Part III: Habitats

Chapter 20

Vulnerability of island flora and fauna in the Great Barrier Reef to climate change

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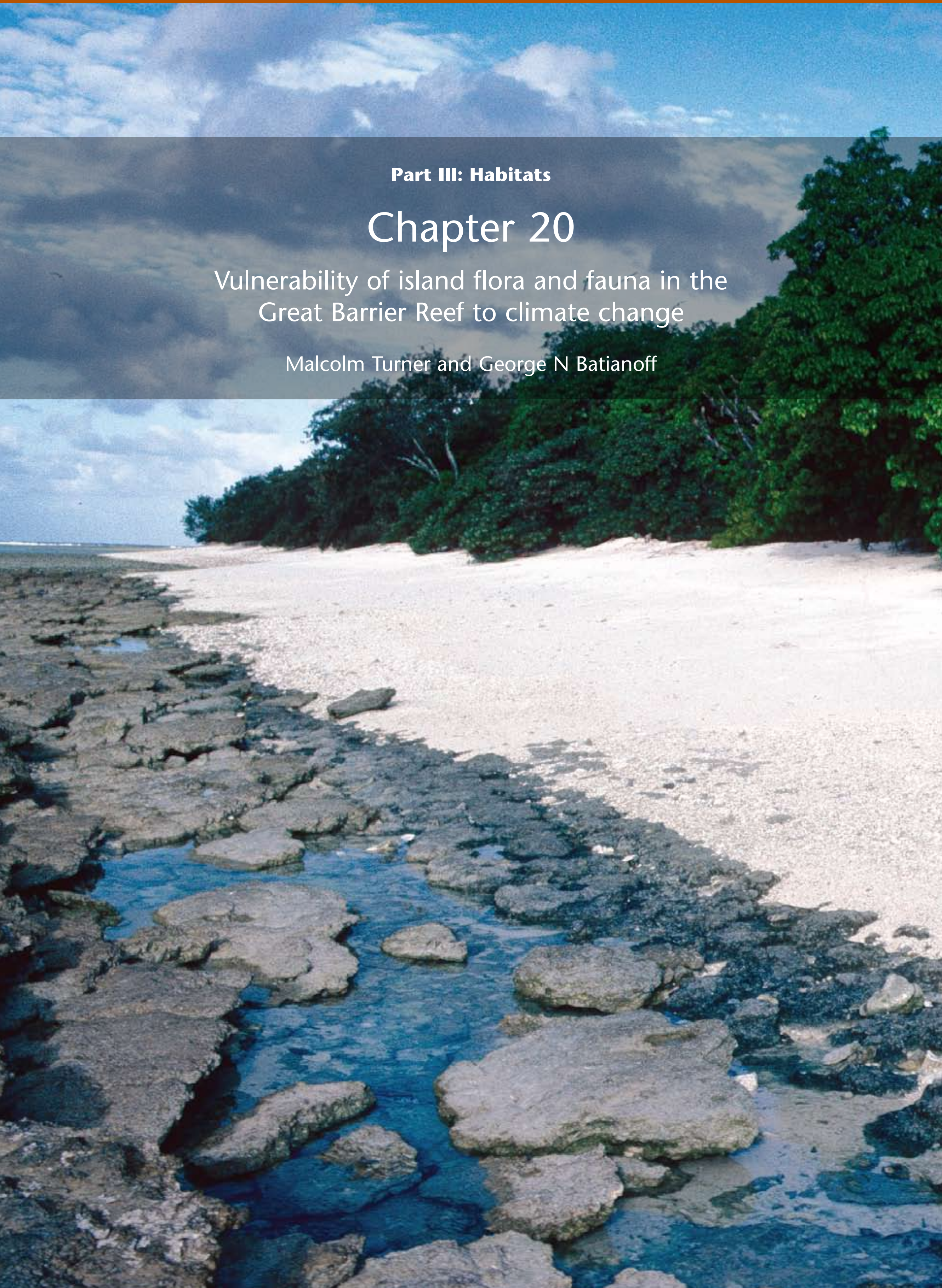


20.1 Introduction

The emphasis of this chapter is on terrestrial and freshwater flora and fauna, and key nesting habitats on the islands of the Great Barrier Reef (GBR). This chapter should be read in conjunction with other chapters of this volume detailing the specific effects of climate change on different components of island habitats: mangrove and tidal wetlands are discussed in chapter 9, seabirds in chapter 14, marine turtles in chapter 15 and geomorphology in chapter 21.

Below is a brief description of flora and fauna of islands in the GBR. For more information refer to the State of the GBR[24]. Several references are made to threatened species in this chapter. Unless otherwise stated, the status refers to Queensland threatened species status[a].

20.1.1 Islands of the Great Barrier Reef

The GBR includes about 900 islands, of which approximately 600 are continental or high islands (Smithers et al. chapter 21). The majority of these high islands are composed of granite or their volcanic equivalents (rhyolite or acid volcanic), with some mixing with other rock types on some islands[51]. Some of the inshore islands in the southern GBR are predominately sand islands. The largest continental islands are Curtis, Hinchinbrook and Whitsunday Islands (Figure 20.1). Approximately 300 low islands or coral cays are found in the GBR. They are formed by the accumulation of sediments on reef flats. Shingle cays form on the windward side of reef flats and sand cays on the leeward side (Smithers et al. chapter 21). There are 44 low wooded islands in the northern half of the GBR, which has both shingle and sand cays, cementation of beach rock and mangroves on the reef flats[57].

The types, formation, and distribution of islands within the GBR are discussed in Smithers et al. (chapter 21). Smithers et al also discuss climate change vulnerabilities with some changes leading to an increase in island size and other impacts leading to a decline in the number and area of islands.

Most GBR islands are north of the Tropic of Capricorn and are considered 'tropical'. They receive approximately 80 percent of their rain in the summer wet season with the rest in the winter dry season (Lough chapter 2). Most of the Capricorn Bunker Group, the Swains Cays and the southern inshore sand islands are south of the Tropics and considered 'sub-tropical'. These islands have some influence from winter rains. The boundary between tropical and sub-tropical regions is a gradation affected by temperature, aspect and elevation.

Islands are an important component of the GBR ecosystem. Several species of terrestrial flora are endemic to the islands. Some habitats, such as pisonia closed-forests, are largely confined to the islands. The intertidal habitats of islands including mangroves, beaches, rocky shores (including beach-rock shores on coral cays), and coral reef flats provide living space and nesting sites for a range of marine and terrestrial plant and animal species, including turtles, seabirds and shorebirds. Freshwater wetland habitats are scarce on the low islands, however several larger continental islands have seasonal streams and swamps that frequently dry out in the dry season. For example, Hinchinbrook and Magnetic Islands have melaleuca wetland habitats and Hinchinbrook Island features a continuous supply of freshwater creeks[77]. Many islands have salt marsh and mangrove wetlands.

a Environmental Protection Agency (2007) http://www.epa.qld.gov.au/nature_conservation/wildlife/threatened_plants_and_animals

Figure 20.1 *Map of the GBR region indicating key islands and their locations*

20.1.2 Terrestrial flora

To understand the potential effects of climate change on the flora of GBR islands, awareness of the baseline flora is necessary. The following section describes the flora of GBR continental islands, low islands and coral cays before advising about the potential effects of climate change on the islands.

20.1.2.1 Flora of continental islands

Approximately 2000 native species of vascular plants have been recorded on continental islands and low sandy mainland islands within the GBR, representing a quarter of Queensland's vascular flora[9]. About 70 (less than 5%) of these plant species are listed as rare and endangered in Queensland[111], and eight species are considered as endemic to the continental islands within the GBR (see Table 20.1).

Vegetation types on continental islands range from rainforest to dry open-woodlands and grasslands. Woody species comprise 70 percent of the island flora in the north of the GBR, gradually reducing to 50 percent of the island flora below the Tropic of Capricorn[9]. The majority of plants in the north of the GBR are rainforest species and this trend continues south to the Whitsunday region where an equal number of rainforest and open-forest species occur. Further south in the Capricornia region, 65 percent of the flora belongs to open-forest communities, including an increased number of grasses[9]. Differences in species composition reflect the location of each island, and differences in response to climate change are likely to reflect this.

Floristic analyses of the continental islands in the GBR indicate that an increased distance from the mainland results in decreased floral species richness. Batianoff and Dillewaard[9] found that species diversity increases linearly with island size up to 5000 hectares. For islands larger than 5000 hectares, other factors such as habitat diversity, remoteness, paleo-climate and fire activity also

Table 20.1 *Plant species endemic to Great Barrier Reef islands*

Species	Location	Details
Albizia (*Albizia* sp.)	South Percy Island	Beach scrub small tree (GN Batianoff 11444)
Allocasuarina (*Allocasuarina* sp.)	Shaw Island (Whitsunday Group)	Open forest tree (GN Batianoff 3360)
Berrya rotundifolia	Calder (Cumberland Group) and Middle Percy Islands	Vine scrub tree – rare status
Buchanania mangoides	Central GBR islands	Rainforest tree – rare status
Gossia sp.	Lizard Island	Open-scrub shrub species (GN Batianoff AQ 454451)
Kunzea graniticola	Hinchinbrook Island	Scrubland shrub
Psychotria lorentzii	Lizard Island	Vine scrubland, scrambling shrub – rare status
Tetramolopium sp.	Mt Bowen on Hinchinbrook Island	Scrubby herb – rare status (DG Fell+ DGF1224)

determine species richness[9]. The vegetation of Hinchinbrook Island is diverse due to the island's size, height and proximity to the mainland. Of particular interest are the montane heaths, dominated by banksias and casuarinas, which are confined to the island's mountains. The cooler peaks have a more continuous supply of moisture brought by south-easterly winds than the lower parts of the island. Eight species of orchids only grow in rainforest pockets above 700 metres in altitude (W Lavarack pers comm). Another unusual type of vegetation is found on the dune complexes on the northern part of Hinchinbrook Island[29].

The proximity of an island to the mainland also affects the arrival of new species. Some components of the vegetation of continental islands, such as the hoop pine (*Araucaria cunninghamii*) on Lizard Island, are remnant from when the islands were connected to the mainland during the last ice age. Other species that have successfully colonised islands arrived by sea-dispersed seeds or other propagules spread by wind, birds or fruit bats.

20.1.2.2 Flora of coral cays and low islands

The species richness of coral cays of the GBR is affected by their location and size. Within the GBR, coral cays and low islands are more numerous on the inner and outer shelves of the far northern section of the GBR, with larger coral cays occurring in the Capricorn Bunker Group in the southern GBR. The northern low islands are more complex, with greater species richness than southern cays[110,40,116]. Some 200 to 250 native vascular plants are recorded north of latitude 16° 57' S and only 80 to 90 are recorded on southern cays.

The ecological factors differentiating these two regions are that many northern low islands are closer to the mainland and experience more tropical conditions with higher rainfall and more cyclones. As a result, the northern cays have more complex low wooded habitat with mangroves, and contain many woody beach scrub and littoral rainforest species. In the southern region many islands have a higher winter rainfall, and, as the distance from the mainland is greater, fewer seeds are brought by terrestrial birds. The result is that there are fewer rainforest species, and about 50 percent of the native flora is herbaceous (Batianoff unpublished data).

Freshwater availability is limited on coral cays. Surface freshwater rarely occurs on sand or shingle islands, but freshwater frequently occurs in a subterranean freshwater lens that floats within the centre of the island with saltwater to the sides and below. In areas where rainfall is low, this freshwater lens is an important factor in coral cay ecology.

20.1.2.3 Physiological aspects of flora

Carbon dioxide gas in the atmosphere is utilised by plants during photosynthesis and its availability limits plant growth. According to Drake et al.[31] and Lovejoy and Hannah[76], terrestrial plants belong to three major groups based on their differences in photosynthetic processes and productivity. These plant groups are referred to as C_3 (includes about 95% of the world's flora), C_4 (about 4%) and Crassulacean Acid Metabolism (CAM) plants (about 1%). The terrestrial plants of the GBR include all three forms of photosynthesis. The ancestral C_3 plants are represented by the woody species of rainforests, open-forests and shrublands, and the non-woody sedges and rushes of wetlands. The C_4 plants are predominantly the tropical grassland and savannah species. In the GBR the succulent CAM plants, which globally are considered species of desert and semi-arid ecosystems, are mostly found in the saline herblands at the inter-tidal margins.

The impact of climate change on island flora will largely be determined by the differences in photosynthetic potential of each plant group present in island environments.

20.1.2.4 Fire

Fires started by lightning strikes are a natural part of the Australian environment and various species and ecosystems have developed adaptations to survive fire[108]. The vegetation reflects an area's fire regime, which is defined by fire intensity, fire frequency, and the season of burn[119]. Any change in fire frequency is likely to have major impacts on the composition, age-distribution and biomass of forests and rangelands[67,3]. In Australia fire management considers the concept of fire danger, which is a combination of the chances of a fire starting, its rate of spread, intensity and the difficulty of its suppression[119].

The burning of vegetation on GBR islands by humans has occurred for thousands of years, first by indigenous peoples and then by early European settlers. The Queensland Parks and Wildlife Service (QPWS) aims to manage fire frequency with regard to historic human burning patterns[98]. Grasslands on several continental islands in the GBR, such as the Whitsunday and Flinders Groups, are ecologically maintained using prescribed burning to prevent invasion of grasslands by shrubs. Heathland on Hinchinbrook Island is regularly burnt at an interval of several years to prevent invasion by ferns and rainforest.

20.1.3 Fauna

Much of the terrestrial fauna on islands is similar to populations on the adjacent mainland, but with fewer species. Some species, such as the yellow spotted goanna (*Varanus panoptes*) of Lizard Island, were stranded on islands as sea levels rose following the last glaciation several thousand years ago. Other fauna species are more widespread as they can colonise by air (eg bats) or on floating vegetation (eg rats).

Some significant terrestrial fauna of GBR islands are listed in Table 20.2.

20.1.3.1 Reptiles

At least 40 species of terrestrial reptiles, including 31 lizards and nine snakes, are found on the islands of the GBR[50]. Most of these reptiles occupy similar habitats to those they occupy on the mainland. Species richness decreases with increasing latitude and increasing distance from the mainland[81]. A number of lizard species are endemic to GBR coral cays[50].

Thirty-eight islands have important marine turtle nesting sites, especially Raine Island, Milman Island and the cays of the Capricorn Bunker Group. Globally important populations of loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and flatback (*Natator depressus*) turtles[74] nest at these sites. Turtles nesting in the littoral vegetation zone of coral cays and continental islands physically disturb island vegetation. Estuarine crocodiles (*Crocodylus porosus*) and, inhabit mangrove islands and low wooded islands, visit islands well offshore in the far north[82], and breed at Deluge Inlet and several creeks of Hinchinbrook Island[99]. For impacts of climate change on marine reptiles see Hamann et al. (chapter 15).

Table 20.2 *Significant terrestrial fauna of Great Barrier Reef islands*

Species	Location	Notes
Proserpine rock-wallaby (*Petrogale persephone*)	Gloucester Island, Hayman Island (Whitsunday Group)	Endangered. On mainland and two islands[87]
Bramble Cay melomys (*Melomys rubicola*)	Bramble Cay	Endangered. Endemic to the cay[73]
Northern quoll (*Dasyurus halluctatus*)	Magnetic Island	Rediscovered on Magnetic Island (G Ryan pers comm)
Coastal sheathtail-bat (*Taphozous australis*)	Magenetic Island	Vulnerable.
Koala (*Phascolarctus cinereus*)	Magnetic Island, St Bees Island (Cumberland Group)	Introduced, but stable populations
Striped–tailed delma (*Delma labialis*)	Magnetic Island	Vulnerable in Action Plan for Australian Reptiles[25]
Sadliers dwarf skink (*Menetia sadlieri*)	Magnetic Island	Endemic to the island[83]
Common death adder (*Acanthophis antarcticus*)	Gloucesfer Island	Rare. Death adders on adjacent mainland are northern species
Rusty goanna (*Varanus semiremex*)	Magnetic Island	Rare.
Dawson yellow chat (*Epthianura crocea macgregori*)	Curtis Island	Critically endangered in Action Plan for Australian Birds[44]
Capricorn white-eye (*Zosterops lateralis chlorocephala*)	Capricorn Bunker Group	Endemic to the island group
White-rumped swiftlet (*Collocalia spodiopygius*)	Dunk Island	Rare, nests in caves
Whitsunday azure butterfly (*Ogyris zosine zolivia*)	Whitsunday Group	Endemic to Whitsunday Group. Habitat dependent[113]
A skipper butterfly (*Hesperilla malindeva dagoomba*)	Magnetic Island, Scawfell Island (Cumberland Group)	Recently described, endemic to GBR islands

20.1.3.2 Coastal birds

Birds of the GBR may be categorised as seabirds, shorebirds, waterbirds and terrestrial (or land) birds. Approximately 215 species of birds have been reported from the GBR but many are not resident[111].

Seabirds

Climate change impacts on seabird feeding and breeding success is discussed in Congdon et al. (chapter 14). This chapter considers the impact on the island nesting habitat of seabirds and other birds.

Fifty-five islands have been identified as the most important seabird breeding islands of the GBR[66]. Approximately 736,000 pairs of seabirds of about 24 species were reported breeding in the GBR in 1995[117]. Some significant seabird species are listed in Table 20.3. About 80 percent of seabirds breed on low islands such as coral cays and 20 percent breed on high continental islands, with most breeding in the far north or southern regions of the GBR[58]. Distribution depends on the suitability of the islands as nesting sites and the proximity of suitable food. Faeces, food scraps, dead chicks and expired adults are a major source of nutrients for plants on many islands and some species such as pisonia thrive on these nutrients.

Key seabird populations have declined in recent years at four localities on the GBR[112]. According to Batianoff and Cornelius[8], a comparison of Raine Island's breeding seabird populations from 1979–1993 to 1994–2003 showed a greater than 65 percent reduction in population size for five species of seabirds. These were the red-footed booby (*Sula sula*) (68%), lesser frigatebird (*Fregata ariel*) (68%), bridled tern (*Sterna anaethetus*) (69%), sooty tern (*Sterna fuscata*) (84%) and common noddy (*Anous stolidus*) (95%). Batianoff and Cornelius[8] and other authors have suggested the declines at all four localities are related to warmer water affecting food availability rather than impacts of human disturbance or other impacts on the nesting islands (see Congdon et al. chapter 14).

Shorebirds

Shorebirds feed on the mudflats and beaches of GBR islands and the adjacent mainland. Some significant shorebirds are listed in Table 20.3. Several species are resident all year and breed on remote island and mainland beaches. Hundreds of thousands of migratory shorebirds from the northern hemisphere utilise the GBR as a wintering ground, or on passage to and from wintering grounds further south. Many of the shorebirds and seabirds of the GBR are listed under international treaties for the protection of migratory birds[111].

Table 20.3 *Significant seabirds and shorebirds of Great Barrier Reef islands*

Species	Location	Notes
Little tern (*Sterna albifrons*)	Widespread in small colonies	Endangered in Qld. Nests on sand spits
Roseate tern (*Sterna dougallii*)	Swain cays, Capricorn Bunker Group	Internationally threatened. Both migratory and breeding populations
Herald petrel (*Pterodroma heraldica*)	Raine Island	Endangered in Qld. On edge of range. A few pairs only
Red-tailed tropicbird (*Phaethon rubricauda*)	Raine Island, Lady Elliott Island	Vulnerable. Several nesting pairs
Beach stone-curlew (*Esacus neglectus*)	Widespread but rare on inshore islands	Vulnerable. Nests on isolated beaches. Resident shorebird
Sooty oystercatcher (*Maematapus fuliginasus*)	Widespread but rare on rocky inshore islands	Rare. Resident shorebird. Nests on isolated rocky shores
Eastern curlew *Numemius madagascariensis*)	Widespread on intertidal mudflats	Rare. Non-breeding migrant. Nests in Siberia

Waterbirds

Waterbirds feed on intertidal reefs and mudflats and in freshwater wetlands on islands. Several species, especially herons, breed on GBR islands.

Terrestrial birds

Terrestrial bird species biodiversity on GBR islands is lower than the nearby mainland. Of 180 birds recorded from Magnetic Island[118], approximately 50 appear resident[83]. The density of particular species is often higher on the islands than the mainland (eg buff-banded rail, *Gallirallus philippensis*, mangrove golden whistler, *Pachycephala melanura*) (M Turner pers obs). One sub-species, the Capricorn white-eye (*Zosterops lateralis chlorocephala*), is endemic to the Capricorn Bunker Group. The majority of recorded sightings of the nationally critically endangered Dawson yellow chat (*Epthianura crocea macgregori*) are confined to Curtis Island (J Olds pers comm).

Hundreds of thousands of pied imperial pigeons (*Ducula bicolor*) roost and nest on many GBR islands north of Mackay, particularly north of Three Islands[65]. They prefer mangroves on low wooded islands or closed vine forest on continental islands. Each evening in summer the pigeons return to the islands from mainland rainforests depositing droppings containing nutrients and fruit seeds. On Milman Island, about 70 percent of the plant species were assisted to the island by pied imperial pigeons[20].

20.1.3.3 Terrestrial invertebrates

Islands of the GBR support a diverse array of invertebrates including pseudoscorpions, mites, spiders, centipedes, isopods from twenty order of 109 insect famililies[78]. Like other fauna, the assemblages of invertebrate fauna on the islands are likely to be similar to those in equivalent mainland habitats but with some differences due to island zoogeography.

Island invertebrates are highly dependent on habitat. Some species such as scale insects on the pisonia of Tryon and Wilson Islands in the Capricorn Bunker Group have caused damaging effects on island vegetation[64,88].

Up to 118 species of butterfly have been recorded for GBR islands including two endemic species (Table 20.2)[113]. Island isolation may contribute to the rapid speciation of butterflies. Butterfly distribution depends on the distribution of host plants for larval feeding. Several islands are dry season (winter) aggregation refuges for some butterfly and moth species, especially from family Nyphalidae[114] (M Turner pers obs).

20.1.3.4 Freshwater wetlands fauna

Of all of the GBR islands, Hinchinbrook Island has by far the greatest number of freshwater wetlands, including permanent wetlands, and the best representation of aquatic fauna. Twenty-eight species of freshwater fish have been recorded in the freshwater habitats of Hinchinbrook Island, including the jungle perch (*Kuhlia rupestris*)[77]. All fish species surveyed on Hinchinbrook Island have also been recorded in adjacent mainland wet tropical freshwater habitats.

At least seven species of frog have been recorded on islands of the GBR although this is probably an underestimate[111]. Frogs and many aquatic invertebrates are adapted for life in ephemeral wetlands and perennial freshwater stream habitats on the islands.

20.2 Vulnerability of Great Barrier Reef islands to climate change

Predictions of the potential impacts of climate change on island terrestrial flora and fauna are not certain. Most of our assumptions for determining vulnerabilities are based on our observations, case studies and literature reviews, bearing in mind that the current knowledge of flora and fauna on GBR islands is fragmented and incomplete. Figures 20.2 and 20.3 depict potential changes to GBR islands in association with climate change.

Figure 20.2 *Potential impacts on continental islands based on climate change projections for the GBR*

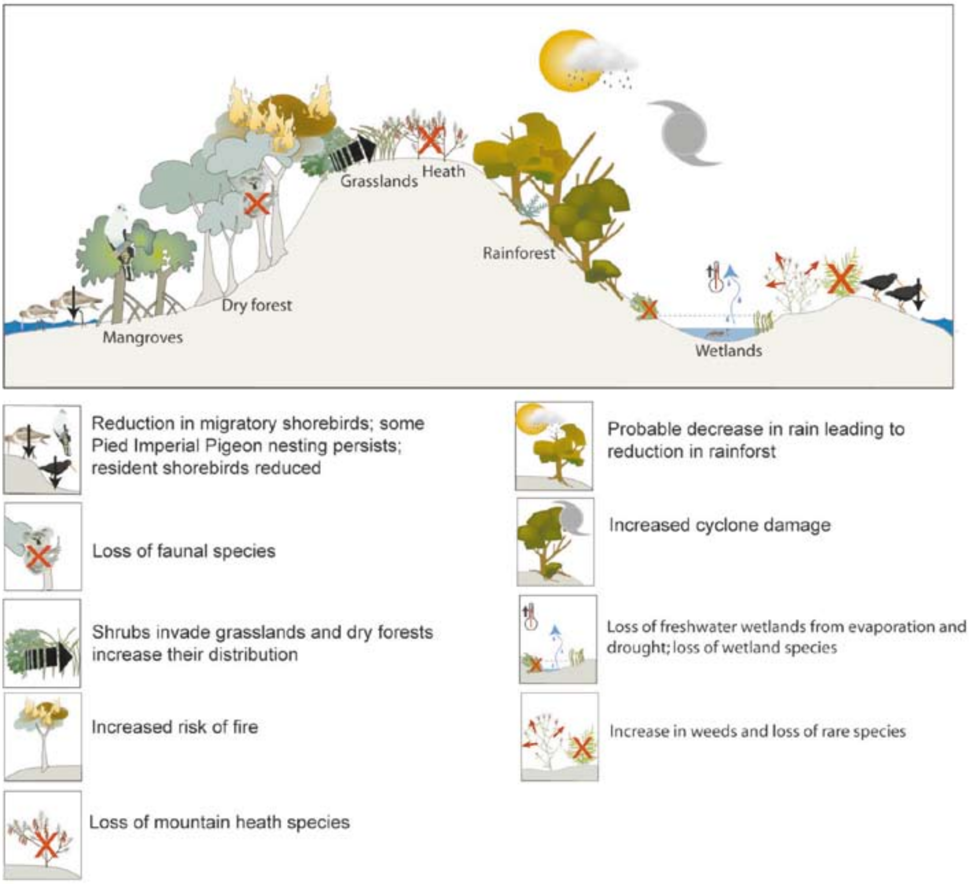
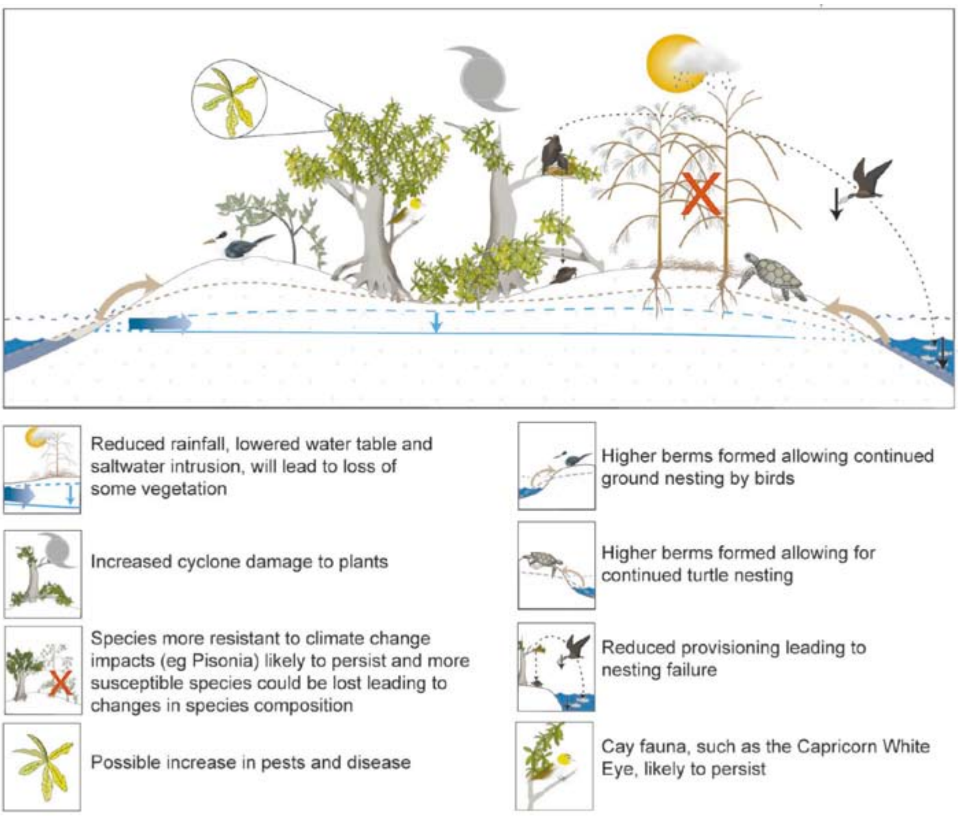


Figure 20.3 *Potential impacts on coral cays and low islands based on climate change projections for the GBR*



20.2.1 Changes in El Niño Southern Oscillation and ocean circulation

The major direct impacts of El Niño-Southern Oscillation (ENSO) events on islands are from changes in rainfall and tropical storm severity and frequency. These are discussed in sections 20.2.6 and 20.2.7. Changes to Enso and ocean circulation may also lead to changes in ocean productivity, which affects seabird food availability, and may affect their current impacts on island vegetation. This section discusses the effect of changes in ocean currents on plant colonisation of islands.

20.2.2.1 Impact – changing ocean currents

Cays and low wooded islands form on reef flats as unvegetated low sand banks and are colonised by pioneer plants. Many of these plants are transients that may never succeed as permanent residents but help to develop cay soils and provide better habitat for other colonising plants[49]. Waterborne dispersal is a common method of colonisation of islands by terrestrial plants[28,105,86], even for islands where birds bring many seeds. On Masthead Island in the Capricorn-Bunker Group, 52 percent of 40 plant species are ocean dispersed[7]. In particular, many plant species favouring the supra-littoral zones of sandy and rubble shores produce buoyant seeds, and most mangrove species have buoyant propagules[49,105,47]. Shores of islands are dynamic, providing bare ground for colonising plants[86]. Sea currents carry seeds long distances to islands from mainland Australia, Papua New Guinea, other GBR islands and islands in the Pacific[20,47]. Most of the drift propagules reaching the Swains Reef cays for instance, come from the New Caledonia, Vanuatu and Fiji region[105].

Although local currents around islands are principally the result of winds and tides, ocean currents can have an affect. If the direction or speed of ocean currents is altered by climate change the number of seeds from the Pacific arriving on GBR island beaches may increase or decrease. Any change may alter the species composition of island seashore vegetation.

20.2.2 Changes in air and water temperature

Increases in air and sea temperature are two of the more predictable alterations that will occur with climate change (Lough chapter 2). Air temperature increases will have direct and immediate impacts on island flora and fauna, as will the temperature of freshwater wetlands. Islands have little direct exposure and sensitivity to sea surface temperature but may be impacted indirectly. Each of these temperature increases is discussed below.

20.2.2.1 Impact 1 – increase in air temperature

Terrestrial flora and fauna live in climatic conditions that are often determined by air temperature and rainfall. Temperature can have a direct impact on organism functions and can also affect evaporation rates and moisture content of plant tissues. Warmer air temperatures compound the effects of lower rainfall and increased droughts (discussed in section 20.2.7.1).

Increase in air temperature: flora

Increased temperatures will favour some plant species and disadvantage others. For example, some tropical and semi-arid species will be advantaged and able to colonise new habitats at higher latitudes or higher altitudes as the air temperature and habitats warm[84].

Higher temperatures improve photosynthesis, with peak productivity in tropical plants at 27°C under optimal light conditions[70]. However, for plants growing under less than optimal light conditions, such as in the shade or under frequent cloud cover, the impact of temperature on photosynthesis is less pronounced[70]. As a result, local weather conditions of cloudiness and shading by the forest canopy may be important factors in the responses of plants to increased temperatures.

Higher air temperature may increase evaporation rates making less water available to plants, thus favouring CAM plants that are adapted to dry conditions[70,126]. Higher temperatures may also increase the rate of transpiration of water from plant foliage. The result is increased water stress on plants. Frequent droughts may also change the composition of tropical species by favouring the more resilient drought-tolerant species of deciduous and deeper rooted tree plants[84].

In the open vegetation, other species which are more adapted to water stress, including grasses, succulents, herbs, hardy shrubs such as the grass trees (*Xanthorrhoea* spp.) and other woody sclerophyll species such as eucalypts, acacias and casuarinas, will most likely be favoured with increased evaporation. On the islands of the GBR, climatic changes could lead to a gradual replacement of rainforest by eucalypt and acacia woodlands, and a replacement of shrubs by short-lived herbaceous plants including grasses.

Warmer air temperatures increase fire risk, especially if there is an increase in the number of very hot days[119]. Higher temperatures reduce the moisture content of plant leaves and stems making them more susceptible to fire. More frequent and severe fires will favour some of the most common open-forest species now growing on the islands. The fire resistant C_3 woody plants such as the acacias may increase in many areas at the expense of herbaceous species. The fate of grasslands on the GBR islands is difficult to speculate. We suspect that some grasslands are already challenged by invasive C_3 plants such as *Xanthorrhoea* spp., eucalypts, casuarinas and acacias. However, under frequent fire conditions some grasslands are likely to increase in area at the expense of closed-scrubland. Much depends on the response of the grass species to changing conditions.

Hilbert[52] and Williams and Hilbert[121] have suggested that lowland mesophyll vine forests (a rainforest type) that occur on the mainland and continental islands adjacent to the Wet Tropics World Heritage Area may be at an advantage through an increase in temperature, and could increase in area. However, this will only occur if rainfall and light intensity is adequate[52,70]. Rainfall, not temperature, is the main determinant of rainforest distribution[53].

In a warmer climate, weeds and other invasive plants appear to be at an advantage thus creating the potential for dominance[31]. According to Richard Clarkson (pers comm), higher temperatures will assist lantana growth. All plants affected by temperature or water stress are more susceptible to attacks by pests and diseases such as insects, fungi and viruses[79,10].

The latitudinal distribution of flora along the length of the GBR is influenced by tropical conditions such as the temperature and day length, which mirrors plant distribution on the mainland. As air temperature increases some cooler climate species may not flourish and their distribution will shrink southward. Examples from the Keppel Group are the swamp mahogany (*Eucalyptus robusta*), now occurring on Great Keppel Island at its northern limit of natural distribution, and the lemon scented gum (*Corymbia citriodora*) open-forests on North Keppel Island. Both may be lost from the GBR due to warmer temperatures and drier conditions. Local extinction of eucalypts and reduction of acacia species has already occurred on small islands such as Prudhoe Island in the Whitsunday Group and Palfrey Island, near Lizard Island in the far northern GBR. Other species tolerant of higher temperatures that are more common in the northern GBR may spread further south. For example, tropical seashore plants such as *Pemphis acidula*, wongai plum (*Manilkara kauki*) and *Pouteria obovata* may expand from northern cays and establish on southern coral cays if dispersal processes are still operating.

Altitudinal retreat and extinction of flora and fauna has been predicted for mountains of the Queensland Wet Tropics as temperature rises[122]. There is little altitudinal variation on GBR islands, except for Hinchinbrook Island. At 1142 metres, Mt Bowen is the highest of several peaks on Hinchinbrook that, with cooler temperatures and cloud moisture, supports montane banksia heaths, rainforest patches and several species of localised orchids (W Lavarack pers comm). With a general rise in temperature and light, the mountains will become unsuitable habitat and the banksia heaths and orchids may be lost.

Increase in air temperature: invertebrate fauna

An increase in air temperature, especially a rise in minimum temperatures, may allow cold sensitive invertebrates to expand their ranges. An increase in air temperature may also speed up metabolic rates of insects and other invertebrates and lead to shortened life cycles. For example, herbivorous grasshoppers that reproduce each summer on Raine Island may be able to produce more generations each summer, rather than the current one or two generations (G Batianoff pers obs).

Higher temperatures may be speeding up the metabolic rate of the scale insect, which increased to outbreak proportions on Tryon and Wilson Islands, Capricorn Bunker Group in 2006[12]. No link has been made between scale insect outbreaks and climate change in this case but the potential for native and introduced invertebrates to rapidly increase in population is greater with higher temperatures. Of course there is also the potential for warmer temperatures to speed up the life cycle of the scale insect's main predators: ladybird beetles and parasitic wasps.

One observed consequence of faster insect development relates to pollinator species. Adult population pollinator levels may no longer peak when appropriate flowers are at their most abundant. This could disadvantage both the plants requiring pollination and the insect pollinators requiring nectar.

The distribution of butterflies is likely to alter with increased temperatures. The results of BIOCLIM modelling of Australian butterflies in general shows a rise in temperature of 0.8 to 1.4°C will cause a distribution decrease for 88 percent of the species. With an increase of 2.1 to 3.9°C, 92 percent of species will have a decreased distribution, with 83 percent experiencing distribution shrinkage of greater than 50 percent[13]. The capacity of butterflies to change their range is highly dependent on their host plants. The species most likely to survive will have the ability to range over large distances and rely on food plant species that occur in many climate zones. Other butterflies are much more restricted and will have little capacity to move. The lycaenids, such as the endemic species in the Whitsundays Islands, have limited capacity to disperse if temperatures rise[68] and will probably disappear under these conditions.

Most butterflies rely on vegetation for food during their caterpillar stage. If higher temperatures dry the foliage, increase fire risk or cause the habitat to evolve to be more sclerophyllous, some species of foliage feeding butterflies will be advantaged and others disadvantaged. The food plants of butterflies and other herbivorous insects may become too dry or their food plants may disappear from an island, which could lead to local extinction of the butterfly.

Increase in air temperature: vertebrate fauna

The effects of higher temperatures on vertebrate fauna distribution will follow a similar pattern to flora and plant eating invertebrates, especially for species closely tied to particular habitats. Some fauna will move in response to increased temperatures, depending on their sensitivity to climate change, their mobility, life span and availability of key needs[102]. Others cannot cross the ocean to alternative sites.

Water requirements for animals increase as temperatures rise, and individual animals may suffer heat and water stress. For example shorebirds and seabirds nesting on open ground during summer are already exposed to high temperatures and any increase may affect their capacity to keep themselves and their chicks cool.

Williams and Hilbert[121] predict that in the tropical rainforests of the Wet Tropics of Queensland the most vulnerable species are at higher elevation locations while lowland species such as most of those on GBR islands will be less affected. If lowland tropical rainforest areas of GBR islands and adjacent mainland do increase as suggested above, birds that favour that habitat may increase[104].

The higher temperatures that shift tropical conditions and fauna species further south will also cause sub-tropical ecosystems and their fauna to contract to the south. Species currently at the northern limit of their range on GBR islands may be lost from the GBR. Not all changes may be detrimental. The red fox (*Vulpes vulpes*) is an introduced pest, which has serious adverse impacts on Australian wildlife[45]. Currently the only GBR island with foxes is Curtis Island, where it predates on turtle nests (J Cruise pers comm). Foxes do not like tropical humid conditions[124]. Increasing temperatures, especially if humidity is also increases, may weaken the existing population and lessen the chances of it colonising other islands.

Any change to insect life cycles can also affect their competitors and predators[115]. For example, the timing of terrestrial bird nesting often coincides with times when insects are abundant to provide food for chicks. If insect life cycles change because of increased metabolic rates, the birds' food supply may not be available at this critical time[125,22]. In addition, temperature is a major cue for the timing of short distance bird migrations[19]. Migration is discussed further in section 20.3.

Increase in air temperature: animal diseases

Considerable attention has been focused on the potential spread of diseases of humans and livestock under a climate change scenario[38,36]. Temperature rises may trigger dormant stages of diseases, and increased heat and water stress on animals may increase their susceptibility to disease[48]. Tropical diseases may widen their distribution as tropical conditions spread further south from the equator. For example, the spread of West Nile disease in the United States of America is linked to warmer temperatures[35]. Avian malaria and avian pox in Hawaii are predicted to spread as their mosquito vector expands its range and capacity with warmer temperatures[48]. While these diseases are not currently present in Australia, they demonstrate how temperature can increase the impacts of indigenous or introduced diseases.

One study that demonstrates the climate change impacts of diseases involves the chrytid fungi disease that is devastating frog species worldwide. The impact is being driven by temperature increases[95]. In the American tropics, 67 percent of *Atelopus* frogs have declined or vanished. Some frogs most vulnerable to the disease include those living in the highlands of north Queensland. Extinctions of frog species worldwide (122 species possibly extinct), including Queensland species, demonstrate the limited adaptive capacity of frogs to the disease effects of climate change. Increased temperatures may increase the virulence of chrytid disease in frogs on the mountains of Hinchinbrook Island. The vulnerability of flora and fauna to existing or new diseases is not well known but, as demonstrated by the frog extinctions, the consequences may be very high.

20.2.2.2 Impact 2 – increase in water temperature of freshwater wetlands

Increased air temperature will raise the water temperature of freshwater wetlands and increase evaporation rates. Freshwater habitats on islands vary with location and tend to be ephemeral, shallow and dynamic with many having limited species richness. Plant and animal species in small water bodies tend to have high tolerances to short-term temperature fluctuations. However there are limits to their tolerance, and higher water temperatures may lower the capacity of aquatic life to obtain food or reproduce.

Some freshwater fishes of GBR islands, particularly freshwater jungle perch, rainbow fish (Melanotaeniidae) and blue-eyes (Pseudomugilidae) are vulnerable to increased water temperature. Jungle perch on Hinchinbrook Island favour deeper pools in hillsides of permanent streams. As water temperatures increase, the thermal tolerance threshold of jungle perch is likely to be exceeded; however the exact threshold is unknown.

Fauna, including frogs and many invertebrates, that must complete their life cycles in ephemeral wetlands are vulnerable if ephemeral wetlands evaporate at a faster rate than at present.

Some species may be able to adapt to increased water temperature, as increased temperatures will favour individuals with greater thermal tolerances. The capacity for non-flying fauna to move is limited in island freshwater systems since the systems are small and rarely interconnected. Recruitment to freshwater wetlands on islands has all of the challenges of freshwater wetlands on the mainland but with the additional barrier of the sea. Freshwater habitats are likely to become less diverse, with fewer species.

A decline in wetlands will affect the eastern water rat (*Hydromys chrysogaster*) that relies on wetlands for food and nesting sites although it can live and migrate through saltwater wetlands.

Waterbirds can move from island wetlands to mainland wetlands as the island wetlands decline. The future of most waterbird species depends more on what happens to wetlands on mainland Australia than what happens on the small part of their range on islands.

20.2.2.3 Impact 3 – increases in sea surface temperature

The impacts of increases in sea surface temperature on island flora and fauna are indirect. Increases in sea surface temperature will kill coral and other calcium-accumulating organisms (eg algae) and their skeletons will break down into rubble and sand, providing a short-term increase in island building materials, particularly for cays on the windward side of reefs (Smithers et al. chapter 21). Colonisation by plants tolerant of the alkaline fresh rubble (pH greater than 8) is likely to follow. However, the death of calcium-accumulating organisms, such as corals, will eventually reduce the supply of sand and rubble available for island building (Hoegh-Guldberg et al. chapter 10).

Increased sea surface temperature impacts seabird feeding (Congdon et al. chapter 14) reducing the nutrients seabird guano contributes to island plants.

20.2.3 Changes in atmospheric and ocean chemistry

Island habitats in the GBR will be directly impacted by atmospheric increases in carbon dioxide (CO_2) concentrations but only indirectly affected by changes in ocean chemistry. These impacts are discussed separately.

20.2.3.1 Impact 1 – elevated atmospheric CO_2 concentrations

Elevated atmospheric CO_2: flora

Carbon dioxide concentration is increasing in the atmosphere (Lough chapter 2). Under current CO_2 levels the C_4 plants generally have higher CO_2-fixation rates than the ancestral C_3 plants, giving C_4 plants a competitive advantage. In tropical and sub-tropical Africa the competitive advantage of C_4 grasses over C_3 trees gives as much as 40 percent superiority under a dry climate and low CO_2[61]. However, C_3 plants can survive droughts by adaptations such as reducing leaf area and/or loss of leaves during dry periods[27].

Increases in atmospheric CO_2 will increase the growth rates of many plants, thus driving vegetation dynamics at a more rapid rate. For C_3 plants, an increase in CO_2 concentrations will generally enhance photosynthesis, stimulate additional plant growth and increase the carbon to nitrogen ratio in plant tissues[85,84]. Most importantly, this will provide a competitive advantage for C_3 plants over C_4 grasslands[31,76]. According to Bond and Midgley[15], the effects of elevated CO_2 may already be contributing to tree invasions and the thickening of woody vegetation within tropical grasslands. Observed invasions of woody vegetation into mainland Queensland grasslands that are occurring despite frequent burning[37] may be partly explained by elevated CO_2. In the same way, the grasslands of the GBR islands would also be vulnerable to the impact of elevated atmospheric CO_2. Weed invasion is also favoured by the enhanced C_3 plants[127].

According to Long and Drake[75] the combination of elevated CO_2 and temperature will stimulate photosynthesis in low light such as in understorey trees and shrubs.

As CO_2 increases, stomatal conductance reduces so the effective water consumption of plants improves[93]. The increase in water use efficiency may offset the effects of elevated temperatures and lower rainfall (ie the effect of drought may be ameliorated). If the concentration of CO_2 doubles in the next 50 years as predicted, an improvement in water efficiency will offset a 10 percent decrease in rainfall[93]. This presumes that other factors such as adequate nutrients are not inhibiting growth. Vegetation on some coral cays that receive nitrogen from bird guano, will respond well. However, vegetation on nutrient poor islands, such as young cays and granitic-based continental islands will be less likely to respond unless they are nitrogen fixers which are highly responsive to increased CO_2 levels[94]. Under these scenarios habitats may be structurally similar but have a different species composition.

Elevated atmospheric CO_2: wetlands

A higher CO_2 gas level favours the growth of mangroves if salinity is low[4]. Mangroves may therefore expand into brackish and freshwater wetlands (Lovelock and Ellison, chapter 9) including those on islands.

Elevated atmospheric CO_2: fauna

Elevated CO_2 will probably have little effect on the respiration of fauna due to their ability to adapt and/or survive under relatively high CO_2 levels. Current and expected atmospheric CO_2 levels are in the order of hundreds of parts per million[59] (Lough chapter 2). Currently humans survive in submarines with 9000 parts per million, bees survive in hives with 30,000 parts per million, and termite mounds and mammal burrows may have 50,000 parts per million[123,46].

Increased leaf growth due to increased concentrations of CO_2 means that the ratio of carbon to nitrogen in the leaf is altered. Plants grown at increased concentrations of CO_2 have reduced amounts of nitrogen[63] and are less nutritious for folivores, including possums and insects. The leaves of these plants are also tougher and contain more concentrated defence compounds[72]. Koalas on Magnetic Island will be impacted since they already eat and digest large amounts of leaves to obtain adequate nutrition. A decrease in the nutritional value of leaves will force koalas to eat more leaves to get the same total amount of nitrogen. For such a species, on the edge of its range, any additional survival stress such as poorer quality leaves may lead to local extinctions.

Leaf-eating insects are important parts of many food chains. If these insects decrease in abundance or vigour due to decreased leaf quality, the predators of the insects will also be impacted. Conversely, some plant pest invertebrates may increase in abundance with rising CO_2 concentrations[62].

20.2.3.2 Impact 2 – ocean acidification

The sea is projected to become more acidic (Lough chapter 2). Increased acidity of ocean waters may affect the ability of marine life to accumulate calcium carbonate (Hoegh-Guldberg et al. chapter 10), and decrease the long-term supply of sand and rubble building materials for cays and sand islands. Increased acidity may also decrease the formation of stabilising beach rock on cays and sandy beaches placing the islands at greater risk of erosion (Smithers et al. chapter 21).

20.2.4 Changes in light and ultraviolet radiation

Little change is expected in light and ultra violet-B (UVB) levels for terrestrial ecosystems in tropical areas such as the GBR (Lough chapter 2). Any small increase in UVB and light levels may have some small effect on flora of islands in the GBR. A larger impact may be from the combined effects of elevated CO_2 and temperature, which stimulates photosynthesis in low light[75]. Some understorey and ground cover plants growing in the shade may grow faster.

20.2.5 Sea level rise

Sea levels on the GBR are expected to rise gradually by 0.1 to 0.9 metres by the year 2100 (Lough chapter 2). There is also a risk of a catastrophic rise if the Greenland or West Antarctic Ice Sheets collapse[59].

The potential impacts of sea level rise on GBR islands and cays can be summarised as (adapted from Smithers et al. chapter 21):

- General short-term increase in size and number of coral cays and some sand spits with a rise in sea level up to one metre above the present level (maybe 100 years away).
- General inundation and erosion of all islands as sea level rise continues above one metre (beyond 2100) and inundation and erosion of shorelines for many continental islands beginning now.
- Elimination of most coral cays, inshore sand islands and lowland areas of continental islands if there is a catastrophic rise of several metres due to an ice sheet collapsing.

20.2.5.1 Impact 1: short-term increase in cays and sand spits

Coral cays and islands built of sand or mud are often only a few metres above sea level. Some larger sand islands have higher dunes built of windblown sand that may be stabilised by vegetation. Island shores and dunes tend to be dynamic and can adapt to some changes in land profiles[86]. Cays can migrate across reef flats under a process of accumulation of sand on one side and erosion on the opposite. Most continental islands are predominantly rock but many have sandy beaches and lowland areas of accumulated sands.

With a rise in sea level below one metre, increased wave action will mobilise offshore sources of sand or sediments to build shores and increase the size of many cays and sand spits, and create new cays (Smithers et al. chapter 21).

Short-term increase in cays and spits: flora

An increase in the number and area of cays creates opportunities for colonising plant species that can grow on alkaline sand and coral rubble. On cays that migrate across reef flats, vegetation washed away on the eroded side is replaced by pioneering species on the accumulation side. Colonisation of new cays by plants may take longer and depends on the closeness of the seed source, currents, wind direction and the movement patterns of seabirds and terrestrial birds. Sands deposited to establish new cays or enlarge existing islands will be high in salinity, promoting establishment of salt tolerant seashore plants, including both native species such as saltwater couch (*sporobolur virginicus*) and weed species such as crow's foot grass (*Eleusine indica*). Once established, weeds can invade native vegetation and cause severe impacts on native habitats.

An increase in the area of cays may enlarge the areas available to pisonia closed-forests and other woody species, increasing total area of pisonia closed-forest on islands such as the Capricorn Bunker Cays.

Short-term increase in cays and spits: fauna

An increase in the number and area of cays and spits will provide new opportunities for nesting seabirds and turtles. An expansion of woody forests on cays may increase the area of suitable habitat for tree-dependent species of fauna, including the endemic Capricorn white-eye, the pied imperial pigeon, coastal raptors and some seabirds.

Mangroves on low wooded islands and inshore sediment islands may be able to trap sediment and continue growing with an increase in sea level and island heights (Lovelock and Ellison chapter 9). Sediment infilling may provide opportunities for the establishment of rainforest species, especially if pigeons or fruit bats roost and deposit seeds and nutrients on the islands.

Short-term increase in cays and spits: freshwater wetlands

An increase in wave energy leading to an increase in berm height (highest part of beach) may help to retain water in some lowland wetlands behind beaches and dunes on sand and continental islands.

20.2.5.2 Impact 2 – inundation and erosion from gradual sea level rise

As sea level gradually rises there will be two major effects, especially at high tides and during storm surges:

i) Inundation.

ii) Erosion of shorelines.

Many continental islands will erode and inundate at even low levels of sea level rise. After a period of cay building there will be a point where offshore sediment supplies are used up and any further sea level rise will begin to erode and inundate cays.

Inundation and erosion: freshwater lenses

An increase in sea level may cause an intrusion of saltwater into the freshwater lens within coral cays or islands[18]. The saline contamination of freshwater lenses of smaller islands has already been reported from Pacific islands[60]. Lenses are impacted at their edges and therefore larger cays with a greater area of lens will be affected at a slower rate than smaller cays.

Inundation and erosion: cay flora

Some island flora can tolerate short-term inundation with brackish water but not for extended periods. Deep-rooted woody plants, such as some rainforest species, do not survive prolonged saline intrusions. Pisonia closed-forests have special physiological and morphological adaptations to withstand environmental stresses such as drought and seawater inundation and may replace rainforest species. If inundation of freshwater lenses continues, pisonia forest will eventually be replaced by more tolerant arboreal shrubs such as *Abutilon albescens* and *Argusia argentia*, and ground cover plants such as chaff flower (*Achyranthes aspera*), *Boerhavia* spp., moon flower (*Ipomoea macrantha*), stalky grass (*Lepturus repens*), pigweed (*Portulaca oleracea*) and saltwater couch (*Sporobolus virginicus*). These shrubs and grasses will take over as pisonia trees die, creating glades and open sunlit areas. These scenarios have already been observed on Tryon Island, Capricorn Bunker Group[64,10,12].

Vegetation will be lost on eroded shores. The common beach scrub trees such as droopy leaf (*Aglaia elaeagnoidea*), native persimmon (*Diospyros maritime*), native cherry (*Exocarpos latifolius*), *Manilkara kauki* and beach almonds (*Terminalia* spp.) will be displaced and have to relocate to newly formed beach ridges. In many instances these species will be replaced by salt tolerant woody plants such as octopus bush (*Argusia argentea*), coastal she-oak (*Casuarina equisetifolia*), sea trumpet (*Cordia subcordata*), *Guettarda speciosa, Pemphis acidula, Premna serratifolia,* sea lettuce tree (*Scaevola taccada*) and *Suriana maritima*. Salt tolerant seashore plants are likely to expand their range on many islands and form monospecific stands on some islands. Erosion on Heron Island in the Capricorn Bunker Group has resulted in native plants such as the hairy spinifex (*Spinifex sericeus*) no longer re-establishing on the beaches and being replaced by introduced plants such as sea rocket (*Cakile edentula*). *Cakile* also replaced the coral cay littoral margin herb *Trachymene cussonii* in the mid 1990s that formed succulent mats on the beaches along many Capricornia Cays.

According to Heatwole[49] and Batianoff and Naylor[10] vegetation on cays can become unstable due to drought, sea erosion and/or pest damage. Some cays, such as Gannet Cay, one of the Swains Cays, have lost their vegetation altogether in recent years (P O'Neill pers comm). Although this loss cannot be attributed directly to erosion caused by sea level rise, it is an example of a phenomenon that will become more frequent. Large cays with stable cores, beach or phosphate rock, established soils and large trees, such as Green Island and the Capricorn Bunker cays will be more resistant to erosion than smaller more mobile and less vegetated cays. With continuing sea level rises, exacerbated by periodic cyclones, all cays and their vegetation may eventually disappear.

Inundation and erosion: continental island flora

New dynamic shorelines on continental islands will be constantly changing as sea level rises and pioneering plants establish and in turn perish away. Vegetation behind the beaches, salt marshes and mangroves will be inundated. In mangrove areas sea level rise will cause mangrove vegetation to expand shoreward (Lovelock and Ellison chapter 9) along the inshore low islands. Salt marsh and brackish wetlands may move inland on large sand islands in the southern GBR, particularly Curtis Island.

Inundation and erosion: freshwater wetlands

As shorelines erode and low-lying areas of continental islands are inundated, freshwater wetlands will shrink, severely impacting freshwater aquatic fauna, including fish breeding cycles. Most large freshwater animals may disappear from the islands. Only stream habitats of Hinchinbrook Island and a few ephemeral streams and pools on other continental islands are likely to survive the seawater inundation of the lowland wetlands.

Inundation and erosion: fauna

The nesting habitat of birds that breed above the intertidal zone will be affected by rising sea level. As beaches are eroded away, habitat may be lost and new habitat created. Ground nesting seabirds and shorebirds, such as the beach stone-curlew, the sooty oystercatcher and the red-capped plover (*Charadrius ruficapillus*), frequently select new nesting sites each year. Sudbury Cay was a seabird breeding island until all the vegetation was lost[97]. The unvegetated Gannet Cay in the Swains Cays still supports some species of nesting birds but the numbers and species are less than when it had vegetation cover[97]. A gradual change in sea level and increased erosion will still probably create some beach conditions suitable for shore nesting birds for each breeding season.

Several island bird species will be at risk if their pisonia closed-forest habitat disappears through rising sea level inundation and erosion. On the Capricorn Bunker Cays the Capricorn white-eye will lose its major habitat, black noddies (*Anous minutus*) will no longer have pisonia branches to nest on and wedge-tailed shearwaters (*Puffinus pacificus*) will no longer have pisonia root mass to support their burrows and bare ground to walk on under pisonia trees. On Tryon Island (Capricorn Bunker Group) where pisonia closed-forest was lost through insect attack, shearwater nesting has substantially declined (P O'Neill pers comm). Black noddies can nest on other trees such as casuarina on Lady Elliott Island (B Knuckey pers comm) but their nesting success may be reduced. The more salt tolerant shrubs and grasses that colonise the areas now devoid of pisonia may provide nesting habitat for other seabird species that prefer low vegetation. However there are many islands with shrub and grass vegetation in the GBR but few with pisonia closed-forest, and black noddies and wedge-tailed shearwaters may have few other options for nesting sites[10].

Loss of littoral rainforest and beach sands through inundation will impact fruit pigeons, pied imperial pigeons and other fauna species that use these habitats. Some species will be able to find alternative habitat. Pied imperial pigeons, for example, can also roost in mangroves.

In addition to nesting sites, roosting sites are critical for shorebirds and seabirds. Birds use isolated roosting sites in intertidal areas during the rise and fall of tides and at sites above high tide during the height of the tides. Roosts may be sand spits, sand banks, salt marsh areas or beaches behind mangroves. Roosts where birds can rest safe from most predators and disturbance are very important for the energy balance of shore birds. Any loss or relocation of bird roosting sites due to rising sea level effects will mean shorebirds and seabirds move further from feeding areas, increasing the energy expended by the birds to access food. The option to move to other roosting sites can be compromised in areas densely settled by humans, as the birds require roosting sites with little or no disturbance.

The eventual loss of most coral cays after the initial general increase will have devastating impacts on seabirds and shore birds. There are no nearby continental islands to provide potential alternative nesting sites for birds currently breeding on remote coral cays such as Raine Island, the Swains Cays and the Capricorn Bunker Group. Some seabirds, such as the bridled tern, are able to nest on forested continental islands but the vegetated slopes of most continental islands are not suitable for most seabirds and shorebirds.

Rising sea level will erode away Bramble Cay causing extinction of the Bramble Cay melomys as it is not found elsewhere[73].

The coastal plains habitat of the Dawson yellow chat will be inundated and the landward progression of salt marsh habitat is possible. The impact on the Dawson yellow chat is highly dependent on the future of coastal plains habitat, but as the species is in such low numbers, minor impacts will have catastrophic effects on the species.

The impact of rising sea levels on turtles is discussed in Hamann et al. (chapter 15). Turtles dig up cubic metres of sand when they nest, often churning up vegetation at the top of beaches and creating bare ground favourable for plant colonisation. On very active nesting beaches such as Raine Island no plants can establish during the summer nesting season as the entire area is turned over frequently[47,10]. If the nesting turtle population decreases the foreshores of many islands will be less dynamic and the plant community may shift away from pioneering species to plants favoured by stable soil.

Inundation and erosion: intertidal mudflats

Intertidal mudflats are important habitats for a range of invertebrates, and as feeding areas for fish at high tide and for shorebirds at low tide. Sea level change is likely to be an important influence on intertidal habitats. Resident shorebirds that breed on GBR Islands, in particular beach stone-curlews, are at risk if key mudflats are inundated. Migratory shorebirds are also at risk (see section 20.4.1).

Inundation and erosion: rocky intertidal

Intertidal rocky reef communities are highly dependent on tides to provide moisture, food and oxygen. Plants and animals are distributed on the rocks depending on their ability to survive the periods they are covered by sea water or exposed to the air. Some species such as many molluscs and echinoderms are mobile while others including algae, barnacles and oysters are fixed on the rocks[34]. Rocky intertidal communities are accustomed to living in a dynamic environment. Sea level rise will affect species fixed to the rocks as some individuals at the lower end of their distribution will be disadvantaged and will be swamped. Individuals on the landward side may be advantaged, and colonies of organisms will migrate up the rocks. Individuals of mobile species will be able to move landward if there is suitable similar substrate landward. Species in intertidal rock pools have less capacity to adapt as the formation of rock pools is a long-term process too slow for the predicted rate of sea level rise.

20.2.5.3 Impact 3 – elimination of low islands by a catastrophic sea level rise

A dangerous climate change event would occur if either the West Antarctica or Greenland Ice Sheets collapsed[92] (Lough chapter 2). The risk of this occurring has not been quantified but if the Greenland Ice Sheet was eliminated the sea level worldwide would quickly rise approximately seven metres[59].

A sudden inundation of several metres will eliminate all coral cays, inshore sand and mud islands and beaches, and lowland areas of continental islands. The impacts on the flora and fauna described in the section above will occur but much faster and with very little capacity for adjustment. Nesting and roosting sites of most GBR seabirds, shorebirds and turtles will be destroyed and intertidal feeding sites submerged.

If sea level eventually stabilises, new beaches will form on continental islands providing nesting habitat for birds and turtles that have survived.

20.2.6 Physical disturbances – tropical storms

Winds and waves of tropical storms can severely impact island habitats. Tropical cyclones are predicted to increase in magnitude, but it is not certain if frequency will change (Lough chapter 2). This section discusses the effects of waves and winds. The impact of heavy rainfall events will be discussed in section 20.2.7.

20.2.6.1 Impact 1 – storm waves

With the prediction of increased extreme events such as cyclones and storm surges, some GBR low islands will be subjected to periodic floodwater and/or inundation by saltwater. Storm waves can erode shorelines but can also build shorelines if they come from certain directions and sources of sand or rubble are available. Cays have been known to 'move' during storm events as sand is eroded from one side and deposited on another. Storms also threaten to inundate and contaminate freshwater lenses[5].

Storm waves: flora

Waves can physically damage vegetation, particularly during storm events when waves often carry sand and rubble. Hardy shoreline species, such as *Scaevola taccada* and *Argusia argentea*, succulent herbs, and grasses can be advantaged by storm events over more fragile species. The loss of salt sensitive trees and shrubs, especially rainforest species, will limit canopy biodiversity of many coral cays, particularly in the northern region. However some salt tolerant woody plants such as *Argusia argentea, Casuarina equisetifolia, Cordia subcordata, Guettarda speciosa, Pemphis acidula, Premna serratifolia, Scaevola taccada* and *Suriana maritima*; may expand their range and on some GBR islands. Short-term inundation will have little or no affect on pisonia closed-forests.

Sand formations on continental islands are vulnerable to storm waves, particularly sand spits and barriers, which are often unstable and change shape and size naturally. Vegetation growing on these formations is therefore at risk from storm waves. The unusual dune vegetation growing on a ten kilometre long and narrow dune barrier at Hinchinbrook Island is one site at risk (R Cumming pers comm). The dune barrier separates an ocean beach from the extensive mangroves in the sheltered waters of Missionary Bay. Wave impacts during a cyclone could cut through the barrier, especially at its lowest point. Ocean waves could quickly open up a channel causing extensive damage to the dune vegetation. If the channel persists, there may be major negative impacts to the mangrove forests of Missionary Bay. Similar vegetation types at risk from storm waves in the GBR include dune flora at Whitehaven Beach on Whitsunday Island, and on the sand islands in the southern GBR, such as Curtis and Facing Islands.

Wave damage may create open bare ground providing new opportunities for pioneering native plants and invasive weed species.

Storm waves: fauna

Ground nesting seabirds and shorebirds are at risk from tropical storms. Waves can drown or smother eggs and young or destroy vegetation and nests. In 1999 a cyclone completely buried most nests of breeding terns on Michaelmas Cay and one episode of seabird breeding was completely destroyed (M Short pers comm). Eighty per cent of the vegetation was buried with most covered by 20 centimetres of sand. After the storm, vegetation slowly grew through the sand or sprouted from seed and many adult birds came back to re-nest on top of the deposited sediments. Within 11 days, 72 percent of adults had returned and were re-nesting. The island was replenished at a higher level but at the cost of a breeding event. De'ath[30] analysed the effect of four cyclones at Michaelmas Cay and determined that long-term average breeding effort was not significantly impacted by these storms. However with cyclones predicted to increase in intensity with climate change, the impact on sand movement, vegetation loss and bird breeding success is likely to increase.

Other fauna impacted by storm waves include turtles whose nests can be eroded or buried during storm events and the Bramble Cay melomys. A severe cyclone may destroy all the vegetation of Bramble Cay, the entire habitat of the Bramble Cay melomys.

20.2.6.2 Impact 2 – storm winds

Storm winds: flora

Increased severity of cyclones means higher wind speeds and greater damage to vegetation. This was observed during the 2006 category five Cyclone Larry that impacted Dunk Island, the Frankland Islands and the Barnard Islands (G Redenbach pers comm) in the northern GBR. Trees, especially taller specimens, were stripped of leaves and branches and the forest floor was littered with broken plants. Melaleucas in wetlands may topple, snap trunks or drop branches during windy storms. Plant debris from storm winds can dry out and increase the risk of hot fires burning in vegetation such as rainforest and melaleuca swamps that do not normally carry fire.

Recovery of forests from buds or seed can occur but it can take many decades to replace large trees. Higher frequency of storm winds may prevent re-establishment of taller forests. On coral cays, pisonia forests are adapted to shed branches during storms. The fallen trees and/or branches sprout and revegetate the damaged forest areas.

Storm winds: fauna

Many birds, mammals, reptiles and invertebrates are killed during cyclones such as Cyclone Larry, but many find shelter and survive (QPWS field staff pers comm). Food may be scarce after a cyclone, particularly for fruit eating fauna. Mobile species, such as fruit bats and birds, can leave islands to seek unaffected forests. Possums, wallabies and rodents are more vulnerable as they cannot leave affected islands. Some tree species, such as figs (*Ficus* spp.) and beach almonds (*Terminalia* spp.), recover and fruit quickly, providing food for the fauna that remain.

Storm winds can impact birds nesting in tree branches, to the point of blowing eggs and chicks out of nests. Damage to trees may affect future nesting opportunities with birds settling for less optimal conditions that may in turn lower the number of successfully fledged chicks. A severe cyclone in the Capricorn Bunker group may adversely impact part or all the habitat of the Capricorn white-eye. Decreases in rainforest species will impact on fruit pigeons and other fauna that rely on rainforests for food and shelter. Pied imperial pigeons may move to mangrove forests to nest and roost if favoured rainforest is impacted.

20.2.7 Rainfall and river flood plumes

Rainfall is a critical factor in island ecology and any change will impact directly on island flora and faunal species richness. Rainfall provides water to plant roots near the soil surface and replenishes sub surface reservoirs, including the freshwater lens of coral cays and ground water on continental islands. Plant distribution is determined by a number of factors, including temperature and soil, but moisture availability is a key factor[107,108].

Rainfall predictions under climate change for the GBR are not certain. More intensive ENSO events may have an effect on rainfall. Rainfall may increase in some places and decrease in others. Most likely there will be more intense rainfall events with longer periods of low rainfall or drought in between (Lough chapter 2). Without certainty on rainfall we have examined two scenarios:

i) Generally drier conditions caused by a decrease in the average rainfall or longer periods of drought

ii) Generally wetter conditions due to an increase in average rainfall or episodes of flooding rains

20.2.7.1 Impact 1 – drier conditions

Many of the effects of drier conditions are similar to or compound the effects of increased air temperature discussed in 20.2.2.1.

Drier conditions: flora

Without considering other factors, a decrease in average rainfall or decreased frequency of rainfall events will increase water stress in many plants. These plants would have reduced growth and lose leaves. Species susceptible to water stress would not compete successfully with species that have access to permanent water tables, water lenses or have water storage systems (succulent leaves, root storages). This will lead to changes in the distribution of plant species, and the composition of vegetation communities and their fauna.

As discussed in section 20.2.3.1, an increase in CO_2 improves the efficiency of plant metabolism so plants require less water. This may help plants compensate for lower rainfall conditions. However, improved efficiency requires adequate availability of nutrients, which are generally lacking on some continental islands and cays of the GBR, except those with many nesting bird colonies.

With a decrease in average rainfall, freshwater lenses are likely to shrink and contract from the outer edges of islands to be replaced with brackish water. Drought on North Tarawa atolls in the central Pacific caused freshwater wells to become saline progressively from the shore towards the centre of the island (M Turner pers obs). Salt tolerant species such as *Argusia Pemphis* and *Scaevola* are advantaged progressively as the freshwater lens shrinks.

One of the harshest environments for plants in the GBR is cays that are too small to have a freshwater lens (islands less than about 60 metres diameter). Plants rely on rain for water as the sand has little moisture-holding capacity and saltwater permeates through the sandy base of the cay. Only grasses and low shrubs are able to grow on these cays. Although the vegetation on such cays is very hardy, a decreased frequency of rainfall is likely to lead to its decline.

Drier conditions: rainforest

Leaving aside the effect of increased CO_2, the effect of decreased rainfall on rainforest patches on GBR islands would be increased water stress. According to Kleidon and Lorenz[69] under these drier conditions forest structures may change, with greater selection for deeper rooting or deciduous species. Evergreen species would then be replaced with more deciduous or structurally shorter 'dry rainforest' species or sclerophyll species such as eucalypts, casuarinas and acacias. Island rainforests with access to more permanent water sources, such as a freshwater lens, permanent underground water, stream courses or wetlands, will be more resilient to decreased rainfall. Although, without sufficient rains, these underground sources may not be adequately replenished.

Moisture provided by low cloud cover is an important source of water for plants on the mountains of the Wet Tropics, particularly in the dry season. Climate modelling has predicted that with a doubling of CO_2 the cloud base will be shifted upwards by several hundred metres on tropical mountains[52]. Plant species of mountain top rainforest and montane heath have little ability to extend their ranges and will die out. They include orchids, such as the oak orchid (*Dendrobium jonesii*) that grows in the clouds on top of Mount Cook on Magnetic Island and several species which grow in rainforest pockets above 700 metres in altitude on the mountains of Hinchinbrook Island: *Bulbophyllum shepherdii, B. baileyi, B. johnsonii, B. lilianae, B. macphersonii, Dendrobium adae, D. jonesii,* and wedge tip yellow rock orchid (*Liparis angustilabris*) (W Lavarack pers comm). Temperature increases will compound the loss of mountain top species (see section 20.2.2.1).

Drier conditions: grasslands

Grasslands thrive in conditions of fire and adequate water. According to Bond and Midgley[15] woody resprouters stimulated by elevated CO_2 and fire may fundamentally replace herbaceous grassland communities. On GBR continental islands monospecific stands of acacias and other fire resistant woody species are common. We speculate that C_3 woody plants may invade and potentially replace many of our current grasslands under fire regimes that favour woody plants, particularly some of the eucalypts and acacias that have lignotubers and/or epicormic buds. However, during prolonged droughts all woody plants are susceptible to dieback, with dead branches creating a greater fuel load, causing hot fires to be hotter and favouring grasslands to replace shrubs.

Drier conditions: freshwater wetlands

Lower average rainfall will adversely affect freshwater wetlands. Many wetlands on islands are small and ephemeral and it would only take a small decrease in water input to compromise their viability. Less water means ephemeral wetlands will dry for longer periods. This will be exacerbated by an increase in evaporation due to increased air temperature. Aquatic freshwater invertebrates, frogs and fish may not have sufficient water or time to complete their seasonal aquatic breeding cycles in ephemeral wetlands. Of particular interest is the possible impact on the big-clawed shrimp (*Macrobrachium rosenbergi*) that inhabits sub-surface ephemeral streams above the northern beaches of Magnetic Island (D Savage pers comm). A drought event on Magnetic Island illustrated the plight of brackish water fauna. An open pool was isolated from the sea and dried out. In this case, trapped fish were netted by Queensland Parks and Wildlife Service and re-located to a safer site (M Turner pers obs). Although drying events are natural, their frequency and magnitude is likely to increase with less rainfall or longer droughts.

With lower average rainfall, larger freshwater wetlands may shrink, leading to a succession of vegetation from wetland to terrestrial species. Open water and wetland vegetation will be replaced by melaleuca trees, which will be replaced by rainforest gallery vegetation, which in turn will be replaced by eucalypts and wattles.

Most streams on GBR islands and cays are seasonal. With decreases in rainfall amount and frequency, permanent streams on Hinchinbrook Island are likely to have a reduced water volume. This may result in more stagnation in pools, in turn affecting stream invertebrates, frogs and fish. Jungle perch and other freshwater fish will have less habitat and food, compromising the ability of island habitats to maintain viable populations of freshwater fish.

Wetland birds on GBR islands are likely to disperse to mainland sites as island wetlands shrink. Waterbird visitors to GBR islands face many other climate change impacts whilst at mainland sites[89].

Drier conditions: fire

A general drying of the vegetation from less rainfall and/or droughts will lead to greater fire risk on GBR islands and cays and a shift to fire tolerant species. Many small islands have a limited range of plant species. Their capacity to alter species composition in response to a decrease in water and an increase in fire may be limited. Wetlands, especially on their fringes, are also more susceptible to the increased fire risk due to the drying of foliage.

Drier conditions: weeds

Declines in the vigour of native plants due to water stress may make them more vulnerable to invasion by weeds that are able to flourish under dry conditions. An increase in fire frequency or severity will also expose bare ground enabling weed establishment and competition with the established native vegetation. This effect may occur on cays and within wetlands, rainforests and sclerophyll woodlands on GBR islands.

One of the greatest risks of weed infestation is in areas of good quality soil currently supporting melaleuca forests or rainforest. If trees are lost to water stress, the extra light and bare soil will allow exotic tropical grass species to establish, as has occurred on Brampton Island (Cumberland Group) and Lindeman Island Whitsunday Group (G Batianoff pers obs). Although not linked to climate change, an example of how weeds can establish on GBR islands if the woody plants are lost is Lady Elliot Island. Humans cleared the plants in this case. At least 40 percent of the island is affected by introduced weedy flora species, including lantana (*Lantana camara*) and *Bryophyllum delagoense*[6], which out-competed coral cayendemic plants such as Trachy and that are unique to the area.

Drier conditions: fauna

Changes to the moisture content of plants and the species composition and structure of vegetation due to decreased rainfall will have major implications for fauna dependent on vegetation for food and shelter. Rainforest and wetland species will be particularly disadvantaged as their habitat is at greatest risk. Fruit-eating birds and fruit bats will have a reduced food source, particularly since edible fruit suitable for larger animals is already a scarce resource on islands.

The loss of melaleuca trees from wetland areas will disadvantage the large diversity of insects, bats, lorikeets and honeyeaters that feed on nectar and pollen, and the birds and microbats that feed on the insects attracted to the flowers. The rare rusty monitor (*Varanus semiremex*) of the melaleuca wetlands of Magnetic Island is unlikely to have migration options if its habitat is destroyed, and therefore it may become extinct in the GBR.

Changes in vegetation due to decreased rainfall will affect many invertebrate species including butterflies, such as the endemic Whitsunday azure butterfly. The large number of butterflies that use gullies shaded by rainforest tree species as dry season roosts on continental islands will be impacted as increased water stress causes leaf drop in their favoured trees, and there is a vegetation succession to less shady sclerophyll trees.

A decrease in moisture content in leaves may compromise survival of browsing mammals such as possums and wallabies, especially if heat stress from rising temperatures affects them. An increased fire risk may also disadvantage them. Many animals, such as the unadorned rock-wallaby (*Petrogale inornata*) on Magnetic Island, cannot migrate to other islands as vegetation changes. The endangered Proserpine rock-wallaby confined to Gloucester Island, Hayman Island (Whitsunday Group) and a restricted area of the nearby mainland, is at increased extinction risk if there are changes to its vine thicket and beach scrub habitat[87].

Periods of dry conditions do not generally favour soil or herbivorous invertebrates. In rainforests, insect biomass declines during dry periods[42]. If there are longer dry periods, or if ground clouds decrease, there will be fewer soil and leaf litter microbes and invertebrates. Carnivorous fauna feeding in the leaf litter such as skinks, birds and mammals will be adversely affected[120].

Longer dry seasons will also probably affect the life cycle of fruiting plants and decrease the yield of fruit[120]. Fruit eaters including insects, birds and mammals would be adversely affected. This in turn could affect seed dispersal and plant recruitment processes[120].

Although many changes in vegetation due to dry conditions will adversely affect certain fauna species, some species will be favoured. Animals that are more tolerant of water stress and drier habitats will out-compete species with higher water requirements for themselves or their habitat.

20.2.7.2 Impact 2 – wetter conditions: increase in average rainfall and/or flood events

Wetter conditions: flora

An increase in rainfall, CO_2 and temperature will favour some species of plants and some vegetation types. Rainforest will be supported if rainfall is over 1500 mm, such as on a few inshore continental islands along the wet tropical coast. If average rainfall increases, rainforests may expand into surrounding drier sclerophyll forests. Encroachment of pioneer rainforest species such as rusty pittosporum (*Pittosporum ferrugineum*) onto grasslands may occur, shading out grasses and creating conditions more suitable for rainforest species. Increased rainfall may promote less flammable vegetation and lessen fire risk. On cays, pisonia can tolerate full water lenses and waterlogged conditions better than other woody competitors. Fire and lenses are also discussed in section 20.3.1.

Wetter conditions: freshwater wetlands

Wetlands will also be favoured by an increase in average rainfall. Higher rainfall may compensate for increased evaporation caused by higher air temperature. If total rainfall exceeds evaporation, wetlands may increase in size, but there is little room on islands for such an expansion. Soil waterlogging and wetland overflows will have little negative impact on the wetlands of GBR islands. Many wetland fauna species will take advantage of full wetlands for reproduction. Changes in wetlands may provide opportunities for some common invasive wetland weed species such as para grass *Urochloa mutica*.

Wetter conditions: erosion and rainfall runoff

An increase in heavy rainfall events will lead to greater surface runoff, sheet erosion and gully erosion. Erosion gullies will expand and sheet erosion may occur on flatter ground. Waterlogged soils will produce more landslips on steep continental islands, a common occurrence on rocky islands with poorly consolidated shallow soils such as Magnetic Island (M Turner pers obs).

Increased runoff from mainland rivers will have little direct impact on most islands although there may be some build-up of sediments on inshore sand and mud islands. Increased runoff may impact reef-building organisms with indirect impacts on the availability of sediments for island building. River runoff can carry individual animals to islands, such as the individual python (Boidae) reported from one island. The arrival of shingle animals on islands, and even enough individuals to begin a population, is more likely if floods increase in frequency or size.

An increase in heavy rainfall events and floods will carry more seeds out to sea from the mainland and inshore islands, therefore increasing the amount of drift seed carried by currents to islands of the GBR[105]. For example, a flood event was observed to deposit large amounts of seed on Raine Island[47]. Seeds and any sprouting plants in the supra-littoral zone on Raine Island are churned over by nesting turtles, preventing colonisation[11]. Despite these limitations seeds do strike on many islands and new specie may persist if conditions are suitable. There is high turnover of plant species on GBR coral cays with frequent colonisation and extinctions[49].

20.3 Interactions and linkages between stressors

20.3.1 Interactions

The combined effect of multiple climate change factors may produce a range of possible outcomes on the various island habitats of the GBR. Impacts of changes to one or more climate variable can cause flow-on effects throughout island habitats. Particularly strong interactions will be discussed and other linkages listed.

Interactions: fire

Increased fire risk includes an increase in the likelihood of a fire starting and spreading, and an increase in the intensity and size of fires. Fire risk in many island habitats will increase due to higher temperatures[119], a shift to more sclerophyll vegetation and possibly more droughts. A decrease in average rainfall and increased cyclone damage will also increase fire risk.

More frequent and severe fires will favour fire tolerant open-forest species such as eucalypts and acacias over rainforest and wetland species. Eucalypt and acacia communities in turn promote more frequent fires, reinforcing fire effects. Pioneer native species such as casuarinas (*Allocasuarina littoralis*) will colonise ash beds after fire on Keswick Island (Cumberland Group), and Hook Island (Whitsunday Group). *Xanthorrhoea* spp. will be favoured on the Newry Islands and Percy Isles. Grasslands and/or woody vegetation that are favoured by fire and other climatic events are likely to sporadically expand. If higher rainfall episodes are interspersed with droughts the increased growth will dry, creating a greater standing fuel load.

Interactions: freshwater lenses

A rise in sea level and lower rainfall will cause the fresh water lenser of cays to shrink. Larger cays will be affected at a slower rate than smaller cays as the lenses are more affected at the edges of islands where saltwater intrudes to replace the shrinking lens. If the average rainfall increases, or heavy rain events are more frequent, the lenses will replenish. Lens changes will affect flora, especially at the islands' margins.

Interactions: weeds

Weeds compete with native pioneering vegetation on disturbed ground and can spread into established native vegetation impacting dependant fauna. Increases in number and biomass of weed species are likely with climate change induced effects[32]. Weeds will prosper due to more bare ground exposed by dynamic shorelines, increases in fire frequency or severity, drying of wetlands, and erosion and vegetation damage from storms[55]. Weed invasions of native vegetation will also be enhanced if higher temperature, less rainfall and increases in plant pests stress the current flora. C_3 weeds in particular will be favoured more than C_4 natives or weeds.

Interactions: effects of birds on plants

At seabird and pied imperial pigeon nesting colonies, large amounts of soil nutrients are supplied from bird guano, regurgitated food whilst feeding chicks, dead eggs and chicks and occasional dead adult birds killed by disease or misadventure[2]. Some plant species can tolerate or thrive in high nutrient soils. For example, pisonia can utilise nitrogen gained via thin threads of fungal mycorrhizas attached to their roots[103]. Pisonia are favoured over species that cannot tolerate or take advantage of nitrogen rich soil[110]. Climate induced decreases in seabird or pigeon numbers may provide greater opportunity for plants better adapted to lower nutrient levels to out-compete pisonia and others favoured by nutrients. Seabirds also deposit phosphates in their excretions that dissolve in the soil and redeposit as phosphorous rock at about 30 cm depth. The rock helps stabilise the islands and is particularly obvious on Raine Island. This process takes many years so changes due to a decline in seabirds will take decades.

20.3.2 Other linkages

Additional linkages between factors that affect island habitats include:

- Increased air temperature, lower rainfall and increased CO_2 will affect water stress in island flora and fauna
- Atmospheric CO_2 levels, UV light, moisture and nutrient levels will affect photosynthesis and plant growth
- Decreased and/or increased rainfall, rising sea level and higher temperature will combine to impact freshwater wetlands
- Rising sea level and more intense cyclones may build more cays in the short term and/or erode many continental islands
- Changes to either the structure or species composition of island vegetation will greatly impact island fauna
- Productivity changes in foliage, flower and seed production will affect island faunal food chains
- Climate change impacts in other habitats and locations in the world will impact migratory fauna to the GBR
- Changes to water chemistry, water temperature, and rainfall runoff that disrupt calcium-accumulating organisms will impact island formation

20.3.3 Constraints to adaptation

The key constraints to adaptation to climate change for most island flora and fauna are probably similar to constraints for mainland species, with some variations for island conditions. A changing environment impacts on both the phenology, which is the way individuals grow and change, and the genetics, which is the way a population of flora or fauna changes its characteristics[101]. Adaptation to a changing climate can take place in three ways:

i) Phenotype adaptation – individuals changing to accommodate a changed environment

ii) Genetic adaptation – a change in the genetic diversity of the population

iii) Migration to more suitable conditions (avoidance/escape)

Phenotype adaptation

Much of the flora and fauna that colonise newly formed sand or mud islands are opportunistic and have the capacity to survive and adapt to changing environmental circumstances. They often exhibit phenotype plasticity, which is the ability of an organism to express different phenotypes depending on its environment[1,43]. Their genes contain flexibility to allow for physical or behavioural change of individuals. Animals of this type are generalists and are more likely to alter lifestyles and food items to survive, than species with specialised habitat requirements or food items[125]. Phenology is the most responsive aspect of nature to climate change and the simplest to observe[106]. Climate change has already had significant impacts on both plant and animal phenologies in temperate regions, particularly the timing of life cycles induced by temperature[102]. Temperature effects on timing of life cycle are not as obvious in tropical areas because temperatures do not fluctuate as widely between seasons.

Remnant flora and fauna on continental islands were isolated when the islands were cut off from the mainland by rising sea level after the last ice age. Many are unlikely to have the same level of plasticity to adjust to a changing climate as pioneering species on cays and sand islands. There are limits to the adaptability of all individuals and this will vary from species to species. Small islands, with limited area and habitats offer little flexibility for species to change their lifestyles. Eventually the capacity of individuals to adapt runs out and only evolutionary genetic change will allow the survival of a species.

Genetic adaptation

Genetic adaptation alters some of the characteristics of a population. Individuals who are better adapted to a changing environment will survive and pass on those characteristics to the next generation. The plasticity of a genotype determines how wide a range of genetic variation is in a population[101]. The greater the range of genetic options the more likely a species can adapt. An example of rapid evolutionary change to a climate fluctuation is the annual plant *Brassica rapa*[41]. An abbreviated growing season caused by drought led to the evolution of an earlier onset of flowering in just a few generations . A genetic shift of photoperiodic response by a short generation mosquito showed a detectable adaptive evolutionary (genetic) response over just five years[17]. Species with large population sizes and short generation times are more likely to adapt than species, such as most vertebrates and trees, which have longer generation times. The ability of a species to keep adapting to a changing environment has limits, which will vary with the species. For example a study of the Australian tropical rainforest fly (*Drosophila bircha*) showed that there is variation across the population to resist desiccation. After intense selection for 30 generations, the fly lacked the ability to evolve further resistance[56]. The population is now at the edge of its ability for genetic evolution to change, in this case, to the potential climate change of increased dryness.

For island species, flexibility or plasticity is an advantage when the environment changes. The change could be either by the island changing or the species colonising a new island. For birds, foraging flexibility is the primary variable affecting success of colonisation[21]. Plasticity for phenotype may assist genetic evolutionary change to a better-adapted species for the new environment[96,39]. For example, a change in behaviour by an animal may favour selection for another feature of the animal, such as beak size. However, climate change impacts that decrease the population size of isolated flora and fauna species may result in decreased genetic diversity within the population. This may make them less able to adapt to the stresses of climate change[123].

Migration of flora and fauna to more suitable conditions

Many islands have a limited climate range or diversity of habitat and there is little capacity to move or migrate to another habitat on an island. There are few options for flora to migrate between islands especially if they do not have long distance dispersal mechanisms. Many of the plants and animals, including freshwater species, that were marooned on continental islands when sea level rose since the last ice age cannot disperse long distances over water and will die out as the climate changes. As islands change and some species disappear new opportunities for pioneering species may arise. The capacity for propagules to reach new island sites is always a constraint on islands. Colonisation capacity depends on the location of suitable source material of seeds and other propagules, distance from land, ocean and tidal currents and weather patterns. The number of species at risk on continental islands is greater than the number of available long distance colonisers and so the biodiversity of flora and fauna on continental islands will decrease. As sea level rises above one metre and cays and low islands disappear, the distances between the remaining islands and to the mainland will increase, making colonisation even more difficult.

Fauna will move depending on their sensitivity to climate change, their mobility, life span and availability of key needs[102]. Any emigrating fauna might face the challenges of finding enough food, avoiding new predators, finding new breeding sites, and new courtship requirements[125]. Even if new habitat was available, the ability for many fauna to migrate across water is limited.

20.4 Summary and recommendations

20.4.1 Summary of key vulnerabilities

Key flora and fauna at most risk from climate change are discussed below.

Vulnerability of continental island vegetation

Increases in air temperature causing greater evaporation, if combined with a decrease in average rainfall and increased periods of drought, and a higher fire risk, will result in a general shift in vegetation from rainforest and wetland vegetation to more sclerophyll shrubs and trees. Water stress will be moderated through the increasing concentration of atmospheric CO_2 improving the efficiency of photosynthesis. However, this is only likely on islands with adequate nutrients such as bird breeding islands, or with nitrogen fixing plants, and where temperature is not hindering metabolic processes. Weeds, pests and diseases are likely to have greater impacts on stressed and changing vegetation. Continental vegetation is likely to be less diverse and be more sclerophyllous. The most important factor affecting the uncertain future of rainforest patches on GBR islands is the amount of rainfall.

Vulnerability of island flora biodiversity

The impact of multiple factors may favour some flora and fauna species and disadvantage others. Conditions on islands may become suitable for new species as they become unsuitable for others. Some remnant flora species on continental islands are unlikely to have as much plasticity as pioneering cay foreshore plants and may not adapt to the changing environment. Remnant vegetation on Hinchinbrook Island peaks will disappear. Colonisation of new species onto islands is slow, slower than the expected rates of species loss from islands. Biodiversity of the island is likely to decrease as losses of species outweigh recruitment of new species.

Vulnerability of rainforests and montane heathlands

Rainforests and montane heathlands will be reduced by warmer, drier conditions, particularly if the average rainfall decreases, or rain events become more infrequent. Increased fire risk, greater cyclone damage, decreases in nutrients brought by pigeons and other frugivores, less pollinators and seed dispersers and increased pest risk will affect rainforest habitats. Rainforests are likely to decrease in area on GBR Islands. Conversely, if rainfall increases, some lowland mesophyll rainforest may expand. Shaded understorey plants may increase their photosynthesis and biomass with higher atmospheric CO_2.

Vulnerability of grasslands

Grasses are favoured by drier conditions and increased fire risk over herbaceous species. However, an increase in photosynthetic efficiency by C_3 shrubs with higher CO_2 concentrations in the air may cause them to out compete and expand into some of the C_4 grasslands. Other climate-induced effects on grassland include increased weed and insect pest risks. The future for island grasslands is uncertain with increases or decreases possible and fire management remaining a critical issue.

Vulnerability of foreshore vegetation

Most foreshore flora species are pioneers and show plasticity to adapt to changing conditions. They will adapt as sea level rises and storms alter shorelines. Beach and seashore vegetation on continental islands will be relocated further inland. The rise in salinity of soil in the newly formed coastlines will promote salt tolerant seashore plants at the expense of current established plant species. Dynamic shorelines are vulnerable to weed infestation that may out-compete native vegetation.

Vulnerability of cay vegetation

On large cays, larger trees depend on the freshwater lenses. Decreases in rainfall or increased evaporation rates will affect the freshwater lenses, which will affect the growth of trees.

Pisonia forests are tolerant of temporary saltwater and freshwater inundations. Cay vegetation will be more vulnerable to pest impacts as temperature increases improve the metabolic rate of pests. If seabirds decline the subsequent nutrient loss will disadvantage pisonia trees. Reduced turtle nesting will make the shoreline less dynamic. Cay vegetation is likely to adapt to changes with an altered species composition, until cays are lost completely in the long term high sea level rises.

Vulnerability of freshwater wetlands

Most wetlands on continental islands will be greatly affected by a combination of higher evaporation due to increases in temperature, inundation from a rise in sea level, decreases in rainfall (if this happens), an increase in the number or length of droughts and increased fire risk. If average rainfall increases and there are not also prolonged dry periods, wetlands will be enhanced. Overall a net loss of wetlands is predicted in the short term and a severe loss in the long term when lowland areas of continental islands are inundated. The only wetlands that will persist will be the mostly ephemeral streams on slopes and perched swamps on hills on a few islands.

Vulnerability of island fauna

Terrestrial fauna species are highly dependent on the condition of their habitat and as vegetation alters the fauna must adapt, move or perish. Foliage feeders such as possums, koalas, rock wallabies and insects will be disadvantaged by the decrease in the food quality of leaves due to increased CO_2 in the air altering the carbon and nitrogen balance in the leaves. An increase in sclerophyllous vegetation, due to increased water stress from higher temperature and lower rainfall, will disadvantage some plant eaters and advantage others. If rainfall decreases or becomes less frequent, drier conditions will lower the productivity of the leaf litter. Fauna that depend on invertebrates on the ground or in trees will find less food. A decrease in plant food quality and availability will affect eaters of nectar, pollen, fruit, and seed. The impact will continue up the food chain to insectivores and carnivores. Fauna can migrate, adapt or die-out. With many island fauna species unable to migrate between islands, adaptation is the only option for survival. Many animals are likely to decrease in abundance. A relative few fauna species will be advantaged by changes to island habitats.

Vulnerability of island fauna biodiversity

Impacts on terrestrial fauna depend on the faunal species ability to migrate to suitable habitat elsewhere, their ability to move to find new habitat or are tied to their plasticity to survive or adapt to an altered environment. Wetland and rainforest species are particularly vulnerable as their limited island habitats at risk. Endemic and rare species at risk include: the Capricorn white-eye which favours pisonia forests, the Bramble cay melomys as it only lives on one small island[73], the Proserpine rock-wallaby as it favours a limited vegetation type including beach scrub on Gloucester Island[87], the Whitsundays azure butterfly as it depends on food plants on Whitsunday Islands[113], and the Dawson yellow chat as it is confined to coastal saline plains[44]. All these species are likely to decline or disappear. Fauna on islands are likely to show a decline in species biodiversity similar to flora.

Vulnerability of seabird and shorebird nesting

Increases in sea surface temperature, changes in ocean currents and ENSO events can decrease food availability for seabirds and lower their breeding success (Congdon et al. chapter 14). For many seabirds the impact of decreased food availability will be far more significant than short-term changes to nesting habitat[8,33].

In the short term, as sea level rises new cays may be created and small ones increase in size. Increased wave action and greater cyclone strength will probably make cays, sandy beaches and spits more dynamic. Beaches may be new or altered but they will provide seabirds with places to nest. Many seabirds return to nest on familiar beaches but if those sites no longer exist, seabirds have some capacity to find alternative sites, including on other islands if they are available. Potential new seabird breeding sites must have sufficient food within foraging range to support breeding and not be already occupied. Ground nesting shorebirds and seabirds that nest on bare ground close to the intertidal mark such as the black-naped tern (*Sterna sumatrana*) and little tern are adapted to nesting in dynamic landscapes and frequently select new sites each year[97].

Some seabird species, such as the brown booby (*Sula leucogaster*), show strong nesting site fidelity[90]. If nesting becomes unsuitable on one island they will move to nearby islands for nesting but the potential for moving to distant islands if an island group such as the Swains Cays disappears is much less certain.

In the longer term most cays and low sandy islands are expected to disappear, reducing nesting options for seabirds and forcing them to the higher ground of continental islands and the predator-inhabited mainland. Some seabird species, such as the bridled tern (*Sterna Anaethetus*), will be able to nest among rocks and vegetation on continental islands. Birds preferring open ground may struggle to find sites. Eventually there will be a loss of breeding islands close enough to feeding grounds with sufficient food to raise chicks. The population of breeding seabirds on the GBR is likely to decrease when the Swains Cays, Capricorn Bunker Group and Far Northern Cays disappear.

Several species of seabird will be impacted if woody island vegetation is altered; including black noddies that nest on tree branches, red-footed boobies that nest on shrubs and wedge-tailed shearwaters that use the pisonia forest roots to support nesting burrows. Even changes to island fauna can affect coastal birds. Rufous night herons (*Nycticorax caledonicus*), that time their nesting on Raine Island to feed on turtle hatchlings[8], will be affected if climate change affects turtle breeding success.

Vulnerability of migratory birds

Migratory animals are particularly vulnerable to climate change as they rely on multiple habitats and time their arrival and departure from locations to coincide with food availability and suitable weather. Assessments of migratory birds in Europe and North America predict serious declines as a result of even small changes in temperature[125]. Changes have been observed in Australian birds including species expanding their ranges southward and altering timings of migration patterns[23].

Migratory birds that time their migration to coincide breeding with the time when most food is available are more at risk than resident birds. Migrations may get out of synchronisation with peak food availability[22]. A reduction and/or loss of low islands, such as inshore sand islands and coral cays and their surrounding intertidal mud or sand flats could reduce the survival of migratory shorebird species. Many shorebirds of the GBR breed in the Arctic regions of northern Asia during the northern summer and migrate to feed on the intertidal mudflats of the GBR for the southern summer, or pass through as migrants. The eastern curlew, red knot (*Calidris canutus*), and bar-tailed godwit (*Limosa lapponica*) are good examples[54].

These shorebirds must get sufficient food from the intertidal mudflats to put on as much as a third of their body weight as fat to fuel migration flights[71]. The tight energy budgets of shorebirds will be compromised if GBR intertidal flats are inundated and the birds will be similarly impacted at re-fuelling stops on intertidal wetlands in Asia on their migration route. Their nesting sites are also vulnerable. Many northern hemisphere shorebird breeding grounds are moving north as temperatures warm and vegetation changes, increasing migration distances to the GBR. For some species such as the red knot that breed in the Arctic, habitat is running out and there is nowhere further north to go[100].

The requirement for functioning ecosystems en-route and at each end of the migration also applies to some populations of seabirds which migrate to the GBR from nesting sites in the northern hemisphere, for example, the population of roseate terns that breeds in North Asia and winters on the Swain Cays[91]. Populations of northern hemisphere breeding shorebirds and possibly seabirds are likely to decline in the GBR.

Vulnerability of migratory land birds

Most land birds of the GBR do not migrate but several species, such as pied imperial pigeons, spangled drongos (*Dicrurus bracteatus*) and several cuckoos, migrate to northern islands such as Papua New Guinea. These are not the long migrations of land birds from temperate to tropical areas typical of many terrestrial European and North American nesting song birds, where timing is essential for breeding success[125,16]. Land birds migrating to southeastern Australia from islands to the north of Australia have arrived on average 3.1 days per decade earlier, and departed 8.1 days per decade later, since 1960[14]. Timing shifts for the GBR land birds are unlikely to be as pronounced, as most species are confined to the tropics where temperature changes between seasons are not as critical for bird life cycles[26]. GBR migratory birds still depend on having functioning ecosystems at both summer and winter habitats and on islands on the migration routes. Pied imperial pigeons have the capacity to roost and nest in a variety of vegetation and are likely to adapt to changes in island vegetation in the short term. A loss of low wooded islands may limit their roosting options in the long term.

Vulnerability of turtle nesting

In the short-term beaches of cays and continental islands will become more dynamic, but they will still be available for turtle nesting. The long-term loss of cays and many beaches of islands will reduce turtle nesting options.

20.4.2 Summary of impacts

This chapter cannot provide a quick or definitive answer to the question of *'What is the future of the GBR's terrestrial island environments during current and predicted climate change?'* The impacts of climate change are inevitable. According to Melillo et al.[80] biogeography models, climate change has the potential to affect the structure, function and distribution of all terrestrial ecosystems. The timing and strength of these impacts on the diverse GBR islands depends on many variables including current factors such as soil type, nutrient availability, salinity tolerance, food webs, migration and dispersal potential as well as all the expected changes in climate including rainfall, storm strength, temperature, CO_2 concentration, weed and pest risk and interactions with other plants and animals.

For GBR islands, the point when cays cease to build and begin to erode is a critical moment. We have used this moment to differentiate short-term and long-term impacts.

In the short term, during the next several decades, the greatest impacts are likely to be due to variations in rainfall and rising air temperature causing water stress to plants and animals, and an increased risk from fire, weeds and disease. The effects of elevated CO_2 at plant community levels are uncertain. Habitats may become structurally similar to those we see today, but with shifts of competitive balance among existing island species resulting in very different species in the communities.

Many islands with reduced land area, increased isolation and heightened competition among wildlife will most likely have a reduced plant and animal biodiversity. Tropical habitats and communities as well as tropical weeds and diseases will extend further south and the ranges of more temperate species will shrink. Increased cyclone strength and rising sea level will make cays, sandy beaches and spits more dynamic but most seabirds and turtles will still have places to nest if they are flexible and able to adapt.

In the long term, as sea level rises more than one metre above present levels, most cays and lowlands of continental islands will erode or be inundated. Some vegetation types, such as pisonia closed-forest and wetlands, will be reduced to refuge sites. Some plant and animal species will become locally extinct.

If there is a major sudden rise in sea level of several metres from a Greenland or Antarctic Ice Sheet melting, the impacts will be immediate and catastrophic for habitats on cays and lowlands of continental islands.

Eventually climate changes will stabilise and a new dynamic of flora and fauna will become established. However, as community reconstruction often takes millennia, there will be continuous changes for centuries at least[123].

A summary of impacts in the short and long term is presented in Table 20.4.

Table 20.4 *Summary of the effects of climate change on key natural values of GBR islands*

Short-term impact *– Less than one metre sea level rise, air temperature increases 2 to 3°C, sea water temperature increases 1 to 2°C, small rainfall and cyclone changes, and moderate CO_2 increases*

Long-term impact *– Greater than one metre sea level rise, air temperature increases greater than 3°C, sea water temperature increases greater than 2°C, moderate rainfall and cyclone changes, high CO_2 increases*

GBR Island Value	Short-term impact	Long-term impact
Flora		
Coral cay vegetation	Altered species composition	Coral cays disappear, some species survive on continental islands
Pisonia forests	Maintained	Survive as refuge patches on continental islands associated with seabird nesting.
Continental island sclerophyll forests and scrubs	Increased in area, altered species composition, higher fire risk	Fewer species, high fire and disease risk
Rainforests	Uncertain. Possible reduction in area and species but may expand if rainfall increases	Uncertain. Possibly contract to small remnants
Montane heathlands	Reduced in area and species	Local extinction is highly probable
Freshwater wetland vegetation	Reduced in area and species	Survive only in water holes and streams on slopes
Dune and shore vegetation	Relocation and alteration to species composition	Major relocation and reduction in area
Continental island grasslands	Impacted by expanding C_3 shrubs but depends on fire regimes and drought. May increase or decrease	Uncertain future. Dependent on fire management
Rare continental island flora	Uncertain future	Mostly extinct on islands
Weeds	Increase in area affected by the elevated disturbance	Increased area affected on continental islands
Invertebrate pests	Possibly increase	Possibly increase

GBR Island Value	Short-term impact	Long-term impact
Fauna		
Endemic coral cay fauna	Probably survive	Uncertain, likely to be extinct
Endemic and rare continental island fauna	Possibly survive	Uncertain, some future, possibly extinct on islands
Seabird and turtle nesting sites	Adapted to new nesting sites on cays, continental islands and mainland	Reduced to a few new sites on continental islands and the mainland
Freshwater wetland fauna including fish and frogs	Reduced number of species	Uncertain future, reduced to stream species only
Pied imperial pigeons	Survive as opportunistic migratory birds in island rain forests and mangroves	Reduced to refuge sites in residual rainforest and mangroves on continental islands
Fauna of sclerophyll forest, scrub and grasslands	Uncertain, some species may increase and others decrease	Possibly survive. Foliage herbivores likely to be reduced, higher disease risk
Fauna of rainforests and montane heaths	Reduced abundance and species richness, except if rainfall increases	Some species may survive in small refuge sites as rare island species
Migratory shorebird feeding and roosting sites	Probably viable but altered composition and size of flocks	Uncertain future, may adapt to refuge sites in lower numbers
Resident shorebird nesting, feeding and roosting sites	Relocated along new shores and viable	Reduced to new sites on continental islands and/or mainland shores

20.4.3 Management actions

The most important management action is to lessen the impact of climate change by encouraging global reductions in CO_2 and other greenhouse gases[109]. However given current trends, many impacts of climate change are inevitable, already occurring or will be impossible to prevent on islands of the GBR. Policy decisions should be made, particularly:

- What time scale to manage for: 20 years, 100 years or 200 years?
- What values and attributes of GBR islands are most important to protect and support by building their resilience, and what values can we accept to lose?

Potential management actions for GBR islands include:

- Implement biological inventories to identify high value sites on islands and predict the impacts of climate change, particularly changes to island vegetation and geomorphology.

- Minimise other human related impacts on islands and maximise natural resilience of habitats to climate change.
- Ensure management and site plans, and environmental impact assessment, for islands and their surrounds consider climate change.
- Educate managers, the public and interest groups about the impacts of climate change on islands and other components of the GBR ecosystem.
- Implement actions to ensure the survival of the Bramble Cay melomys and other endemic fauna and flora including establishing populations at alternative sites.
- Plan fire management to consider the increased fire risk and growth of fire adapted woody plants on islands and increase fire management actions accordingly.
- Increase weed and pest monitoring, control and eradication actions to take account of an increased risk of weed establishment and spread. Focus on C_3 weeds.
- Use pest and disease monitoring data to prepare response actions for pest and disease outbreaks on GBR islands.
- Monitor coastal bird breeding effort and turtle hatchling success to determine if any declines are related to changing nesting habitat.
- Define nesting requirements for coastal birds and turtles on GBR islands, and actively manage bare substrates and island vegetation at key existing and potential future coastal bird nesting sites.
- Monitor roosting and feeding sites for shorebirds and undertake works that ensure safe roosting sites are maintained or provided.
- Determine the risk and feasibility of management actions to reduce impacts on key wetland sites including water management works and barriers to saltwater incursion.
- Monitor changes to significant vegetation communities eg montane heath on Hinchinbrook Island, grasslands at the Whitsundays Group and pisonia forests on the Capricorn Bunker Group.
- Conduct site assessments of the potential impacts of sea level rise and intense storms for key visitor sites.
- Determine the feasibility of reducing impacts on key visitor sites and facilities, including engineering work or barriers, or relocating sites.
- Design any future visitor facilities to take account of sea level rise and changes to island geomorphology and vegetation.

20.4.4 Research actions

Research should identify specific risks to important natural values and how the risks can be minimised and the values made more resilient. Specifically:

- Identify and systematically observe relevant variables that provide an increased understanding of changes in vegetation caused by both non-climate change factors and climate change factors.
- Monitor and diagnose vegetation as it evolves during climate change, being cognizant of the complex interactions between climate, the islands and the vegetation.
- Investigate potential impacts of climate change on key vegetation communities including pisonia forest and grasslands, rainforest, banksia/casuarina montane heathlands and wetlands.
- Investigate if habitat of key fauna (eg Proserpine rock-wallaby, Capricorn white-eye, Dawson yellow chat, Bramble Cay melomys and Whitsundays azure butterfly) will continue to exist on their current islands, and investigate if other islands are, or may become, suitable habitat.
- Investigate the geomorphology of key coral cays and whether they are likely to increase or decrease in size as sea level gradually rises, especially Raine Island and other far northern outer reef cays, the Capricorn Bunker Group and the Swains Reefs.
- Identify and determine control strategies for weeds most likely to adversely impact islands under current and predicted climate change.
- Investigate if impacts of pests and diseases of island species and habitats are linked to climate change, (eg scale insect infestation on pisonia vegetation in the Capricorn Bunker Group).
- Identify current and potential seabird feeding areas and potential nesting sites within feeding range suitable for active enhancement as nesting sites.
- Investigate techniques for actively managing turtles and seabirds nesting on beaches and islands.
- Investigate techniques to actively manage island wetlands and coral cays including revegetation and reintroduction of key species, engineering works and water management.

Climate change impacts on GBR islands are large, inevitable and challenging. The only certain thing is that we live in interesting times.

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