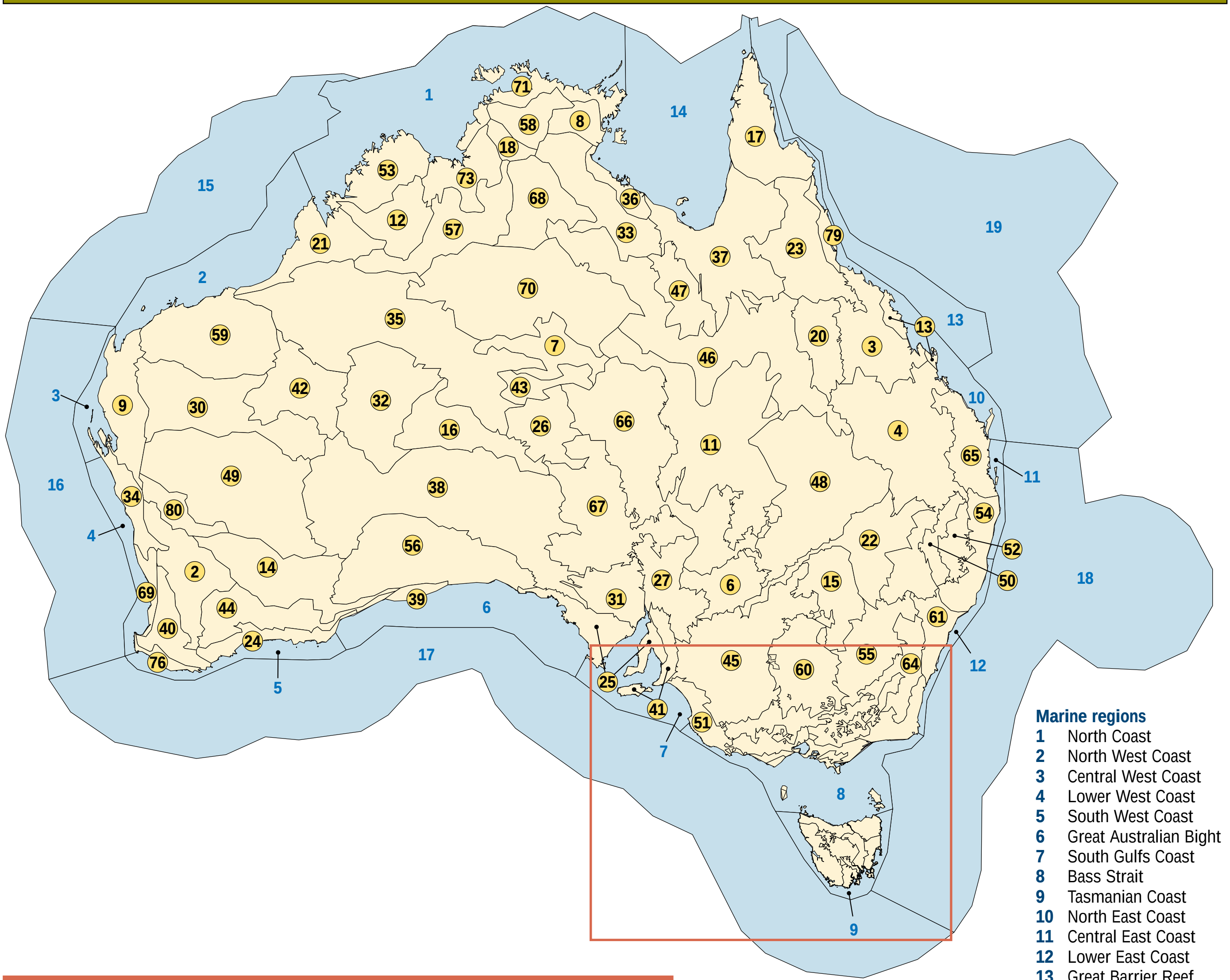
Biogeographic regions — a closer look

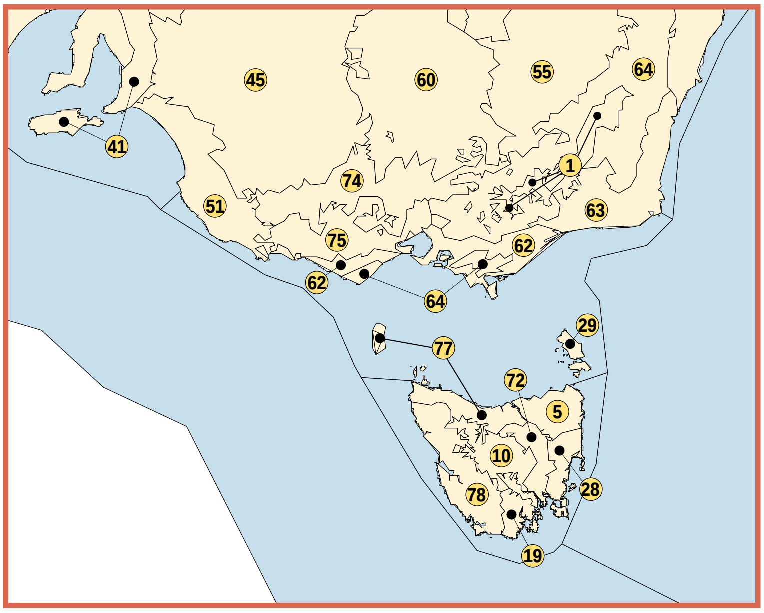
The New South Wales north coast (A) is one of the major biogeographic regions in eastern Australia (see Fig. 4.9). The region has been subdivided into six major vegetation structural units (B) — rainforest, moist open forest, dry open forest, woodland, and sclerophyll complexes on the coast and tablelands. Each of these units can be considered an ecosystem at a finer scale than the region as a whole. At a finer scale still, forest types (C) can be distinguished within the major vegetation types. So rainforest in the Dorrigo area can be subdivided into dry, warm temperate, cool temperate and subtropical and the open forest into many more types. Each of these forest types can be characterised by particular environmental variables and physical processes and a distinctive flora and fauna.
At another level of detail, the ground surface of any one forest type can be mapped as a mosaic of surfaces (D), including the bases of trees, accumulated bark nearby, bare rock, disturbed bare soil, litter of leaves and small branches and fallen logs. The different surfaces also have distinctive physical and biological characteristics and large populations of macro-invertebrates and micro-organisms.



Source: compiled by NSW Parks and Wildlife Service.

Figure 4.9 Australian marine regions and terrestrial bioregions





Marine regions

1 North Coast
2 North West Coast
3 Central West Coast
4 Lower West Coast
5 South West Coast
6 Great Australian Bight
7 South Gulfs Coast
8 Bass Strait
9 Tasmanian Coast
10 North East Coast
11 Central East Coast
12 Lower East Coast
13 Great Barrier Reef
14 Gulf of Carpentaria
15 North West Oceanic
16 West Oceanic
17 South Oceanic
18 South East Oceanic
19 North East Oceanic

Terrestrial bioregions
(see table opposite)

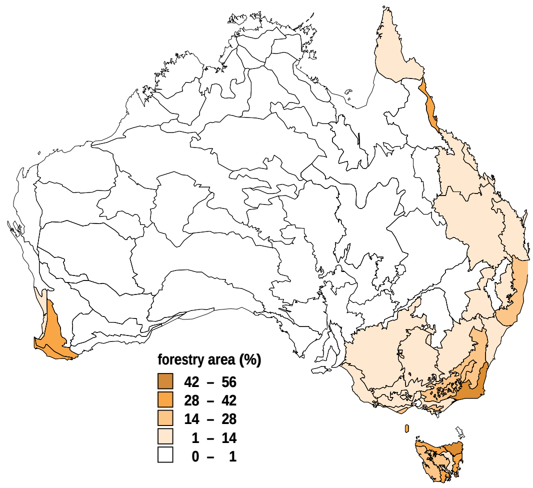
Note:
CL: areas of vegetation cleared (%)
IP: areas affected by intensive production (%) IP is larger than CL in some regions because some intensive production does not always require cle and because of discrepancies between the separate data sources.
GRd: average livestock densities on pastoral land (nos/ha)
FO: areas used for commercial forestry on public land (%)
MI: mineral deposits currently mined or potentially mined in the future (no.
PR: protected areas (National Parks, nature reserves and equivalent tenures
Some small or irregularly shaped IBRA regions were merged for the analysis intensive production and grazing because the data for these enterprises are available only for Statistical Local Areas (SLAs). Merging produced the follow 12 combinations of regions: Australian Alps and South Eastern Highlands; No and eastern Tasmania: Ben Lomond, Central Highlands, D'Entrecasteaux, Frey Furneaux, Tasmanian Midlands and Woolnorth; Burt Plain and MacDonnell Ra Central Arnhem, Daly Basin, and Pine Creek–Arnhem; Esperance Plains and M Gulf Fall and Uplands and Gulf Coastal; Hampton and Nullarbor; Jarrah Fores Swan Coastal Plain and Warren; Murchison and Yalgoo; Nandewar and New England Tableland; Naracoorte Coastal Plain, Victorian Midlands, and Victoria Vocanic Plain; South East Coastal Plain and South East Corner.

Data compiled by ANCA.

Table 4.5 State of terrestrial biogeographic regions indicated by extent of major threatening processes and coverage by conservation reserve

		CL	IP	GRd	FO	MI	PR
1	Australian Alps	38	35	2.08	27	3	18.9
2	Avon Wheatbelt	88	81	0.96	0	26	0.5
3	Brigalow Belt North	60	17	0.76	2	29	1.2
4	Brigalow Belt South	64	16	1.01	9	28	2.0
5	Ben Lomond	37	19		44	29	9.3
6	Broken Hill Complex	0	0	0.15		8	1.4
7	Burt Plain	0	0	0.09		5	2.3
8	Central Arnhem	2	1	0.14		2	7.6
9	Carnarvon	0	7	0.08		3	6.9
10	Central Highlands	37	19		18	4	9.3
11	Channel Country	0	0	0.15	0	3	6.6
12	Central Kimberley	0	0	0.15		8	0.0
13	Central Mackay Coast	34	63	1.12	9	2	6.6
14	Coolgardie	3	13	0.08	1	325	7.6
15	Cobar Peneplain	33	25	0.50	1	14	0.9
16	Central Ranges	0	0	0.06		3	0.0
17	Cape York Peninsula	0	0	0.10	1	4	11.7
18	Daly Basin	2	1	0.14		6	7.6
19	D'Entrecasteaux	37	19		42		9.3
20	Desert Uplands	15	19	0.44		4	1.6
21	Dampierland	0	0	0.17		3	0.3
22	Darling Riverine Plains	51	28	0.85	0		0.5
23	Einasleigh Uplands	7	4	0.34	1	72	0.8
24	Esperance Plains	43	47	1.41	0	17	19.3
25	Eyre and Yorke Blocks	76	48	0.59	0	6	6.6
26	Finke	0	0	0.6		2	0.0
27	Flinders and Olary Ranges	7	4	0.18		25	10.1
28	Freycinet	37	19		28		9.3
29	Furneaux	37	19				9.3
30	Gascoyne	0	0	0.04		31	1.9
31	Gawler	0	11	0.06		5	9.9
32	Gibson Desert	0	0	0.0			12.0
33	Gulf Fall and Uplands	0	0	0.07		15	0.9
34	Geraldton Sandplains	52	56	0.73		4	14.0
35	Great Sandy Desert	0	0	0.10		12	1.9
36	Gulf Coastal	0	1	0.07		12	0.0
37	Gulf Plains	0	1	0.25			0.0
38	Great Victoria Desert	0	2	0.04		8	17.1
39	Hampton	0	1	0.04			28.6
40	Jarrah Forest	44	55	2.82	34	25	8.1
41	Lofty Block	81	64	1.58	1	6	4.9
42	Little Sandy Desert	0	0	0.03		2	4.9
43	MacDonnell Ranges	0	0	0.09		1	2.3
44	Mallee	43	47	1.41		32	19.3
45	Murray–Darling Depression	39	33	0.55	2	7	12.8
46	Mitchell Grass Downs	3	2	0.28		9	0.3
47	Mount Isa Inlier	0	0	0.21	0	52	2.3
48	Mulga Lands	8	5	0.30			1.6
49	Murchison	2	4	0.05	0	393	1.1
50	Nandewar	74	45	2.41	1	2	2.1
51	Naracoorte Coastal Plain	78	73	2.52	6		4.7
52	New England Tablelands	74	45	2.41	6	9	2.1
53	Northern Kimberley	0	0	0.15		1	12.0
54	NSW North Coast	37	21	1.78	21	64	8.0
55	NSW South Western Slopes	80	55	2.16	1	30	1.2
56	Nullarbor	0	1	0.04			28.6
57	Ord-Victoria Plains	0	1	0.18		7	5.4
58	Pine-Creek Arnhem	2	1	0.14		47	7.6
59	Pilbara	0	0	0.08		224	5.6
60	Riverina	72	38	1.05	2	4	0.2
61	Sydney Basin	26	22	1.22	6	33	32.4
62	South East Coastal Plain	41	37	0.97	4		16.6
63	South East Corner	41	37	0.97	53	4	16.6
64	South Eastern Highlands	38	35	2.08	25	46	18.9
65	South Eastern Queensland	60	23	1.33	12	26	3.0
66	Simpson-Strzelecki Dunefields	0	0	0.09		1	26.7
67	Stony Plains	0	0	0.05		5	4.9
68	Sturt Plateau	0	0	0.15			0.0
69	Swan Coastal Plain	44	55	2.82	5	33	8.1
70	Tanami	0	0	0.11		33	0.0
71	Top End Coastal	1	1	0.19		4	9.8
72	Tasmanian Midlands	37	19		4		9.3
73	Victorian Bonaparte	1	1	0.17		4	11.2
74	Victorian Midlands	78	73	2.52	9	44	4.7
75	Victoria Volcanic Plain	78	73	2.52	2		4.7
76	Warren	44	55	2.82	36	14	8.1
77	Woolnorth	37	19		29	12	9.3
78	West and South West	5	7	2.95	18	19	49.0
79	Wet Tropics	23	22	0.93	35		16.1
80	Yalgoo	2	4	0.05	0	13	1.1

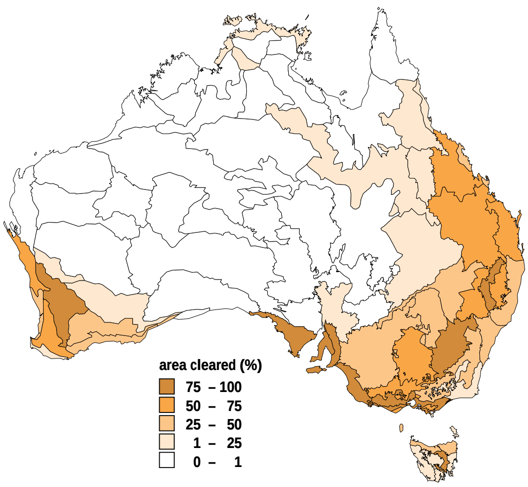
Figure 4.10 Percentages of terrestrial biogeographic regions used for commercial forestry on public land



Source: compiled by ANCA.

Commercial forestry affects far fewer regions than clearing or grazing and is strongly concentrated in the south-east and south-west. Its overall effects on biodiversity can, however, still be substantial because forests are richer biologically than other terrestrial habitats.

Figure 4.11 Percentage areas of vegetation cleared in terrestrial biogeographic regions



Source: compiled by ANCA.

The most extensive clearing has been in regions that are both topographically and climatically suitable for large-scale cropping or improved grazing. These form a band from east to west in the southern half of the continent and include Nandewar, New England Tablelands, New South Wales South-Western Slopes, Riverina, Victoria Midlands, Victoria Volcanic Plain, Naracoorte Coastal Plain, Lofty Block, Eyre and Yorke Blocks and the Avon Wheatbelt.
Source: estimates of cleared areas are derived from two sources. The major one is the Australian Heritage Commission wilderness inventory which is a compilation of information supplied by the States and Territories, except Western Australia. For south-western Australia, clearing data come from interpretation of satellite imagery by the Environmental Resources Information Network.

Marine regions, like terrestrial ones, can be defined at many scales. For example, the Gulf of Carpentaria is a large marine region with much internal variation in physical and biological characteristics. The eastern side contains large estuaries with extensive mangroves, fine sediments, high turbidity and lowered salinity in the monsoon season. On the western side, much of the coastline is rocky, sediments are mainly coarse, the water is relatively clear and extensive beds of seagrasses grow in sheltered areas. Further subdivision of these large areas is also possible using biological and physical data.

Ecosystem diversity

Researchers have used satellite imagery to examine changes in land cover on the Australian continent (Graetz *et al*., 1995). They found that 39 per cent of the continent was in the intensive-land-use zone (characterised by clearing for cropping, pasture, plantation and urban development) and 61 per cent in the extensive-land-use zone (the central core of the continent characterised by pastoral activities on native vegetation and unallocated land).

The extent of clearing of native vegetation in the intensive-land-use zone ranged from 30 to 99 per cent with a mean value of 47 per cent. Within this zone, the remaining land cover was highly fragmented. In the extensive-land-use zone, 26 per cent of the area had significant disturbance to land cover and 15 per cent had been substantially disturbed. Land cover over 48 per cent of the continent is either significantly or substantially disturbed and no vegetation types remain completely unaffected by human activities.

Processes threatening major terrestrial ecosystems

In contrast to species, ecosystems have no nationally agreed classification system and, more importantly for this report, no agreed listing of the extent to which they are threatened. It is also difficult to specify when an ecosystem is extinct. How many of the components have to be lost and what degree of alteration of processes is necessary to make such a proclamation? This report uses the extent of various threatening processes in each biogeographic region to summarise the state of our ecosystems. In this way, it is possible to make some national generalisations about the patterns of impacts on major Australian ecosystems and to augment these with some examples of altered ecosystems at finer scales than the national classification.

Figures 4.10 and 4.11 illustrate the continental patterns of two threatening processes in terrestrial environments — forestry and clearing/intensive production. The overall extent of both is summarised in Table 4.5. Clearing combines the impacts of human settlements and transport systems, cropping and the mechanical removal of woody vegetation for increased carrying capacity of stock. Of these, clearing for human settlements and associated activities is relatively minor in extent and strongly concentrated on the south-eastern seaboard, with smaller areas in the south-west and north-east. Human settlements, therefore, affect mainly the biogeographic regions in coastal parts of the continent and cover small percentages of their total areas. Nevertheless, urbanisation can have severe impacts on ecosystems defined at finer scales than IBRA regions. For example, some of the vegetation types in the Sydney region have been largely eliminated by the expansion of the metropolitan area while others are still extensive (Benson and Howell, 1990).

By far the largest proportion of clearing has been for cropping and grazing, either on improved or unimproved pastures. The extent of these impacts is demonstrated by the fact that 49 of the 80 biogeographic regions are affected to some extent (see Table 4.5). Incentives for clearing are largely determined by rainfall, soil type and available stream flow for irrigation. Clearing is therefore concentrated in the south-west, the east and the monsoonal north (see Figs 4.11 and 6.6).
Large variations in the percentage of area cleared exist between biogeographic regions. The highest percentages are in regions that are both topographically and climatically suitable for large-scale cropping or improved grazing. Overall, most of the southern half of the continent is highly disturbed by clearing.

Percentages of biogeographic regions cleared give a national picture but hide variation in land use at finer scales. In the Avon Wheatbelt of Western Australia, clearing has avoided the more rugged outcrops (see the box on page 4-13). Similarly, in the New South Wales North Coast biogeographic region, overall clearing is about 37 per cent but this has been highly selective (see the image on page 4-27). Some ecosystems such as the ‘Big Scrub’, formerly the largest tract of subtropical rainforest in Australia, are almost completely cleared because they possess rich soils and gentle topography. Other large parts of the region are still trackless wilderness because they are topographically unsuitable for intensive land uses.

The national patterns of clearing are complemented by accounts of clearing in other

A snapshot of change to some of Australia’s ecosystems: 1788–1995

- Seagrass beds in temperate areas have declined significantly.
- About 43 per cent of forests have been cleared.
- More than 60 per cent of coastal wetlands in southern and eastern Australia have been lost.
- Nearly 90 per cent of temperate woodlands and mallee have been cleared.
- More than 99 per cent of temperate lowland grasslands in south-eastern Australia have been lost.
- About 75 per cent of rainforests have been cleared.

ecosystems. Forests, for example, are among the least-extensive ecosystems in Australia, but are rich biologically. Of the original nine per cent of the continent that was once forested, only five per cent remains (AUSLIG, 1990) (see Chapter 6). Rainforests are thought to have once covered more than 80 000 sq km, but are now reduced to 20 000 sq km. Much of the remaining rainforest is in steep and inaccessible areas, on infertile soils, whereas most of that cleared was in lowland and tableland areas with more fertile soils (Winter *et al*., 1987). Given the often specific requirements and limited distribution of rainforest organisms, there is a real possibility that clearances have already resulted in massive loss of biological diversity.

Until recently, the importance of grasslands to the conservation of biodiversity has been neglected. For a long time, graziers have regarded many grasslands as natural pastures. Only about 10 000 ha of the original grassland vegetation of south-eastern Australia is still intact, which represents only 0.5 per cent of the original area (Kirkpatrick *et al*., 1995). Less than 0.2 per cent of Victoria's original grasslands now remain in fragmented remnants, mostly restricted to roadsides, railway lines, cemeteries and lightly grazed unimproved pastures. Some 21 species of vertebrates originally found in grasslands in Victoria are no longer present in that State and six are extinct (Victorian Department of Conservation and Natural Resources, 1992). More than 83 per cent of the original lowland grasslands and grassy woodlands in Tasmania have been destroyed or greatly modified.

Only about five per cent of the more than six million hectares of brigalow (*Acacia harpophylla*) in Queensland still remain (Biodiversity Unit, DEST, 1995). Other woodland communities have been entirely eliminated. For example, no natural stands remain of *Eucalyptus crenulata*, a Victorian endemic. Others are close to elimination: grassy woodlands of white box (*E. albens*) on the central and western slopes of New South Wales have only 0.01 per cent of their original area in approximately natural condition — these survive in four small sites on roadsides and in cemeteries (Prober and Thiele, 1993).

Grazing by domestic stock is the most widespread of the threatening processes listed in the Table 4.5. It affects most of the continent to some extent, occurring in almost all of the 80 biogeographic regions. While grazing often involves clearing in wetter regions, the most extensive grazing in the country is on native vegetation in the arid and semi-arid zones. Low densities of livestock in arid areas can be at least as damaging to soil, vegetation and fauna as higher densities in wetter regions. This is because the arid rangelands are less productive and so have a much lower carrying capacity for stock. It is also possible that stock grazing in the arid zone has serious impacts on some restricted ecosystems such as the isolated, relatively moist refugia on which many native as well as introduced animals rely during droughts (Morton, 1990; Morton *et al*., 1995).

Landsat image of part of the New South Wales North Coast biogeographic region; altogether, about 37 per cent of the region is cleared, but, as the image shows, clearing has been highly selective. Some environments are still completely forested while others have almost no natural vegetation remaining.

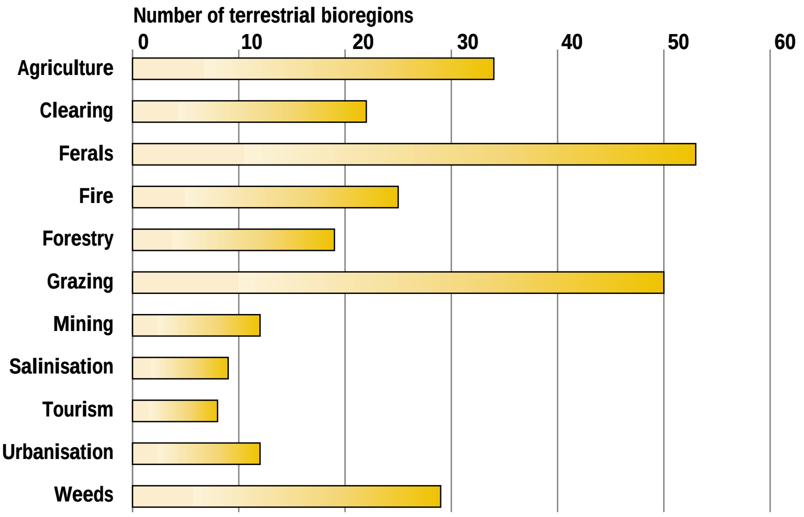
Commercial forestry affects relatively few biogeographic regions and relatively small areas of the continent (see Fig. 4.10 and Table 4.5), although the high biological diversity of forests calls for careful management of logging and associated activities. Forestry alters hydrology (increasing erosion and sedimentation), removes the major structural components of the ecosystem such as foliage, canopy and root systems and reduces the availability of suitable habitat for many animals including forest-dependent endangered species, particularly arboreal mammals.

No national figures are available on the extent of mining, but the overall distribution of this threatening process is indicated by the number of major mines and potentially exploitable mineral deposits (see Table 4.5 and Fig. 6.3). Although some mines are extensive, the total area of land directly affected by mining in Australia is small relative to the other threatening processes shown in the table. Much progress has been made in recent decades with techniques for rehabilitation of mined sites, although serious impacts from some mined areas persist. These include long-term changes to soil profiles and topography after sand-mining in coastal dunes. Sand-mining on the coast of New South Wales and Queensland has also destroyed extensive areas of coastal forest, heathland and swamps. Processing of minerals has led to pollution with heavy metals in areas such as estuaries in Tasmania, with unknown effects on marine organisms. On land, smelter gases have devastated vegetation in places such as Queenstown in Tasmania (see photograph on page 4-22).

Other threatening processes discussed earlier in this chapter and not covered in Table 4.5 are pollution, introduced species and climate change. These pressures do not lend themselves to geographic analyses in the same way as those in the table and, in the case of climate change, the potential effects at the ecosystem level are still uncertain.

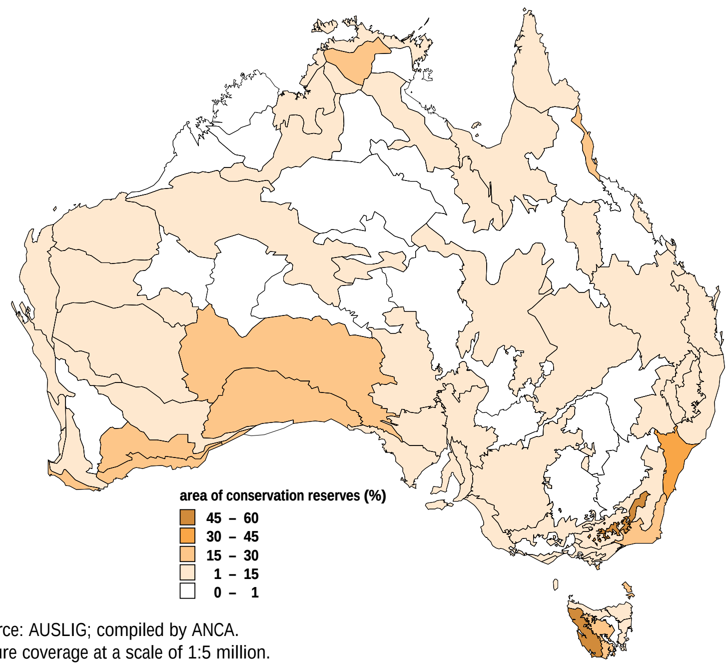
The important threatening processes in each terrestrial biogeographic region are summarised in Fig. 4.12 (Thackway and Cresswell, 1995). The results support the analyses in Table 4.5 regarding

Figure 4.12 Number of terrestrial biogeographic regions in which each of 11 threatening processes are considered important by State and Territory conservation agencies



Source: Thackway and Cresswell, 1995.

Figure 4.13 Percentage of biogeographic regions covered by nature conservation reserves



Source: AUSLIG; compiled by ANCA.
Tenure coverage at a scale of 1:5 million.

Table 4.6 Assessments of the condition of terrestrial biogeographic regions

Assessment by State and Territory conservation agencies	No. of regions
Natural ecosystems dominant with no known risk	5
Natural ecosystems dominant with no widespread degrading land uses but processes of disturbance present	19
Natural ecosystems present but coexisting with pastoral or timber industries	40
Modified ecosystems dominant with natural ecosystems occupying a very small proportion of the regions	16

Source: Derived from Thackway and Cresswell, 1995.

the relative extent of clearing, grazing, forestry and mining. They also emphasise the widespread problem of feral animals and weeds for nature conservation at the regional level and indicate that land managers in many regions perceive altered fire regimes as an important issue.

The information indicates that all biogeographic regions have been affected to some extent by one or more threatening processes. Some have been largely altered from their pre-European condition and others severely changed over small areas. While it is not possible to create a reliable index of ecosystem condition from these data, several pieces of information help to illustrate the condition of terrestrial ecosystems in Australia.

A general recognition that some ecosystems are more prone to serious impacts than others has led to a process for proposing and listing endangered ecological communities under the *Endangered Species Protection Act 1992*. In New South Wales, Benson (1991) has rated major vegetation groups according to reservation status and degree of threat in a similar way to previous ratings for plant species (Briggs and Leigh, 1988). Of 432 vegetation groups, he considered 27 (six per cent) to be endangered and 84 (19 per cent) to be vulnerable. A national view comes from assessments by State and Territory conservation agencies of the overall condition of each biogeographic region (Thackway and Cresswell, 1995) (see Table 4.6). Only five regions (six per cent) are considered to be largely natural with no significant impacts. Alteration is widespread in 56 (70 per cent) and almost complete in 16 (20 per cent).

Analysis of major threatening processes gives no indication of the extent of impacts on fresh-water habitats. Large areas of Australian wetlands have been seriously altered by factors such as drainage, filling, alteration of stream flows, changed burning regimes and invasion by weeds and introduced animals (Pressey and Adam, 1995). Overall, the greatest loss and degradation of wetlands and impacts on flowing waters have occurred in agricultural districts (see Chapter 7).

Table 4.7 summarises the condition of marine ecosystems for each interim marine region. For more detail on marine and estuarine habitats, see Chapter 8.

Protected areas

The condition of ecosystems can sometimes also be inferred from the extent to which they are represented in protected areas. Like threatening processes, the patterns of protected-area coverage vary widely between biogeographic regions. There is no clear geographical pattern (see Table 4.5 and Fig. 4.13), but many biogeographic regions are below the 10 per cent level of representation recommended by the IUCN. This assessment says something about the need for more protected areas and the degree to which regions are separated from threatening processes. However, the figures need to be qualified carefully. Extent is not equivalent to effectiveness for protecting biodiversity for a number of reasons.

Table 4.7 Summary of condition of marine regions

North Coast
Estuaries and coast generally in good condition. Impact of prawn trawling not known but large amounts of bycatch are discarded.

North West Coast
Coast and estuaries generally in good condition. Some wetlands destroyed for salt production. Significant traffic in bulk carriers for gas and iron ore. Impact of prawn trawling not known. Offshore, the seabed is recovering from damage from fish trawling.

Central West Coast
Coast generally in good condition. Impact of prawn trawling and lobster fishing not known.

Lower West Coast
Estuaries in the south are eutrophic. Inshore waters generally in good condition, especially in the north. The impacts of a large commercial rock lobster fishery and extensive recreational fisheries are not known. A natural predator *(Drupella)* is damaging corals.

South West Coast
Localised pollution, severe in some places, has been reduced in recent years. Impacts of fisheries for shark and abalone as well as a purse seining fishery are not known. Inshore waters in good condition.

Great Australian Bight
Coastal waters generally in pristine condition.

South Gulfs Coast
Gulf St Vincent and northern parts of Spencer Gulf are polluted by nutrients and heavy metals. Major loss of seagrasses associated with sewage discharges. Heavy recreational and commercial fishing pressure in finfish, abalone and lobster. This pressure is exacerbated by large-scale illegal fishing for high value shellfish. Impacts of the prawn trawl fishery are unknown.

Bass Strait
Bass Strait has exceptionally high biodiversity of seabed organisms which, in the case of Port Phillip Bay, appear to be crucial in preventing eutrophication from the high input of nutrients. Extensive seagrass loss has occurred in Westernport Bay, possibly through siltation or pollution. Other impacts include introduced marine pests and scallop dredging. Effects of the large recreational and commercial fisheries on finfish and abalone are not known but populations of rock lobsters have declined and poaching of shellfish is increasing the pressure of harvesting.

Tasmanian Coast
Some inshore areas such as the Derwent estuary are badly polluted by heavy metals. Introduced species such as starfish, macroalgae and dinoflagellates are posing threats to a large aquaculture industry. The high wave energy coasts are in good condition. Impacts of large abalone and lobster fisheries are not known.

North East Coast
Much of the coast is adversely affected by run-off of nutrients and silt from coastal catchments. Extensive urban development in the south and central areas have affected coastal habitats. There has been a major loss of wetlands through ponding of coastal flats for pastures. Impacts of the large trawl fishery for prawns and scallops are not known.

Lower East Coast
Extensive impacts from urban and tourist developments, agriculture, and commercial and recreational fishing on the estuaries which are subject to pollution. The coast is mainly in good condition except near centres of population. Impacts of fish and prawn trawling are not known.

Central East Coast
Extreme impacts from urban and tourist developments, agriculture,and commercial and recreational fishing on the estuaries which are subject to pollution. Acid sulfate soils are a problem for water quality caused by drainage of the coastal floodplains. Impacts of prawn trawling not known.

Great Barrier Reef
Subject to an overall management plan with zoning for conservation, tourism, fishing and research. Generally in good condition but there has been loss of coastal coral reefs, apparently from nutrient enrichment of coastal waters due to nearby land use. Impacts of prawn trawling and recreational and commercial line fishing are not known.

Gulf of Carpentaria
Generally pristine but localised impacts from dredging for port access. Impacts from prawn trawling in coastal waters are not known but large amounts of bycatch are discarded.

North West Oceanic
Generally pristine. Adverse impacts could come from the offshore extraction of gas and petroleum

West Oceanic
Apparently pristine

South Oceanic
Longline fishery in the south affecting seabirds. Impacts of finfish trawl fishery in the Bight are not known.

South East Oceanic
Deepwater seabed in the northern section is generally pristine. Deepwater trawl fisheries (up to 1000 m depth) in the south on seamounts could have adverse impacts on seabed fauna. Longline fishery around the edge of the continental shelf adversely affecting seabirds.

North East Oceanic
Pristine.

Major ecosystems are heterogeneous in terms of physical and biological characteristics. High overall percentages in reserves can mask the fact that much internal variation is unprotected. In north-eastern New South Wales, for example, about seven per cent of the region is covered by national parks and nature reserves but some environments are protected poorly or not at all (Pressey, 1995). High levels of bias in the distribution of reserves within ecosystems are common in Australia (Thackway and Cresswell, 1995). Within many ecosystems, protected areas are concentrated in environments least prone to disturbance from intensive land uses while the most vulnerable environments are missed (see the box on page 4-52).

The effectiveness of protected areas also depends on the types of threatening processes operating, funding for management and the size and boundaries of the areas. Strict reserves are generally good at preventing the effects of clearing, grazing by domestic stock, forestry and mining. For other threatening processes, they are less useful. Reserves do not protect against introduced species without intensive management to control weeds and feral animals. They can be subject to run-off and sedimentation from surrounding land uses if their boundaries are not aligned with catchments. No matter how well managed the reserve itself, species can be lost if their food sources in one season are outside the reserve and lost to clearing. Species can also be lost if reserves are too small to maintain populations of sufficient size to escape the problems of chance population changes that lead to extinction. In fragmented landscapes, only relatively small areas of natural habitats remain. Although this limits the viability of some species, many others will persist. Fragments offer the only chance of protecting parts of ecosystems that are heavily cleared and are vitally important for conserving biodiversity.

The state of species diversity

Of the 12 nations in the world that contain major repositories of species diversity, Australia is the only developed country. Others include Indonesia with its wealth of islands and different habitats, Zaire in equatorial Africa and Brazil with its expanses of rich tropical rainforests, rivers and mountains. The state of species diversity in Australia — particularly the large proportions of some groups that are threatened by the pressures outlined earlier — is cause for national concern.

The species is the basic unit of biological classification. It is defined as a group of interbreeding (or potentially interbreeding) natural populations that are reproductively isolated from other such groups. Certainly for organisms like larger plants and animals this is a useful definition. For micro-organisms, however, it poses considerable problems with identification. The species concept is difficult to apply to organisms with different modes of reproduction from the 'higher' organisms. Even some larger life forms such as algae and lichens are under-represented in censuses of biodiversity because of problems of identification.

Table 4.8 Estimated extent of Australia's species diversity and of those formally described

Major group	Estimated no. of species	Percentage described
Micro-organisms		
Protozoans	65 000	40
Fungi	160 000	5
Bacteria	40 000	0.1
Invertebrates		
Arthropods		
Coleoptera (beetles)	30 000	67
Lepidoptera (moths and butterflies)	20 000	53
Hymenoptera (ants, wasps and bees)	23 000	33
Diptera (flies and mosquitoes)	11 000	75
Other insects	15 000	20
Arachnids (e.g. spiders and mites)	39 000	14
Crustaceans (e.g. crabs and prawns)	18 000	5
Springtails	2 500	14
Other arthropods	?	?
Molluscs (e.g. snails, oysters, squid)	19 000	?
Sponges	1 400	28
Nematodes	150 000	1
Other invertebrates	?	?
Vertebrates	5588	90+
Plants		
Higher plants	20 000	90+
Algae	22 000	50

Estimates were taken from several published sources, each of which is not comprehensive. For some groups the level of knowledge is so poor that estimates are unavailable and are indicated by '?'. Sources are Kennedy, 1990; Williams, 1990; Castles, 1992 and Biodiversity Unit, DEST, 1994. Updated information was obtained from CSIRO Division of Entomology, Australian Museum, Queensland Museum and ABRS.

Species inventory

Despite these difficulties, we still need to estimate the extent of biodiversity. To do this, we usually count published, recognised species. For groups that are poorly collected and described, we use estimates of species richness based on the rate at which new species are being discovered and described (see Fig. 4.14). This rate is high and not diminishing. Table 4.8 illustrates the strong bias in knowledge towards large, conspicuous life forms and shows that most biodiversity is either invertebrate or microbial. Australian flowering plants are reasonably well known, as are the vertebrate animals, but many of our invertebrate groups are poorly known — both poorly collected and not yet adequately described. However, even for conspicuous life forms, new species are still being discovered (see the box on the Wollemi pine).

The outlook is not good for those groups of organisms where scientists estimate only a small fraction have been described. Many of these species may become extinct before they are collected and described. This lack of information (highlighted on page 4-51) about something as basic as inventory points out one of the most important issues relating to biodiversity — our ignorance. It is extremely difficult to respond to changes in the state of biodiversity if we do not possess the basic information about what it is and how it is distributed. The best approach may be to select groups for study that have known biological significance rather than trying to catalogue parts of all groups.

Australia is one of the world's six floristic realms — regions of the world supporting a characteristic flora. Most of our plant species are found naturally only here. However, the special nature of our flora is not limited to its global uniqueness. We have some of the world's most primitive plants, now found only in the rainforests of northern Australia.

Much of our terrestrial vegetation is dominated by eucalypts and acacias. Most forests and woodlands feature several species of eucalypts, while acacias dominate the extensive shrublands of the inland. Each genus has more than 700 species, almost all of which occur naturally only here. Neither group is distributed evenly across the continent. The acacias are particularly abundant in the semi-arid region of southern Western Australia while the eucalypts are richest in the south-eastern region. The recent assessment of the Blue Mountains in New South Wales for World Heritage Listing showed that parts of this area contain the greatest variety of eucalypt species anywhere.

The animal kingdom provides similar striking examples. Australia has two of the only three species of monotremes (egg-laying mammals), it has a large proportion of the living marsupials (pouched mammals) and it is the only nation to have the large arid-adapted kangaroos.

The numbers of taxa listed in different families of plants depend on the extent to which they have been studied. Recent research on eucalypts for example, has doubled the known number of species. Our knowledge of the distribution of species is also incomplete; for some groups, a map at one degree resolution is unreliable. Even for well-known groups, the data become patchy as we move to finer scales. In one of the best surveyed parts of Australia, the south-east forests of New South Wales, all the survey plots add up to only 0.1 per cent of the landscape.

Number and distribution of species

Of the four groups of vertebrate animals for which data are available, bird species are most numerous along the east coast and in the south-eastern region; their numbers diminish in the arid interior (see Fig. 4.15). In contrast, reptile species-richness is high in the arid zone and the tropics. The pattern for mammals is different again, with high numbers along the eastern margin of the continent and in the far north, the south-west and part of the arid zone. Lastly, amphibian species-richness is highest for parts of the eastern region and across the north, with some pockets in the south-west.

Our seas also support many forms of life unique to this region. For example, Australia has an extremely diverse flora of macroalgae (seaweed). Temperate waters alone contain nearly 1200 species, of which 62 per cent are endemic. Bass Strait has more than 500 species. The introduction of Japanese kelp to Tasmania, probably in ballast water, appears to be threatening indigenous macroalgae because it grows rapidly and smothers other species. This invader is spreading along the Tasmanian coast at a rate of between four and 40 km a year.

Australia has about 30 species of seagrasses (see page 8-24 and Table 8.8). They form rich beds in shallow water and are important as nursery grounds for the juvenile stages of many species of crustaceans and fish. Seagrasses have suffered severe reductions in recent years from a variety of causes, including pollution and siltation as well as natural causes such as floods and cyclones. The most recent major loss resulted from the construction of the third runway at Sydney Airport, which destroyed an important seagrass bed in New South Wales by filling part of Botany Bay.

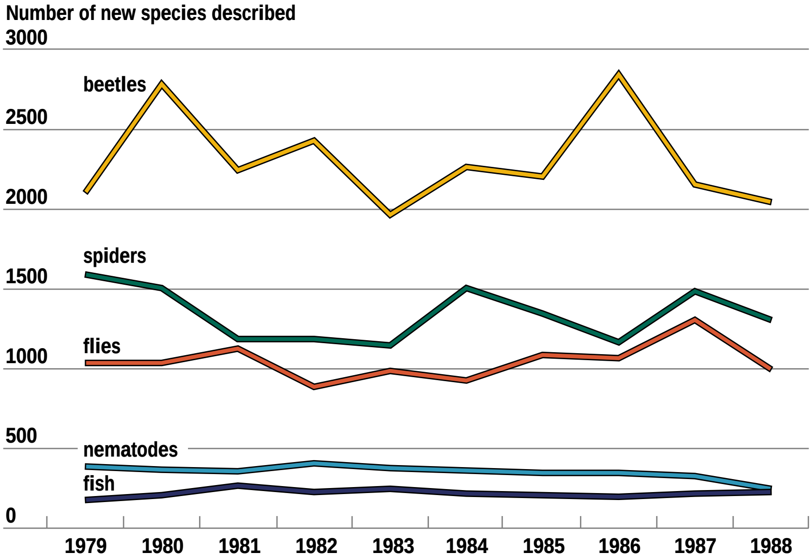
Although a high proportion of our temperate marine plants and animals are endemic, most tropical marine fauna are Indo-West Pacific. This means that many species are also found in the Indian and Western Pacific Oceans. For example, the blue swimmer crab (*Portunus pelagicus*), also known as the manna or sand crab, occurs in the Pacific and Indian Oceans and the Red Sea and has even extended into the eastern Mediterranean by migrating through the Suez Canal. Such wide distributions have, however, not lessened the threat to many species. Massive clearance of mangroves in South-East Asia for aquaculture as well as destructive fishing practices, including the use of explosives on coral reefs, have severely depleted many tropical marine habitats in the Indo-Pacific.

Australia now has the largest intact coral reef in the world and some of the best-preserved mangrove forests. Some species, such as turtles and dugongs

The Wollemi pine — a relic from the age of dinosaurs

The discovery in December 1994 of a new kind of tree near Sydney caused great excitement, as Australia's flora is considered to be well known. The Wollemi pines (*Wollemia nobilis*) reach about 35 m in height with a main trunk up to one metre in diameter. The discovery of a new species of tree, especially one that grows to such an impressive height, is extremely unusual. The habitat of the trees — protected steep-sided canyons north-west of Sydney, which acted as refuges from fires that frequently burn the adjacent plateaus — contributed to their continued existence. The tree, given the common name of 'pine', is a conifer but is closer to the Norfolk Island pine than to the true pines. The discovery is a dramatic demonstration that parts of our biological heritage remain unknown.

Figure 4.14 The number of new species described each year world-wide for five groups



Source: derived from World Conservation Monitoring Centre, 1992.

Figure 4.15 The distributions of species-richness for four vertebrate groups

Grid cells (one degree of latitude by one degree of longitude). The boundaries indicate Interim Biogeographic Regions for Australia.

Source: compiled by ANCA

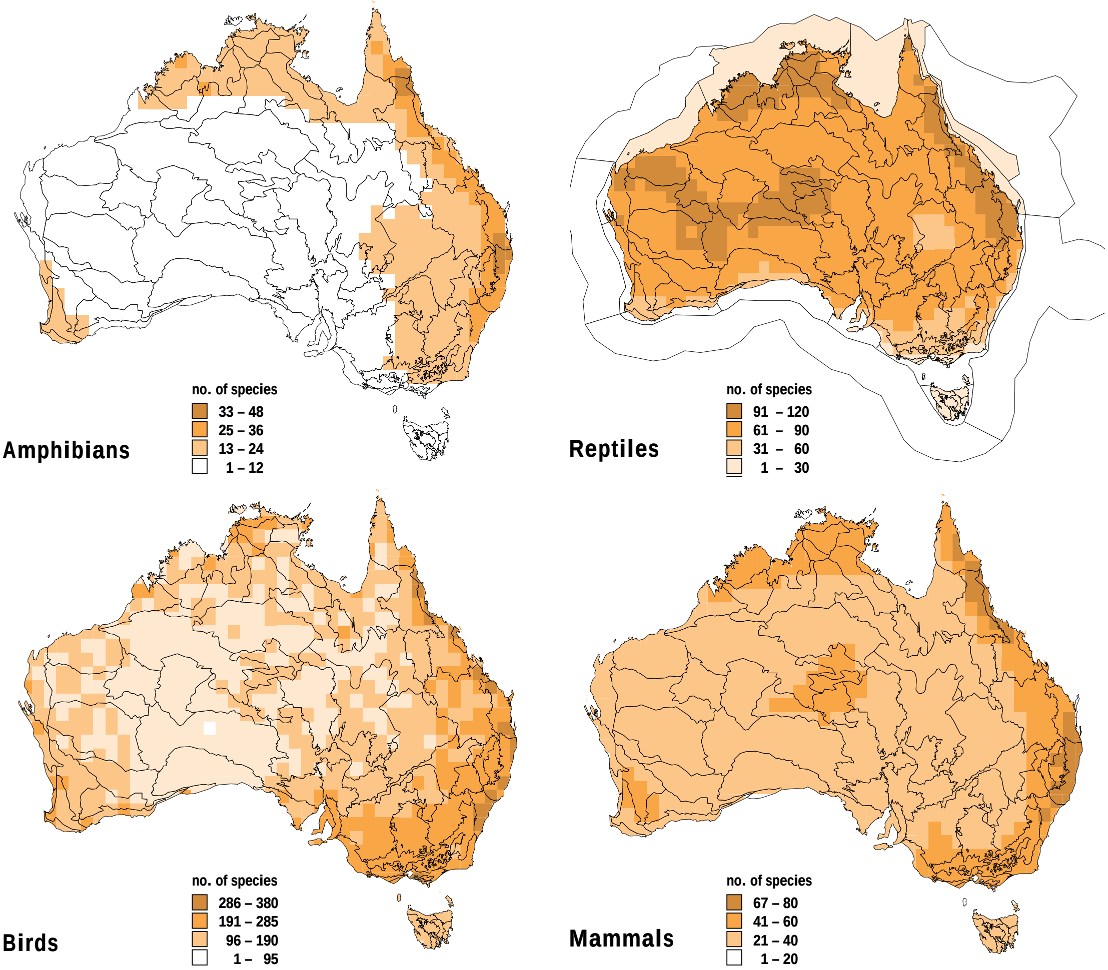
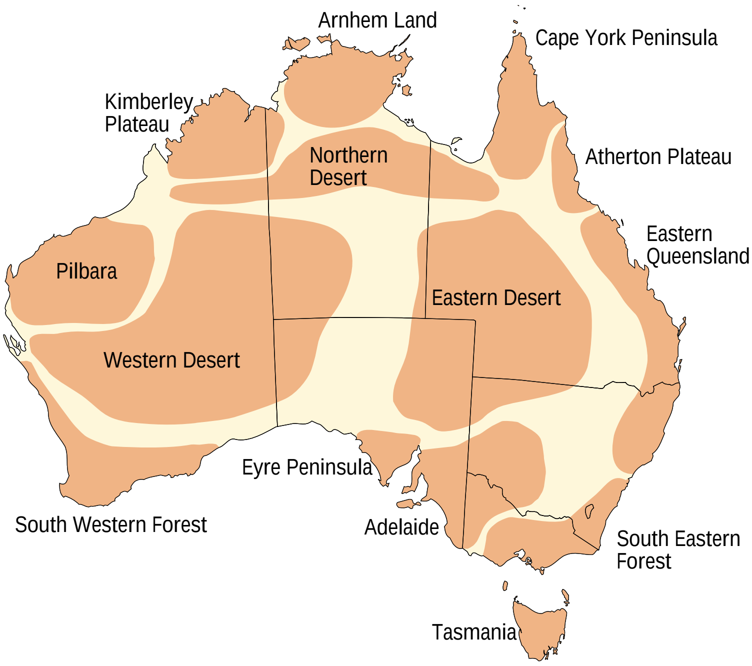


Figure 4.16 Areas of endemism based on distribution patterns of birds



Each of the 14 recognised areas has a unique assemblage of bird species.
Source: Cracraft, 1991.

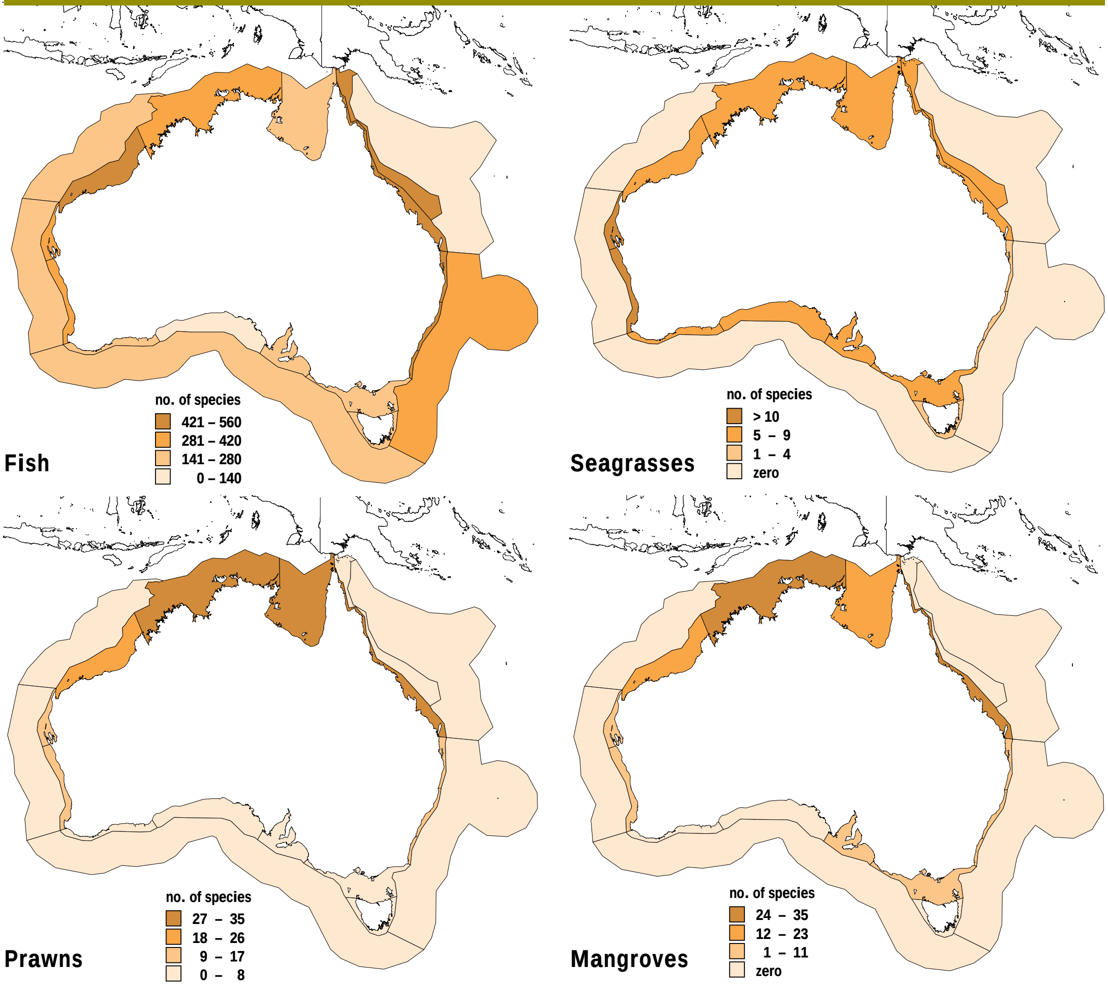
(*Dugong dugon*), may eventually survive only in Australian waters. Hence, the conservation of Australia's tropical marine flora and fauna is of global significance.

Some of the sea's most-threatened species are edible ones that, unlike most marine species, are (or were) abundant. Modern fishing techniques are extremely efficient and overseas experience shows it is possible to fish formerly abundant species to near extinction. Many exploited marine species are now subject to management plans that seek to exploit them at sustainable levels or try to rebuild depleted stocks. Nevertheless, several formerly abundant animals have been reduced to seriously low levels. They include eastern gemfish and eastern rock lobster off New South Wales, school shark and southern rock lobster off Victoria, King George whiting off South Australia and southern bluefin tuna in the Southern Ocean.

Status of species

All groups of higher plants and vertebrates have species that are highly threatened. The real situation is worse than indicated in Table 4.9 because many groups include species in decline. The cumulative effect on birds of the threatening processes will be accelerated loss of bird species paralleling the loss of mammal species (Recher and

Figure 4.17 Number of species of fish, seagrasses, prawns and mangroves by marine region



Source: compiled by ANCA.

Lim, 1990). Many species of frogs are declining in part of their range and several, including the unique gastric brooding frog (*Rheobatrachus silus*), have disappeared in recent years (Tyler, 1994). Tables 4.9 to 4.18 and Fig. 4.18 indicate the current conservation status of various groups of Australian plants and animals.

Australia's record of mammal species extinctions is the worst for any country. In the past two centuries, the country has lost ten species of the original marsupial fauna of 144 species and eight of the 53 species of native rodents (see Table 4.17). More than one hundred mammal species are considered endangered, vulnerable or potentially vulnerable. This number includes marine mammals such as dugong. Some marine species, like whales and seals, which were hunted in Australian waters until recently, now show signs of recovery. The sightings of whales close to the coast, even within Sydney Harbour, herald a positive response to embargos imposed on harvesting.

Many species were illustrated or even photographed before becoming extinct. For example: the Tasmanian tiger (*Thylacinus cynocephalus*) — last specimen died in 1936; the pig-footed bandicoot (*Chaeropus ecaudatus*) — last recorded sighting 1907; the desert rat kangaroo — (*Caloprymnus campestris*) — 1935; lesser bilby (*Macrotis leucura*) — 1931; long-tailed hopping-mouse (*Notomys longicaudatus*) — 1901; lesser stick-nest rat (*Leporillus apicalis*) — 1933; Alice Springs mouse (*Pseudomys fieldi*) — 1895; Darling Downs hopping-mouse (*Notomys mordax*) — 1840s.

Not surprisingly, the main regions containing threatened species coincide with those of high species-richness. However, there are some

The lesser bilby *(Macrotis leucura)* was last recorded in 1931.

Table 4.9 The status of flowering plants and vertebrate animals

Major group	Estimated number of species	Percentage of endemic species	Number presumed extinct (since 1788)	Number of endangered species	Number of vulnerable species	Number of naturalised (introduced) species
Flowering plants	20 000	85	76	301	708	1500– 2000
Fish						
freshwater	195	90	0	9	8	21
marine	4000	13 (tropical inshore)	0	0	-	8
		85 (temperate inshore)				
Amphibians	203	93	3	10	19	1
Reptiles	770	89	0	11	40	2
Birds	777 (1074 species and subspecies)	45	20[1]	25	25	32
Mammals (terrestrial)	268	84	19	25	18	25

1. Nineteen once existed on Australian territorial islands, including Lord Howe and Norfolk Islands; only one is extinct on the mainland.

Table 4.10 The conservation status of Australia's freshwater fish

Conservation status	Number of species	Percentage of estimated total
Presumed extinct	0	0
Endangered	9	4.1
Vulnerable	8	3.7
Poorly known	19	8.8
Rare	36	16.6

Approximately one-third of the species are either threatened or rare. Source: derived from Wager and Jackson, 1993.

Table 4.11 The conservation status of Australia's reptiles

Conservation status	Number of species	Percentage of estimated total
Presumed extinct	0	0
Endangered	11	1.4
Vulnerable	40	5.2
Rare or insufficiently known	148	19.2

A total of 770 species of Australian reptiles has been identified from a world total of approximately 6500 species.

Source: derived from Cogger *et al.*, 1993; H.G. Cogger (pers. comm.).

Table 4.12 The conservation status of Australia's amphibians

Conservation status	Number of species	Percentage of estimated total
Presumed extinct	3	1.5
Endangered	10	4.9
Vulnerable	19	9.4
Indeterminate	2	1.0

A total of 203 species of Australian amphibians has been identified from a world total of approximately 4000. It is estimated that a further 25–30 species in Australia await discovery.

Source: derived from Tyler, 1994.

The meaning of rarity and threat

Rarity, while it can predispose some species to extinction, can be a natural, inherent characteristic that has nothing to do with the pressures discussed earlier in this chapter. In some cases species are rare because of human pressures, particularly habitat destruction. However, rarity may be the result of a natural condition such as specialised habitat requirements. Most marine species, for example, are rare. A large proportion of the flora of south-western Western Australia is endemic to the region and many of these species are rare. Threat, on the other hand, is explicitly the result of pressures. The conjunction of large numbers of species (including many rare ones) and many threatening processes — especially vegetation clearance for intensive agriculture — leads inevitably to large numbers of threatened species.

Table 4.13 The conservation status of Australia's non-marine invertebrates

Conservation status	Number of species	Percentage of estimated total
Presumed extinct	3	?
Endangered	40	?
Vulnerable	78	?
Indeterminate or insufficiently known	291	?

The number of non-marine invertebrates is unknown, hence no percantage of total can be calculated.

Table 4.14 The preliminary conservation status of Australia's algal, lichen and bryophyte species

Conservation status	Lichens	Bryophytes	Algae
Presumed extinct*	2	12	-
Endangered	94	83	-
Vulnerable	74	43	1
Potentially vulnerable	31	12	6

*Not found during recent surveys.

Information on the conservation status of these groups is poor and there is insufficient information to nominate any species or communities as endangered or rare.

Source: 'Overview of the Conservation of Non-Marine Lichens, Bryophytes, Algae and Fungi', report for the Endangered Species Program, ANCA, 1994.

Table 4.15 The conservation status of Australia's higher plants

Conservation status	Number of species*	Percentage of estimated total
Presumed extinct	76	0.4
Endangered	301	1.5
Vulnerable	708	3.5
Rare	1570	7.9
Poorly known	2376	11.9

*The numbers of species of vascular plants listed in the 1995 CSIRO Rare and Threatened Plants (ROTAP) publication.

Table 4.16 The conservation status of Australian native rodents

Conservation status	Number of species	Percentage of estimated total
Presumed extinct	8	15.0
Endangered	6	11.3
Vulnerable	5	9.4
Rare	4	7.5
Insufficiently known	7	13.2

Rodents, along with marsupials, have taken the brunt of mammal extinctions in Australia since European settlement. Source: derived from Lee, 1995.

Table 4.17 The conservation classification of Australian terrestrial native mammals recorded since 1778

Major group	No. of described extant species	Extinct	Endangered	Endangered as a percentage of total extant
Monotremes	2	0	0	0
Marsupials	144	10	19	13.2
Placentals				
Dingo	1	0	0	0
Rodents	53	8	6	11.3
Bats	68	1	0	0

Principal sources: derived from Kennedy, 1990 and 1992; Williams, 1990; Castles, 1992; Endangered Species Protection Act, 1992, schedules 1, 2 & 3, July 1994; Biodiversity Unit, 1994 and Census of Australian Vertebrate Species, 1994.

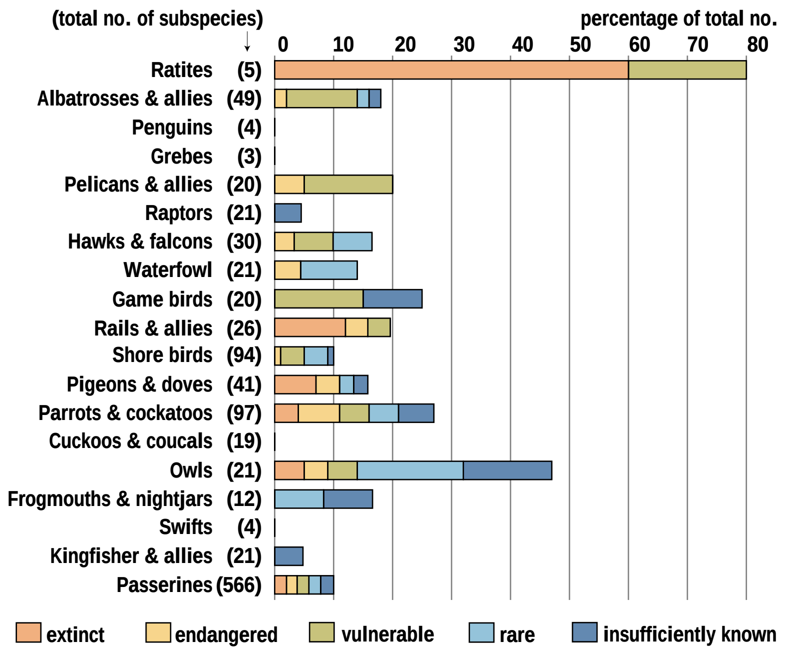
Table 4.18 The conservation status of Australian monotremes and marsupials

Major group	Total	Presumed extinct	Endangered	Vulnerable	Insufficiently known
Monotremes	2	-	-	1	-
Dasyurids	51	1	6	12	1
Bandicoots and bilbies	11	3	2	4	-
Marsupial mole	1	-	-	1	-
Wombats, possums koala and kangaroos	81	6	11	23	1

Australian marsupials are facing many threats. The bandicoots and bilbies are particularly vulnerable.

Source: derived from Kennedy, 1992.

Figure 4.18 The proportion of Australia's birds (by sub-species) that are extinct, endangered, vulnerable, rare or insufficiently known



Source: Garnett, 1992b.

Figure 4.19 Australia's threatened vertebrate species

Numbers of threatened species from each of the four groups for which data are available are shown. The various threat categories are combined. Grid cells (one degree of latitude by one degree of longitude). The boundaries indicate Interim Biogeographic Regions for Australia.

Source: compiled by ANCA.

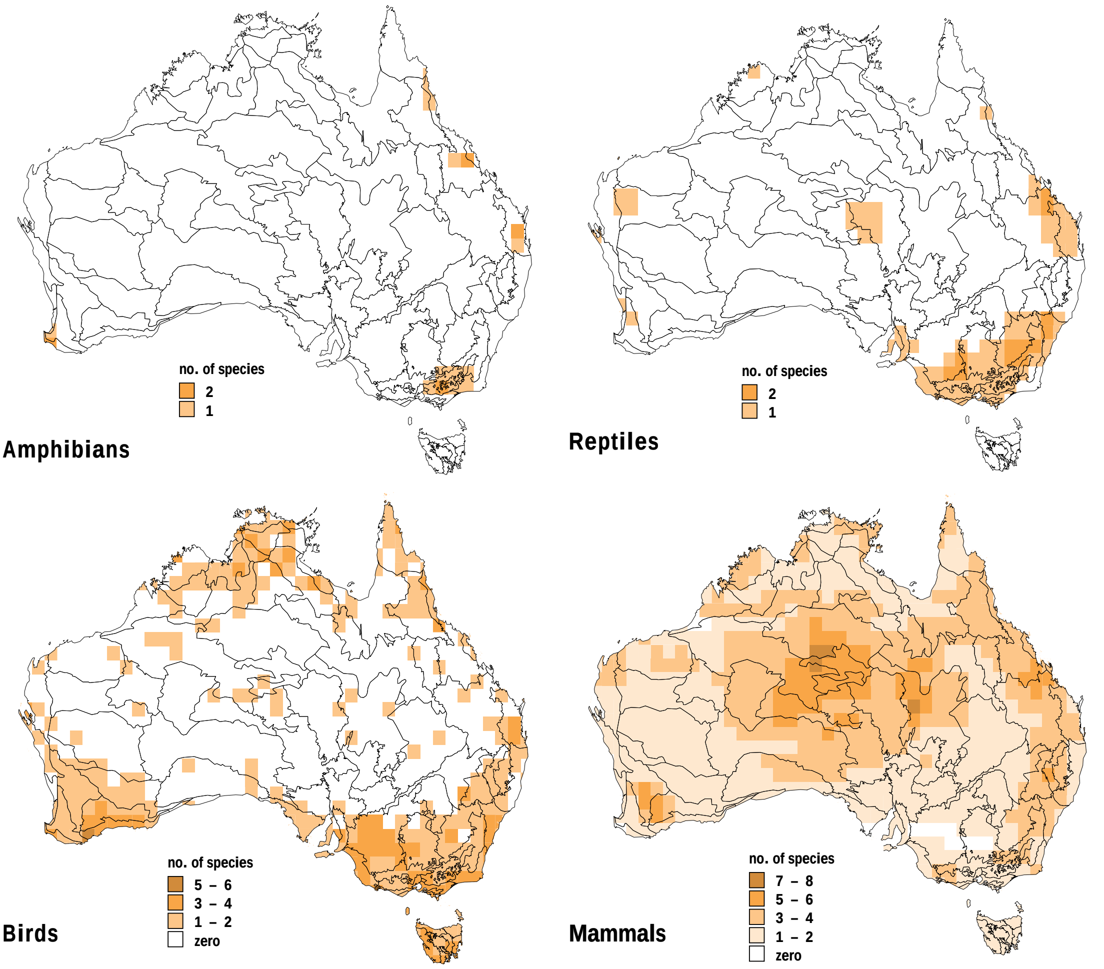
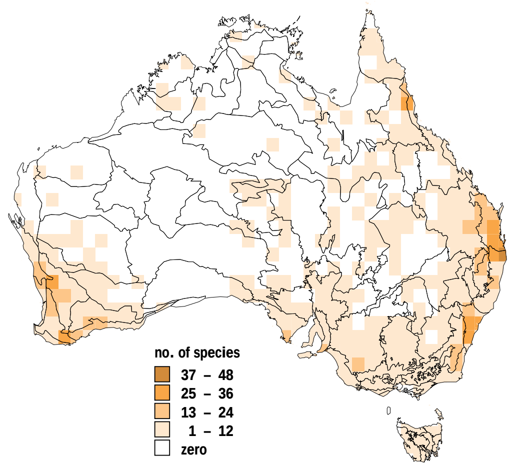


Figure 4.20 Numbers of threatened plant species

Grid cells (one degree of latitude by one degree of longitude). The boundaries indicate Interim Biogeographic Regions for Australia.

Source: compiled by ANCA.



exceptions. For birds, threatened species are mainly concentrated in the south-east, the north and the far south-west. Reptile species are richest in the arid interior, although threatened species are most numerous in the high-rainfall forested south-east of the continent. A strong pattern emerges for mammal species, with arid Central Australia clearly the zone of pressure. The amphibian pattern is a cluster of discrete regions along the eastern margin.

Figure 4.18 shows the proportions of Australian birds (by Order) that are presumed extinct, endangered, vulnerable, rare or insufficiently known. A similar situation exists for Australia's mammals (see Table 4.17). Alarmingly high proportions of each Order are in one of the threat categories. Similarly, 17 species of freshwater fish (see Table 4.10) and 29 species of amphibians (see Table 4.12) are either endangered or vulnerable. Many and varied pressures or threats have led to this situation. One study has been made of the current and former threats affecting Australian birds (see Table 4.2). The main differences between the perceived current threats and those that operated earlier are: altered fire regime, grazing, forestry operations and shortage of nest hollows.

Looking at the continental distribution of threatened plant species (see Fig. 4.20), the south-western region and parts of eastern Australia are clearly regions for concern but action is needed over most of the continent to offset threatening processes. Of Australia's presumed extinct and endangered plant species the overwhelming number are from woodland habitats (Leigh and Briggs, 1994). This reflects both the pressures on this habitat and its vast geographic extent. Combining woodland and scrub reveals 97 instances of endangered plant species — almost half the national total for all habitat types.

Genetic diversity

One measure of the degree of genetic diversity within a species is the recognition of identifiable subspecies. For example, the dingo (*Canis familiaris dingo*) is a subspecies of the domestic dog (*C. familiaris*). Although most inventories are made at the species level, the full diversity may be better expressed at the subspecies level. For example, worldwide the number of butterfly species is thought to total about 17 500; however, the number of currently recognised subspecies is closer to 100 000. The genus *Calyptorhynchus* contains four species of black cockatoo in Australia, but it has nine recognised subspecies.

Good scientific evidence now exists that, as populations decline, the amount of genetic diversity that remains in them is crucial to their survival. Very often, small populations lose genetic diversity and, consequently, suffer lowered fertility and lowered ability to adapt to changing environments. Because populations of many Australian species have declined through habitat loss or fragmentation, genetic issues are crucial to the management of biodiversity for conservation. Although there are relatively few Australian examples, some studies do provide clear illustrations of the genetic effects of habitat destruction and the consequent declines in population size.

Habitat loss and degradation

When habitats shrink, populations decline and lose genetic diversity. This reduces their ability to compete, fight disease or adapt to changing conditions.

Northern hairy-nosed wombat

Unlike the more abundant southern hairy-nosed wombat (*Lasiorhinus latifrons*), which is distributed in forests and grasslands in southern Australia, the northern hairy-nosed wombat (*L. krefftii*) is an example of a rare Australian animal that has experienced severe loss and degradation of habitat and consequent loss of genetic diversity. It is one of Australia's rarest mammals, existing as a single colony of about 65 individuals in Epping Forest, central Queensland.

By using a genetic technique known as microsatellite technology, scientists can detect losses in genetic diversity with astonishing accuracy using a tiny amount of DNA — the amount contained in a single wombat hair is enough. Every individual or population has a distinct complement of microsatellite labels and scientists have strong evidence that the northern species has lost significant amounts of the genetic diversity it once possessed (Taylor *et al.*, 1994). The genetic diversity of the northern species is less than half that of the southern hairy-nosed wombat. Because the two species are closely related and fill similar ecological niches, it is reasonable to expect that they should have similar measures of genetic diversity, especially heterozygosity. The fact that they don't is most likely a direct result of the steep decline in the number of animals, together with a process known as genetic drift, which occurs when the breeding population is so small that too few offspring are born in each generation to successfully carry all of the genetic variability in the parent population.

The population at Epping Forest cannot regain the lost genetic variability except by the long-term process of random mutation, but it is hoped that the problems associated with inbreeding and genetic drift can be overcome through careful management.

Koala

The koala (*Phascolarctos cinereus*) in south-eastern Australia has suffered severe population declines since European settlement due to loss of habitat. An extensive but *ad hoc* program of restocking has led to recolonisation of many regions throughout its original range. Many of the animals have come from the island populations of Westernport Bay in Victoria. These colonies were themselves founded artificially with low numbers and represent a narrow genetic base.

Comparisons of mainland populations derived from island colonies (restocked populations) and undisturbed mainland populations have shown that genetic diversity is severely reduced in the restocked populations (Taylor *et al.*, 1991). This work highlights the need to be cautious when re-establishing locally extinct or depleted populations of endangered species. Thorough characterisation of the genetic variability of remaining colonies will help to ensure that diversity is maximised to give new populations their best hope of survival.

Habitat fragmentation

Many kinds of habitats have become greatly fragmented and, without suitable connecting habitat, the movement of organisms and the mixing of genes are slowed down or stopped. The resulting isolated gene pools may follow different evolutionary paths. If they are too small, they lose genetic variability, especially heterozygosity, more rapidly than if they were connected with each other. Very often small populations isolated from each other are like islands, frequently surrounded by inhospitable 'seas' of urban or rural development (see page 4-13).

Sleepy lizards

The sleepy lizard (*Trachydosaurus rugosus*) is a large lizard that bears live young and is found over much of southern Australia. It experienced a large-scale natural experiment on the genetic effects of fragmentation. As sea levels rose 6000 to 8000 years ago, populations were isolated on offshore islands, preventing gene flow with the mainland. Comparisons of the genetic diversity of island and mainland populations have shown that sufficient time has elapsed to allow significant genetic divergence between them (Sarre *et al.*, 1990). The island populations lack some rare mainland genes — probably because of genetic drift. Changes in the smaller island populations have been greater than those between mainland populations.

Some patterns of genetic diversity

Cryptic species

Animals that look the same may be a complex of cryptic or hidden species distinguished only by genetic means.

Rock wallabies

The rock wallabies (genus *Petrogale*) are found throughout Australia. They live in rocky habitats such as cliffs, gorges and boulder outcrops. Researchers have investigated the problem of distinguishing those that are merely races, between which gene flow can still occur, from those that are true species, where it does not. The most informative genetic technique used so far has been cytogenetics, the study of chromosomes. In mammals, all individuals within the same species have the same number of chromosomes. Also, genes lie along the chromosomes in the same order. Individuals with different chromosome numbers and different gene orders usually cannot reproduce. They may mate but their offspring are sterile. This is one of the mechanisms that separates species.

Rock wallabies inhabiting the east coast were thought to belong to eight races, several of which cannot be distinguished morphologically. Each race has distinctive genetic markers, but where their ranges overlap hybridisation has occurred and hybrid animals can be found. However, genes found in these contact zones have not spread into the populations outside the zone; thus the races are maintaining their genetic identity despite these 'mixed marriages'. In addition, the offspring of the hybrids are sterile. The chromosome and sterility data strongly suggest that these similar-looking animals are, in fact, eight distinct species (Eldridge and Close, 1992).

Two wallabies that look alike but belong to two species: *Petrogale assimilus* and *P. sharmani.*

Velvet worms

The velvet worms or peripatus live in moist habitats such as rotting logs and leaf litter in forests around the southern hemisphere. Peripatus look like caterpillars but they have antennae and 'glue guns' on either side of the jaw with which they capture prey. In Australia they occur in the forests of eastern Australia, Tasmania and south-western Australia.

Velvet worms show little variation in body structure and, until recently, Australia was thought to have only eight species, or eight per cent of the world's species. However, genetic techniques, such as allozyme electrophoresis, have shown that at least 100 species occur in this country (Briscoe and Tait, 1995). Consequently, the number of recorded velvet worm species in the world has doubled. Almost everywhere a suitable habitat occurs, a new species unique or endemic to that area is found.

Single species

A single species can harbour a broad range of genetic diversity across its range.


Genetic variation within a single species: Sturt's desert pea.

Barramundi

The barramundi perch (*Lates calcarifer*) is a large fish whose range extends from the Persian Gulf in the west to Australia and Papua New Guinea in the east. It inhabits fresh-water ponds and rivers, tidal swamps and estuaries and coastal reefs. It can live to 20 years of age and weigh over 50 kg. In Australia and Papua New Guinea it spends the first six or seven years as a male then metamorphoses into a female, producing 15–45 million eggs per year.

Genetic analysis using allozyme electrophoresis has uncovered great genetic diversity across Australian waters (Shaklee and Salini, 1993). More than 14 genetically distinct stocks have been identified so far: seven in Queensland, six in the Northern Territory and one in Western Australia, and there are likely to be many more as surveys continue into the more remote populations of north-western Australia.

A number of factors have contributed to the high degree of population subdivision. Large gaps between its habitats along the Australian coast have restricted dispersal between isolated breeding populations. Offshore dispersal of larval and juvenile forms is also limited because the females spawn at the mouths of estuaries, not offshore.

The degree of genetic variation across the range of the barramundi and its partitioning into distinct genetic stocks makes it important that local populations are properly managed. If genetic differentiation has occurred, it could well be because the local environment requires that the stock in that region have their own particular set of adaptations. Allowing stocks to mix or moving individuals from one region to another (for aquaculture or restocking, for example) could disrupt a delicate equilibrium brought about by evolution.

Papilionid butterflies

Another important genetic consequence of habitat fragmentation is known as inbreeding depression. As a population declines and numbers dwindle, matings between related individuals become unavoidable. This leads to inbreeding and in many cases a reduction in fitness — inbreeding depression. The decline in health and in reproductive output causes the population to shrink further, often leading to extinction.

Papilionid butterflies in the rainforests of northern Australia illustrate the phenomenon. These northern rainforests persist today as highly fragmented remnants. Normally wide-ranging species of large and beautiful swallowtail butterflies are now often confined within the remnant patches. Experimental breeding between related individuals in captivity showed inbreeding depression in three species (Orr, 1994). The proportion of eggs hatching, the number of caterpillars surviving to adulthood and growth rates were all severely affected in offspring from related parents. These results show that even wide-ranging species can be susceptible to the effects of inbreeding depression and reserves must be large enough to prevent it.

Other processes that lead to steep declines in the size of populations are excessive harvesting, as in some fisheries, and the presence of introduced predators such as foxes and cats and of introduced diseases.

Introduction of exotic genes

Mating between organisms that are related but genetically distinct may result in hybrids and the loss of the identity of the original gene pools. The escape of domestic dogs into the Australian bush and their mating with the dingo has led to a variety of hybrids. Changes in the patterns of genetic diversity of the dingo have probably occurred in some areas of Australia as a result.

Changes in gene-flow vectors

Animals feed on many Australian plants and pollinate them. After brushing against flowers and receiving a dab of pollen, many kinds of animals function as pollen vectors, depositing pollen on neighbouring flowers. Animal pollinators include honeyeaters, pygmy possums, fruit bats and native bees. Likewise, animals that feed on fruit spread seeds in their droppings, and many seeds have special adaptations that prevent them from being destroyed during digestion.

The effects of changes in or losses of pollen and fruit vectors are not well understood. The introduced honeybee appears to compete with native bees, removing nectar and monopolising flowers. However, it is not known whether the effects on native bees are serious. Australian rainforest plants depend heavily on fruit bats for both pollination and seed dispersal, but there is little information on the effects of changes in their numbers and distribution on forest plant species. However, elsewhere in the world, losses of pollen and seed vectors have had drastic effects on plant populations.

Response

Since the 1980s a number of major international agreements (briefly outlined below) have addressed biodiversity. The United Nations has declared an International Day for Biological Diversity (29 December). As a result, biodiversity has become the focus for a number of national policy statements and is now influencing decisions being made at national, State and local levels. This increases the scope for integrating biodiversity with social and economic considerations. It is also being institutionalised in Australia through legislation such as the Queensland *Nature Conservation Act 1992* and the South Australian *Native Vegetation Act 1992*.

In 1987, the General Assembly of the United Nations adopted a report from the World Commission on Environment and Development (1987) (the Brundtland Report or *Our Common Future*). This inspired the National Strategy for Ecologically Sustainable Development, agreed to by all Australian governments in November 1992 (see the box on page 4-40). One of the three core aims of the Strategy is to 'protect biological diversity and maintain essential ecological processes and life support systems'. A key strength of this strategy is its potential to bring together the social, economic and environmental aspects of society's goals and aspirations.

The Brundtland Report fostered the concept of sustainable development and paved the way for the Earth Summit in Rio de Janeiro in June 1992. One of the outcomes of the summit was the presentation for signature of the Convention on Biological Diversity. The key aims of this convention are:

> *'The conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding.'*

The spirit of this convention is reflected in the National Strategy for the Conservation of Australia's Biological Diversity (Commonwealth of Australia, 1996) that has been developed by Commonwealth, State and Territory governments. Its aim is to bridge the gap between current activities and the effective identification, conservation and management of Australia's biological diversity.

The strategy recognises the significant cultural, economic, educational, environmental, scientific and social benefits of biodiversity and the need for more knowledge and understanding of our biodiversity. It contains nine principles to be used for its implementation. These note that biodiversity is best conserved *in situ* and that, although levels of government have clear responsibility for the conservation of biodiversity, the cooperation of conservation groups, resource users, indigenous peoples and the community in general is critical to its successful conservation.

Types of responses

Responses to pressures on Australia's biodiversity are generally based on the assumption that natural resources can be managed sustainably to balance conservation and development. However, much is yet to be learned in order to achieve this ideal (see the box below). Societal responses to the management of biodiversity can be grouped into three broad categories: government, community and industry. Many responses involve feedback and collaboration between different sections of society and there is considerable overlap. Although some of the responses discussed in this section are not specifically targeted at biodiversity, they all affect it.

Government responses

Australia is a party to numerous major international agreements (see the box opposite).

National approaches by governments

In 1989, the Prime Minister committed the Commonwealth Government to preparing a national strategy for the conservation of biodiversity. Subsequently, conservation of biodiversity has become a major focus for policy. It is a core aim of the National Strategy for Ecologically Sustainable Development and a principle of the Intergovernmental Agreement on the Environment (IGAE, see Chapter 2 for details). A number of policy frameworks for different sectors have included conservation of biodiversity; for example, the National Forest Policy Statement, the draft National Rangeland Management Strategy and the National Ecotourism Strategy.

The National Strategy for the Conservation of Australia's Biological Diversity has been signed by the Commonwealth and all State and Territory governments (Commonwealth of Australia, 1996). It provides an integrated framework of actions to strengthen conservation efforts across Australia with the object of protecting biological diversity and maintaining ecological processes and systems. It covers six main areas:

- Conserving biological diversity across Australia
- Integrating biological diversity conservation and natural resource management
- Managing threatening processes
- Improving our knowledge
- Involving the community
- Australia's international role

The Commonwealth established the Biodiversity Unit in the Department of the Environment, Sport and Territories to coordinate the development and implementation of the strategy. Ultimate responsibility for the strategy at the national level rests with the Australian and New Zealand Environment and Conservation Council. The Biological Diversity Advisory Council has been established to report to governments on issues related to the conservation of biodiversity and the further development and implementation of the strategy. Its aim is to ensure governments receive timely advice from sources such as relevant industries, the scientific community and non-government organisations.

While the strategy takes a broad approach to the conservation of biodiversity, it has also been necessary to provide a specific focus on endangered and vulnerable species, and on ecological communities and the threats acting on them. Commonwealth, State and Territory governments have finalised the Conservation of Australian Species and Ecological Communities Threatened with Extinction: The National Strategy.

Funding

The cost of conserving biodiversity forms part of the overall cost of environmental protection. This includes funds spent on activities as varied as improving water quality, waste management, preventing and mitigating soil erosion, combating weeds, pests and feral animals, rehabilitation of mine and industrial sites, research and education and programs such as Landcare. Australian and overseas studies show a high benefit-to-cost ratio for money spent on the environment, with benefits coming, for example, from enhanced tourism opportunities, improved land values and public health as well as reduced costs of land management and agriculture (Driml, 1994).

Ecologically sustainable development and biodiversity: the need for research

One of the core objects of the National Strategy for Ecologically Sustainable Development (ESD) is to protect biological diversity and maintain essential ecological processes and systems. However, the relationships between ESD and the protection of biodiversity are not well understood and it is widely assumed that, once a human activity appears sustainable, biodiversity will be protected. Some support for this assumption comes from conservation practices such as the reforestation of farmland, the establishment of wildlife corridors and the introduction of forestry and fishery practices sympathetic to wildlife. Although these initiatives are important, we still need research to measure their success in achieving conservation of biodiversity.

Two examples illustrate the need for research. First, some of the species of soil bacteria required to produce leguminous crops are well known, but the contributions of most soil fungi and invertebrate species to the success of these crops are less well understood. In the second case, many native insects are required for crop pollination, but the ecological processes that sustain them and the other species that contribute to their availability are rarely known in any detail. In these contexts, it is likely that once those components of biodiversity necessary to grow a particular crop are working, and apparently sustainable, other components that do not appear to be necessary for growing it will be ignored. This would mean sustainable development without biodiversity conservation.

Sustainability anticipates the needs of Australians many generations into the future. The only way to determine whether new production methods are sustainable is to establish well-designed experiments now, which, when monitored in the future, will identify the improvements and changes required to meet both production and conservation goals. Knowledge of sustainability, by definition, comes only with time. To obtain the baseline data requires an immediate start on the research and monitoring required to ensure that ESD and biodiversity conservation really are achieved together.

International and regional biodiversity agreements to which Australia is a party

- International Convention for the Regulation of Whaling (1946)
- Ramsar Convention on Wetlands of International Importance (1971)
- Washington Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (1973)
- International Convention for the Prevention of Pollution from Ships (1973 and its 1978 protocol) (MARPOL 73/78)
- Convention Concerning the Protection of the World Cultural and Natural Heritage (1974)
- Japan Australia Migratory Bird Agreement (JAMBA) (1974)
- Convention on Conservation of Nature in the South Pacific (Apia) (1976)
- Bonn Convention on Conservation of Migratory Species of Wild Animals (1979)
- Convention on the Conservation of Antarctic Marine Living Resources (1980)
- London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1985)
- China Australia Migratory Bird Agreement (CAMBA) (1986)
- Convention for the Protection of the Natural Resources and Environment of the South Pacific Region (SPREP) (1986 and related protocols)
- Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal (1989)
- Convention on Biological Diversity (1992)
- Framework Convention on Climate Change (1992)

However, despite the benefits, only a small proportion of government expenditure is specifically directed to the environment. For example, only 0.52 per cent of the Commonwealth Government's budget in 1994–95 was allocated to the Department of the Environment, Sport and Territories and of the DEST budget, only 29 per cent was allocated to the environment (Commonwealth of Australia, 1994). Even allowing for funds spent on the environment by the States, Territories and other Commonwealth bodies such as the Department of Primary Industries and Energy, the total spent on the environment is a small proportion of the total Commonwealth, State and Territory budgets.

Policy responses

Governments have a range of policy instruments for the conservation of biodiversity. These include legislative, economic and social instruments.

Legislation

No broad Commonwealth, State or Territory legislation for the conservation of biodiversity currently exists. However, governments have, over many years, recognised the need to manage and conserve the environment and natural resources through legislation. Laws relevant to the management of fauna and flora date back more than 100 years, although only since the late 1960s has legislation increased significantly . Few examples, however, specifically identify the conservation of biodiversity. Some key legislation is given in the box on page 4-43.

The effectiveness of legislation varies widely and, in general, depends on the capacity and willingness of the responsible agency to administer the powers provided by the legislation together with the political agenda of the government of the day. The box on page 4-43 clearly shows the central role of the States and Territories in conservation of biodiversity.

One example of Commonwealth legislation to assist in the conservation of particular species and ecological communities is the Endangered Species Protection Act, which came into force in 1993. This Act lists endangered species and commits the government to producing recovery plans for their protection. The total annual budget of the Endangered Species Program in 1994–95 was $5.5 million. This level of funding is inadequate given that the recovery plan for one species alone, the western swamp tortoise (*Pseudemydura umbrina*), will require about $100 000 per year. With 148 recovery plans in operation and more planned (see Table 4.19), the Endangered Species Program is grossly underfunded.

Individual States and Territories have their own protection programs. In Western Australia, for example, the Department of Conservation and Land Management is using poisoned baits to control foxes that prey on native animals as part of a 10-year recovery plan aimed at protecting the chuditch (*Dasyurus geoffroyi*), the numbat (*Myrmecobius fasciatus*) and other native animals.

Research and education

Many organisations are involved in research related to biodiversity. The Commonwealth funds such research through CSIRO and the Environment portfolio. CSIRO has established a multi-divisional program to improve coordination and focus for research on biodiversity. Research on biodiversity has focused on:

- strengthening knowledge of the role of biodiversity in ecosystem function
- planning and management regimes that better integrate biodiversity conservation considerations

Migratory species

Australia's biodiversity includes species of birds, marine mammals and fish that depend on areas outside Australia for part of their life cycle.

Migratory species are subject to pressures in areas other than those under Australian jurisdiction, and so the Commonwealth Government has negotiated several bilateral agreements, for example the Japan and Australia Migratory Bird Agreement and the China and Australia Migratory Bird Agreement. Following meetings between Australia, China and Japan in 1995, the Migratory Waterbird Conservation Strategy and the Shorebird Reserve Network are being developed. A trilateral agreement between Australia, Japan and New Zealand is designed to protect stocks of southern bluefin tuna mainly through imposition of quotas to restrict catches.

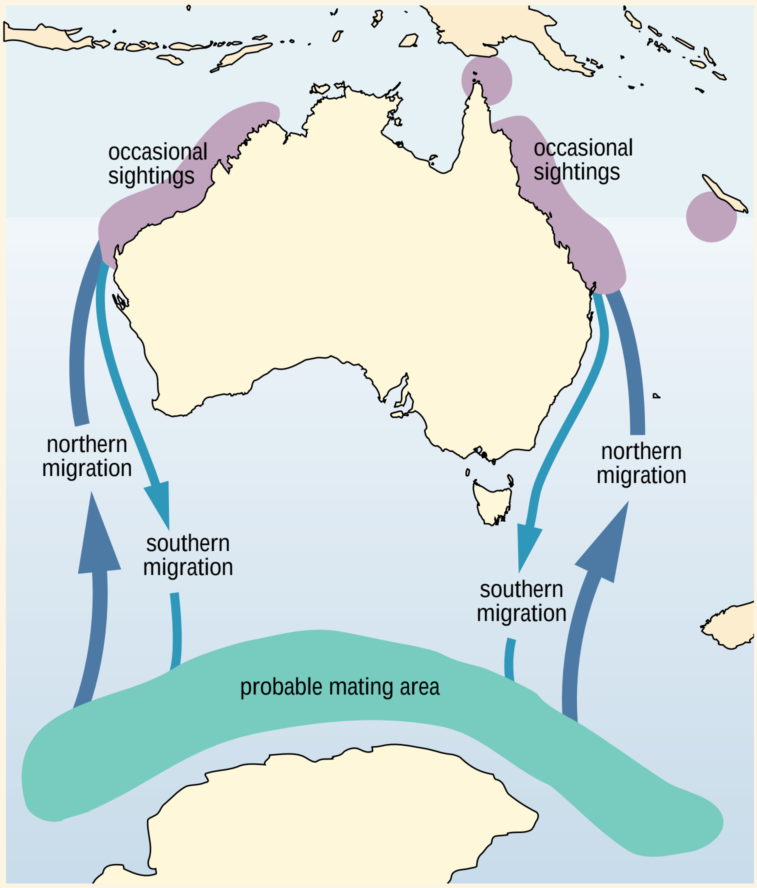
Of the 50 species of wading or shorebirds that regularly occur in Australia, 33 (66 per cent) breed outside Australia and migrate in autumn and spring between Australia and places such as central Asia, Siberia and the Arctic zone of North America (Blakers *et al.*, 1984). The red-necked stint (*Calidris ruficollis*), for example, is a small (about 30 g) wading bird that breeds in eastern Siberia and western Alaska, spends the non-breeding season in Australia and migrates to and from its breeding grounds via Indonesia, the South China Sea, Vietnam, China, Japan and probably up the east coast of Asia. About two million waders of various species avoid winter each year by making the 20 000 km round trip to Australia. Of the 71 species of coastal or seabirds that regularly occur in Australian waters, 25 (35 per cent) breed elsewhere — mainly on islands in the Southern Ocean, in the Antarctic or around New Zealand (Blakers *et al.*, 1984). As well as the migratory waders and sea birds, at least 36 terrestrial species of bird that breed in Australia seasonally migrate between Australia and Papua New Guinea. Large changes in species diversity occur locally on a seasonal basis because of north south migrations undertaken by many birds within Australia.

Migratory species also enhance the species diversity of marine mammals. Southern right whales (*Eubalaena australis*) and humpback whales (*Megaptera novaeanglieae*) migrate from the Southern Ocean to Australian coastal waters to calve (see Chapter 8). Whaling reduced the numbers of whales to dangerously low levels worldwide. Commercial whaling was banned in 1978 in Australian waters and in 1986 in all international waters. Southern right and humpback whales are listed as endangered under the Commonwealth Endangered Species Protection Act and their numbers appear to be increasing. Estimates indicate that nearly 1000 humpbacks migrate to eastern Australia where they have become a popular tourist attraction. Regulations have been introduced to prevent boats and divers harassing them.

Some of Australia's highly diverse fish fauna are migatory species. Marlin (Family Istiophoridae) and tuna (Family Scombridae) are fast-swimming fish that range over large areas in the Pacific, Indian and Southern Oceans and spend part of their life in Australian waters. Southern bluefin tuna for example, spawn in the Indian Ocean south of Indonesia and the young fish migrate southwards along the coast of Western Australia. Some then swim westwards to the waters off South Africa while others swim eastwards across the Great Australian Bight to south of Tasmania and New Zealand. Many species of shark also travel large distances; school shark (*Galeorhinus galeus*) tagged in New Zealand have been caught in Australian waters.

Migratory species are subject to pressures in many of the places they visit. In Australia, migratory birds face a range of pressures including loss of habitat through processes such as urbanisation of the coast, drainage of wetlands and agricultural development. However the main threats come during their breeding migration. Large numbers are shot or trapped in the northern hemisphere each year. Illegal hunting in China is also a serious problem as is habitat loss.

Seabirds also face threats in Australia. Longline fishing in Australian and international waters threatens populations of some species such as the wandering albatross (*Diomedea exulans*) (see page 8-33). Others, such as the brown booby (*Sula leucogaster*), are harvested illegally (Blakers *et al.*, 1984). Most of our pelagic species of fish appear to be in a healthy condition but stocks of southern bluefin tuna have been greatly reduced through fishing by Australian and Japanese fleets (see Fig. 8.13).



The humpback whale migrates northwards in winter to calve. It feeds in Antarctic waters.
Source: Marsh *et al.*, 1995.

- elucidating trends on the state of Australia's biota resulting from various impacts and the development of geographic information systems to assess terrestrial biodiversity at the scale of landscapes, biogeographic regions and ecosystems

Research by Australian Biological Resources Study concentrates on the systematics of a wide variety of groups of organisms, especially the lesser-known ones. Several universities and most major museums sponsor research and educational programs. These include: the Cooperative Research Centre for Tropical Rainforest Management in north Queensland, the Commonwealth Key Centre for Biodiversity and Bioresources at Macquarie University, and the Invertebrate Biodiversity Conservation Program at the Museum of Victoria.

Biodiversity is increasingly a focus for tertiary and secondary curricula. For example, in Victoria, biodiversity now forms one of the major components of the Year 12 course in environmental studies. Professional development courses for teachers include one on biodiversity and ecologically sustainable development being prepared by the Australian Association for Environmental Education.

A range of information and education materials has also become available recently. These include a primer on biodiversity produced by the Research Unit for Biodiversity and Bioresources at Macquarie University (Beattie, 1995), a CD-ROM on insect biodiversity produced by CSIRO's Division of Entomology, a series of reports on biodiversity, the State of the Marine Environment Report (Zann, 1995; Zann and Kailola, 1995) (see Chapter 8) and other materials produced by the Commonwealth Department of the Environment, Sport and Territories.

Community responses

Over the last two decades, public awareness of environmental issues has grown rapidly. Since the 1970s, many surveys of public attitudes to the environment have been conducted. Of these, only eight have identified specific environmental concerns and the priority that people attach to them (Lothian, 1994). Although a study by ANOP Research Pty Ltd into public attitudes to the environment (commissioned by DEST) found that few people have a good understanding of the term biodiversity, the Lothian study indicates that the public are concerned about many of the issues surrounding it, such as species loss, deforestation, vegetation clearance, logging, harvesting kangaroos and the role of national parks. Overall, biodiversity issues ranked second in the eight surveys behind pollution and waste production/disposal.

In recent years, concern for the long-term ecological sustainability of Australia's natural resources has led to the rapid growth of local and regional environmental community groups. Many groups have changed from being passive recipients and distributors of information to taking a proactive role. They are demanding to be involved in planning and decision-making processes undertaken by governments for management of biodiversity.

Conservation of biodiversity: relevant legislation

The fragmented approach to the conservation of biodiversity is illustrated by the range of legislation for the management of fauna and flora.

Commonwealth

Environment Protection (Impact of Proposals) Act 1974

Australian Heritage Commission Act 1975

Great Barrier Reef Marine Park Act 1975

National Parks and Wildlife Conservation Act 1975

Antarctic Treaty (Environment Protection) Act 1980

Whale Protection Act 1980

Antarctic Marine Living Resources Conservation Act 1981

Wildlife Protection (Regulation of Exports and Imports) Act 1982

Protection of the Sea (prevention of pollution from ships) Act 1983

World Heritage Properties Conservation Act 1983

Endangered Species Protection Act 1992

Australian Capital Territory

Nature Conservation Act 1980

New South Wales

National Parks and Wildlife Act 1974

Heritage Act 1977

Environmental Planning and Assessment Act 1979

Wilderness Act 1987

Threatened Species Conservation Act 1995

Queensland

Marine Parks Act 1982

Nature Conservation Act 1992

South Australia

National Parks and Wildlife Act 1972

Native Vegetation Act 1992

Tasmania

National Parks and Wildlife Act 1970

State Policies and Projects Act 1993

Victoria

Wildlife Act 1975

National Parks Act 1975

Planning and Environment Act 1987

Flora and Fauna Guarantee Act 1988b

National Parks (Alpine National Park) Act 1989

National Parks (Wilderness) Act 1992

Western Australia

Soil and Land Conservation Act 1945

Wildlife Conservation Act 1950

Conservation and Land Management Act 1984

Northern Territory

Territory Parks and Wildlife Conservation Act 1977

Source: DEST, Biodiversity Unit.

Public awareness of native flora and fauna is symbolised by community support for replacing traditional symbols such as the Easter bunny with native species like the endangered bilby (*Macrotis lagotis*).

Community involvement

The National Strategy for the Conservation of Australia's Biological Diversity relies on community support and community-based actions for its successful implementation. The Commonwealth of Australia House of Representatives Standing Committee on Environment, Recreation and the Arts (1992) stressed the need to develop innovative strategies for increasing community awareness and

Response to species endangerment

A number of legislative and administrative actions have occurred in response to the decline and extinction of a number of species.

The Commonwealth enacted *The Endangered Species Protection Act 1992*, which came into force on 30 April 1993. It introduced a statutory process for the listing of nationally threatened species, communities and key threatening processes. It also led to the establishment of two ministerially appointed committees: the Endangered Species Advisory Committee and the Endangered Species Scientific Subcommittee. These bodies provide advice to the Federal Minister for the Environment on a range of matters prescribed in the Commonwealth Act, including priorities for preparation of plans, scientific advice on listings, and significant statutory responsibilities and powers that affect Commonwealth agencies and areas. The Australian and New Zealand Environment and Conservation Council has developed a strategy titled 'The Conservation of Australian Species and Ecological Communities Threatened with Extinction: The National Strategy'.

Two major Commonwealth programs: the Endangered Species and Feral Pests Programs, address the conservation of threatened species and communities, and the major threats to their conservation. The Endangered Species Program, which was established in 1989, seeks to prevent further extinctions of Australian biota and to restore endangered species and ecological communities to secure status in the wild. Funding for the program in 1994–95 was $5.5 million and cumulative funding since its inception has been $23 million. The Feral Pests Program began in 1992–93 with annual funding of $2.2 million. Foxes, feral cats, feral rabbits and goats are listed as key threatening processes under the Commonwealth Endangered Species Act, as is dieback caused by the fungus *Phytophthora cinnamomi* and longline fishing which poses a threat to albatross.

Action plans have been prepared for birds, marsupials, freshwater fish, reptiles, rodents and vascular plants, and are in preparation for amphibians, bats, cetaceans, seals and dugongs. Conservation overview statements have been prepared for non-vascular plants, and non-marine invertebrates including butterflies. These plans and statements are commissioned to help identify endangered and vulnerable species and nationally agreed priorities for action. The status of recovery action on individual species listed in the schedules to the Commonwealth Endangered Species Act is summarised in Table 4.19. No ecological communities are listed in the Commonwealth Act, however, a discussion paper was published by the Endangered Species Scientific Subcommittee in January 1995 to stimulate comment from the scientific community, conservation organisations, industry groups and interested individuals.

Examples of recovery plans

The western swamp tortoise (*Pseudemydura umbrina*), which is listed as endangered, consists of one wild population of about 48 individuals in Ellen Brook Nature Reserve near Perth and 112 captive individuals that form part of a captive breeding program. The recovery plan aims to increase the population in Ellen Brook Nature Reserve and to establish a second population of up to 40 at a nearby nature reserve that formerly had a population of tortoises. It also aims to maintain a captive breeding population of at least 50 individuals (Burbidge and Kuchling, 1994). The estimated cost of implementation of the recovery plan to 2002 is $1.7 million.

At present, the main threats to the tortoise come from the surrounding agricultural matrix and the availability of water. Conservation of the species depends on the management of two small swamp nature reserves surrounded by extensive agricultural development. Winter water levels need to be maintained. Since 1990, Ellen Brook Nature Reserve has been surrounded by a fox-proof fence and extensive predator control is conducted within the reserve. However, unless the surrounding land is managed to remove any threats to the tortoise population, the plan may still fail in the long term. This case highlights the need for management plans to integrate conservation of biodiversity as an essential part of total landscape management (see page 4-53).

The western swamp tortoise

The Lord Howe Island woodhen (*Tricholimnas sylvestris*) is a flightless rail (Family Rallidae) occurring only on Lord Howe Island, off the coast of New South Wales. Its nearest relative was the wood rail of New Caledonia, which is now extinct. Before human settlement, the woodhen occurred over most of the island. Estimates based on known habitat requirements and the original area of preferred habitat suggest an original population of several hundred. By the mid 19th century the woodhen was confined to the summit regions of Mounts Gower and Lidgbird and between 1974 and 1980 the population had been reduced to about 30 individuals, including at most 10 breeding pairs. The decline was probably initially due to hunting pressure but subsequently to predation and habitat alteration by introduced animals.

An extensive study of the ecology of the remaining birds began in 1971, followed by management to offset the identified threats, and a program of captive breeding and re-introduction. By 1984, more than 80 birds had been bred and released and the wild population had grown to an apparently stable level of 200 individuals, including 50 breeding pairs. Further increases appear to be limited by lack of suitable habitat for more breeding territories. Twice-yearly counting continues for early detection of any further problems, and there is a proposal to establish a captive colony off the island in case of a catastrophic impact on the native population.

involvement. The committee identified several strategies for facilitating community involvement at the grassroots level:

- provision of seeding funds for projects
- government involvement and encouragement in community projects
- extension and dissemination of practical technical advice based on scientific research and knowledge
- bioregional planning and management to coordinate and direct local community actions within a broader perspective
- practical equipment to facilitate on-ground actions

Many mechanisms exist for obtaining input from the community on specific environmental matters. For example, most planning legislation requires opportunity for public comment. Governments have created a range of advisory bodies to better inform people involved in the policy development process. Many non-government groups also provide advice to government through their participation in government committees, such as the Biological Diversity Advisory Council and the Endangered Species Advisory Committee. However, feedback from community groups indicates a need for increased government support, since community input generally relies on the work of volunteers.

Many community groups regularly monitor the environment and undertake field activities to either protect or restore biodiversity (Saunders *et al*., 1995). Programs such as Worm Watch, Frog Watch and NatureSearch collate information about species collected by members of the public. Community groups monitor organisms as diverse as orchids, birds, frogs, earthworms, dung beetles and butterflies on a nationwide basis. The information collected by these groups has greatly increased our knowledge of the diversity of organisms such as earthworms in Australia. An important example of the role of the community in gathering data is *The Atlas of Australian Birds* (Blakers *et al*., 1984), which is based on information provided by bird-watchers all over Australia.

The public also donate money towards research related to biodiversity. In New South Wales, for example, the New England community established a 'dieback fund' for research into the causes of dieback killing native trees in the district. Trees for Life provides two million indigenous trees annually free of charge to landholders to assist in the rehabilitation of farmland in South Australia. The restoration of native bush in urban areas is a popular and rapidly growing community activity that seeks to re-establish local species.

Community–government initiatives

Community groups, conservation and government bodies often collaborate on environmental projects.

Table 4.19 Status of recovery action on individual species*

Species	No. of endangered or vulnerable species	Recovery plan prepared or in preparation	Recovery plan being implemented
Mammals	48	13	11
Birds	50	12	8
Amphibians	9	7	2
Reptiles	21	2	1
Freshwater fish	13	6	2
Vascular plants	890	224	124
Total	1031	264	148

*As listed in the schedules to the Commonwealth Endangered Species Act.
No ecological communities are listed in the Act, however, the endangered species scientific subcommittee published a discussion paper in January 1995 to stimulate comment from the scientific community, conservation organisations, industry groups and interested individuals.

Planting trees as part of a community–government initiative, Greening Australia.

A successful example of a community–government initiative is the Land for Wildlife scheme run by the Victorian Department of Conservation and Natural Resources and the Bird Observers Club of Australia. Private landholders are encouraged to conserve flora and fauna and given support by the program. The scheme does not require landholders to enter into agreements with the government, but instead provides a structural framework for the support of voluntary management of wildlife habitat on private land.

Greening Australia and the One Billion Trees campaigns are collaborative projects between government, conservation groups and the community, which have arisen in direct response to loss of native vegetation. The establishment of a number of community networks such as the Community Biodiversity Network, the Marine and Coastal Community Network and the National Threatened Species Network are other examples of collaborative projects. The latter is an active community-based network that increases public support and involvement in the protection of threatened species and their habitats throughout Australia.

The Landcare movement has the potential to be the most important mechanism for integrating conservation of biodiversity into agricultural and

Economic mechanisms for conserving biodiversity

A range of economic instruments is being developed to help achieve the sustainable use of natural resources. However, few 'economic' instruments have been introduced specifically for managing biodiversity.

Environmental pricing

Charges, levies and the setting of prices to fund conservation of biodiversity are rare in Australia — beyond fees for park use, trail access and other uses within reserves. The Great Barrier Reef Marine Park Authority has introduced a one-dollar visitor fee that is expected to raise about one million dollars per year. Most of the funds are being allocated to the Cooperative Research Centre concentrating on the ecological management of the reef.

Some local authorities, such as the Brisbane City Council, have introduced environmental levies on ratepayers. Funds raised in this way are used to buy environmentally sensitive land in order to protect habitats and their associated flora and fauna.

Conservation easements

Conservation easements, like South Australia's heritage agreements, bind owners to a set of conditions, such as prohibition of clearing or cropping an area of land. Other States and Territories also have legislation that facilitates the use of conservation easements, but their limited budgets mean progress has been slow.

Funding arrangements

A revolving fund is one of several ways to maximise the effect of funds for managing biodiversity. This involves buying land and placing a permanent covenant on it to manage part or all of it for conservation. The land is then sold to someone who agrees to abide by the covenant and the money used to buy more land. The Victorian Conservation Trust has established a revolving fund, and other environmental organisations, like the Australian Bush Heritage Fund have expressed a desire to do likewise.

Taxation

Some income-tax deductions are available for control of land degradation, but they are narrowly defined and do not reflect concerns for the conservation of biodiversity. Local governments grant rate relief for land maintained for biodiversity conservation purposes. Rate reimbursements apply in South Australia under the *Native Vegetation Act 1992* and further reductions are available under a heritage agreement. In Victoria, new financial provisions in the *Local Government Act 1991* allow local authorities to charge rates under a method of capital improvement valuation. This would reduce the tax burden associated with a decision to lease undeveloped land. However, these provisions have not yet been used.

Transferable development rights

This mechanism is designed to limit development in conservation areas without affecting the underlying value of individual assets. Transferable development rights enable people who own valuable habitat to sell clearing rights to others who own land of lesser biological importance and need a development right in order to proceed with a proposed development. The use of transferable development rights is allowed under the *Resource Management Act 1991* in New Zealand and opportunities exist for its application in Australia.

Performance bonds

Environmental performance bonds are best suited to situations where there is one source of potential environmental damage that can reasonably be estimated. Apart from their use for land rehabilitation in the mining industry, bonds are used as a permit condition for aquaculture in South Australia and New South Wales and by the Great Barrier Marine Park Authority for tourist development.

Financial assistance

Financial assistance forms part of many voluntary management schemes offered by the States and Territories and usually takes the form of payment to assist with the cost of purchasing material associated with the work required. For example, a 50 per cent fencing subsidy exists under the remnant vegetation protection scheme in Western Australia and the Victorian action statement program also pays subsidies.

Land management funding schemes such as the National Landcare Program and the Murray–Darling Management Strategy's Investigations and Education and Integrated Catchment Management programs, while broadly directed towards activities of significance to the conservation of biodiversity, do not contain any explicit biodiversity conservation requirements. The Commonwealth Department of Housing and Regional Development Program (established in 1994 with funding of $15 million over four years) funds three major regional development programs, none of which contains biodiversity conservation criteria.

pastoral production. Landcare was originally established by the National Farmers Federation and the Australian Conservation Foundation in the 1980s (see page 6-43). More than 2000 Landcare groups now exist across Australia, involved in a wide range of activities aimed at improving production, land and water restoration and conservation. Some of these activities contribute directly or indirectly to conservation of biodiversity (Commonwealth House of Representatives Standing Committee on Environment, Recreation and the Arts, 1992).

Industry responses

As the Australian public's attitudes to environmental issues change, so do those of industry. The agricultural sector is increasingly incorporating nature conservation into landscape programs. Some industry responses are driven by consumer demand — that is, the desire to buy more 'environmentally friendly' products. Conservation groups such as WWF, for example, endorse some products. In many cases industries have failed to respond of their own accord to pressures on biodiversity and have only acted in response to government legislation. However, some responses are based on industry's need to preserve natural resources. Commercial fishing organisations in several States employ environmental officers and take active roles in widening the debate on issues such as coastal development and protection of seagrasses. In response to industry lobbying, governments have legislated to protect seagrasses and mangroves over much of northern Australia.

A number of industries have introduced initiatives, such as codes of practice, cleaner production and best practice environmental management, to reduce the impacts of their operations by minimising use of materials and energy and by reducing wastes. These initiatives focus on pollution control and reduction of environmental degradation and do not specifically address biodiversity.

Community actions to integrate the landscape

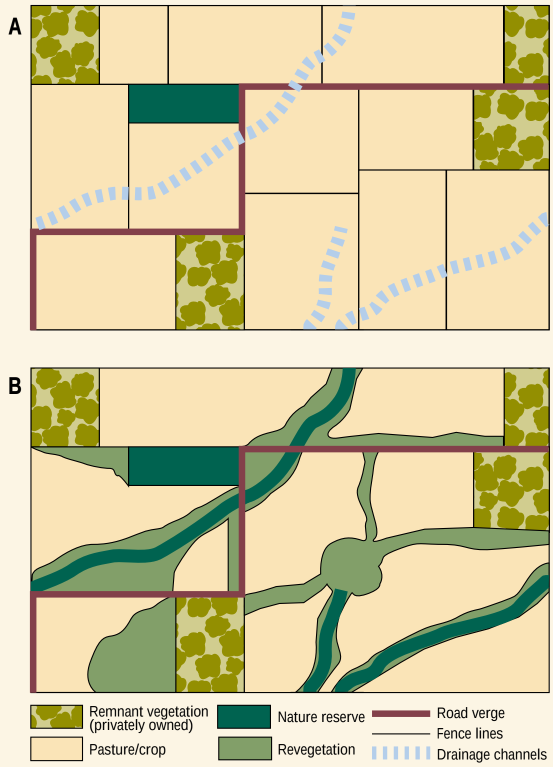
Technological advances since World War II have made large-scale clearance of native vegetation easier. As a consequence, more land has been cleared in the last 50 years than in the preceding 150 years, bringing associated problems of land degradation and loss of biodiversity. These problems have aroused concern in many sectors of the community, and a number of responses have evolved to address the impacts of clearance.

Since the early 1980s, governments and key community sectors have increasingly recognised the economic, ecological and social benefits of remnant native vegetation and have initiated programs, not only to ensure the protection and management of remnants, but to re-establish large areas of vegetation.

This has resulted in a number of community-based projects supported by programs like the National Landcare Program, whose components include Save the Bush and One Billion Trees. However, while the enthusiasm for 'tree planting' has generated activity on many fronts, this activity has proceeded without any underlying ecological rationale or planning framework. Concern is now being expressed about the planning and preparation for revegetation activities, the appropriateness of plantings and the species selected (Commonwealth House of Representatives Standing Committee on Environment, Recreation and the Arts 1992). Many of the plantings have had a single purpose (such as control of soil erosion or salinisation) and planned solely within the confines of one property. Clearly, it is better to ensure that tree-planting has potential multiple benefits (for example plantings for soil erosion control can be designed to provide habitat) and is placed within a broader planning framework.

Some schemes now advocate the concepts of integrated landscape ecology and bioregional planning as a basis for developing an integrated approach to landscape management. These approaches offer the potential to place previously ad hoc community activities within a regional framework. Using catchments as a basis for designing National Landcare Program projects and planting along corridors — for example Corridors of Green by Greening Australia — are indicative of moves towards an integrated landscape management approach.

The way in which the landscape has been managed is illustrated in a study by Hobbs *et al*. (1993) using a hypothetical section of the Western Australian wheat belt. Individual segments in the landscape, such as road verges, paddocks and patches of remnant vegetation, are usually managed in isolation. The landholder is mainly concerned with individual paddocks and the conservation authority with nature reserves, while the authority responsible for the



Landscape linkages. **A** – A hypothetical section of an agricultural landscape showing remnant vegetation, reserves, roads, paddocks and drainage lines.
B – Revegetation plan that provides linkages along road verges and drainage lines to connect remnant vegetation.

Source: Hobbs *et al*., 1993.

roadside verges — usually the local council — is unlikely to share much interest in either of these. While resource managers and landholders manage their own piece of land in isolation, landscape segments are unlikely to operate as an interconnected system. Landscape linkages can be established by planning and planting in line with landscape features. This approach, applied on a regional scale, offers opportunities to enhance the benefits from tree-planting activities at a property/local level.

The benefits of extensive networks of vegetation for the protection of water and soils and for the maintenance of biodiversity now have wide recognition. However, few data are available to either support or refute the value of interconnecting areas of vegetation (corridors) for conservation and maintenance of biodiversity, and their merit continues to be hotly debated in the scientific literature (Noss, 1987; Simberloff *et al*., 1992). Despite this, it is generally accepted that corridors serve to ameliorate the process and consequences of fragmentation, which constitute a serious threat to biodiversity.

Responses to key issues

On the basis of the preceding sections, the following key issues for management of biodiversity emerge:

- human population patterns
- land clearance
- harvesting of native species
- introduced species
- pollution
- mining
- climate change
- lack of knowledge
- integrated ecosystem-based management of natural resources

The state of Australia's biodiversity is ultimately a consequence of the number of people, our patterns of movement and the resources required to fulfil our desires and to maintain our living standards. Without limiting human population growth and developing management systems that recognise the critical role of biodiversity in human economics the pressures on biodiversity will continue.

Human population patterns

Urbanisation

Australia is the most highly urbanised society in the world (see Chapter 3). The National Strategy for the Conservation of Australia's Biological Diversity has identified a number of goals to minimise the impact of urbanisation on biodiversity, including the following:

- encouraging habitat retention
- improving strategic planning to enhance biodiversity
- reducing fringe development
- encouraging use of indigenous species
- integrating biodiversity conservation into relevant policies and programs such as the Better Cities program

French Track, Simpson Desert, SA. Use of four-wheel drive vehicles enables people to appreciate remote parts of Australia but can also lead to disturbance of sensitive ecosystems.

The Bubbler Mound Springs near Lake Eyre South, northern SA. Visitor impact on sensitive sites is often unwitting, highlighting the importance of public education and adequate signage.

Tourism and recreation

Tourism is a relatively unregulated activity in Australia and consequently government bodies have made little response to the pressures associated with it. However, the Commonwealth Government has responded to growth in the ecotourism industry with the National Ecotourism Strategy designed to provide guidelines to ecotour operators.

All States and Territories have produced policy documents on ecotourism or tourism. Some have also recognised the value of tourism-based activities and contribute some of the revenue gained from using natural resources into the management of those resources. However, the challenge remains to design and implement systems that will link the growth of tourism with conservation of biodiversity (Preece *et al*., 1995). One example is the Northern Territory Tourism Masterplan, under which the Northern Territory tourism industry and the Northern Territory Conservation Commission are working together to investigate the tourist potential of protected areas.

The growth of ecotourism itself reflects the community's desire to participate in more sustainable types of tourism and to learn more about the natural environment. However, since anyone can call him- or herself an ecotour operator there is no proof that the activities of ecotourists are any more sustainable than other forms of tourism. To overcome this problem a number of accreditation schemes have recently been introduced and the Commonwealth Department of Tourism is investigating the merits of a national scheme (Preece *et al*., 1995).

Some forms of recreation, such as fishing (see page 8-12), require intensive management to ensure their sustainability. Intertidal rock platforms near large cities such as Sydney and Perth are easily accessible and so shellfish may be over-collected. Recreational abalone fishers near Perth, for example, take between 80 and 100 tonnes each season — about 40 per cent of the available stocks and one and a half times the tightly controlled commercial catch. Controls have been introduced to protect the resource. These include a limit of 20 abalone per person, size limits for common species and regulations on collecting methods (scuba diving, for example, is banned). Fishing is also restricted to two hours a day on eight weekends each year.

Many States and Territories have restrictions on shell collecting — usually a limit on the numbers that can be collected — to reduce the harvest by amateur collectors.

Recreational fishing is an important leisure activity for more than 4.5 million Australians. However, increasing fishing pressure on inshore stocks from recreational and commercial fishing, coupled with environmental damage, is causing the decline of many fish stocks. A working group set up under the Australian and New Zealand Fisheries and Aquaculture Council has developed a national policy on recreational fishing. The key principles for sustainable fishing include protecting the resource and habitat, and involving government and the community. The policy seeks responsible land use and farming practices, protection of shoreline and floodplain areas and wetlands, and careful use of chemicals and fertilisers that have an impact, direct or indirect, on aquatic habitats or fish stocks (National Recreational Fisheries Working Group, 1994).

Land clearance

The clearance of native vegetation is the single greatest threat to terrestrial biodiversity and a significant threat to aquatic and some inshore marine biodiversity. Thus it is extraordinary that nobody has accurately assessed its extent over the last one to two decades, despite the availability of the appropriate technology (Graetz *et al*., 1992). The Department of Environment, Sport and Territories is supporting a number of projects to rectify this gap in knowledge. One recently completed project, undertaken by CSIRO, used satellite imagery to assess landcover disturbance at a continental scale (Graetz *et al*., 1995). The Department has also released a compilation that provides an overview of the pattern of recent vegetation clearance (Biodiversity Unit, DEST, 1995).

Reserves have only limited value as an antidote because most of the land set aside is in small blocks that are infertile and/or steep. Fertile land is less likely to be preserved (see the box on page 4-52). The problem will continue without changes to policies on land clearance and reserve selection.

About 70 per cent of Australia's land mass is under the control of private landholders and resource managers, including indigenous peoples. Vegetation clearance on lands under freehold and leasehold tenure is a major concern. Controls on native vegetation clearance and the provision of incentives for native vegetation retention vary between States and Territories. In South Australia, vegetation clearance is tightly controlled, but other States and Territories have less stringent rules (see page 6-39 and Table 6.8). New South Wales, Queensland and Western Australia are in the process of strengthening measures to control native vegetation clearance. In 1995, the Queensland Government released a package of measures including draft tree-clearing guidelines that demand 30 per cent retention of trees on most leasehold properties throughout the State and prohibit large-scale clearing of mulga (*Acacia aneura*).

Governments have also implemented a range of economic mechanisms to address the issue of land clearance (see the box on page 4-46). For example, all the 1950 taxation provisions designed to encourage it have now been removed from the *Income Tax Assessment Act 1936*, although farmers can still deduct the full cost of clearing in the year of expenditure by using their own equipment and employees.

The removal of incentives that encourage deforestation or land degradation is an effective response to conservation of biodiversity. In the past, it has been argued that drought policy has encouraged land degradation, including the loss of biodiversity values. Recent changes to drought policy at both State and federal levels are making farmers more self reliant in a way that may reduce threats to biodiversity values during time of biological stress.

Environmental lobby groups have focused on issues of native vegetation clearance, especially those resulting from logging operations, conversion to agricultural land and mining activities. The power of large-scale environmental protests over the past two decades to influence government policy and change public perception should not be underestimated. Community groups have also responded to removal of forests by cooperating with government–community initiatives such as Landcare, Greening Australia and Save the Bush programs.

Harvesting native species

Rights to harvest and/or use Australia's flora and fauna vary between States and Territories. In recent years the Commonwealth, several States and the Northern Territory have increased the market orientation of harvesting licences, such as in the kangaroo- and timber-harvesting industries.

The Commonwealth, States and Territories require a permit or licence to take, kill, trade or export protected flora and fauna. These licences, however, are usually issued for a short period with no guarantee of renewal. Beyond these provisions, Australia is a party to the CITES convention which restricts the international trade in endangered species and bans trade in most threatened species. There is continuing debate on the conservation benefit, economics and ethics of using wildlife commercially.

In the fishing industry, measures have been introduced to reduce fishing pressure. These include reductions in the number of trawlers in some prawn fisheries and the number of pots in lobster fisheries, smaller quotas for finfish in the south-east trawl fisheries and controls on mesh size of nets, sizes of animals caught and fishing times. New Commonwealth, State and Territory fisheries legislation emphasises the importance of managing fisheries to achieve ecological sustainability including maintenance of biodiversity (see Chapter 8). Research is being conducted to reduce the quantity of bycatch in prawn trawl fisheries.

Fraser Island

Fraser Island, the largest sand island in the world, supports rainforest, freshwater lakes, coastal heathland and sand dunes. Over the years it has faced a number of threats, including sand-mining, logging, feral animals and (being only four hours drive from a region supporting two million people) tourism and recreation — especially recreational angling.

Numbers of visitors to the island have increased from 50 000 in 1985 to 250 000 in 1994. Following a long public campaign, the Commonwealth Government — against the wishes of the then Queensland Government — refused to issue export licences for minerals produced on the island and so sand-mining was stopped. In response to continuing public pressure, the Queensland Government banned the logging of the island's rainforests. The Commonwealth subsequently obtained listing of Fraser Island as a World Heritage Area and now the island — together with the mainland immediately to its south — has been incorporated into a national park. This park (and areas outside it) are subject to the Great Sandy Region Management Plan, which covers an area of about 840 000 ha.

The plan provides for protection of natural and cultural features of the region, while allowing for provision of services for residents and visitors and ensuring that development is sustainable. It contains a range of strategies, including rehabilitation of degraded areas, removal of feral animals, catchment management, controls on recreational and commercial fishing, rationalisation of vehicle access — including use of four-wheel drive vehicles on beaches — and development and control of tourist areas. If the plan meets its targets, it will provide substantial protection and restoration of the island's biodiversity.

Recreational fisheries have generally had few limits apart from controls on the type of equipment used for fishing and minimum size of fish caught. Most States and Territories now limit the number of fish that can be caught each day. Despite these measures, some species are still declining or their numbers are not recovering and it is likely that controls will be increased in the future.

Introduced species

The devastation caused by introduced plants and animals has elicited a number of government, community and industry responses. The Commonwealth Government established the Cooperative Research Centre for Vertebrate Pest Control, which involves five research groups in developing humane methods to combat vertebrate pests such as rabbits and foxes. Their main approach is to investigate methods of fertility control in vertebrate pests. The Feral Pests Program was set up in 1992–93 to address threats to endangered species posed by feral pests (see the box on page 4-44).

Growing public awareness of the effects of feral animals and introduced plants on native fauna and flora has led to numerous community-based projects. Bush-regeneration groups are common in urban areas, where remnant vegetation is especially prone to invasion by exotic weeds. Individuals and community organisations such as Landcare groups shoot or poison feral cats, rabbits and foxes.

In 1991, the Australian Quarantine and Inspection Service introduced voluntary controls on the discharge of ballast water. These guidelines provide a number of options — the most common being exchange of ballast water offshore to prevent water loaded in foreign ports from being discharged here. In this way, many shallow-water organisms from other ports are dumped at sea in deep water where they are unlikely to survive. Despite modern anti-fouling paints, many organisms are still being transported on the hulls of ships on parts not protected by the paint or on sections where the paint has been scraped off. The Centre for Research on Introduced Marine Pests established by CSIRO under the auspices of the Australian Ballast Water Management Advisory Council, established by the Commonwealth Government in 1994, is researching ways of dealing with marine pests. However, it is unlikely that introduced marine organisms will be eradicated.

Pollution

The National Environment Protection Council is a significant initiative being established jointly through legislation by the Commonwealth, States and Territories to develop harmonised goals, standards and guidelines for the protection of the environment. The areas it covers include: ambient air and water, assessment of contaminated sites, impacts of hazardous wastes and recycling.

Although the amount of government legislation on pollution control has grown steadily in recent years, its effectiveness has been limited by the dispersal of responsibility for enforcing pollution laws across many government departments. This situation has changed recently with the centralisation of responsibility under State environmental protection authorities (EPAs). In New South Wales and Victoria, for example, EPAs can impose fines of up to one million dollars on companies that pollute illegally and in Western Australia the head of one company was gaoled as a result of pollution by the company.

Government legislation generally dictates industry responses to pollution. For example, the Australian Maritime Safety Authority has recently prepared a national plan to combat pollution of the sea by oil. However, industry also reflects changing attitudes towards environmental issues in society generally. Many companies are using a variety of waste-minimisation measures and recycling programs to increase profits and improve their image with an increasingly critical public. Consumer demand for 'greener', 'cleaner' products has generated a flurry of activity and competition in companies to develop products that are seen to be more environmentally friendly. Products are increasingly made from, or packaged in, recycled materials and frequently contain less non-biodegradable chemicals.

The Cooperative Research Centre for Waste Management and Pollution Control involves 18 different research and industry groups and is responsible for research into all aspects of waste management and minimisation. Although it covers all elements of waste, the Centre's research focus is on the treatment of liquid waste.

Mining

When planning new mining developments, companies now must carry out environmental impact assessments that include plans for rehabilitation. In most States, mining leases include a condition requiring the holder to lodge a security deposit, which may be forfeited if the rehabilitation conditions are not met. In 1990, the Australian Mining Industry Council published a handbook that lists standard rehabilitation procedures (AMIC, 1990). These include landscaping, management of topsoil, revegetation, managing waste dumps, acid, alkaline and saline sites, heavy metals and toxic chemicals as well as removal of access roads and constructions. Considerable effort is now applied to rehabilitation of sand-mining areas. However, thousands of abandoned mine sites remain with no rehabilitation apart from natural processes.

In South Australia, mining operators are required under the Mining Act to pay a royalty (presently 10 cents per tonne) on all materials produced. The Extractive Areas Rehabilitation Fund is used to finance approved rehabilitation projects. Some of the larger mining companies employ horticultural advisers or rehabilitation consultants.

Climate change

Commonwealth, State and Territory governments and the Australian Local Government Association on behalf of local governments have accepted the National Greenhouse Response Strategy.

Under the United Nations Framework Convention on Climate Change, the OECD countries are committed to stabilising gas emissions at their 1990 levels by the year 2000. Australia's greenhouse gas emissions in 1990 have been estimated at 572 megatonnes of carbon dioxide equivalent and at present rate of growth would increase by 14 per cent by the year 2000. Vegetation clearing for agricultural purposes in 1990 was estimated to have contributed about 27 per cent of Australia's total net emissions in carbon dioxide equivalent (National Greenhouse Gas Inventory Committee, 1994).

The National Greenhouse Gas Inventory aims to assemble a comprehensive information base of human-induced net emissions of greenhouse gases in Australia. As part of the long-term program to develop an improved capacity to compile this national inventory, about $1.1 million has been directed to scientific research over the three years 1995–97 (see also Chapter 5).

Lack of knowledge

Major research programs are required in three key areas to improve knowledge of Australian biodiversity and its conservation and management.

Inventory

Australian biodiversity consists of hundreds of ecosystems, more than one million species and millions of genes.

Although the country has been divided into biogeographic regions (see Fig. 4.9), each of these contains undescribed ecosystems. Thus, we have a long way to go before we understand ecosystem diversity. Commonwealth, State and Territory agencies are using Geographic Information Systems (GISs) to establish a national inventory of ecosystems. In the future, GISs should enable us to predict, for any given area, how many species live there, species turnover from one habitat to another and numbers of rare, vulnerable and endangered species.

Like the rest of the world, Australia has described only a small proportion of its species (see Table 4.8). While most flowering plants and vertebrates are known, the 'lower' plants (mosses and their relatives) are relatively unexplored. Less than half of the invertebrates are described and the micro-organisms remain little known. We have too few taxonomists to carry out a full inventory of Australian species.

The establishment of the Australian Biological Resources Study (now incorporated in the Australian Nature Conservation Agency) provides a major incentive for the documentation of Australia's species diversity. Funding has been provided, under the aegis of the Commonwealth agency, for the scientific investigation of major groups of animals and plants. Researchers publish their findings in the Flora of Australia and the Zoological Catalogue of Australia and ancillary publications.

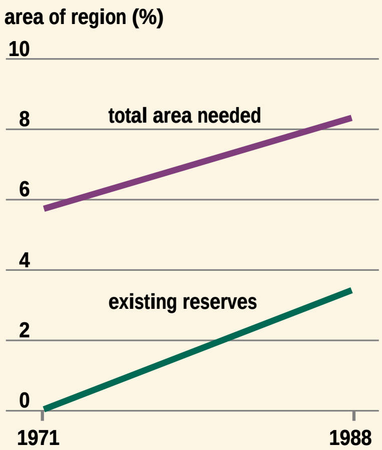
The massive task of understanding genetic diversity is being directed towards two goals. The first is to understand the genetics of species in decline or going extinct and to manage their threatened populations to retain the genetic diversity required for recovery. The second is to locate and bring into the laboratory genes that are commercially important, including those from the wild relatives of crop plants (see the box on page 4-5), bacteria and fungi for industrial use and invertebrates for biological control and biological monitoring.

Location and effectiveness of conservation reserves

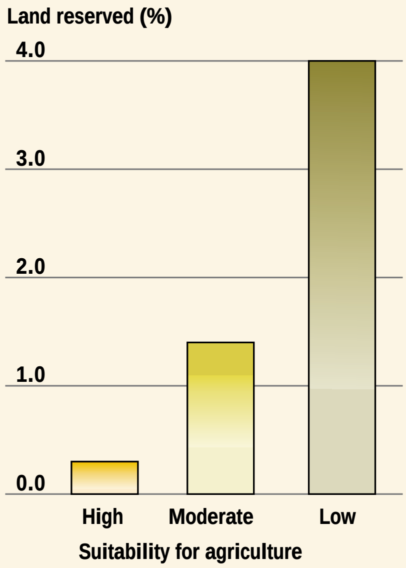
Conservation areas are parts of the land or sea where special management is applied for nature conservation. Management is intended to separate elements of biodiversity (ecosystems, communities, species, populations, genes) from processes that threaten their persistence. National assessments of conservation areas have been limited to 'strict' reserves (those in IUCN, 1994 Categories I–IV). Regional studies have shown that other types of formal protection measures can be very extensive, but we lack information on these for large parts of the continent. Because of the sheer number and extent of these other formal protection measures and the lack of computerised data bases, it is not possible to examine their distribution and coverage of elements of biodiversity.

It seems obvious that strict reserves should be located so that the elements of biodiversity most needing this type of protection are able to persist in the landscape. However, this does not occur. The location of reserves in Australia has been largely shaped by a process of ad hoc acquisition of land that is determined by its availability for conservation purposes, its cost, and a wide variety of aims, some of which lead to very different priorities for protection. Only recently have more systematic approaches to establishing protected areas had some effect on acquisition priorities. Several decades of ad hoc protection have led to two serious limitations of the national reserve system.

The first is that reserves often do not effectively represent the natural features (such as ecosystems or species) within regions. Some features are represented many times and others not at all. This means that the total area needed to represent all the features in a region, starting with the existing reserve system, is greater than if a whole new reserve system were designed from scratch. An example of this tendency occurs in the Western Division of New South Wales (see figure below). The same results have emerged wherever similar analyses have been done in other parts of Australia. The upward trend in required area as more ad hoc reserves are added to the system indicates a steadily increasing cost of reserving all the natural features in a region and a decline in the likelihood of achieving a fully representative reserve system.



Existing reserves and total area of reserves required to represent all land types in the Western Division of New South Wales. In 1971, before any reserves were dedicated, all land types could have been represented in 5.7 per cent of the region. In 1988, following acquisition of reserves totalling 3.3 per cent of the region, the minimum area of reserve needed to represent all land types, starting with existing reserves, was 8.3 per cent.



Reservation in relation to three classes of agricultural suitability in the Mt Lofty Ranges of South Australia.

Source: Department of Housing and Urban Development, SA, GIS Unit.

The second limitation is that reserves tend to be a 'residual' land use, with more extensive protection given to land that is least useful for intensive commercial purposes (see the diagram above). In many areas, this means that reserves do not occur where threatening processes are greatest. For example, ecosystems most in danger of outright replacement by crops and pastures often receive zero or minimal protection. The major conservation battles tend to be fought in a small subsection of the environments in need of protection. In eastern and southern Australia, this is typically on areas of Crown land where the main alternatives are forestry or reservation. Crown land itself is usually the residual tenure after freehold land has been released for intensive land use. A residual reserve system is a poor starting point for regional-based planning, which requires a mix of protection measures with the strictest protection applied to those areas least able to persist under any form of extractive uses — particularly intensive ones like agriculture. A residual reserve system provides the opposite starting point.

Ad hoc reservation consumes limited conservation resources and often gives the appearance of conservation progress (for example, increasing area of reserves) without genuinely contributing to the protection of biodiversity. Two critical questions should be asked in a regional context about proposals for new reserves.

- Will the proposed reserve represent features that are poorly protected?
- Will it cover features that most need this form of protection?

If the answer to one of these questions is 'no', conservation resources will not be spent in the most effective way for conserving biodiversity.

Source: Pressey, 1990.

Monitoring

Monitoring reveals the success or failure of strategies designed to conserve biodiversity and the sustainability or otherwise of industrial practices. Three types of monitoring correspond to the three levels of biodiversity: ecosystems, species and genes.

Australia is a world leader in ecosystem monitoring by GIS. Satellite imagery can reveal the extent of clearing, deforestation, over-grazing, urbanisation, siltation of rivers or coasts or reef dieback from one period to another. Much work remains to be done on 'ground-truthing'— that is, making sure that the interpretation of satellite data corresponds to what is really happening on the ground or in the sea.

Scientists commonly use the distribution and abundance of flowering plant and selected vertebrate species for environmental monitoring. However, they are also increasingly using invertebrates and micro-organisms. Freshwater and marine environments are routinely monitored by assessing the responses of selected vertebrate and invertebrate species to disturbance such as pollution. Research is required to test the reliability of indicator species when monitoring natural resource management, industrial pollution and conservation practices in all kinds of environments.

Declines in genetic variation need to be monitored in populations of endangered species so that, where possible, they can be managed to stabilise losses and reverse the trend. Australian conservation geneticists have contributed to the management of many endangered plants and animals in the field and to captive breeding programs of species on the verge of extinction in the wild.

Reserve systems

The box opposite highlights the problems and shortcomings of Australia's reserve system. Too often the reservation of a piece of land has been for economic or political rather than biological reasons, with the result that ecosystems that are unproductive — for example, because they are on poor soils — are well reserved while those on more productive land or at highly desirable locations may not be reserved at all. Australian ecologists are developing the criteria and guidelines for establishing reserve systems representative of terrestrial and marine ecosystems. Much information and some software are already available, but much needs to be done to integrate the scientific criteria and guidelines into mainstream political and legislative procedures.

Integrated ecosystem-based management of natural resources

Planning and management should be integrated and regionally based to overcome a number of problems. These include large numbers of public agencies involved in management decisions; administrative boundaries that do not reflect any particular physical, geographic or ecological feature; and the cumulative effects of multiple and continuous developments.

One of the principles of the national biodiversity strategy states that 'biological diversity is best conserved *in situ*'. In view of the limitations of the reserve system, bioregional planning is one way of integrating options for conservation of biodiversity. Bioregional planning has been defined as an ecological and social framework within which government, business and community interests share responsibility for coordinating land use planning and formulating and implementing development options which meet human needs in a sustainable way (World Resources Institute, 1992). However, the boundaries of a region can vary depending on the context for which they are being established. To date, commonly used regionalisations include local government boundaries, catchment boundaries and the Interim Biogeographic Regionalisation for Australia regions.

Traditional planning, while it is effective for controlling site-specific development proposals, has proved ineffective for addressing cumulative, off-site and incremental impacts such as habitat fragmentation and soil salinisation that result from land clearance. Bioregional planning can be used to integrate the often ad hoc approaches in planning decisions, as it facilitates a system-based approach. The move towards greater integration across all levels of government, the community and industry in regional planning is indicative of a move towards a more holistic approach.

It is generally agreed that we will not reconcile production and conservation values simply by expanding the national system of reserves and national parks. Many ecosystems and species will be sustainable only if the environment is managed in accordance with natural rather than economic or political boundaries. For example, it makes little environmental sense if an endangered species is protected under one jurisdiction but not in an adjacent one, or a land-use practice is illegal on one side of a political boundary but not on the other.

Bioregional planning and management is a vehicle designed to overcome problems of fragmented decision-making or the tyranny of small decisions. Many Australians, including landholders, government agencies, industries and conservation groups, are already involved, but much knowledge (not only biological) is required to implement it. While scientific knowledge of the biodiversity of a region is essential, ways of creating the infrastructure to include all interested parties and to resolve their conflicts are, in most cases, still to be worked out. Planners also have yet to evaluate adequately existing knowledge of the effects of one type of activity upon others and upon the environment. Where they do not yet exist, data should be gathered so that facts remain the basis for planning and for dispute resolution.

Table 4.20 Summary				
Key issue	**State**	**Adequate Info.**	**Response**	**Effectiveness of response**
Ecosystem diversity				
Northern rainforests Habitat destruction	Highly fragmented; many areas degraded	✓✓	Listing as protected areas, including World Heritage Register; improved land management	Limited; some unique areas not protected; clearing, fire management, grazing and weeds still problematic
Southern rainforests Habitat destruction	Highly fragmented	✓✓✓	Listing as protected areas	Adequate in some areas only
Tall open forests (wet sclerophyll) Altered fire regimes; land clearance; logging	Extensive losses in area and alteration of species composition	✓✓✓	Improved management; reservation	Reserve system inadequate; management practices still in development
Acacia forests, woodlands and shrublands Clearance; grazing	Habitat loss and degradation; species diversity reduced	✓✓	Improved land management	Locally effective
Eucalypt scrubs and shrublands Clearance; grazing	Extreme fragmentation; possible inability to regenerate	✓✓	Reservation; restoration	Very limited; reserves inadequate
Heathlands Clearance, altered fire regimes, urbanisation, agriculture and sand-mining	Widespread habitat loss; fragmentation	✓✓	Reserves	Limited and only locally effective
Chenopod shrublands Grazing	Widespread habitat degradation; many plant species endangered	✓✓✓	Improved land management; reserves	Locally effective only
Native grasslands Grazing	Many areas highly degraded or altered by introduction of exotic species	✓✓✓	Improved land management/legislation; reservation	Locally effective; reserves inadequate
Alpine and subalpine vegetation Grazing; tourism; predicted to be vulnerable to global warming	Some areas highly degraded	✓✓✓	Reservation; improved land management	Many areas now in national parks; others remain degraded and vulnerable
Salt marshes and mangroves Habitat destruction and degradation	Extensive loss near urban areas	✓✓	Protected areas; development controls; community awareness	Limited; loss and degradation continue in many areas
Species diversity				
Micro-organisms Habitat modification and loss	Unknown but population composition and size likely to be affected	✓	Little direct response	Not known
Marine invertebrates Habitat modification and loss; harvesting of edible species; competition from marine pests	Reduction in population size of exploited species	✓✓	Management plans for exploited species; controls on illegal harvesting	Pressures are continuing; very few successes
Freshwater invertebrates Habitat modification and loss	Insufficient information to assess	✓	Integrated catchment management; waste-water treatment; restoration of wetlands; control of introduced pests	Little known
Land invertebrates Habitat modification and loss	Massive reduction in population size of affected species	✓✓	Little direct response; protected areas	Little known
Marine fish Harvesting of edible species	Many important species overexploited but majority in good condition	✓✓	Management plans for most of the major species	Pressures are continuing on most species
Freshwater fish Habitat modification and loss; competition and predation from introduced species	Generally in poor condition; many species endangered	✓✓	Integrated catchment management; waste-water treatment; restoration of wetlands; control of introduced pests	Very limited effect because of difficulty of controlling introduced species and long time needed to rehabilitate habitat
Amphibians Substantial habitat loss but often pressures not identified	Several species have disappeared or are declining	✓✓	Protected areas; community-initiated protection	Lack of knowledge of causes of declines prevents effective action

Table 4.20 Summary (continued)

Key issue	State	Adequate Info.	Response	Effectiveness of response
Reptiles Habitat loss	Massive reduction in numbers in urban and agricultural areas	✓✓✓	Protected areas; protection of marine and freshwater turtles	Partially effective
Birds Habitat modification and loss; predation from feral animals	Some species disappearing, others threatened; a few increasing their range	✓✓✓	General protection; protected areas	Partially effective
Mammals Habitat modification and loss; competition with and predation by feral animals	Several species lost, others threatened; a few increasing in numbers and range	✓✓✓	General protection, protected areas	Partially effective; pressure from feral cats and foxes continues
Marine plants Habitat modification and loss; pollution; natural events - floods and cyclones	Extensive loss of seagrasses; localised loss of mangroves	✓✓✓	Protection for seagrasses and mangroves but destruction still allowed in some areas by permit	Effective for mangroves; loss of seagrass likely to continue through coastal development and natural events
Freshwater plants Habitat modification and loss	Species threatened	✓✓	Limitation on water licences; protected areas	Little known
Land plants Clearance; habitat modification and loss	Many species endangered or vulnerable	✓✓✓	Protected areas	Effective in some areas
Genetic diversity Habitat fragmentation and loss	Some species show reduced genetic diversity	✓	Protected areas; captive breeding programs; reintroductions; regulation of exploitation	Little known; research in progress.

Conclusion

Australia has a world-class heritage of unique ecosystems, species and genes. Although the country was already occupied by Aboriginal people, recent colonisation by people predominantly from European countries has resulted in the introduction of many practices that, while appropriate in their land of origin, have radically altered and degraded much of the Australian landscape, initiating widespread changes with many flow-on effects still to appear. We are now dealing with a continent-wide ecological experiment, the results of which we are struggling to understand and manage.

Australia has a biodiversity comparable to that of many equatorial countries covered in rainforest but, unlike those countries, is industrialised and has a comparatively small human population. Consequently, we have the opportunity to balance conservation of biodiversity, human population growth and economic development. This will come about only with substantial changes in the way that land and oceans are managed. Clearly, many current practices are not sustainable and biodiversity-based industries such as agriculture, pastoralism, forestry, fisheries and tourism often erode the resources upon which they depend. Biodiversity is also a source of profound inspiration to Australians and an essential part of our culture. It is a reservoir of resources that as yet remain relatively untapped. All these issues demonstrate the urgency of establishing major, often nation-wide, coordinated programs for the discovery, monitoring, management and sustainable use of biodiversity.

The use of new management strategies, particularly ecologically sustainable development and the precautionary principle, if implemented, would enable this country to provide world leadership for the wise use of natural resources for future generations. Our Commonwealth, State, Territory, and local governments have a central role to play in balancing conservation of biodiversity and economic production. Future generations are unlikely to forgive further losses of biodiversity through bad management or lack of commitment, especially now that its precarious state is recognised.

References

AUSLIG (1990). 'Atlas of Australian Resources (3rd series) Volume 6 - Vegetation, 64.' (Department of Administrative Services: Canberra.)

ABARE (1995). Australian Fisheries Statistics 1995. (Australian Bureau of Agricultural and Resource Economics: Canberra.)

Australian Mining Industry Council (1990). Mine Rehabilitation Handbook. (Australian Mining Industry Council: Dickson, ACT.)

Beattie, A.J. (ed.) (1995). 'Biodiversity: Australia's Living Wealth.' (Reed: Sydney.)

Behn, G., and Campbell, N. (1992). 'Dieback Assessment, Using Multispectral Data, over the Stirling Range National Park.' (CSIRO: Perth.)

Benson, D.H. (1985). Maturation periods for fire-sensitive shrub species in Hawkesbury Sandstone vegetation. *Cunninghamia*, 1, pp. 339–49.

Benson, D.H., and Howell, J. (1990). Sydney's vegetation 1788–1988 — utilization, degradation and rehabilitation. *Proceedings of the Ecological Society of Australia*, 16, pp. 115–27.

Benson, J. (1991). The effect of 200 years of European settlement on the vegetation and flora of New South Wales. *Cunninghamia*, 2, pp. 343–70.

Biodiversity Unit, DEST (1994). Australia's biodiversity: an overview of selected significant components. *DEST Biodiversity Series Paper* No 2.

Biodiversity Unit, DEST (1995). Native vegetation clearance, habitat loss and biodiversity decline. *DEST Biodiversity Series, Paper* No 6.

Biodiversity Unit, DEST (in press). Status of Australia's biodiversity. *DEST Biodiversity series paper* No. 11.

Blaber, S., Battam, H., Brothers, N., and Garnett, S. (in press). Threatened and migratory seabird species in Australia: an overview of status, conservation and management. *Proceedings of the National Seabird Workshop*.

Blakers, M., Davies, S.J.J.F., and Reilly, P.N. (1984). 'The Atlas of Australian Birds.' (Melbourne University Press: Melbourne.)

Briggs, J.D., and Leigh, J.H. (1988). Rare or threatened Australian plants. *Australian National Parks and Wildlife Service Special Publication* No. 14.

Briscoe, D.A., and Tait, N.N. (1995). Allozyme evidence for extensive and ancient radiations in Australian Onychophora. *Zoological Journal of the Linnean Society (London)*, 114, pp. 91–102.

Brown, A.H.D., Grant, J.E., Burdon J.J., Grace J.P., and Pullen R. (1985). Collection and utilisation of wild perennial *Glycine*. World Soybean Research Conference III, Proceedings, Ames IA 12–17 Aug. 1984, ed. R. Shibles. (Westview Press: Boulder, Colorado.)

Burbidge, A.A., and Kuchling, G. (1994). 'Western Swamp Tortoise Recovery Plan. Western Australian Wildlife Management Program No. 11.' (Western Australian Department of Conservation and Land Management: Como, WA.)

Burbidge, A.A., Johnson, K.A., Fuller, P.J., and Southgate, R.I. (1988). Aboriginal knowledge of the mammals of the central deserts of Australia. *Australian Wildlife Research*, 15, pp. 9–39.

Burbidge, A.A., and McKenzie, N.L. (1989). Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. *Biological Conservation*, 50, pp. 143–98.

Callinan, R.B., Fraser, G.C., and Melville, M.D. (1993). Seasonally recurrent fish mortalities and ulcerative disease outbreaks associated with acid sulphate soils in Australian estuaries. *International Institute for Land Reclamation and Improvement, Publication*, No. 53, pp 403–10.

Castles, I. (1992). 'Australia's Environment: Issues and Facts.' (Australian Bureau of Statistics: Canberra.)

Census of Australian Vertebrate Species (1994). Australian Biological Resource Study. (Australian Nature Conservation Agency: Canberra.)

Cocks, K.D. (1992). 'Use With Care: Managing Australia's Natural Resources in the 21st Century.' (University of New South Wales Press: Kensington, NSW.)

Cogger, H.G., Cameron, E.E., Sadlier, R.A., and Eggler, P. (1993). The action plan for Australian reptiles. *Australian Nature Conservation Agency, Endangered Species Program, Project* No. 124.

Commonwealth of Australia, House of Representatives Standing Committee on Environment, Recreation and the Arts (1992). 'Biodiversity. The Contribution of Community-based Programs.' (AGPS: Canberra.)

Commonwealth of Australia (1994). Budget Statements 1994–95. (AGPS: Canberra.)

Commonwealth of Australia (1992). *Endangered Species Protection Act, 1992.*

Commonwealth of Australia (1996). 'The National Strategy for the Conservation of Australia's Biological Diversity.' (AGPS: Canberra.)

Cracraft, J. (1991). Patterns of diversification within continental biotas: hierarchical congruence among the areas of endemism of Australian vertebrates. *Australian Systematic Botany*. 4, pp. 211–27.

Dexter, E.M., Chapman, A.D. and Busby, J.R. (1995). 'The Impact of Global Warming on the Distribution of Threatened Vertebrates. (Environmental Resources Information Network: Canberra.)

Driml, S. (1994). Protection for profit: economic and financial values of the Great Barrier Reef World Heritage Area and other protected areas. *Great Barrier Reef Marine Park Authority Research Publication* No. 35.

Eldridge, M.D.B., and Close, R.L. (1992). Taxonomy of rock wallabies, Petrogale (Marsupalia: Macropodidae). I. a revision of the eastern Petrogale with the description of three new species. *Australian Journal of Zoology*, 40, pp. 605–25

'Endangered Species Protection Act 1992, Schedules 1, 2 & 3.' (Australian Nature Conservation Agency: Canberra.)

Fox, B.J. (1990). Two hundred years of disturbance: how has it aided our understanding of succession in Australia? *Proceedings of the Ecological Society of Australia*, 16, pp. 521–9.

Fox, M.D., and Adamson, D. (1986). The ecology of invasions. In 'A National Legacy', 2nd edition, eds H. Recher, D. Lunney and I. Dunn, pp. 235–55. (Pergamon Press: Sydney.)

Garnett, S. (1992a). The action plan for Australian birds. *Australian National Parks and Wildlife Service Endangered Species Program, Project* No. 121.

Garnett, S. (ed.) (1992b). Threatened and extinct birds of Australia. *Royal Australian Ornithologists Union Report* No. 82.

Graetz, D., Fisher, R. and Wilson, M. (1992). 'Looking Back: the Changing Face of the Australian Continent, 1972–1992.' (CSIRO Office of Space Science and Applications: Canberra.)

Graetz, R.D., Wilson, M.A., and Campbell, S.K. (1995). Landcover disturbance over the Australian continent: a contemporary assessment. *DEST Biodiversity Series, Paper* No. 7.

Hart, R. (in press). Dieback caused by *Phytophthora cinnamomi*. In: 'The Natural History of Two Peoples Bay Nature Reserve, Western Australia', ed. A.J.M. Hopkins and G.T. Smith (Department of Conservation and Land Management Science Supplement: Perth.)

Hill, B.J. (1992). Minimum legal sizes and their use in management of Australian fisheries. *Bureau of Rural Resources, Proceedings* No. 13, pp. 9–10.

Hill, B.J., and Wassenberg, T.J. (1990). Fate of discards from prawn trawls in Torres Straits. *Australian Journal of Marine and Freshwater Research,* 41, pp. 53–64.

Hillman, K., Lukatelich, R.J., and McComb, A.J. (1990). The impact of nutrient enrichment on nearshore and estuarine ecosystems in Western Australia. *Proceedings of the Ecological Society of Australia*. 16, pp. 39–53.

Hobbs, R.J. and Hopkins, A.J.M., (1990). From frontier to fragments: European impact on Australia's vegetation. *Proceedings of the Ecological Society of Australia*, 16, pp. 93–114.

Hobbs, R.J., and Saunders, D.A. (eds) (1993). 'Reintegrating Fragmented Landscapes: Toward Sustainable Production and Nature Conservation. (Springer-Verlag: New York.)

Hobbs, R.J., Saunders, D.A., and Arnold, G.W. (1993). Integrated landscape ecology. *Biological Conservation*, 64, pp. 231–8.

Holliday, J.E., and Nell, J.A. (1987). The Pacific oyster in New South Wales. *Agfacts*. F2.1.3: (Agdex 486): pp. 1–4.

Hoskin, E.S., Hindwood, K., and McGill, A.R. (1991). 'The Birds of Sydney, County of Cumberland, New South Wales, 1770–1989.' (Surrey Beatty and Sons: Chipping Norton, NSW.)

Humphries, S.E., Groves, R.H., and Mitchell, D.S. (1991). 'Plant Invasions of Australian Ecosystems. Kowari 2.' (Australian National Parks and Wildlife Service: Canberra.)

IUCN (The World Conservation Union) (1994). 'Guidelines for Protected Area Management Categories.' (IUCN: Gland, Switzerland.)

Kennedy, M. (ed.) (1990). 'Australia's Endangered Species.' (Simon and Schuster: Brookvale.)

Kennedy, M. (1992). 'Australia's Marsupials and Monotremes: an Action Plan for their Conservation. (IUCN: Gland, Switzerland.)

Kirkpatrick, J., McDougall, K., and Hyde, M. (1995). 'Australia's Most Threatened Ecosystems. The Southeastern Lowland Native Grasslands. (Surrey Beatty and Sons and Worldwide Fund for Nature Australia: Chipping Norton, NSW.)

Lee, A.K. (1995). The action plan for Australian rodents. *Australian Conservation Agency Endangered Species Program, Project* No. 130.

Leigh, J.H., and Briggs, J.D. (eds) (1992). 'Threatened Australian Plants; Overview and Case Studies.' (MacMillan: Melbourne.)

Leigh, J.H., and Briggs, J.D. (eds) (1994). 'Threatened Australian Plants: Overview and case studies.' (Australian National Parks and Wildlife Service: Canberra.)

Lothian, A.J. (1994). Attitudes of Australians towards the environment: 1975 to 1994. *Australian Journal of Environmental Management,* 1 (2), pp. 78–99.

McComb, A.J., and Lake, P.S. (1990). 'Australian Wetlands.' (Collins/Angus & Robertson: Australia.)

Marsh, H., Corkeron, P.J., Limpus, C.J., Shaugnessy, P.D., and Ward, T.M. (1995). The reptiles and mammals in Australian seas: their status and management. In Zann and Kailola (1995) (eds), pp. 151–66.

Morton, S.R. (1990). The impact of European settlement on the vertebrate animals of arid Australia: a conceptual model. *Proceedings of the Ecological Society of Australia* 16, pp. 201–13.

Morton, S.R., Short, J., and Barker, R.D. (1995). Refugia for biological diversity in arid and semi-arid Australia. *DEST Biodiversity Series Paper* No. 4.

National Greenhouse Gas Inventory Committee (1994). 'National Greenhouse Gas Inventory, 1988 and 1990.' (DEST: Canberra.)

National Recreational Fisheries Working Group (1994). 'Recreational Fishing in Australia. A National Policy.' (Department of Primary Industries and Energy: Canberra.)

Noss, R.F. (1987). Corridors in real landscapes. A reply to Simberloff and Cox. *Conservation Biology* 1, pp. 159–64.

National Population Council (1992). 'Population Issues and Australia's Future. Environment, Economy and Society. Consultant's Report. (AGPS: Canberra.)

Olsen, P., Fuller, P., and Marples, T.G. (1993). Pesticide-related egg shell thinning in Australian raptors. *Emu,* 93, pp. 1–11.

Orr, A.G. (1994). Inbreeding depression in Australian butterflies: some implications for conservation. *Memoirs of the Queensland Museum,* 36, pp. 179–84

Paterson, R.A. (1990). Effects of long-term anti-shark measures on target and non-target species in Queensland, Australia. *Biological Conservation,* 52, pp. 147–59.

Pender, P.J., Willing, R.S., and Cann, B. (1992). NPF by-catch a valuable resource? *Australian Fisheries,* 51(2), pp. 30–1.

Preece, N., van Oosterzee, P., and James, D. (1995). Two Way Track - Biodiversity conservation and ecotourism: an investigation of linkages, mutual benefits and future opportunities. *DEST Biodiversity Series Paper,* No. 5.

Pressey, R.L. (1990). Reserve selection in New South Wales: where to from here? *Australian Zoologist,* 26(2), pp. 70–5.

Pressey, R.L. (1995). Conservation reserves in New South Wales: crown jewels or leftovers? *Search*, 26, pp. 47-51.

Pressey, R.L., and Adam, P. (1995). A review of wetland inventory and classification in Australia. *Vegetatio*, 118, pp. 81–101.

Prober, S., and Thiele, K. (1993). Surviving in cemeteries - the grassy white box woodlands. *National Parks Journal*, February, pp. 13–15.

Recher, H.F., and Lim, L. (1990). A review of current ideas of the extinction, conservation and management of Australia's terrestrial fauna. *Proceedings of the Ecological Society of Australia*, 16, pp. 287–301.

Reid, D.D., and Krogh, M. (1992). Assessment of catches from protective shark meshing off New South Wales beaches between 1950 and 1990. *Australian Journal of Marine and Freshwater Research*, 43, pp. 283–96.

Reid, J., and Fleming, M. (1992). The conservation status of birds in arid Australia. *Rangeland Journal*, 14, pp. 65–91.

Resource Assessment Commission (1992). 'Forest and Timber Inquiry, Final Report.' (AGPS: Canberra.)

Resource Assessment Commission (1993). 'Coastal Zone Inquiry, Final Report. (AGPS: Canberra.)

Sainsbury, K.J. (1988). The ecological basis of multispecies fisheries, and management of a demersal fishery in tropical Australia. In 'Fish Population Dynamics' (2nd ed.), ed. J.A. Gulland, pp. 349–82. (John Wiley and Sons: Chichester and New York.)

Sarre, S., Schwaner, T.D., and Georges, A. (1990). Genetic variation among insular populations of the sleepy lizard, *Trachydosaurus rugosus* Gray (Squamata:Scincidae). *Australian Journal of Zoology*, 38, pp. 603–16.

Saunders, D.A. (1991). The effect of land clearing on the ecology of Carnaby's Cockatoo and the inland red-tailed black cockatoo in the wheatbelt of Western Australia. *Acta XX Congressus Internationalis Ornithologica*, pp. 658–65.

Saunders, D.A., Craig, J.L., and Mattiske, E.M. (eds) (1995). Nature Conservation 4. The Role of Networks (Surrey Beatty and Sons: Chipping Norton NSW.)

Saunders, D.A., and de Rebeira, C.P. (1991). Values of corridors to avian populations in a fragmented landscape. In: 'Nature Conservation 2. The Role of Corridors', eds D.A. Saunders and R.J. Hobbs, pp. 221–40. (Surrey Beatty and Sons: Chipping Norton, NSW.)

Saunders, D.A., Hopkins, A.J.M., and How, R.A. (eds) (1990). Australian ecosystems: 200 Years of utilization, degradation and reconstruction. *Proceedings of the Ecological Society of Australia* 16, pp. 1–602.

Shaklee, J.B., and Salini, J. (1993). Electrophoretic characterisation of multiple genetic stocks of barramundi perch in Queensland. *Transactions of the American Fisheries Society*, 122, pp. 685–701.

Short, K. (1994). 'Quick Poison, Slow Poison: Pesticide Risk in the Lucky Country. (Southwood Press: Sydney.)

Simberloff, D., Farr, J.A., Cox, J., and Mehlman, D.W. (1992). Movement corridors: conservation bargains or poor investments. *Conservation Biology*, 6, pp. 493–504.

Taylor A.C., Marshall Graves, J.A., Murray, N.D., and Sherwin, W.B (1991). Conservation genetics of the koala (*Phascolarctos cinereus*) II. Limited variability in Minisatellite DNA sequences. *Biochemical Genetics*, 29, pp. 355–63.

Taylor A.C., Sherwin, W.B., and Wayne, R.K. (1994). Genetic variation of microsatellite loci in a bottlenecked species: the northern hairy-nosed wombat *Lasiorhinus krefftii*. *Molecular Ecology*, 3, pp. 277–90.

Thackway, R., and Cresswell, I.D. (eds). (1995). 'An Interim Biogeographic Regionalisation for Australia: a Framework for Establishing the National System of Reserves. Version 4.0.' (Australian Nature Conservation Agency: Canberra.)

Tidemann, S.C., McOrist, S., Woinarski, J.C.Z., and Freeland, W.J. (1992). Parasitism of wild Gouldian finches (*Erythrura gouldiae*) by the air-sac mite (*Sternostoma tracheacolum*). *Journal of Wildlife Diseases*, 28, pp. 80–84.

Tyler, M. (1994). 'Australian Frogs.' Revised edition. (Reed Books: Chatswood.)

Victorian Department of Conservation and Natural Resources (1992), 'Draft Conservation Program for Native Grasslands and Grassy Woodlands of Victoria.' (Scientific Publications: Kew, Victoria.)

Wager, R., and Jackson, P. (1993). The action plan for Australian freshwater fishes. *Australian Nature Conservation Agency, Endangered Species Program, Project* No. 147.

Williams, G. (1990). Invertebrate conservation. In 'Australia's Endangered Species', ed. M. Kennedy. (Simon & Schuster: Brookvale.)

Winter, J.W., Atherton, R.G., Bell, F.C., and Pahl, L.I. (1987). An introduction to Australian rainforests. *Special Australian Heritage Series* No. 7(1), pp. 95–118. (AGPS: Canberra.)

World Commission on Environment and Development (1987). 'Our Common Future.' (Oxford University Press: Oxford.)

World Conservation Monitoring Centre (1992). 'Global Biodiversity — Status of the Earth's Living Resources.' (Chapman and Hall: London.)

World Resources Institute (1992). 'Global Biodiversity Strategy.' (Prepared by WRI, World Conservation Union, United Nations Environment Programme in consulation with FAO and the UNESCO. (World Resources Institute: Washington.)

Zann, L.P. (1995). 'Our Sea, Our Future. Major Findings of the State of the Marine Environment Report for Australia.' Published by the Great Barrier Reef Marine Park Authority for DEST, Ocean Rescue 2000 Program, pp. 1–112.

Zann, L.P., and Kailola, P. (1995). 'The State of the Marine Environment Report for Australia. Technical Annex 1: the Marine Environment.' Published by the Great Barrier Reef Marine Park Authority for DEST, Ocean Rescue 2000 Program, pp. 1–193.

Acknowledgments

The following people reviewed the chapter in draft form and provided constructive comments.

Professor Rhonda Jones (James Cook University)
Dr Sam Lake (Monash University)
Dr Judith Lambert (Community Solutions)
Professor Henry Nix (Australian National University)
Professor Harry Recher (Edith Cowan University)

A number of people from government departments, private industry and voluntary organisations provided information. We especially thank the following who assisted in the preparation of this chapter:

Jim Crennan (Australian Nature Conservation Agency)
Rohan Fernando (Australian Nature Conservation Agency)
Andreas Glanznig (Community Biodiversity Network)
Andrew Taplin (Australian Nature Conservation Agency)

In addition, Commonwealth Government departments and members of the Commonwealth/State ANZECC State of the Environment Reporting Taskforce also helped identify errors of fact or omission. Their assistance is also gratefully acknowledged.

Photo credits

Page 4-1: Richard Weatherly
Page 4-4: (*from top*) CSIRO Division of Fisheries; D. McKillop (GBRMPA); GBRMPA
Page 4-5: (*top*) Kathie Atkinson; (*bottom*) Beth Seviour
Page 4-6: (*top*) Kathie Atkinson; (*bottom*) CSIRO
Page 4-7: Denis Saunders (CSIRO Division of Wildlife & Ecology)
Page 4-8: Kathie Atkinson
Page 4-10: CSIRO Division of Fisheries
Page 4-12: Kathie Atkinson
Page 4-15: Kathie Atkinson
Page 4-18: Ian Morris
Page 4-20: CSIRO Division of Fisheries
Page 4-21: Denis Saunders (CSIRO Division of Wildlife & Ecology)
Page 4-22: Kathie Atkinson
Page 4-27: Land Information Centre, Bathurst; from data captured by ACRES
Page 4-31: (*from left*) Michael Sharp (NSW Parks & Wildlife Service); Wyn Jones (NSW Parks & Wildlife Service)
Page 4-33: Painting by Oldfield Thomas (ANT Photo Library)
Page 4-38: (*left column*) Robert Close; (*right column*) Manfred Jusaitis (Botanic Gardens of Adelaide)
Page 4-44: D. Whitford (ANT Photo Library)
Page 4-45: Greening Australia, Victoria
Page 4-48: Colin Harris (Dept E&NR SA)
Page 4-50: Nick Alexander (Oryx Films)