CHAPTER 12

Biodiversity in Australia: An Overview

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12.1 Introduction

12.1.1 Geography, Geology, Climate, and History

Australia has the unique distinction of being both a single country and an island continent. In addition to its continental land area of 7,595,342 km^2, at least 5,442 islands 0.01–5,786 km^2 in size (total area 32,969 km^2) lie offshore (SEWPAC, 2012; http://www.ga.gov.au/scientific-topics/national-location-information/dimensions/area-of-australia-states-and-territories). The island state of Tasmania, located off the southern coast of eastern Australia, covers an additional 64,519 km^2, excluding its surrounding islands. Australia's jurisdiction covers seven external territories, including almost 5.9 million km^2, or 42% of Antarctica, and also extends 200 nautical miles (370 kms) seaward from all land areas except in the north due to the close proximity of New Guinea. The vast area of ocean encompassed within the 200 nautical miles (~14 million km^2: Watford et al., 2005) is the Exclusive Economic Zone. Here, Australia has sovereign rights that include the conservation and management of natural resources in the waters superjacent to the seabed and of the seabed and its subsoil (http://www.ga.gov.au/scientific-topics/marine/jurisdiction/maritime-boundary-definitions#eez). Encompassing a very broad range of land systems and different climatic zones, and experiencing a prolonged period of isolation in its long geological history, Australia is home to an extraordinarily rich and largely endemic biota. For these reasons, it has been recognized by Conservation International as one of the world's 17 megadiverse countries (Mittermeier et al., 1997). To understand where Australia's biota came from and the forces that maintain its biodiversity now, we need to consider briefly the physical geography and history of this great southern continent.

Lying between latitudes 10° 40' and 43° 39' S and longitudes 113° 09' and 153° 39' E, the Australian land mass is bounded to the west by the Indian

Ocean and to the east by the Pacific Ocean. The tropical Timor Sea and Arafura Sea lap the northern coast, while the great Southern Ocean lashes the continent's southern shores. Renowned as the world's driest inhabited continent, Australia has few large freshwater lakes and relatively few major rivers. The largest body of water, sometimes referred to as the continental 'sump' owing to its elevation 15 m below sea level, is Lake Eyre. Although it covers up to 10,000 km^2 when full, this saline lake is ephemeral and fills only after prolonged rains throughout the catchment area.

As might be expected for a continental landmass, Australia is geologically complex and comprises rocks and minerals of hugely varied age and origin. Crystals of zircon discovered recently in Western Australia have been dated to 4.374 billion years. Forming just 125 million years or so after the creation of the Earth-moon system, these ancient crystals represent the oldest known pieces of the Earth's crust (Valley et al., 2014). Other materials, from the Yilgarn craton in the southwest of Western Australia and from the Pilbara craton in the state's northwest, are at least 3.5 billion years old (Griffin et al., 2004; Hickman and Van Kranendonk, 2008). The Pilbara region holds the record for the oldest exposed surface strata, with cherts embedded in volcanic basalts that date to 3.5 billion years. This region also hosts some of the world's earliest known sedimentary rocks. Aged 2.5–3.5 billion years, these strata confirm the presence of rivers and lakes or seas in which the eroded sediments were deposited (Johnson, 2004).

Around 1.3–1.4 billion years ago these ancient cratons—or 'proto-continents'—collided in the east with the North Australian and South Australian cratons, creating a landmass that now underlies much of the modern continent. These cataclysmic events resulted in the upthrust of mountain ranges, the eroded remnants of which can still be seen in northern South Australia, Western Australia and the Northern Territory (Johnson, 2004). More recently, just 80–100 million years ago, the Great Dividing Range began to arise near the eastern edge of the Australian landmass. This event accompanied the opening of the Tasman Sea and the rifting of New Zealand from Australia's east coast, resulting in uplift of the continent's eastern margin. The geology of the Great Dividing Range is exceedingly complex, with sedimentary strata and granites dating from more than 300 million years and more recent episodes of volcanism that have resulted in basaltic outcrops in many places (Johnson, 2004). Erosion of the Great Dividing Range has softened and lowered what would have been once a towering cordillera. The highest point now—Mount Kosciuszko—is 2,228 m a.s.l., with most of the range just 300–1600 m a.s.l. Nonetheless, running 150–400 km inland from the east coast and extending more than 3500 km from north Queensland to western Victoria, the Great Dividing Range is an outstanding and significant landform—the third longest mountain chain in the world after the Andes and the Rocky Mountains.

The great antiquity and stability of the Australian continent have exposed the land to prolonged weathering. This has resulted in the generally subdued topography of the country's landscapes, and soils that are leached and impoverished over vast areas. Two of the major processes that renew soils in other parts of the world have operated much less conspicuously in Australia. Firstly, orographic activity has been limited, with few episodes of mountain-building occurring since the uplift of the Great Dividing Range. Secondly, glaciation has been relatively inconsequential. Although Australia has experienced intense cycles of arid glacial and humid interglacial conditions, especially over the last 4–5 million years, ice accumulated primarily only in Tasmania and in the southeastern highlands of the Great Dividing Range (Johnson, 2004). Immense glaciers in other regions, especially in the Northern Hemisphere, scraped and gouged the landscapes as they advanced and left vast areas of 'new' soils as they retreated. Australia's modest glaciers were much more localized in their effects. The immense period of weathering and limited opportunities for soil renewal have left Australia with a legacy of shallow, skeletal soils that are depleted in many of the nutrients that are needed for plant growth. The nutrient-poverty of the soils, in turn, has had profound consequences for the evolution of Australia's biota (Augee and Fox, 2000; Orians and Milewski, 2007).

In addition to the physical environment, climate plays a key role in dictating the distribution and abundance of biota. Australia's continental climate has varied greatly over time, oscillating between tropical 'greenhouse' conditions that were associated with extensive forests, rivers and freshwater lakes, to cool, arid 'icehouse' conditions when freshwater was limited and landscapes were dominated by grasslands rather than by forest. The early Miocene, beginning 23 million years ago, marks the start of one of the lushest greenhouse phases. This lasted for 8 million years before giving way to an icehouse event that heralded a prolonged period of continental drying. This latter period has continued, with several oscillations, to the present, with characteristically arid landforms such as sand dunes developing over the last million years (Byrne et al., 2008). The intensification and spread of arid conditions have affected the evolutionary history of many groups of plants and animals, and contribute to the powerful imagery associated with Australia's expansive and iconic 'outback' landscapes.

Australia's current climate has many influences. At the largest geographical scale are massive oceanic and atmospheric circulation phenomena that affect flows of water and air, in particular, moist air that leads to rainfall. In the west, the Indian Ocean Dipole (IOD)—which is defined by relative differences in sea surface temperatures between two areas in the Indian Ocean—is associated with more rainfall (if the IOD is negative) or less rainfall (if the IOD is positive) across the Top End and southern Australia, as well as with differences in degree of cloud cover in the northwest (Bureau of Meteorology, 2012). In the east, the El Niño – Southern Oscillation (ENSO)—which is driven by relative differences in sea surface temperatures between the central and eastern tropical Pacific Ocean—can bring flooding rains to central and eastern regions in the La Niña (positive) phase and droughts in the El Niño (negative) phase. IOD and ENSO phenomena dominate regional climates every few years; the coincidence of both cycles can result in extreme and widespread rainfall or drought events. Near-shore currents affect weather more locally. Warm waters flowing down the east and west coast of Australia bring moisture that condenses on the cold land surface in winter, resulting in frequently heavy rains in this season (Bureau of Meteorology, 2012).

At the continental scale, rainfall is lowest in the arid regions of southern and central Australia, with annual averages as low as 150–200 mm. These regions are associated with high-pressure belts and descending dry air that reduces cloud cover; in consequence, levels of both solar radiation and evaporative water loss from the soil are high. Air temperatures on hot days can exceed 50°C, and surface temperatures of 60–70°C are not uncommon (Williams and Calaby, 1985). Rainfall increases with distance from the arid heartland, especially in coastal and subcoastal areas as proximity to both moisture sources and reliable rain-producing weather systems increases (http://www.bom.gov.au/climate/averages/maps.shtml). The exceptions to this pattern are the arid Pilbara region in the northwest and along parts of the equally dry Great Australian Bight in the south. Average annual rainfall is greatest at higher elevations; for example, mountainous parts of northeastern Queensland and western Tasmania receive average annual rainfall of 3,000 mm or more. In Tasmania and higher parts of the Great Dividing Range, precipitation in winter occurs as snow. In general, rainfall in northern Australia occurs in summer and is associated with tropical monsoons, whereas rainfall at higher latitudes occurs mostly in winter. Eastern Australia, especially east of the Great Dividing Range, is the only region that reliably receives both summer and winter rainfall, although heavy rainfall can occur unpredictably during any season in the central arid zone (http://www.bom.gov.au/climate/averages/maps.shtml).

Both climate and physical geography shape patterns in the occurrence of present-day biota, but to understand where a biota comes from we must consider its historical biogeography. This is particularly important for a now-isolated island continent. If we step back to the beginning of the Triassic Period, some 250 million years ago, the world's landmasses were coalesced into a single supercontinent, termed Pangaea. Pangaea began to break up during the Triassic, with the vast northern landmass, Laurasia, separating from its southern counterpart, Gondwana (Johnson, 2004). These huge continents themselves also began to fracture, with Africa breaking free from the eastern Gondwanan landmass about 170 million years ago, and India, Madagascar and New Zealand separating in turn over the next 100 million years. Australia and eastern Antarctica separated some 38–45 million years ago (Long et al., 2002). South America and western Antarctica were the last components of the ancient Gondwanan landmass to dissociate, sundering perhaps 30 million years ago. Laurasia, comprising modern-day Asia, Europe and North America, remained united as the break-up of Gondwana took place. These titanic deep-time events occurred because the continental land masses sit on plates in the Earth's crust and are propelled by convection currents that lie deep beneath the surface. These currents were responsible for the collision of the cratons that form the bedrock of much of modern Australia and, since the sundering of the Australian plate with Antarctica, they continue to push the Australian continent northward at the rate of about six centimeters per year (White, 2006). Some 30 million years ago, the northward-drifting Australian plate collided with the Pacific plate, resulting in buckling and massive uplifting of land along the active edges. The uplifted land now forms part of present-day New Guinea. This rugged landmass was connected by land to Australia at the time of uplift 30 million years ago, but lower-lying areas have been submerged on several occasions since (White, 2006). The most recent land connection formed during the last ice age when sea levels fell by as much as 160 meters. New Guinea has been an island since rising sea levels breached the land bridge to form Torres Strait 15,000 years ago.

For Australia, the reshaping of the Earth's surface over the last 200 million years has had profound consequences. The sundering of Antarctica from Australia and South America allowed the formation of the circumpolar current, and with it, increased productivity of the southern oceans. This, in turn, appears to have fostered the evolution of large filter-feeding whales (Mysticetes) that now abound in the oceans around modern Australia (Fordyce and

Barnes, 1994; Fordyce, 2006). On land, elements of the biota such as many flowering plants and invertebrates have Pangaean origins and share deep affinities with relatives on other continents (Augee and Fox, 2000). Other elements, such as the marsupials, are descended from Gondwanan stock that entered Australia some 60–65 million years ago when the continent was connected by the Antarctic land bridge to South America (Archer and Kirsch, 2006). By contrast, the first Australian rodents invaded from the north, arriving via Melanesia some 5 million years ago by crossing the newly formed Torresian land bridge (Aplin and Ford, 2014). Still other biota arrived by rafting. For example, the ancestors of modern nasute termites arrived in Australia on 2–3 occasions between 10 and 20 million years ago, completing oceanic migrations from perhaps as far away as South America (Arab et al., 2017). The ancestors of a Kangaroo Island trapdoor spider, *Moggridgea rainbowi*, appear also to have made a long crossing over the Indian Ocean, arriving 2.27–16.02 million years ago (Harrison et al., 2017). Phylogenetic analyzes are being used increasingly to uncover the origins of Australia's biota, with the composition of many groups turning out to be a complex mix of Gondwanan endemism and more recent immigration (e.g., Sniderman and Jordan, 2011; Heads, 2014; Jarvis et al., 2014; Oliver and Hugall, 2017).

In essence, Australia's biota has diverse origins that comprise resident lineages of varied antiquity and immigrants that have arrived and settled at different times since at least the end of the Cretaceous 65 million years ago. Once in Australia, of course, organisms were then subject to forces that caused further divergence and contributed to the pattern of diversity that we see today (Heads, 2014). For example, many closely related species of plants and animals occur in southeastern and southwestern Australia, and represent taxa descended from ancestral populations that were split by marine inundation or the onset of hostile climatic regimes (Crisp and Cook, 2007). Seasonally arid conditions began to arise in northwestern Australia in the late Palaeocene and moved into inland areas towards the mid-Miocene by about 15 million years ago (Martin, 2006; Morton et al., 2011). Aridity intensified throughout the Pliocene, culminating in the last very arid glacial maximum 18,000–20,000 years ago (Hesse et al., 2005). Phylogenetic evidence indicates that many lineages of arid-adapted plants and animals began to diverge from mesic-adapted ancestors from mid-Miocene times as the climate began to dry, with speciation taking place both *in situ* and in association with severe climatic oscillations that repeatedly fractured and then reassembled species populations across the inland environment (Byrne et al., 2008, 2011; Martin, 2017). Many species persisted in evolutionary refugia in permanent freshwater habitats, in the central ranges, and in high elevation sites in eastern and western Australia, their isolation leading to high levels of disjunction and endemism (Davis et al., 2013). In addition to these large-scale forces, local climatic conditions, fire regimes, soils and interactions between species dictate the patterns of biodiversity at local and regional scales (Dickman et al., 2014; Gibson et al., 2017). I consider next the biomes that are so formed.

12.2 Major Ecosystems

Australia's great size, diverse landscapes and multiple climatic zones mean that it supports a bewilderingly large range of ecosystem types. Many formal classification systems have been proposed to organize and distinguish them. One of the earliest and simplest recognized four broad biogeographic regions: the Eyrean (encompassing the central deserts), Torresian (across the monsoonal north), the Bassian in the southeast and the Westralian in the southwest (Spencer and Gillen, 1912). More recent schemes recognize many more regions. For example, Olson et al. (2001) recognized 40 ecoregions within Australia and its island territories, out of a total 867 ecoregions worldwide. In Australia, however, perhaps the most widely used scheme is the Interim Biogeographic Regionalization for Australia (IBRA), which has now progressed to version 7.0 (https://environment.gov.au/land/nrs/science/ibra/australias-bioregions-maps). Earlier versions of IBRA helped to inform the ecoregions of Olson et al. (2001), which often represent clusters of two or more similar IBRA regions. IBRA uses a landscape-based approach to classify Australia's terrestrial environment and those of its external territories. In total, IBRA delineates 89 biogeographic regions and 419 subregions, each reflecting a unifying set of major environmental influences that shape the occurrence of flora and fauna and their interaction with the physical environment (Department of the Environment and Energy, 2017). Each IBRA subregion itself usually contains at least two regional ecosystems, with the result that thousands of this finest-scale ecosystem type can be recognized. For brevity here, I describe a higher-level grouping of the 89 biogeographic regions into biomes. Developed initially by the World Wildlife Fund, 14 terrestrial biomes are recognized worldwide, with eight of these in Australia (Olson et al., 2001; Figure 12.1). I also describe equivalent classification schemes that provide recognition of Australia's marine (Spalding et al., 2007) and freshwater (Abell et al., 2008) systems.

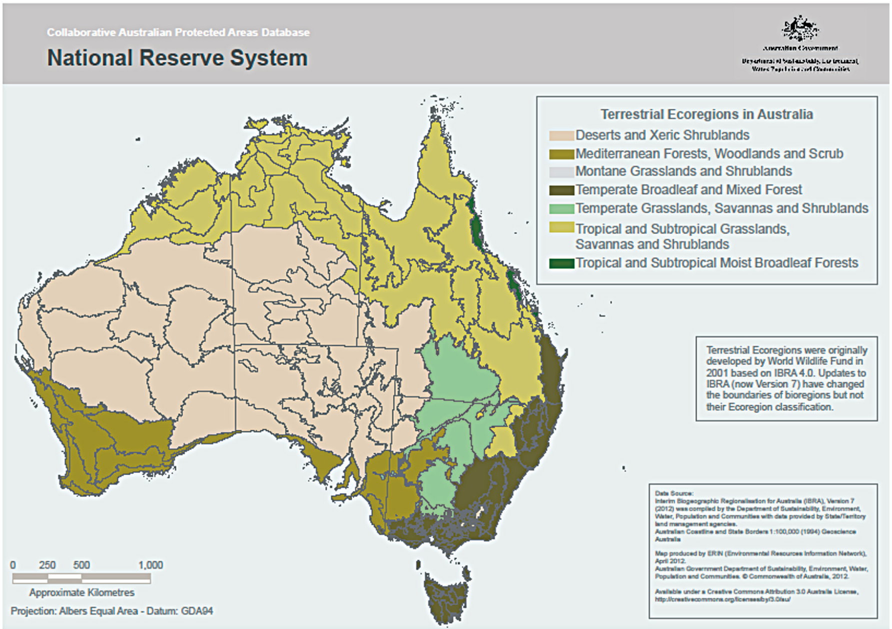

Figure 12.1 Terrestrial biomes in Australia. Biomes are represented by different shading, and Interim Biogeographic Regionalization for Australia (IBRA) regions by lines. Source: Australian Government Department of the Environment and Energy. Note that biomes are termed ecoregions in this figure, whereas this chapter uses the term 'biome' to accord with original usage (Olson et al., 2001).

12.2.1 Deserts and Xeric Shrublands

Covering 3,468,165 km^2, this is the largest of Australia's biomes. It spans the continent's arid center and encompasses 21 IBRA regions. This biome contains the continent's five major deserts: the Great Sandy Desert, Gibson Desert, Great Victoria Desert, Simpson Desert and Sturt's Stony Desert, which together occupy some 20% of Australia's landmass (Williams and Calaby, 1985). Not surprisingly, rainfall is generally low (< 375 mm) but also highly variable and greatly exceeded by potential evaporation. Spinifex or porcupine grass (*Triodia* spp.) dominates much of the central and northern parts of this biome, especially on nutrient-impoverished sand plains and sand dunes; the grassland in places has no shrubs or trees, but in most areas the cover of Spinifex is punctuated by patches of low woodland or scattered trees. Woodlands dominated by *Acacia* spp. occur in western and some eastern parts of this biome, and chenopod shrublands and mallee eucalypts in southerly areas (Williams and Calaby, 1985). The eastern-most part of the biome encompasses the Channel Country. Covering over 304,000 km^2, landscapes here are some of the most open in the entire country. It is possible to stand in parts of the Channel Country and see the horizon unobstructed by any large trees or shrubs in an arc of 360°. Rains that fall in catchments to the north of the Channel Country surge through this region in south to southwestern directions in river channels that give this region its name (Dickman, 2010).

Areas of rugged upland topography occur in western parts of this biome, as well as in the central MacDonnell Ranges and the Flinders Range in the southeast. Despite the harsh and ostensibly hostile character of the deserts and xeric shrublands biome, this great region sustains the world's richest desert reptile and insectivorous mammal faunas. Diverse and endemic flowering plants occur in all upland areas that have been studied, and endemic algae, aquatic vascular plants, fish, snails, crustacea and many insects are restricted to desert springs (Fensham, 2010). Among the most bizarre and highly derived fauna are the richly biodiverse stygofauna that occur in subterranean aquifers in the western part of this biome (Humphreys, 2006). Here, a projected 4,140 species of invertebrates—some with Gondwanan or Pangean ancestry—have been uncovered, making this the most diverse stygofauna that has yet been described (Guzik et al., 2010).

12.2.2 Tropical and Subtropical Grasslands, Savannas, and Shrublands

This immense biome encompasses almost all of northern Australia, from the western Kimberley to Cape York, with a southern extension into northern New South Wales. It encompasses 23 IBRA regions and occupies 2,407,400 km^2. This region receives higher rainfall than the deserts and xeric shrublands, in the order of 400 mm a year where the two biomes abut, but in the range of 900–1,600 mm a year in some coastal and subcoastal areas. Perennial grassland and sparse, low (4–8 m) species of *Eucalyptus* or *Acacia* dominate the lower rainfall areas, with the structural complexity and diversity of these communities increasing as rainfall increases. Among the most expansive of the grasslands is the Mitchell Grass Downs IBRA region (335,000 km^2), which extends from the interior of the Northern Territory deep into central Queensland. Dominated by Mitchell grasses (*Astrebla* spp.), the heavy clay soils of the downlands crack and flex depending on climatic conditions. Trees do not establish readily due to the instability of the soils, but many vascular plants, invertebrates and some vertebrates (e.g., Julia Creek dunart, *Sminthopsis douglasi*) are endemic to Mitchell grass areas. On the eastern flank of the downlands are vast tracts of *Acacia*-dominated communities, especially brigalow *A. harpophylla*, which has its own endemic flora and fauna (Keith, 2004). Although much of this biome is characterized by undulating plains, areas of rugged and broken topography occur throughout the Kimberley and Top End, as well as around Mount Isa and in the desert uplands of Queensland.

As in the deserts and xeric shrublands, upland areas in the tropical and subtropical grasslands, savannas and shrublands biome harbor diverse and endemic flowering plants and invertebrates, including many insects and crustaceans in stygofauna of the Kimberley (Guzik et al., 2010). Patches of dry rainforest and vine thicket occur in many parts of this biome, especially in coastal locations. Along with large islands such as Groote Eylandt and the Tiwi Islands, these habitats contain many endemic plants, snails, earthworms and other invertebrates (McKenzie et al., 1991). Among the vertebrates, endemic taxa occur in each of the five classes. Many have links with New Guinea and Southeast Asia due to exchanges across Torres Strait. Large numbers of birds make regular crossings of the strait (Pratt and Beehler, 2015); mammals, such as tree-kangaroos (*Dendrolagus* spp.) and cuscuses (*Phalanger mimicus* and *Spilocuscus maculatus*), are the descendants of colonists that evolved in New Guinea (Heinsohn and Hope, 2006).

12.2.3 Temperate Grasslands, Savannas, and Shrublands

The temperate grasslands, savannas and shrublands are restricted to inland areas of southeastern Australia, abutting the deserts and xeric shrublands biome to the west and more heavily wooded biomes elsewhere. This biome differs from the tropical grasslands due to the generally cooler temperatures and wider annual temperature range, as well as the dominant vegetation formations. Rainfall averages 250 mm a year in the west, but can be as much as 650 mm a year at sites along the eastern margin; rainfall occurrence is unpredictable, but shifts from summer dominance in the northern parts of this biome to winter dominance in the south.

Encompassing four IBRA regions, almost half of the 529,779 km^2 extent of this biome is occupied by the Mulga Lands. Soils of the Mulga Lands are poor and dominated by mulga (*Acacia aneura*), but with significant patches of eucalyptus woodland with varied species of box and ironbark. Although generally flat with few hills, the Mulga Lands contain several important wetlands that flood on a seasonal basis and support large populations of wetland birds. To the south of the Mulga Lands lie the remaining IBRA regions that comprise this biome: the Cobar Peneplain, Darling Riverine Plains and Riverina. The Cobar Peneplain is characterized by rolling downs and flat plains, with stony ridges and some locally significant peaks, such as those in the Gunderbooka Range. Mulga infiltrates in northerly areas, with open eucalypt- and cypress-dominated woodlands elsewhere (Keith, 2004). The remaining IBRA regions in this biome are drained by major rivers, in particular, the Darling, Murray and Murrumbidgee Rivers. These form alluvial plains with productive soils that support extensive and well developed gallery forests dominated by river red gums (*Eucalyptus camaldulensis*), a wide variety of box-eucalypts and species of *Acacia*. Soils are generally more sandy and less productive away from the riparian areas, and support shrublands dominated by saltbush (*Atriplex* spp.), bluebush (*Maireana* spp.) and other chenopod species, as well as native grasslands (Keith, 2004). It is likely that this biome retains some endemic flora and fauna, especially in the less disturbed range country, but this has been little studied. Unfortunately, much of the native vegetation of this biome has been obliterated by cropping for wheat and cotton, and especially by the pastoral industry; sheep and goat grazing dominate in most areas. Even now, vast areas of mulga continue to be cleared annually in Queensland to run ever-greater flocks of domestic grazing animals (Cogger et al., 2017).

12.2.4 Mediterranean Forests, Woodlands, and Scrub

Restricted to the southwestern corner and parts of the southeastern mainland, this biome encompasses 14 IBRA regions and occupies 782,952 km^2. It is bounded inland mostly by the deserts and xeric shrublands biome; annual rainfall rises from a minimum of ~250 mm along the boundary to over 1,200 mm in some coastal and subcoastal sites. In general, the Mediterranean-type ecosystems are characterized by hot, dry summers and cool, moist winters; frosts occur infrequently. Only five regions in the world experience similar climatic conditions, ensuring that the habitats they contain are globally rare. Despite this, the Mediterranean forests, woodlands and scrub biome is characterized by extraordinarily high levels of diversity of uniquely adapted animal and plant species. Collectively, the five globally distributed regions of this biome harbor over 10 percent of the Earth's plant species (http://environment.gov.au/land/nrs/science/ibra/australias-ecoregions). Most plants are fire-adapted, and dependent on this disturbance for their persistence.

The Western Australian part of the Mediterranean forests, woodlands and scrub biome supports extensive areas of *Eucalyptus*-dominated woodlands and forests, with different mallee species, jarrah (*E. marginata*) and giant karri (*E. diversicolor*) being well represented. Diverse heath communities line the southwestern coastline and dominate the region's offshore islands. In areas near the coast, such as the Stirling Range, and inland in the Coolgardie IBRA region, some of the most diverse and magnificent floras can be found (Cunningham, 2005). Paralleled only by the South African Fynbos in numbers of species and species density, the shrublands of southwestern Australia have floras that are significantly more diverse than the other Mediterranean biomes (Gibson et al., 2017). More than 5,500 species of plants have adapted to the forests and scrubs of this region, with nearly 70% being endemic (Cunningham, 2005). Many fungi, invertebrates and small vertebrates are restricted also to these rich scrublands. In its northernmost reaches, the southwestern part of this biome harbors living representatives of some of the Earth's oldest known forms of life – stromatolites. Although fossil stromatolites from further north in Western Australia have been dated to 3.45 billion years old, they differ little in appearance from the living forms. Stromatolites and related microbialites are comprised mainly of cyanobacteria and are sometimes termed 'microbial mats' due to their rounded, rug-like appearance (Grey and Planavsky, 2009).

Although the biota on the eastern and western sides of the Mediterranean forests, woodlands and scrub biome share many affinities owing to their connection before the southward expansion of the deserts, the eastern biota is less diverse than its western counterpart. Nonetheless, well-developed shrubland and forest formations occur on the Eyre and Yorke Peninsulas and extend onto Kangaroo Island, Australia's third-largest island (4,405 km^2). The eastern extent of this biome incorporates the expansive Murray-Darling Depression, an immense IBRA region (199,583 km^2) that encompasses the confluence and lower floodplains of the Murray and Darling Rivers. River red gum forests dominate many areas along the rivers and associated wetlands (Keith, 2004). These areas provide habitats for rich communities of aquatic insects and other invertebrates, fish, frogs and water birds. South of the riparian areas, extending into Victoria, diverse shrublands that incorporate Spinifex grasses and a patchy overstory of mallee-form eucalypts occur in the Sunset, Big Desert and Little Desert areas. These sustain rich assemblages of small vertebrates, especially reptiles (Cogger, 2014).

12.2.5 Temperate Broadleaf and Mixed Forests

This is the most complex biome in Australia. Extending continuously from southeastern Queensland to the eastern edge of South Australia, and encompassing the island state of Tasmania, it contains 23 IBRA regions. Although not the largest biome (456,807 km^2), the southeastern forests that define it experience highly varied temperature and rainfall regimes and occur at elevations from sea level to 1585 m in the Barrington Tops National Park. Tall forests dominated by *Eucalyptus* spp. cloak the slopes of the Great Dividing Range, especially in areas receiving higher rainfall; understories in these forests can be structurally complex and floristically diverse, with many species of *Acacia*, *Casuarina*, *Cassinia* and other shrubs, as well as numerous ferns, mosses and lichens. Higher elevations support tangled snow gum (*Eucalyptus pauciflora*) woodlands and, in sheltered locations on the mainland and in Tasmania, cool temperate rainforests dominated by evergreen Antarctic beech (*Lophozonia* spp.). Formerly placed within the genus *Nothofagus* (Heenan and Smissen, 2013), members of the beech group occur widely in southwestern Argentina, Chile, New Zealand, New Caledonia and New Guinea, indicating deep Gondwanan heritage. Warm temperate rainforests occur at lower elevations, often on poorer quality soils, and comprise usually 3–5 tree species in any locality. Subtropical rainforests occur in more northerly parts of the biome and are structurally more complex and species-rich than their temperate counterparts (Keith, 2004). In places where rainfall is less than 1,100 mm, 'dry' rainforests and littoral rainforests may occur, as well as extensive tracts of open forest and woodland dominated by different species of *Eucalyptus*. Other vegetation communities occur in this biome, including grasslands, heathlands and wetlands (Keith, 2004).

Because of its rugged topography and structurally complex physical environment, the temperate broadleaf and mixed forests biome has provided evolutionary refugia for many groups of plants and animals during past episodes of continental cooling and drying (Markgraf et al., 1995; Kershaw et al., 2017). In addition to the very wide range of contemporary habitats the biome provides, the refugia have ensured the persistence of a remarkably diverse spectrum of organisms that show high levels of local and regional endemism (Mackey et al., 2012). These organisms include many plants, fungi, invertebrates, and representatives among the frogs, reptiles, birds and mammals (e.g., Milner et al., 2012; Rix and Harvey, 2012; Baker and Dickman, 2018). Further divergence and endemism has arisen due to the separation of many taxa by river systems that flow eastward to the coast from the upper reaches of the Great Dividing Range. Among the best studied of these systems are the Hawkesbury, Hunter and Clarence Rivers, although many other rivers act as biogeographic barriers—and as habitats for allopatric speciation of freshwater invertebrates, fish, turtles and other taxa—throughout the biome (Heatwole, 1987).

12.2.6 Tropical and Subtropical Moist Broadleaf Forests

This biome (34,591 km^2) is restricted to central and northern coastal areas of Queensland north of the Tropic of Capricorn. The closed forests of this biome occur along the Great Dividing Range and represent a northerly extension of the temperate forests further south. The biome encompasses three IBRA regions—the Wet Tropics, Central Mackay Coast and Pacific Subtropical Islands (Lord Howe Island and Norfolk Island)—as well as many small off-shore islands such as those in the Whitsunday group. Although the climate usually is relatively stable with low variability in annual temperature and high levels of rainfall (usually more than 2,000 mm per year), the biome is subject to disturbance from cyclones over the summer months. Elevations range from sea level to 1,611 m (Mount Bartle Frere). Rainfall at the higher elevations is pronounced; annual rainfall at Mount Bellenden Ker (1,593 m) is over 8,300 mm, and up to 300–400 mm may fall per day during cyclones (http://www.bom.gov.au/climate/averages/maps.shtml). Despite poor granitic soils on the peaks and lower ranges, the tropical and subtropical forests of this biome are extensive, complex and diverse, although most have well-developed climbing vines, creepers, epiphytes, palms and ferns. Depending on the classification scheme that is used, 12–16 different types of rainforest can be distinguished on the mainland, with further types present on Lord Howe Island and Norfolk Island (Pickard, 1983; Mills, 2007). Mangrove forests occur in coastal zones, and small patches of heath can be found at high elevation sites where soils are too thin to support forest cover.

Much like the temperate broadleaf and mixed forests biome, the tropical and subtropical moist broadleaf forests harbor many species and community types that hark back to earlier times when Australia was cooler and drier. Repeated contractions and expansions of biota to and from the refugia of this biome have provided fertile conditions for speciation, and it is a national biodiversity 'hotspot'. Many species claim Gondwanan heritage, such as the rare, large (40 m) stockwellia trees (*Stockwellia quadrifida*) which have affinities with *Eucalyptus*, while others share relatives with taxa in New Guinea that crossed or reverse-crossed Torres Strait during prior rafting or overland dispersal events (Ladiges et al., 2003). The Wet Tropics IBRA region alone boasts some 85 endemic plant species and 68 species of endemic terrestrial vertebrates (http://whc.unesco.org/en/list/486), including such iconic species as Victoria's riflebird (*Ptiloris victoriae*), tree-kangaroos (*Dendrolagus* spp.), several species of rainforest possums, and the bizarre musky rat-kangaroo (*Hypsiprymnodon moschatus*). The rich biodiversity values of this biome have stimulated much research and ensured that attention is focused on conservation. Much of the remaining intact forest is protected, with some 8,940 km^2 listed as a World Heritage site (http://whc.unesco.org/en/list/486). Both Lord Howe Island and Norfolk Island also support many endemic species. At least 113 species of vascular plants and ~950 of 1,600 invertebrates are thought to be endemic to Lord Howe, compared with 50 plant species and ~100 of 700 invertebrates on Norfolk Island (Priddel and Wheeler, 2014). Lord Howe Island received World Heritage status in 1982, as did a historic precinct on Norfolk Island in 2010.

12.2.7 Montane Grasslands and Shrublands

Comprising only a single IBRA region, this biome is the smallest in Australia and covers just 12,330 km^2. It is distinguished primarily by elevation as it includes montane and alpine areas above 1,300 m. Although many peaks in Tasmania exceed this height, this biome is restricted formally to southeastern New South Wales (including parts of the Australian Capital Territory) and adjacent parts of Victoria. This is the highest region in the Great Dividing Range, and the only area where deep snow falls each year. Low woodland formations occur at elevations up to 1,600 m, or even 1,800 m in more sheltered sites. These are dominated by one or two species of *Eucalyptus*, usually the snow gums *E. pauciflora*, *E. debeuzevillei* or *E. niphophila*, as well as black sally *E. stellulata*. A moderately diverse understory of sclerophyllous shrubs is usually present under the low (5–15 m), open woodland canopy; ground cover is provided by tussock grasses and herbs (Keith, 2004).

Above the treeline, woody plants are represented only by short (0.2–1 m), slow-growing shrubs that are able to withstand the freezing winds and seasonal burial under snow. Coral heath (*Epacris microphylla*), yellow kunzea (*Kunzea muelleri*) and mountain plum pine (*Podocarpus lawrencei*) are among the species that are commonly encountered. Interspersed among these low shrubs are patches of tussock grass, alpine meadows dominated by daisies and other herbs, and bogs and fens that sustain sedges, rushes and mosses such as *Sphagnum cristatum*, especially in sites where drainage is poor. Fjaeldmark habitats occur in small patches in the most exposed alpine areas, and are characterized by small, ground-hugging shrubs and herbs that huddle in protected sites amid field of boulders and small rocks (Keith, 2004). At least 70 of the 200 or so species of vascular plants in Australia's alpine regions are locally endemic, but endemism at the generic level is lacking. All genera occur outside Australia, in the southern or northern hemisphere (Costin et al., 1979), reflecting the relatively recent development of the alpine environment since the Miocene (Kershaw et al., 2017). Endemic fauna of this biome include the mountain pygmy-possum (*Burramys parvus*), southern corroboree frog (*Pseudophryne corroboree*) and numerous species of invertebrates, including color-changing grasshoppers in the genus *Kosciuscola*.

12.2.8 Tundra

This last terrestrial biome is not represented in Australia, but rather in the vast area of Antarctica claimed as Australian Antarctic Territory and on sub-Antarctic islands such as Macquarie Island (125 km^2) and the more remote Heard Island (368 km^2) and the McDonald Island group (2.5 km^2). The high latitudes of the tundra environments mean that temperatures are low year round, although the moderating effect of the ocean elevates temperatures above freezing for much of the year on the sub-Antarctic islands. Rainfall on Macquarie Island averages 986 mm annually and falls evenly throughout the year, although snow is common in winter (http://www.bom.gov.au/climate/averages/maps.shtml). Tundra vegetation is limited. Lichens and mosses occur in sheltered sites in Antarctica, but grasses, sedges, herbs, heaths and dwarf shrubs also occur patchily or form carpets on the sub-Antarctic islands. Trees are absent. Heard Island has 34-recorded species of lichen, 44 moss species, 12 liverworts and 12 species of vascular plant (http://heardisland.antarctica.gov.au/). By contrast, Macquarie Island supports at least 150 species of lichen, 81 species of moss, over 50 liverworts and 46 species of vascular plant (with three endemic); 127 species of algae are known, as are more than 200 species of fungus (Parks and Wildlife Service, 2006). About 10% of the ~300 invertebrate species on Macquarie Island are thought to be endemic and, apart from two now-extinct birds, there are no endemic terrestrial vertebrates. Nonetheless, the Antarctic tundra biome provides major breeding grounds for several species of seals and seabirds. For example, penguins are the most numerous of the 29 or so bird species that breed on Macquarie Island, with the endemic royal penguin (*Eudyptes schlegeli*) achieving a population of 850,000 breeding pairs. The outstanding natural values of Macquarie Island, Heard Island and the McDonald Islands led to their inscription on the World Heritage list in 1997 (Parks and Wildlife Service, 2006).

12.2.9 Freshwater Systems

Based on the distribution and composition of freshwater fish species, the Australian landmass has been split into 10 different regions, or ecoregions, out of 426 ecoregions identified worldwide (Abell et al., 2008; Figure 12.2). These ecoregions show some parallels with the country's terrestrial biomes, with the two largest—plus the Pilbara ecoregion—overlapping with the deserts and xeric shrublands and the Murray-Darling Basin coinciding in large part with the eastern section of the Mediterranean forests, woodlands and shrubs biome and the temperate grasslands, savannas and shrublands biome (cf. Figures 12.1 and 12.2). In broad terms, the ecoregional mapping (Abell et al., 2008) shows that Australia's western deserts sustain the smallest numbers of freshwater fish and fewest endemics, whereas the Kimberley, Top End and east coast support both the greatest numbers of fish species (67–101) and most endemics (20–27 species). Intriguingly, however, despite their modest fish diversity, most species (51–71%) in southwestern Western Australia and the immense Lake Eyre

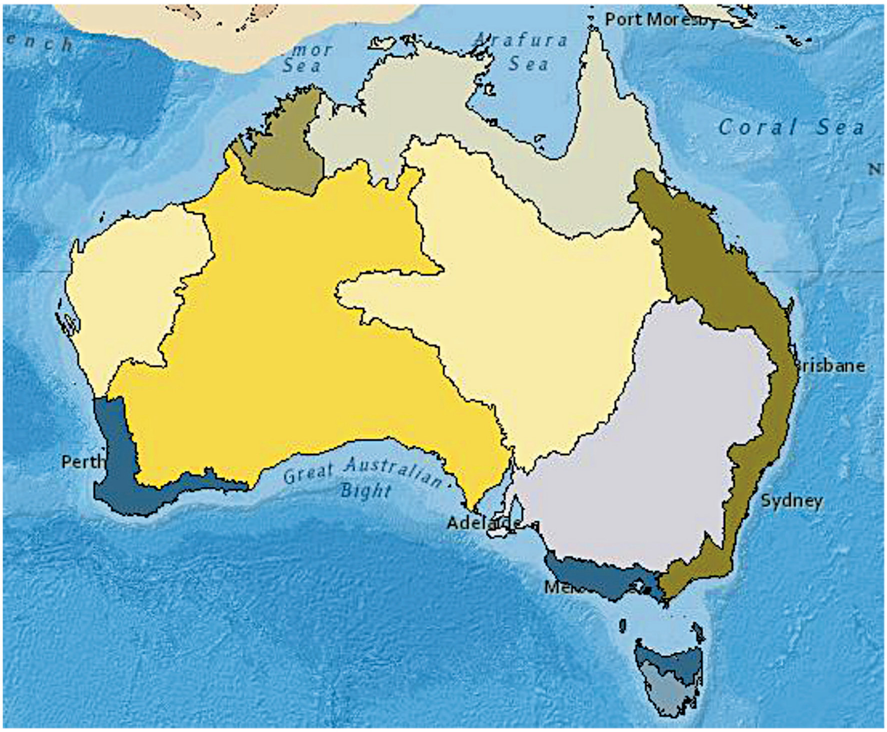

Figure 12.2 Freshwater ecoregions in Australia. Ecoregions are represented by different shading. Source: Freshwater Ecosystems of the World (http://www.feow.org./) and Abell et al. (2008).

Basin are endemic to those regions (Abell et al., 2008). Such high endemism reflects the isolation of freshwater bodies in both regions by the arid lands that surround them (Unmack, 2001). It is not clear how the distributions and compositions of other freshwater organisms align with the ecoregions defined by Abell et al. (2008) but, for species that are as confined for their entire life-cycle to freshwater as fish, substantial levels of concordance might be expected.

12.2.10 Marine Systems

A useful categorization of marine systems was proposed by Spalding et al. (2007), based primarily on the taxonomic configuration of benthic and shelf biota to depths of 200 m. Using this scheme, 10 ecoregions can be distinguished within five provinces in the waters surrounding northern Australia and its island territories in the Indian and Pacific Oceans. Another 10 ecoregions can be discerned in four provinces around southern continental waters, and three further ecoregions in the Southern Ocean realm (Spalding et al., 2007). Use of the 200 m isobath excludes biota of deeper waters that occur within Australia's Exclusive Economic Zone, especially those in the deep ocean troughs off the continent's southern and southeastern coast (Watford et al., 2005). However, this should not greatly affect estimates of biodiversity: marine biota are much better known in shallow than in deep waters, are more diverse and also likely to show greater levels of endemism. Australia's marine systems comprise extraordinarily rich communities of protozoans, algae, sponges, anemones, mollusks, crustaceans, echinoderms, hemichordates and other invertebrates, as well as spectacularly diverse assemblages of fish, marine mammals and reptiles. The extensive ecosystems of the Great Barrier Reef off the coast of northeastern Queensland and Ningaloo Reef in northwestern Western Australia provide good examples. Despite recent bleaching events, the Great Barrier Reef has more than 450 species of hard coral, over 3,000 species of mollusc, 1,300 crustaceans and ~1,625 species of bony fish (Great Barrier Reef Marine Park Authority, 2013). Deepwater (18–144 m) surveys at Ningaloo have recorded 155 species of sponge, 227 species of echinoderm and 236 molluscan species, and many more species in these groups in subsurface waters (http://www.ningaloo.org.au/). Other well-known and iconic species that ply the nearshore waters around Australia's coast include whale sharks (*Rhincodon typus*), manta rays (*Manta* spp.), dugong (*Dugong dugon*) and 58 species of dolphins, porpoises, baleen and toothed whales (Burbidge et al., 2014).

12.3 Organisms and Taxonomic Groups

As one of the world's 17 megadiverse counties (Mittermeier et al., 1997), Australia is highly biodiverse with large numbers of endemic species (to qualify formally as megadiverse, a country must have at least 5,000 endemic plant species and have marine ecosystems within its borders). Yet, estimates of the numbers of species vary widely. This is not surprising. On the one hand, many parts of Australia have been poorly surveyed, and even the better-known sites have usually been surveyed with particular target groups in mind. Relatively little focus has been placed on bacteria, which globally comprise the majority of living species (Larsen et al., 2017), or on protists, archaeans or fungi. Although recent advances in the collection and analysis of environmental DNA (eDNA) should speed the identification of new taxa via their genetic signatures (e.g., Barnes and Turner, 2016), this has been little used to date in Australia, and support for taxonomy generally is low and declining (Weaver, 2017). On the other hand, even in groups that are reasonably well known, recent research has begun to uncover high and previously unsuspected levels of cryptic biodiversity. For example, 1,050 species of frogs and reptiles were known in 2000, but by 2012 this number had increased to 1,218 (Cogger, 2014); many of the new species had been 'hidden' within taxa that had been thought to comprise just a single species. Similarly, the number of species within *Antechinus*—one of the most intensively studied genera of marsupials—increased from 10 to 15 between 2012 and 2016, again from the exposure of cryptic species (Baker and Dickman, 2018).

The following account draws heavily on data compiled by Chapman (2009), who estimated the number of species in Australia to be about 570,000, with 147,579 of these being formally described. Although updates on numbers of species are given where available, the caveats noted above suggest that estimates for some taxa will be based on best guesses rather than on completely reliable information. Underestimates are likely to be most acute for bacteria. Thus, whereas Chapman (2009) accepted a figure for the global number of all species to be about 11 million, Larsen et al. (2017) argued that the true figure is more likely to be 1–6 billion owing to the dominance of bacteria.

In the sections that follow, comments are made on each of the major taxonomic groups. Tables also are provided that summarize the numbers of species in each taxonomic group that are described and estimated to occur in Australia, as well as—where known—estimates of the percentage endemics in Australia and the percentage contribution that Australian species make to the global biota in each group. I acknowledge a great debt in presenting this information to the hundreds of experts whose work is so briefly summarized here, as well as to Chapman (2009) whose collation of a vast amount of scattered information has made the present overview possible. Viruses are the only group not included in the tabular summaries. Not only is there an ongoing debate about their status as living organisms, virus 'species' are notoriously difficult to specify. Chapman (2009) estimated that Australia might contain 200–400 virus species, with up to half of these being endemic, but cautioned that these figures should not be relied upon.

12.3.1 Prokaryota, Protoctista, Chromista, and Others

Species in this group are defined primarily by what they are not: plants, fungi or animals. The group contains single-celled autotrophs and heterotrophs that live in terrestrial, freshwater and marine environments, either as free-living organisms or as organisms that are associated with plants, fungi, animals or other single-celled organisms as endo- or exobionts. The group also contains much larger organisms such as kelps and other seaweeds that have been variously regarded at times as algae or as members of other groups; they are here regarded as chromistans, outside the Kingdom Plantae, following the arrangement of Chapman (2009). Both the species-level taxonomy and higher-level classification of these organisms remain fluid, and the number of species they represent is unclear. Nonetheless, based on extrapolations of known and described species, it is likely that organisms in this 'rag-bag' represent a sizeable component of the alpha-level diversity in many Australian systems (Table 12.1). Protoctista (protozoans, foraminiferans, flagellates, some slime molds and other eukaryotes) probably number in the tens of thousands of species in Australia; at least 40,000 Prokaryota (bacteria) also have been estimated (Saunders et al., 1996), but more recent estimates based on extrapolations of the numbers of unique bacterial species in the guts of insects and other multicellular host species (Larsen et al., 2017) suggest that this figure is a gross underestimate. Further research will probably uncover millions more prokaryote species, with this one group likely to contribute more species than all other groups to both Australian and global biodiversity (Larsen et al., 2017). Levels of endemism in Prokaryota are unknown (Table 12.1), but if bacteria are uniquely associated with host groups that are themselves confined largely to Australia, then high levels of endemism are likely.

Table 12.1 Prokaryota, Protoctista, Chromista and Other Species (Non-Plants, Fungi or Animals) Known and Estimated From Australia in Different Taxonomic Groups, the Percentage Contribution to their Respective Groups in the Global Biota, and the Percentage of Australia's Species that is Endemic

Taxon	Described from Australia	Estimated from Australia	% of global species	% Australian endemic*
Prokaryota (bacteria)	~40	40,000	0.5	>50
Cyanophyta	270	~500	10	?
Chromista	2,130	>15,000	8.5	?
Protoctista	>1,346	~65,000	4.7	?
Total	**>3,786**	**>120,500**	**<10**	**?**

Tabular data extracted from Chapman (2009).

* Extrapolated from known species.

12.3.2 Plants

Australian flora is relatively well known, at least in terms of alpha taxonomy, with ~24,716 described and accepted, and another 2,129 or so species estimated (Table 12.2). Among the major groups, Bryophyta is the least speciose, with mosses and liverworts comprising the great majority of the known and estimated flora. About a quarter of bryophytes are endemic, with many more species having ancient Gondwanan links or more recent links with Southeast Asia and the Pacific region. Some species, such as the moss *Thuidium cymbifolium*, are widespread throughout the Indo-Pacific; others, such as the leafy liverwort *Ptilidium ciliare*, occur from New Zealand to southern South America, or even in the ice-free parts of Antarctica (Schofield, 1992; Ramsay, 2006). In general, members of the Bryophyta achieve greater prominence in mesic areas where moisture is reliably available year round, especially in eastern, southwestern and northern Australia where they may grow on varied soil substrates, on logs and on the trunks of trees (e.g., Ramsay and Cairns, 2004). However, a few species, such as the moss (*Pottia latzii*) occur in sheltered sites in the deserts and xeric shrublands biome, or have distributions that encompass most or all biomes throughout the continent and on many of Australia's offshore islands (https://www.anbg.gov.au/bryophyte/bryogeography-a-intro.html).

Confined largely to freshwater and marine systems, but occurring also in moist soil, hypersaline environments and even in deeply frozen snow banks, algae form the second most speciose of Australia's major plant groups (Table

Table 12.2 Plant Species Known and Estimated From Australia in Different Taxonomic Groups, the Percentage Contribution to their Respective Groups in the Global Flora, and the Percentage of Australia's Species that is Endemic

Taxon	Described from Australia	Estimated from Australia	% of global species	% Australian endemic*
Algae	~3,236	~3,545	~29	?
Charophyta	(1040)	(1099)	(51.7)	?
Chlorophyta	(654)	(904)	(22.3)	?
Glaucophyta	(1)	(1)	(20.0)	?
Rhodophyta	(1541)	(1541)	(25.3)	?
Bryophyta	1,847	~2,200	11.4	25
Mosses	(976)	(>976)	(8.9)	(22.7)
Liverworts	(841)	(>841)	(16.8)	(23–28)
Hornworts	(30)	(>30)	(12.7)	(23–28)
Vascular plants	19,324	~21,645	6.9	91.8
Ferns and allies	(498)	(~525)	(4.2)	(33.8)
Gymnosperms	(120)	(~120)	(11.7)	(96)
Magnoliophyta	(18,706)	(~21,000)	(7.0)	(93.3)
Total	**~24,716**	**26,845**	**7.9**	**~86**

Tabular data extracted from Chapman (2009).

* Extrapolated from known species.

Bracketed figures indicate estimates for major groups within Algae, Bryophyta and vascular plants.

12.2). Recent surveys and taxonomic research suggest that many more species of algae may occur than the 3,500 or so that have been estimated (Table 12.2), especially in remote areas that have been previously under-sampled such as around Australia's northwestern coast (Huisman, 2015). Australian algae are estimated to comprise almost 30% of algae globally; this figure can be expected to rise when new species and genera are formally described. Among the currently described forms, Australia's largest group of algae is the Rhodophyta, or red algae. These are mostly marine and comprise both familiar seaweeds and coralline forms that play key roles in coral reef formation. Charophyta—freshwater green algae—comprise another large group within the Australian flora. These are widespread in natural freshwaters of the inland such as wetlands and riverine systems, but can be found also in such ubiquitous and disturbed sites as farm dams (Casanova and Brock, 1999), brackish, saline and even hyper-saline aquatic habitats (Casanova et al., 2011). These algae form important habitats for many aquatic invertebrates and food for invertebrates, fish, birds and other semiaquatic vertebrates. Species within Chlorophyta range from one-celled organisms to complex multi-celled plants, and are mostly marine. There are, however, green algae within Chlorophyta that occur in saline and hyper-saline situations on land, as well as representatives that live on trees and rocky substrates. One genus, *Halimeda*, is well known as a prominent component of reefs and lagoons in tropical and subtropical waters, where they are major contributors to reef formation (Cremen et al., 2016). Only one glaucophyte has been described from Australia, but more of these rare, unicellular, freshwater algae are likely to be found when further survey work has been undertaken (Guiry and Guiry, 2017).

Vascular plants dominate the Australian landscape, both in terms of species richness and their ubiquity throughout the terrestrial environment (Table 12.2). Magnoliophyta—flowering plants—are particularly prominent. The magnoliophyte family Myrtaceae, for example, contains some 1,850 species in about 70 genera in Australia, and is represented over vast areas of the continent by iconic species of *Eucalyptus*, *Corymbia*, *Melaleuca*, *Angophora* and *Kunzea*. Equally widely distributed are species within Mimosaceae, especially the acacias, or wattles. About 1,000 species of *Acacia* are known and described. They occur in rainforest, desert, alpine and forest habitats, sometimes forming the dominant tree over immense areas (e.g., mulga, *Acacia aneura*; brigalow, *A. harpophylla*) or as minor to major components of eucalypt-dominated woodlands and forests (e.g., silver wattle, *A. dealbata*). Other speciose families in Australia include the peas (Fabaceae), with about 1,500 species in 136 genera, orchids (Orchidaceae) with over 1,700 species, grasses (Poaceae, 1,300 species), and daisies, everlastings and relatives (Asteraceae, ~1,250 species) (https://environment.gov.au/science/abrs). Less speciose families, such as Proteaceae, also are often very well known because they contain emblematic taxa or species with showy flowers such as banksias, waratahs, needlewoods and grevilleas. In the southwest of Western Australia, members of all these families, and many more, co-occur north of Perth, in the Stirling Range and inland, forming a global biodiversity 'hotspot' (Myers et al., 2000). Other regions with rich communities of flowering plants include the Sydney Basin and many sites within the tropical and subtropical moist broadleaf forests biome (Keith, 2004).

Less speciose, but sharing similarly high levels of endemism as the magnoliophytes, are the gymnosperms (Table 12.2). Including cypress-pines, kauri pines, hoop pines, cycads and the ancient Wollemi pine (*Wollemia* *nobilis*), gymnosperms are most prominent on the slopes and in the montane regions of the Great Dividing Range, and also in Tasmania. Several species do, nonetheless, occur in the deserts and xeric shrublands biome, across the tropical north, or in the southwest of Western Australia. Gymnosperms usually occur in mixed communities with magnoliophytes, sometimes as scattered individuals but sometimes also as the dominant members of the community. In north-central New South Wales, for example, white cypress pine (*Callitris columellaris*) covers much of the 3,000 km^2 area of the Pilliga forest region, and is a common tree throughout the inland (Moore, 2005). Members of the genus *Araucaria* share a broadly southern distribution, from South America to New Caledonia and New Guinea, and may exceed 70 m in height (Silba, 1986). One species, the Norfolk Island pine (*A. heterophylla*), is endemic to Norfolk Island, but now also a popular cultivated tree in many parts of the world owing to its distinctive appearance and growth form. The remaining group of vascular plants in Australia, the ferns and fern allies, comprise over 500 species, about a third of which are endemic (Table 12.2). The fern allies are represented by at least 50 native species of lycophytes, psilophytes and sphenophytes, with the remainder being 'true ferns'. True ferns are found in most parts of the continent, but are most numerous in temperate, tropical and subtropical areas where rainfall is high and reliable. Among the best-known species are the giant tree ferns (*Cyathea* and *Dicksonia* spp.) and, in many inland areas, the 'water-clovers' (*Marsilea* spp.); sporocarps of one species—nardoo (*M. drummondii*)—have long been used as a food source by Aboriginal people (Allen, 2011).

12.3.3 Fungi

Research on Australia's fungi remains very much a work in progress, with the result that many species remain undescribed and the level of endemism is uncertain (Table 12.3). Nonetheless, Australia's described species account for about 12% of the world's estimated total number of fungi, and members of all the major fungal groups are represented (Table 12.3). Fungi are widespread and diverse in all environments and biomes throughout the continent (https://www.fungimap.org.au/), occurring in soil, on trees as well as in other organisms, although species richness is greatest in areas where moisture is reliable. Some species occur also in freshwater and marine systems (Hyde et al., 1998). Most of the species described so far from Australia are in the most diverse phyla, Ascomycota and Basidiomycota. The totals shown in Table 12.3 for these groups include 3,488 ascomycete species that are lichenized (i.e., in mutualistic relationships with algae or other organisms)

Table 12.3 Fungi Species Known and Estimated From Australia in Different Taxonomic Groups, the Percentage Contribution to their Respective Groups in the Global Fungal Biota, and the Percentage of Australia's Species that is Endemic

Taxon	Described from Australia	Estimated from Australia	% of global species	% Australian endemic*
Ascomycota	7,187		11.2	?
Basidiomycota	3,730	10,000	11.8	?
Blastocladiomycota	9		5.0	?
Chytridiomycota	15		2.1	?
Glomeromycota	28		16.6	?
Microsporidia	130			?
Neocallimastigomycota	2		10.0	?
Zygomycota	119		11.2	?
Unplaced to phylum	626			
Total	**11,846**	**50,000**	**11.9**	

Tabular data extracted from Chapman (2009).

* Estimates are not available for the phyla separately, but Williams (2001) estimated that about 90% of the species of fungi overall are endemic.

and seven basidiomycotes. P. McCarthy, cited in Chapman (2009), suggested that ~4,500 lichen-forming fungi may occur in Australia, with 34% of these being endemic. The Basidiomycota includes some of the most well-known fungi, including mushrooms, stinkhorns, jelly fungi, rusts and smuts. The Ascomycota includes penicillin-fungi (*Penicillium* spp.), some yeasts and species that are parasitic or pathogenic in plants and animals (e.g., *Candida* spp.), as well as species that produce large subterranean fruiting bodies, or truffles. In southwestern Australia, several species of potoroid marsupials specialize in eating truffles, and have dental and digestive adaptations suggesting that they have coevolved over long periods with rich communities of these fungi (Dickman, 2015). Truffles, other Ascomycota, some Glomeromycota and some Basidiomycota enter into associations with the roots of plants. These associations—termed mycorrhizal—are of critical importance for maintaining vascular plants because the hyphal filaments of these fungi greatly enhance the ability of plants to gather water and scarce mineral nutrients (Wang and Qiu, 2006). In the Australian region, where water and soil nutrients are often in short supply, the importance of mycorrhizal fungi cannot be overestimated. Members of the remaining fungal groups are mostly parasitic, such as the chytrid fungi in the phylum Blastocladiomycota; these have decimated frog communities in Australia and in other parts of the world.

12.3.4 Invertebrates

Nearly 100,000 invertebrates have been described and named from Australia, almost a third of the overall numbers that are estimated to occur (Table 12.4). As in most other parts of the world, one group is overwhelmingly dominant, the Class Insecta. Some 63 – 64% of Australia's known and estimated invertebrates are insects (Table 12.4) and, of these, almost half are Coleoptera (Yeates et al., 2003). Hymenoptera, Diptera and Lepidoptera are each expected also to number in the tens of thousands, with other insects from 23 further Orders making up the remainder (Austin et al., 2004; Raven and Yeates, 2007). The only Orders not known to occur in Australia are Grylloblattodea, a small group of extremophile insects that is restricted to icy montane environments, and Mantophasmatodea, a small group of carnivorous insects endemic to Africa (Cranston, 2010). A single species of zorapteran is known, and that is localized on Christmas Island (Chapman, 2009). Collectively, insects occur in all biomes, terrestrial and aquatic, throughout Australia, with up to 70% estimated to be endemic (Ridsdill-Smith, 2004). Some groups tend to predominate more in certain habitats than others, such as ants in arid habitats and caddis flies, dragonflies and other groups with an aquatic life history stage near freshwater. Surveys in forested habitats suggest that insect diversity may be especially high in the canopy (e.g., Kitching et al., 1993; Houston et al., 1999). Despite such broad patterns in occurrence, there is no doubt that insects dominate all other animal groups in almost all situations in Australia in terms of numbers of individuals and numbers of species, nor that their roles as predators, prey, decomposers, pollinators, seed and spore vectors are of fundamental importance for the functioning of ecological systems and human enterprises (Cranston, 2010).

Other invertebrates in the Australian region can be grouped into 16 further broad categories (Table 12.4). For convenience here, and following Chapman (2009), these include a mix of Classes, sub-Phyla and Phyla, as well as a 'rag-tag' group of Phyla—labeled 'others' in Table 12.4—with often uncertain taxonomic status but generally small numbers of species (e.g., arrow worms, or Chaetognatha, Mesozoa, Priapulida; Zhang, 2011a, b). Arachnida, Crustacea and Mollusca stand out as having the most numbers of described species in Australia, but large numbers are estimated in the taxonomically vexed Nematoda and Platyhelminthes (Table 12.4). Levels of endemism, where known, are varied; perhaps not surprisingly, the groups

Table 12.4 Invertebrate Species Known and Estimated From Australia in Different Taxonomic Groups, the Percentage Contribution to their Respective Groups in the Global Fauna, and the Percentage of Australia's Species that is Endemic

Taxon	Described from Australia	Estimated from Australia	% of global species	% Australian endemic*
Hemichordata	17	22	15.7	~25
Echinodermata	1,475	~2,000	21.1	31
Insecta	~62,000	~205,000	6.2	~70
Arachnida	6,615	31,338	6.5	?
Pycnogonida	215	?	16.0	~50
Myriapoda	553	~3,100	3.4	86
Crustacea	7,266	~9,500	15.5	?
Onychophora	71	~80	43.0	100
Hexapoda	338	~2,070	3.7	~17.6
Mollusca	~8,700	~12,250	10.2	38
Annelida	2,192	~4,230	13.1	67
Nematoda	~2,060	~30,000	8.2	?
Acanthocephala	56	~160	4.9	?
Platyhelminthes	1,593	~10,000	8.0	?
Cnidaria	1,705	~2,200	17.4	?
Porifera	1,476	~3,500	24.6	56
Others	~2,371	~5,015	18.7	?
Total	**~98,703**	**~320,465**	**7.3**	**?**

Tabular data extracted from Chapman (2009).

* Extrapolated from known species.

that contain marine representatives with powers of oceanic dispersal (e.g., Hemichordata, Echinodermata, Pycnogonida, Mollusca, Porifera) tend to have relatively low levels of endemism, whereas strictly terrestrial groups (e.g., Onychophora, Myriapoda) have more endemic representatives. Australian onychophorans, or velvet worms, appear to be wholly endemic and also represent over 40% of the world's known species (Table 12.4). Even without insects, the extraordinary diversity and sheer numbers of individuals and species represented by all the other invertebrates ensure that members of one or more groups will be found in all Australian aquatic and terrestrial environments. Surveys of Sydney Harbor alone, for example, uncovered 2,437 species within just the Echinodermata, Crustacea, Mollusca and Polychaeta (Hutchings et al., 2013). The authors emphasized that many more invertebrates in other taxa remained to be listed, and that many species even in the better-known groups awaited formal description and study.

12.3.5 Chordates

Chordates are relatively less speciose than the other major groups considered so far, but they are generally better known and contain some of the most familiar species that are associated with Australia, notably the marsupials. Almost 90% of the species that are estimated to occur across the eight major chordate groups in Australia have been described, and about 42% of these are endemic (Table 12.5).

Fishes comprise the largest chordate group in Australia, with 5,000 described species and another 750 or so species that are suspected but not yet described. Estimates provided by Hoese et al. (2006) suggest that most fish species in Australian waters are marine (85.4%) or estuarine (9.2%); the remaining species (5.4%) are confined to river systems, lakes, and even to small and highly localized artesian springs within desert regions (Kerezsy, 2011). Fish diversity varies locally. It is, not surprisingly, lowest in isolated inland freshwater bodies where just 1–2 species may occur, but can be as high as 70 or more species, as in the drainages of the Kimberley region (Morgan et al., 2014). Species such as the Murray cod (*Maccullochella peelii*) and yellowbelly (*Macquaria ambigua*) are well known for their contributions to the local inland economy. In marine systems, local and regional fish diversity can be very high. In Sydney Harbor, for example, almost 600 species of fish have been documented (Hutchings et al., 2013), and in the Great Barrier Reef system, some 1,625 species are known (Great Barrier Reef Marine Park Authority, 2013). Of the many iconic species of fish, the large game species, small but showy reef species, sharks and gigantic whale sharks are among the most well known, although the smaller species tend to be endemic. Other marine chordates include small numbers of marine Agnatha (hagfish and lampreys), poorly known Cephalochordata (lancelets) and some 850 species of Tunicata (sea squirts and relatives). At least half of the species in these latter three groups are thought to be Australian endemics (Table 12.5).

The remaining chordate groups have escaped complete dependency on water, but may nonetheless require freshwater for part of their life cycle (Amphibia) or fresh or marine waters for foraging (species in all groups). Amphibia in Australia are represented by five families of frogs (and the introduced cane toad, *Rhinella marinus*, in the toad family Bufonidae), the

Table 12.5 Chordate Species Known and Estimated from Australia in Different Taxonomic Groups, the Percentage Contribution to Their Respective Groups in the Global Fauna, and the Percentage of Australia's Species that is Endemic

Taxon	Described from Australia	Estimated from Australia	% of global species	% Australian endemic*
Mammals	397	~405	7.2	88
Birds	828	~900	8.3	45
Reptiles	985	~1050	11.3	94
Amphibia	237	~250	3.6	94
Fishes	~5,000	~5,750	16.0	24
Agnatha	5	~10	4.3	60
Cephalochordata	8	~8	24.2	50
Tunicata	757	~850	27.4	50
Total	**~8,217**	**~9,223**	**12.8**	**42**

Tabular data extracted mostly from Chapman (2009), with updates from Burbidge et al. (2014) and Cogger (2014).

* Extrapolated from known species.

great majority of which are endemic (Table 12.5). Frogs achieve their greatest diversity in higher rainfall areas in the Great Dividing Range, the southwest of Western Australia and across the Top End and Kimberley. Some species, such as the rocket frog (*Litoria nasuta*), have distributions that stretch for thousands of kilometers in coastal and subcoastal areas, whereas others, such as the 18 species of nursery frog (*Cophixalus* spp.), are confined to usually tiny ranges in montane rainforests in northeastern Queensland (Cogger, 2014). Other species, such as the green tree frog (*Litoria caerulea*), have ranges that extend from the eastern seaboard well into the deserts and xeric shrublands biome. It does this by using small and sometimes ephemeral bodies of water, even artificial sources such as water troughs, toilets and showers, dispersing into the broader landscape during periods of rain. Yet other frogs have the major parts of their ranges in arid regions. Species such as the water-holding frog (*Cyclorana platycephala*) and desert spadefoot frog (*Notaden nichollsi*) may spend years underground, emerging to feed and reproduce in large numbers when heavy rains break their 'dormancy' (Hillman et al., 2009).

Australia is sometimes known as the 'land of lizards' (Morton and Emmott, 2014), a title that reflects the many species that are estimated to occur nation-wide and the large numbers of individuals and species that often co-occur. But reptilian diversity encompasses not just seven families of lizards, but also six families of snakes, four families of turtles and one family of crocodiles; in total, over 1,000 species are estimated to occur (Table 12.5). Most species are endemic. Local reptilian diversity can attain levels of 50–60 species per km^2 in some desert areas (Dickman et al., 2014), with species ranging from tiny dwarf skinks (*Menetia greyii*) that weigh no more than 1 g, to perenties (*Varanus giganteus*) that are more than three orders of magnitude more massive. The distributions of individual species vary greatly. Large sea-turtles in the Family Cheloniidae occur in the waters of northern Australia, extending south of the Tropic of Capricorn on both sides of the continent. By contrast, several species of freshwater turtles are confined to a single river catchment or, in the case of the western swamp turtle (*Pseudemydura umbrina*), to one or two small swamps (Cogger, 2014). On land, contrasting species distributions can be found in many families. For example, while several species of skinks have almost pan-continental distributions (e.g., *M. greyii*; leopard skink *Ctenotus pantherinus*), the Pedra Branca cool-skink occupies a single, wave-swept rock off the southern coast of Tasmania, and the eastern Torres rainbow-skink (*Carlia quinquecarinata*) two small islands in Torres Strait (Cogger, 2014). Reptiles occupy all aquatic and terrestrial environments in Australia and, with species such as the saltwater crocodile (*Crocodylus porosus*), desert taipans (*Oxyuranus* spp.) and thorny devil (*Moloch horridus*), provide some of the most fearsome and bizarre creatures that stalk lands anywhere.

Almost as speciose as the reptiles, Australia's birds are arranged in some 90 families that represent over 8% of the world's avifauna (Table 12.5). Because of their ability to traverse bodies of water, proportionally fewer birds are endemic than the other, primarily terrestrial, chordate groups, but the 45% level of endemism for Australian birds is nonetheless high by comparison with most countries. It is likely that most or all endemic species have been discovered and described; estimates of further species (Table 12.5) include vagrants that wash up occasionally on Australia's mainland and island territories (Christidis and Boles, 2008; http://www.birdlife.org.au/conservation/science/taxonomy). Birds are exceedingly numerous and ubiquitous, living and breeding in Australia's Antarctic Territory and on its sub-Antarctic islands, on the tiniest rocks to the largest offshore islands, and in all terrestrial and freshwater biomes on the continent (Barrett et al., 2003). Species richness is highest in structurally complex forest habitats where sufficient food, foraging site, shelter and breeding resources are available to be partitioned, but large fluxes of mobile species occur also in inland areas in response to shifts in climatic conditions (Runge and Tulloch, 2017). Many species occupy, or have the potential to occupy, large geographical ranges, but some taxa are much more restricted. For example, 13 species are endemic to the Wet Tropics rainforests of northeastern Queensland (Crome and Nix, 1991), the noisy scrub-bird (*Atrichornis clamosus*) to a small area of coastal thicket in southwestern Western Australia, and several species of grasswren (*Amytornis* spp.) to small areas in central and northern Australia (Barrett et al., 2003). The Lord Howe woodhen (*Gallirallus sylvestris*) is confined to that small island. Birds are arguably the most conspicuous and frequently seen chordates in Australia, with such iconic species as emus (*Dromaius novaehollandiae*) observable in all rural areas and an extraordinary diversity of parrots, cockatoos, honeyeaters, kingfishers, finches, magpies, owls and more that occur in urban and nonurban habitats everywhere.

Australia's marsupial mammals are perhaps the best-known component of the country's fauna, but the oft-depicted kangaroos and koala (*Phascolarctos cinereus*) represent only a fraction of the overall marsupial fauna and of the mammals in their entirety. Some 397-mammal species are known, with a few more that are expected to be uncovered in ongoing genetic research (Table 12.5). The mammals provide an excellent example of the diverse origins of the Australian biota more broadly. Thus, ancestors of the country's two living egg-laying mammals—the monotremes (short-beaked echidna, *Tachyglossus aculeatus*; platypus, *Ornithorhynchus anatinus*)—were present on the Australian landmass during the early Cretaceous at least 110 million years ago (Long et al., 2002). Fifty million years later, ancestral marsupials arrived via the Gondwanan migration route through Antarctica from South America, with early bats entering the continent either via the land bridge or across stepping stone islands in the oceans between Australia and Asia (Long et al., 2002; Hand, 2006). The first whales appeared in Australian waters about 28 million years ago after the continent had separated from Antarctica (Fordyce, 2006). The first wave of rodents invaded Australia by 'island-hopping' from Southeast Asia perhaps 5 million years ago, and another, containing ancestral *Rattus*, half a million to a million years ago (Aplin, 2006). All other mammals have been brought in more recently by human activity.

Marsupials now dominate the Australian mammal fauna in terms of number of species (~170) and in their occupation of all terrestrial environments. Carnivorous and insectivorous dasyurid marsupials dominate in the deserts and xeric shrublands biome, whereas possums, gliders, pygmy-possums, kangaroos and rat-kangaroos tend to be more highly represented in all biomes with woodland or forest cover (Dickman, 2015). Bats (~80 species) also are more highly represented in forested areas, with a tendency for more species to occur in tropical regions across northern Australia than at cooler southern latitudes (Hand, 2006). Rodents (~60 species) occur ubiquitously, but with more species co-occurring in central arid and northern tropical regions than in temperate forest biomes (Aplin, 2006). The dugong, dolphins, porpoise, baleen and toothed whales (59 species) occur in all marine waters within Australia's jurisdiction, with the larger species (e.g., humpback whale, *Megaptera novaeangliae*; blue whale, *Balaenoptera musculus*) making extensive migrations between Antarctica and the nearshore and deeper waters of the Australian continent (Fordyce, 2006). Apart from one species of shrew (Christmas Island shrew, *Crocidura attenuata trichura*), which may have become recently extinct, Australia's other mammals—domestic animals, pet cats and dogs, livestock, game animals, commensal rodents and others—have been introduced by people. One of these mammals, the dingo (*Canis dingo*), was introduced at least 5,000 years ago and is regarded by many as an endemic, native species (Crowther et al., 2014).

12.4 Genetic Diversity

With representatives from all the major branches and most of the smaller branches of the tree of life, genetic diversity within Australia's biota is exceedingly high. Because of the country's generally high representation of endemic taxa (Tables 12.1–12.5), much diversity at the genetic level also is found only in Australia. This diversity provides unparalleled insights into the evolution of life on Earth (e.g., stromatolites) and into the origins of major taxa such as songbirds (Low, 2016), as well as glimpses of unique, ancient lineages that occur nowhere else (e.g., Wollemi pine, some stygofauna, monotremes). As might be expected, the biota of Australia's remote external territories is represented by many taxa that occur nowhere else, and on the continental landmass three regions are listed as global biodiversity hotspots because of their rich and highly endemic biotas: the southwest of Western Australia, the Wet Tropics, and the border ranges of northeastern New South Wales and southeastern Queensland (Cresswell and Murphy, 2017). More generally, using measures of phylogenetic diversity that incorporate species' evolutionary history and geographical rarity (Laity et al., 2015), eastern Australia stands out as having the highest levels of phylogenetic diversity for vascular plants and terrestrial vertebrates. The southwest of Western Australia, large areas near Darwin in the Top End and smaller areas in the Pilbara and central desert ranges are also very important for this key aspect of genetic diversity (Laity et al., 2015; Cresswell and Murphy, 2017).

Since European colonization, Australia's genetic diversity has been augmented by the introduction of large numbers of plants, animals, fungi and microbes from overseas. Some of these introductions have detrimentally affected the diversity and status of native species (see section 12.5, below), but others have been made with the deliberate intention of improving pastoral, agricultural and horticultural productivity. Introductions of new genetic stock and manipulations of existing genomes are made for many purposes, including to improve crop yield, speed crop growth and maturation, enhance the taste or flavor of the foods that are grown, increase resistance to pathogens, diseases and other pests, reduce the need for fertilizers, or expand the range of soil and climatic conditions under which the crops will productively grow (e.g., Heal et al., 2004; Cowling, 2007; Tester and Langridge, 2010; Tabashnik et al., 2013). Much research in cereal and fruit growing regions is now focusing on improving genetic resistance to abiotic stressors such as salinized soils and extreme climatic events (Mickelbart et al., 2015), as well as on conserving existing genetic resources and new resources (Mal et al., 2011). Similar efforts are being made to augment and improve genetic stock in aquaculture, viticulture, livestock and other industries that depend on natural resources.

12.5 Threats to Biodiversity

As in other parts of the world, biodiversity in Australia faces many threats. To a large extent, these threats have two common and related causes: human overpopulation, and the excessive demand for resources that people make on the natural world. Although overpopulation is not always considered to be as acute in Australia as in other parts of the world owing to the continent's relatively sparse population (3.3 people per km^2 compared with the world average of > 53 people per km^2; Dickman, 2014), three factors amplify the human impact. Firstly, *per capita* usage of resources is relatively high in Australia compared with most other countries, and resource consumption is exacerbated by the export of much food, gas, oil, coal, minerals and other products that sustain large human populations beyond Australian shores (O'Connor, 2014). Secondly, because the continent's soils are generally thin and nutrient-impoverished, attempts to farm them intensively in the style that was familiar to early European colonists have resulted in immense damage to landscapes over vast areas. Species, habitats and ecological communities have been degraded or destroyed as a consequence (Dickman, 2015). Thirdly, Australia has been more adversely affected by the impacts of invasive predators, competitors, weeds and other organisms than most other parts of the world, except for isolated island ecosystems (e.g., Salo et al., 2007). On average, over the last half-century, for every million people added to the Australian population, almost one (0.95) native vertebrate species has become extinct (Dickman, 2014). Since the arrival of the first European colonists in 1788, 30 species of native mammals alone have become extinct, the highest rate of extinction of mammals for any part of the world over the same period (Woinarski et al., 2014).

Threats affecting Australia's biodiversity have been listed recently (Cresswell and Murphy, 2017) under the major categories of 'pollution,' 'consumption and extraction of natural resources,' 'clearing and fragmentation of native ecosystems,' 'urban development,' 'pressures from livestock production,' pest species and pathogens,' altered fire regimes,' 'changed hydrology,' 'pressures facing aquatic ecosystems,' interactions among pressures,' and 'global climate change and climate variability'. Indifference about biodiversity, poor governance and continually declining funding for biodiversity conservation can be added to this list (Ritchie et al., 2013; Waldron et al., 2017). Of course, there are marked spatial and temporal differences in the intensity with which all these threats operate, making prioritization and conservation planning important components of biodiversity conservation strategies (Stow et al., 2014; Cresswell and Murphy, 2017). In 2016, 1,808 species were listed as threatened under Australian national conservation legislation (Cresswell and Murphy, 2017; and see below); recent advances in our ability to map and forecast changes to ecosystems indicate that many habitats, communities and ecosystems also will be added to lists of threatened entities (Keith et al., 2013).

12.6 National Laws and International Obligations

Every local, state and territory government has passed legislation or regulations that seek to conserve biodiversity, either through the identification and protection of threatened species, populations, habitats, or ecological communities, or the mitigation of key threats. At the state level, protected areas (e.g., National Parks, Nature Reserves, Conservation Reserves) can also be established. At the same time, much tension exists within state and local jurisdictions between conservation agencies and agencies whose mandate it is to develop and exploit natural resources or find new places for the expanding human population to occupy. At the national level, the key legislation relating to biodiversity is the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. This allows for the listing of threatened species, threatened ecological communities and the key processes that afflict them. Although funding from the Australian government is limited, the listing of entities in the schedules of the *EPBC Act* requires proponents of any development or exploitative actions to consider their proposed actions and to mitigate them to reduce further impacts on biodiversity.

In addition to allowing for the listing of threatened species and communities, the *EPBC Act* provides protection for biodiversity under several other categories of national environmental significance. These are the identification, listing and management for conservation of world heritage properties, national heritage places, wetlands of international importance (as listed under the Ramsar Convention), migratory species protected under international agreements, Commonwealth marine areas, and the Great Barrier Reef Marine Park. The *EPBC Act* also seeks to regulate 'nuclear actions' (including, for example, any impacts of mining for ore, storage and safe disposal of nuclear wastes on biodiversity) and the use of water resources in relation to coal seam gas and large coal mining developments (http://www.environment.gov.au/epbc/what-is-protected). The provisions of the *EPBC Act* are variably successful. For example, generally strong protection is provided for Australia's 20 World Heritage-listed sites and 65 wetland sites of international importance, but government-supported proposals to allow fracking for coal seam gas and—especially—a huge coal mine in Queensland have downplayed the impacts of these developments on biodiversity and have been highly controversial (http://www.abc.net.au/news/2017-10-07/thousands-protest-adani-mine-across-australia/9026336). Other national legislation may bear upon biodiversity and its conservation. The *Water Act 2007*, for example, allowed the establishment of the Murray-Darling Basin Authority, a statutory body set up to sustainably manage the water resources and wetlands of the Murray and Darling Rivers and their catchment area.

At the global level, Australia is a signatory to several international agreements. Among these are the *Convention on Biological Diversity*, the *Strategic Plan for Biodiversity 2011–2020*, the *Paris Agreement on Climate Change*, and the international treaties noted above. As with many other nations that sign up to international environmental agreements, Australia's record in meeting its stated objectives under the agreements is patchy (Ulloa et al., 2018) and its allocation of appropriate levels of funding and resources inadequate (Waldron et al., 2017). Acceptance of the scientific evidence for climate change, and perhaps even of the importance of biodiversity, varies with political ideology in Australia (Fielding et al., 2012). This suggests that support for wise environmental stewardship will continue to wax and wane in line with the politics of the day.

12.7 State of the Environment

In 1996 the first independent national assessment of the state of Australia's environment was made, and every five years since an updated and official State of the Environment report has been made. The first report concluded that "some aspects of Australia's environment are in good condition by international standards. Unfortunately, the report also shows that Australia has some serious environmental problems" (State of the Environment Advisory Council, 1996, p 7). The State of the Environment report for 2016 (Cresswell and Murphy, 2017) indicates that little has changed. Among the key findings of the 2016 report are that the major pressures on biodiversity identified in previous reports have not decreased; that the number of threatened species and threatened ecological communities has increased since 2011; that reducing the impacts of feral predators and feral herbivores is an essential action for effective conservation; and that continuing population growth in urban and peri-urban areas is having increasing direct and indirect effects on surrounding natural ecosystems. Cresswell and Murphy (2017) also noted that it was not possible to assess the overall long-term effectiveness of management actions taken to limit the impacts of invasive species, and that the lack of data and information from long-term monitoring of biodiversity was universally acknowledged as a major impediment to biodiversity conservation. Unfortunately, in an act of breath-taking folly, the nation's Long Term Ecological Research Network—the only facility in the country tracking long-term changes in at least some components of biodiversity—was a victim of government funding cuts in 2017; it has been defunded, decommissioned and was set for final closure in June 2018.

On the brighter side, the State of the Environment report for 2016 highlights some improvements that herald a more optimistic outlook. Thus, the potential impacts of climate change on biodiversity are becoming better known; methods of 'future proofing' populations of native species by using *ex situ* management, translocation and other means are becoming used more widely; biodiversity monitoring projects involving 'citizen scientists' are contributing to our understanding of trends for selected species; and technological improvements are helping to uncover and understand Australia's species and genetic diversity (Cresswell and Murphy, 2017). Importantly too, an increasing area of Australia is coming under Indigenous management. This is enabling traditional practices to form the basis of new forms of contemporary, collaborative environmental and resource management, and helping to drive an increase in the overall area of the country within Australia's National Reserve System (NRS). Currently, some 10,500 areas are included within the NRS, covering over 1.5 million km^2 or 19.63% of the country (http://www.environment.gov.au/land/nrs). An intriguing trend over the last two decades has been the rise in privately owned land that is set aside for biodiversity conservation. Between them, for example, Bush Heritage Australia and the Australian Wildlife Conservancy have purchased some 55,500 km^2 of land that is now protected and managed to conserve native species and ecological processes. In addition, national nongovernment organizations such as WWF-Australia and the Australian Conservation Foundation, as well as local and regional alliances, are harnessing the efforts of citizens concerned about conserving the natural world. As stewards of a large country blessed with a spectacularly rich and highly endemic biota, Australians will need to continue to step up to ensure that this living heritage is sustained for generations to come.

Keywords

- genetic diversity
- threats

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