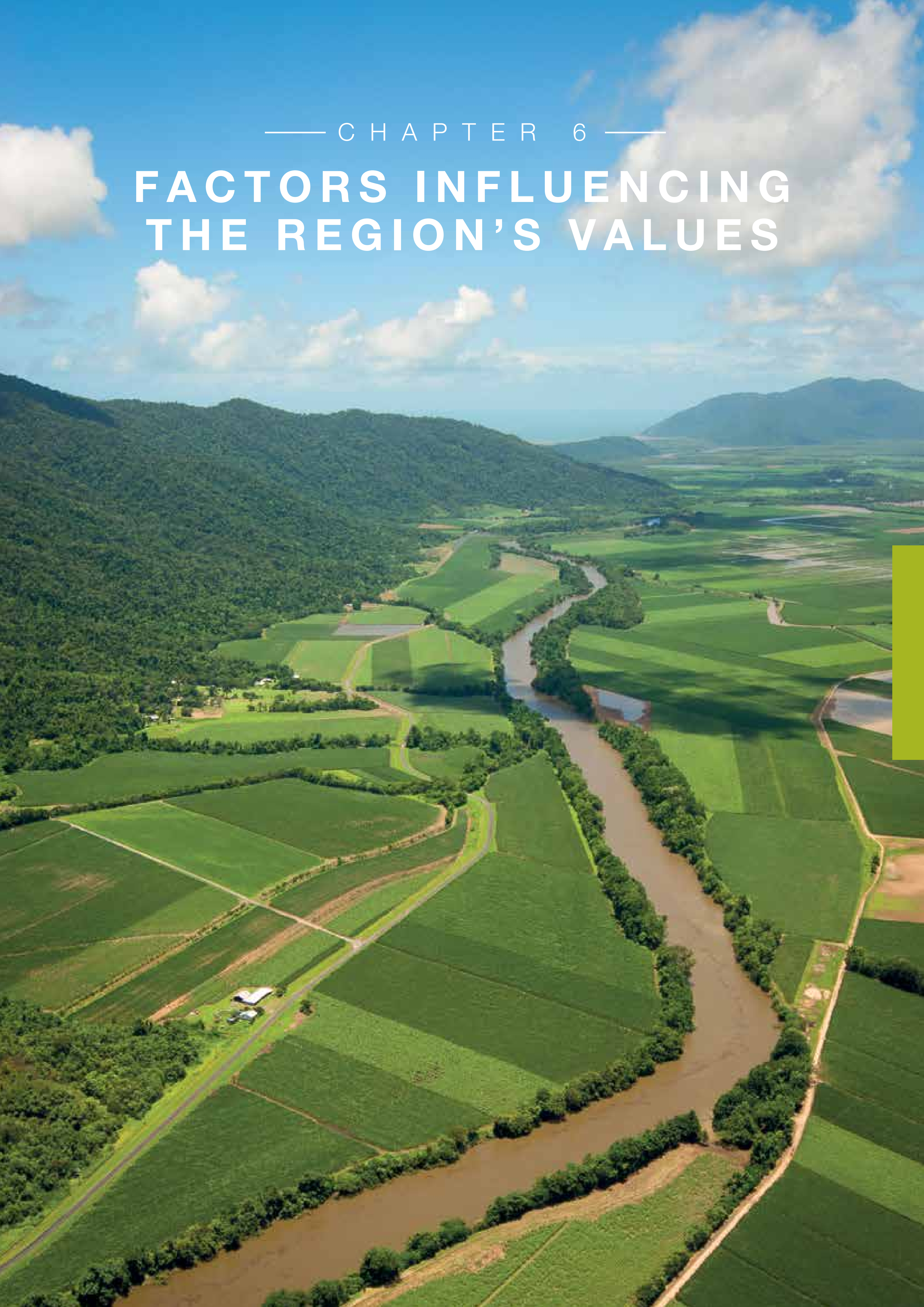
CHAPTER 6

FACTORS INFLUENCING THE REGION'S VALUES



« *Sugarcane cultivation along the Mulgrave River.* © Dieter Tracey 2015

FACTORS INFLUENCING THE REGION'S VALUES

'an assessment of the factors influencing the current and projected future environmental, economic and social values ...' of the Great Barrier Reef Region, s 54(3)(g) of the *Great Barrier Reef Marine Park Act 1975*

'an assessment of the factors influencing the current and projected future heritage values ...' of the Great Barrier Reef Region, paragraph 116A(2)(e) of the *Great Barrier Reef Marine Park Regulations 1983*

6.1 Background

The Region comprises a diverse range of natural values (ecosystems, habitats, species and processes) and Indigenous and historic heritage values described in Chapters 2 to 4. The condition of these values determines the health of the Region and the quality of the social and economic benefits (for example, income, appreciation and enjoyment) the community derives from the Region.

Several major factors influence the Reef's values. The four factors assessed in previous Outlook Reports remain the primary factors influencing the Region: climate change, coastal development, land-based run-off and direct use. This chapter considers the trend of each influencing factor, as well as the Region's vulnerability to those factors. Any impacts the factors have on the Region's outstanding universal value (including natural, Indigenous and historic heritage value) and the benefits derived from those values, provide a basis for predicting future risks to the Region and its long-term outlook (Chapters 9 and 10).

While direct uses occur in the Region, the other three main influencing factors are largely external to the Region. All four factors are, in turn, affected by broader drivers of change (economic growth, population growth, technological development and societal attitudes) that affect how society functions, matures and interacts with the environment (Figure 6.1).

The assessment is based on four assessment criteria:

- impacts on ecological values
- impacts on heritage values
- impacts on economic values
- impacts on social values.

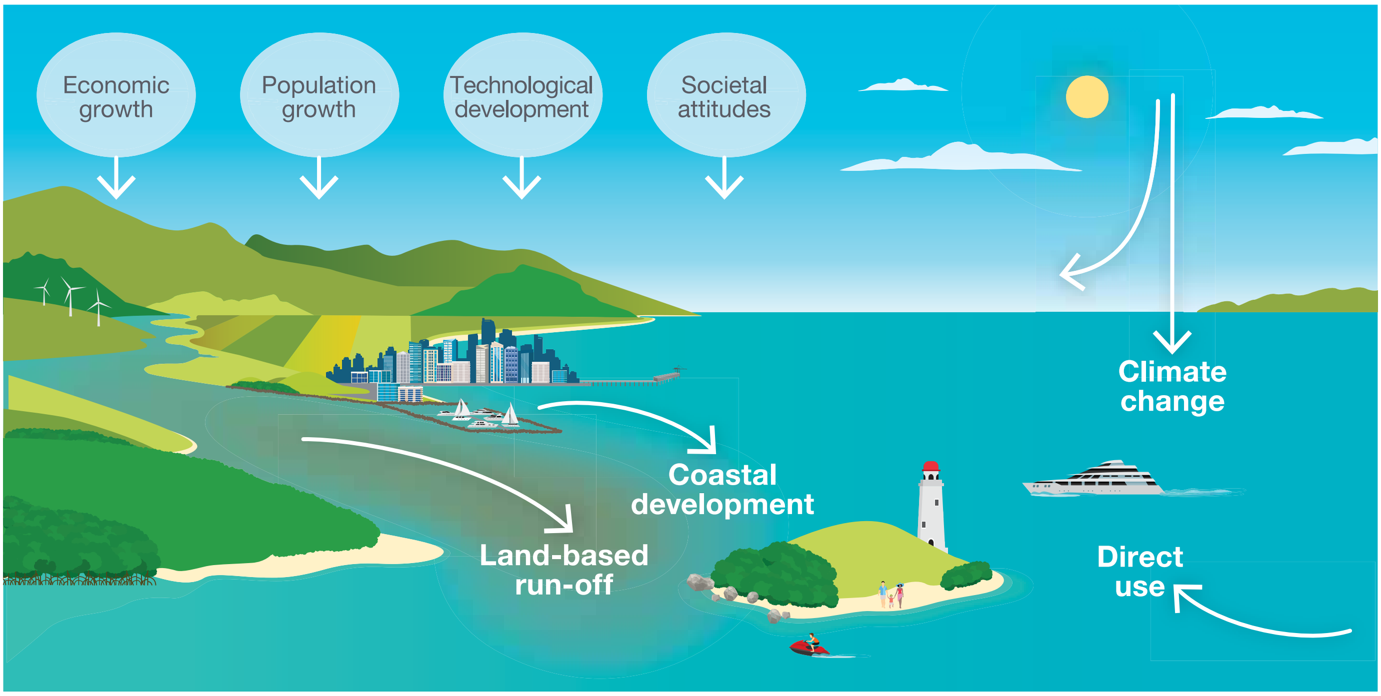


Figure 6.1 Factors influencing the Region's values and drivers of change
The Region's values are influenced by four main factors: climate change, coastal development, land-based run-off and direct use. These are, in turn, affected by broader drivers of change, including economic and population growth, technological development and societal attitudes.

6.2 Drivers of change

Drivers are underlying causes of change in society and ecosystems. The Reef is currently undergoing significant social, economic and environmental change.[969] Drivers affect how society functions and interacts with the built and natural environment, and can act independently or in combination.[1011] Economic and population growth, technological developments and societal attitudes are key drivers and affect the nature and intensity of the four primary factors influencing the Region (climate change, coastal development, land-based run-off and direct use) (Figure 6.1). Drivers lead to challenges for the environment but also benefits, particularly through technological development and societal changes.[1118]

6.2.1 Economic growth

Queensland's economy is driven primarily by tourism, agriculture, resources (mining), construction, manufacturing and services.[1119] It has maintained an average annual growth rate of 2.4 per cent over the last decade (Figure 6.2).[1119] The value of Queensland's economic activity is trending upwards, although growth slowed between 2008 and 2011 (Figure 6.3). The underlying trends driving the Queensland economy (Figure 6.3) have been the housing boom (2004–05 to 2007–08), the coal mining boom (2004–05 to 2008–09), the global financial crisis (2007–08), a cluster of natural disasters (for example, cyclone Yasi and associated floods) (2009–10 to 2011–12), and expanding investment in liquefied natural gas (2012–13 to 2014–15).[1120]

A significant proportion of Queensland's economic activity takes place in the Region and its Catchment

In 2016–17, Queensland recorded economic growth of 1.8 per cent, with the health care and social assistance industry the largest contributor. From 2020–21, the state's economy is predicted to grow by an estimated 2.75 per cent per annum.[1120]

A significant proportion of Queensland's economic activity takes place within the Region and its Catchment. More than 90 per cent of Queensland's saleable coal is exported overseas[1121] from ports within the Region and shipped through the Region. The state's export trade is dominated by mining (64 per cent) and agriculture.[1121] Mining experienced a reduction in 2010–11, but has grown strongly over subsequent years, contributing six per cent to the state's economy in 2015–16 and 2016–17.[1119] Construction activity (engineering, residential and non-residential) contributed eight per cent annually to the Queensland economy between 2015 and 2017.[1119] A boom in liquefied natural gas exports began in 2015–16 and is projected to continue, reaching peak production in 2018–19.[1120,1122]

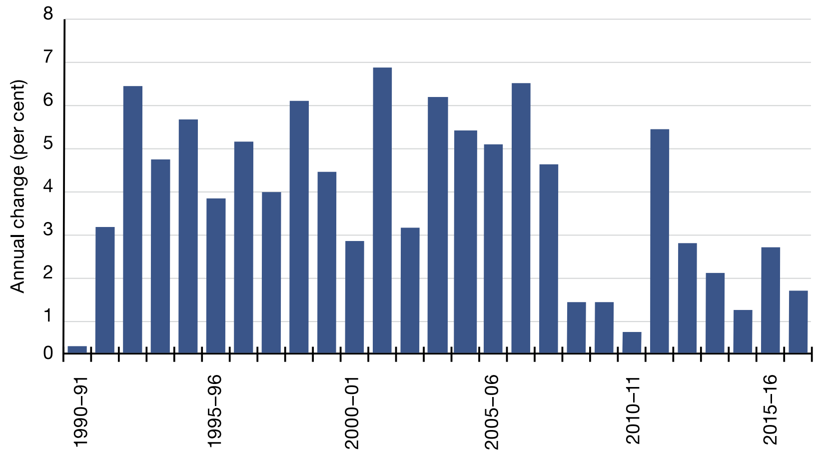


Figure 6.2 Economic growth in Queensland, 1990–91 to 2016–17
Annual percentage change in the Queensland gross state product (chain volume measure) for financial years. Source: Australian Bureau of Statistics 2018[1119]

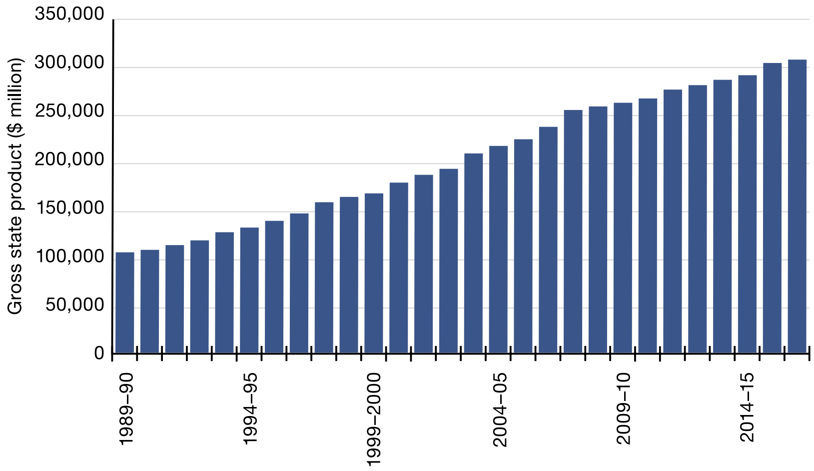


Figure 6.3 Economic activity in Queensland, 1989–90 to 2016–17
Total economic activity in Queensland based on gross state product (chain volume measure) for financial years. Source: Australian Bureau of Statistics 2018[1119]

Since 2010–11, production in the agriculture, forestry and fishing industries has grown steadily. Between 2015–16 and 2017–18 agriculture, forestry and fishing contributed three per cent annually to the Queensland economy, with operations in the Catchment contributing a large component.[1119] In 2016–17, the gross value of agricultural production in Queensland was $14 billion, with approximately half derived from agriculture within the Catchment.[1123] Most of the production value in the Catchment in 2016–17 came from cattle and sugarcane, which accounted for 35 per cent and 22 per cent respectively.[1123] The greatest agricultural output in that period came from the Fitzroy region, mostly from cattle.[1123]

Cattle graze about 320,000 square kilometres of the 480,000 square kilometres in the Catchment (or 67 per cent).[1123] Given its dominance and sensitivity to severe weather, such as droughts and floods, the economic activity of this industry, and thus the Region, can change rapidly.[1119,1121]

Tourism is the Reef's largest economic activity (Section 5.2). In 2016–17, Queensland tourism contributed $11.7 billion (approximately four per cent) to the state economy and areas adjacent to the Reef directly contributed $3.2 billion.[1124] Domestic visitors account for 89 per cent of overnight visitation to Queensland.[1124] The economic contribution of international tourism in Queensland grew from $2.3 billion in 2006–07 to $3.3 billion in 2016–17.[1125] Visitors to the Reef over the last decade have increased in almost all natural resource management regions.[1123] The Mackay–Whitsunday region is an exception, experiencing a slump of 26 per cent between 2006 and 2016, attributed to a decline in domestic visitor numbers.[1123] By comparison, tourism expenditure is far higher in the Wet Tropics region compared with any other, primarily due to Cairns being the point of origin for most visitors to the Reef and the primary destination of international visitors.

6.2.2 Population growth

Population growth is one of the main drivers presenting a challenge to the environmental integrity of the Region. The increasing number of people living close to the coast is a key human-induced pressure on the Reef, primarily due to coastal development and recreational fishing.

In June 2018, the Catchment population was approximately one million with an annual growth rate of 0.3 per cent since 2013.[1126] The Catchment population is expected to climb to 1.32 million by 2041, an increase of 1.1 per cent per year.[1126] Townsville is expected to have the largest population growth to more than 282,000.[1126] Note, these population figures are smaller than those given in the 2014 Outlook Report because they no longer include some local government areas outside the Region.

Annual population growth within the Catchment is forecast to be 1.1 per cent per year until 2041

Employment and lifestyle opportunities in the Region and Catchment influence population growth. The growth of coastal communities generates a variety of impacts, including increased recreational fishing (Section 5.4) and other direct uses of the Region (Section 6.6), coastal development (Section 6.4), and pollution[1127] (land-based run-off; Section 6.5). Coastal infrastructure (roads, marinas and boat ramps), housing development and the demand for more urban support services will inevitably increase with an expanding population.[1126]

6.2.3 Technological development

Technological development refers to the application of knowledge to create tools to solve specific social, economic or environmental problems. Technological development can drive both positive and negative changes.[1118] Advances in technology have changed knowledge, management and use of the Region, and in some instances have helped reduce environmental impacts.

Global cooperation across various industries and sectors is required in order to mitigate the effects of climate change. Technological developments are advancing the production of clean energy goods and services. For example, they assist in reducing emissions from food production (sustainable bio-based feedstocks, water saving irrigation), waste disposal (capturing methane biogas), transport (electric super highways, biofuel) and support renewable energy production.[1128,1129] Carbon capture, utilisation and storage is still in early stages of development, and is being addressed by governments at different rates around the world.[1130]

The most significant technological development in terms of reducing greenhouse gas emissions is large-scale deployment of renewable energy. Queensland is the leading state in planned, large-scale renewable energy projects.[1131] Continuing advances in, and expansion of, renewable energy are occurring adjacent to the Reef[1132], and will reduce emissions of greenhouse gases[1131,1133] in the local energy sector. Technological development, innovation and social buy-in will be driving forces in improving energy efficiency and uptake of renewable energy.

Advances in technology can both reduce and increase environmental impacts

The potential of assisted evolution technologies to enhance the resilience of corals to future sea temperature increases by accelerating natural adaptation is being explored.[1134] Additionally, novel techniques, such as assisted gene flow and hybridisation, are being investigated for their potential to enhance the thermal tolerance, growth and reproduction of corals.[1026]

Underwater and above water surveillance technologies have also advanced. Research and development have produced autonomous underwater robots (remotely operated vehicles), which are being tested to determine their use in surveying large areas of reef environments. This will allow crown-of-thorns starfish to be detected over wide areas and injected as a control measure.[1135] This technology may increase data collection capacity, particularly at greater depths and at night, when scuba diving is a higher risk activity.

Above the water, the adoption of drone technology for compliance is proving a cost-effective and efficient method of surveying and monitoring large spatial areas. Drone use will continue to expand, and their decreasing cost and GPS capabilities will see them becoming a primary cultural monitoring and mapping tool. Drones are already used to enforce compliance within the Reef and are used by Traditional Owners to monitor their sea country and record cultural heritage. Use of personal drones is also likely to continue to increase among people using the Region for activities, including recreation, tourism and recreational fishing. This is likely to increase risks associated with public appreciation and wildlife disturbance.

6.2.4 Societal attitudes

Understanding societal attitudes is essential for long-term planning and evaluation of management decisions.[1136] These attitudes are shaped by culture, social norms, values, information, misinformation, circumstances and personal experiences.[1011] By feeding into planning and management, societal attitudes can drive change.[1011] In 2013, residents perceived that shipping, water quality and fishing were the major threats to the Reef. By 2017, this perception had shifted to focus on pollution, climate change and coral bleaching.[785] Other aspects, such as how individuals identify and use the Reef, can also influence their attitude towards the Reef.[969,1011] How attitudes change over time can be affected by the extent of society's knowledge about the Reef, and the source of that knowledge varies.[969,1011] Word of mouth, print and social media play a persuasive role in informing the public's view about the Reef.[1011]

The understanding of societal attitudes is essential for sustainable use of the Region and long-term planning

Results from the Social and Economic Long-Term Monitoring Program (SELTMP)[785] offer some insights into the human dimensions of the Reef. Participants' responses highlighted the importance of the Reef's exceptional natural beauty and superlative natural phenomena to visitors and stakeholders.[785] A prevailing social expectation is that the Reef will remain beautiful and a relatively natural place to live, work and recreate.[969] However, these values are subject to growing pressures and the survey results indicate that the community does not believe enough is being done to prevent ongoing threats to the Reefs especially threats from climate change (Section 4.5.1).[785] Some Reef stakeholders feel climate change is an immediate threat requiring urgent attention, but that opinion is more common among people from the tourism industry (68 per cent) than the commercial fishing industry (27 per cent).[785]

Stakeholders who rely on the Reef for recreational and economic opportunities will experience greater disruption than other stakeholders as the Reef ecosystem changes.[1137] Tourism industry profit and viability can also be affected by publicity about the decline of Reef health.[1138]

Traditional Owners who are more culturally and socially connected to, and dependent on, the Reef than other groups, will experience widespread adverse consequences from declining Reef health.[969] Aboriginal and Torres Strait Islander people value the Reef as a place where people can continue to pass down wisdom, traditions and a way of life (Section 4.3). As custodians and users of the Reef, Traditional Owner groups have the longest connection to their sea country, integrating nature, heritage and Indigenous culture.[1011]

6.3 Climate change

Climate change due to human activities is a global issue that affects terrestrial, wetland, freshwater, marine and coastal ecosystems and the services they provide. Climate change is the most pervasive and persistent influence on the Region. The most immediate and priority current threat from climate change is thermal extremes that cause mass mortality of corals and other organisms. Effects from sea-level rise and ocean acidification are slowly increasing, but are not having nearly the same immediate and Region-wide impact as increases in sea temperature.

Great Barrier Reef waters have already warmed by more than 0.8 degrees Celsius since 1880 due to anthropogenic climate change, with severe impacts already being observed in the Region

In 2016 and 2017, the Region underwent two consecutive summers of mass coral bleaching, resulting in the loss of at least 30 per cent of the Region's shallow-water coral cover (Section 2.3.5). These events are directly attributed to warmer-than-average sea temperatures due to climate change.[1139] The present-day frequency and severity of climate change-related impacts are increasing and interacting with the other key threats (Sections 6.4 to 6.6), compounding their effects.

Of the four main factors influencing the Region's values in the 2014 Outlook Report, climate change was assessed as having the highest negative impact, with impacts on natural and heritage values expected to increase. In the past four years, many worst-case scenario climate change predictions made over 30 years ago[1140] have now been realised[141], and our understanding of the future conditions of ecosystems in the Region has grown considerably.

6.3.1 Trends in climate change

Human activities have already caused approximately one degree Celsius of global warming above pre-industrial levels, with a likely range of 0.8 degrees Celsius to 1.2 degrees Celsius.[1141] Warming is generally higher over land than over the ocean, but recent evidence suggests oceans are heating up about 40 per cent faster than previously estimated[502] and the pace of change is accelerating at an unprecedented rate[452] (Figure 6.4). Both the magnitude and rate of these changes exceed the extent of natural variation over the last millennium and over glacial-interglacial time scales.[1142,1143,1144] The extent to which the climate will change in coming decades depends on current and future greenhouse gas emissions.

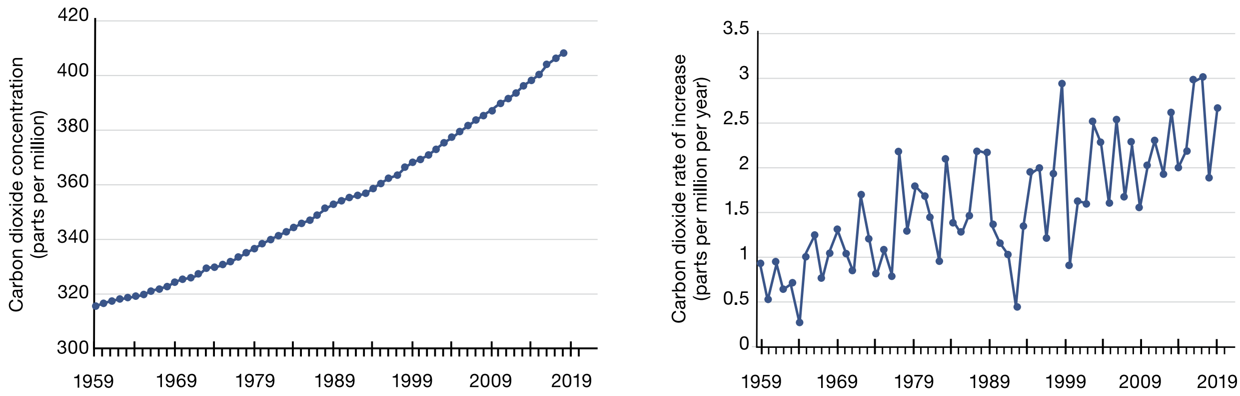


Figure 6.4 Changes in global atmospheric carbon dioxide concentrations
Global carbon dioxide concentrations in the atmosphere have been rising. Both global carbon dioxide concentrations (left) and the annual mean carbon dioxide rate of increase (right) rose steadily between 1959 and mid-2018. Trends shown are based on globally averaged marine surface data. Source: Dlugokencky and Tans 2019[1145]

In 2015, the *Paris Climate Change Agreement* established the goal of holding the increase in the global average temperature to well below two degrees Celsius above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 degrees Celsius.[1146] These aspirational constraints include the warming that has already occurred to date, which in 2017 was approximately one degree Celsius above pre-industrial levels and is currently increasing at 0.2 degrees Celsius per decade.[487] At current rates of warming, global mean temperature would reach 1.5 degrees Celsius between 2030 and 2052.[1141,1147,1148] There is also a very high risk of exceeding 1.5 degrees Celsius and approaching two degrees Celsius by 2065.[487] Warming of 1.5 degrees Celsius would have serious implications for many ecosystems; warming of two degrees Celsius would result in a completely new climate regime under which many ecosystems would undergo irreversible change.[562,1149,1150]

A number of long-term changes in the climate system are already occurring in Australia, such as an increase in mean air and **sea surface temperatures**. Warming over Australia is expected to be slightly greater than the global average[452] (Figure 6.5). In Australia, the best case scenario for halting emissions (referred to as RCP 2.6) would equate to average warming of between 0.6 degrees Celsius and 1.7 degrees Celsius by 2090 (relative to a baseline of average temperatures between 1986 and 2005). Under the worst case scenario (referred to as RCP 8.5), warming would range from 2.8 degrees Celsius to 5.1 degrees Celsius over the same period.[1151] The average air temperature in Australia has already increased by around one degree Celsius since 1910[1151], with severe impacts already being observed in the Region. It is almost certain that the Region will warm by at least another 0.5 degrees Celsius (Section 9.3.2).

From 1925 to 2016, global average marine heatwave frequency and duration increased, resulting in a 54 per cent increase in annual marine heatwave days globally.[1152] In Australia, above-average annual sea surface temperatures have been observed every year since 1994 and have been persistently high in recent years.[1153] Sea surface temperatures in the Australian region have warmed by around 1.0 degree celcius since 1910[452], with the Reef warming by 0.8 degrees in the same period (Figure 6.6).[501] Since 2014, some of the hottest sea surface temperatures ever recorded in the Region's waters occurred in February–March 2016.[165] This marine heatwave was 175 times more likely to occur under the influence of climate change[1154] than without climate change. A second marine heatwave occurred in the 2016–17 summer, with a larger area of the Reef exposed to higher than average sea surface temperatures.[1153] In the future, the chance of a marine heatwave occurring in any given year will be double that of today, if warming reaches 1.5 degrees Celsius and triple if warming reaches two degrees Celsius.[1139]

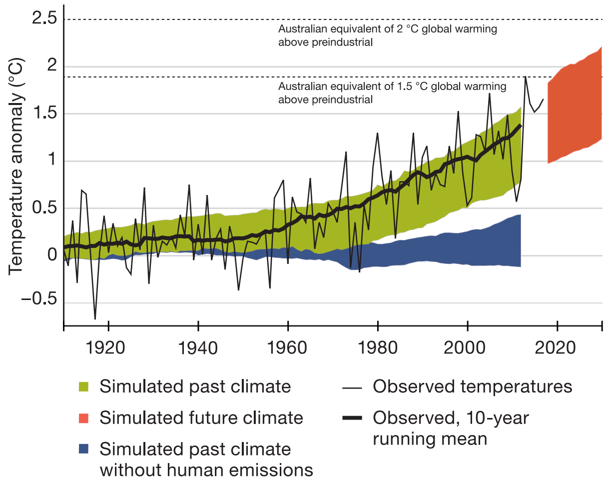


Figure 6.5 Australia's average annual temperature relative to the 1861–1900 period
The thin black line represents Australian temperature observations since 1910, with the bold black line the ten year running mean. The shaded bands are the 10 to 90 per cent range of the 20-year running mean temperatures simulated from the latest generation of global climate models. The green band shows simulations that include observed conditions of greenhouse gases, aerosols, solar input and volcanoes; the blue band shows simulations of observed conditions but not including human emissions of greenhouse gases or aerosols; the red band shows simulations projecting forward into the future (all emissions scenarios are included). Warming over Australia is expected to be slightly higher than the global average. The dotted lines represent the Australian equivalent of the global warming thresholds of 1.5 °C and 2 °C above preindustrial levels, which are used to inform possible risks and responses for coming decades. Source: CSIRO and Bureau of Meteorology 2018[452]

Changes to temperature extremes often lead to greater impacts than changes to the mean climate. For example, it is estimated that by 2090 under the worst-case scenario (RCP 8.5), Cairns would experience 48 days per year of air temperatures exceeding 35 degrees Celsius, a dramatic rise from the current three days per year.[485,1156] The frequency and severity of extreme events, such as heat waves, are critical and have important consequences for the Region's values.

Heatwaves are becoming hotter, lasting longer and occurring more often, affecting both terrestrial and marine environments

As the ocean continues to warm and land-based ice starts to melt, the pace of global **sea-level rise** will accelerate.[485] Although mitigation of greenhouse gas emissions might reduce the overall magnitude of sea-level rise in the long-term, the Earth is already locked into significant sea-level rise this century, regardless of what future emission scenario is followed, due to the lag effects in ocean warming and ice-melt.[1157,1158] Projections for global sea-level rise by 2090 range from 0.6 to 0.86 metres and strongly depend on current and future emissions. However, sea-level rise is currently tracking toward the worst-case scenario (RCP 8.5) of up to 0.86 metres.[1151,1159]

The fastest sea-level rises are being recorded in Australia's northern areas.[486] Since 1993, the average rate of sea-level rise in the Region was between five and seven millimetres per year (and in some locations up to 12 millimetres per year[486]), well above the global average of 3.2 millimetres per year[1160]. Sea-level rise directly threatens low-lying habitats within the Region, such as islands, beaches and coastlines (Chapter 2). As average sea level continues to rise, the height of extreme sea-level events (such as storm surges during tropical cyclones) will also increase, causing increasingly severe impacts on coastal communities, infrastructure and coastal habitats.

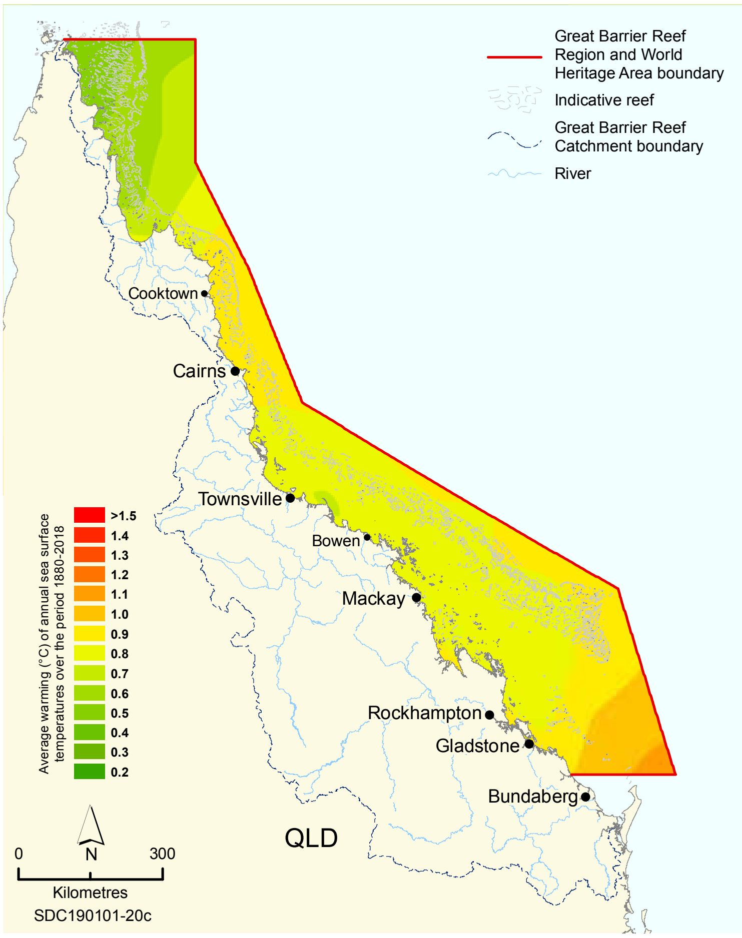


Figure 6.6 Average warming of annual sea surface temperature between 1880 and 2018 for the Great Barrier Reef
Annual sea surface temperature (SST) was extracted from the Met Office Hadley Centre for Climate Prediction and Research (HadISST1 data set) for 1-degree latitude x 1-degree longitude grid boxes for the Region.
Source: Rayner *et al.* 2003[1155]

The ocean provides a critical service to both ecological communities and human society by strongly regulating the climate system, particularly through the absorption of carbon dioxide. Without this service, the amount of global warming to date would have been considerably higher. However, increased carbon dioxide in the ocean alters its **ocean chemistry**. Since the beginning of the Industrial Revolution, the ocean has absorbed roughly one third of the anthropogenic carbon dioxide emissions.[1161] In response, **ocean pH** has decreased close to 0.1 units since the pre-industrial period (Section 3.3.2). The increase in carbon dioxide has also reduced the concentration of carbonate ions in the ocean by 30 per cent[545,1162]; at a rate at least 10 times faster than any concentration change within the last 65 million years[1163].

In the Region, the rate and magnitude of increases of carbon dioxide concentrations are more significant on inshore reefs (those within 10 kilometres of the coast) than reefs further offshore.[162,163,164] In the past 30 years, carbon dioxide concentrations on these inshore reefs have increased at a rate up to three times higher than atmospheric values, suggesting that the Region's inshore coral reefs are more vulnerable to ocean acidification and have less buffering capacity compared to mid- and outer-shelf reefs.[162] However, the effects of this may currently be negligible compared to the observed, severe impact of ocean warming on the Reef.

Global atmospheric and ocean circulation patterns and rising temperatures influence **ocean currents** (Section 3.2.1). The major current in the Region, the East Australian Current, has become one of the fastest warming currents in the world, warming two to three times faster than the global average ocean warming rate.[427] This has led to two major changes in the current's properties: the amount of water it transports southward and the frequency of eddy formation. The East Australian Current has already advanced beyond its normal southern boundary, about 350 kilometres off the coast of New South Wales and this trend is expected to continue.[427]

Although current projections suggest the frequency of **tropical cyclones** is most likely to remain stable or even decrease[56,1164,1165], cyclone intensity is expected to increase (Section 3.2.2)[55,56]. As a result, a marked increase in the frequency of the most intense cyclones (categories 4 and 5) is projected.[1164,1166,1167] Since 1975, the proportion of intense tropical cyclones has increased 25–30 per cent, corresponding to the observed one degree Celsius of global warming.[1167] Modelled projections have indicated that relative to pre-industrial conditions, cyclones in northeast Australia will have both higher wind speeds (by 5–10 per cent on average) and heavier rainfall (by up to 27 per cent for average hourly rainfall rates) under worst-case scenario (RCP 8.5) future climate change.[1168] To date, climate change has not significantly influenced cyclone wind speeds but has significantly enhanced rainfall by 4–9 per cent.[1169] The forward speed of tropical cyclones over Australia has slowed by 22 per cent since 1946, increasing the potential for higher total rainfalls as cyclones remain over certain locations for longer periods.[453]

Rainfall variability is strongly related to changes in sea surface temperatures across the Pacific Ocean associated with El Niño–Southern Oscillation.[1170] However, as the influence of climate change strengthens, the intensity of heavy rainfall events is projected to increase in the Region.[1156] This has already occurred on a global scale; approximately 20 per cent of global heavy rainfall events over land are attributable to the observed temperature increase since pre-industrial times.[1171] Australian weather station records show that a higher proportion of total annual rainfall in recent decades, compared with earlier, has come from heavy rain days.[452] For heavy rain days, total rainfall is expected to increase by around seven per cent for each degree of warming, whereas for short-duration rainfall events, observations in Australia generally show a larger than seven per cent increase per degree of warming.[452] More intense rainfall will increase the likelihood of severe floods and subsequent large freshwater inflows to the marine environment (Section 3.2.3), increasing turbidity and sedimentation (Section 3.2.4) that can damage inshore coral reefs and seagrass meadows. Based on analyses of coral cores, extreme flood events are now occurring more frequently than in the past and fresh water is extending further out to mid-shelf areas of the Reef more often.[457]

The El Niño–Southern Oscillation is the most important driver of inter-annual climate variability in the Region, associated with a sustained period (many months) of warming (El Niño) or cooling (La Niña) in the central and eastern tropical Pacific.[1156] During an El Niño event, the prevailing trade winds that blow from east to west across the Pacific Ocean weaken or even reverse, and the eastern tropical sea surface temperatures warm. The opposite occurs during a La Niña event.

Extreme El Niño events result in the centre of Pacific rainfall moving eastward, away from the Australian coast towards South America. The common result is intense droughts across eastern Australia[1172] and unusually warm late summer sea surface temperatures in the Region[459]. Extreme El Niño events have occurred in the Region in 1982–83, 1997–98 and 2015–16 coinciding with worldwide climate extremes and are predicted to increase in frequency due to climate change.[1173] Compared to the past four centuries, Eastern Pacific El Niño events over the last 30 years have been fewer, but more intense.[1174] Additionally, the link between El Niño and coral bleaching has weakened, because La Niña sea surface temperatures today are warmer than they were during El Niños 30 years ago, due to global heating.[99] Two of the four mass bleaching events on the Reef have occurred during El Niño phases of El Niño–Southern Oscillation cycles (1998 and 2016) and two have not (2002 and 2017).[88] Even if global warming is limited to 1.5 degrees Celsius, the risk of extreme El Niño events is predicted to increase from around five events per 100 years to at least 10 events per 100 years by 2050 (based on the lowest emissions scenario RCP2.6).[1172] During extreme La Niña events, the Australian summer monsoon is more vigorous than usual, with more tropical cyclone activity in the Region. This results in above-average rainfall and river flows, as happened in 2010–11. The extreme rainfall of that summer season was exacerbated by warmer sea surface temperatures around tropical Australia.[1175] The frequency of such extreme La Niña events are also projected to increase in a warmer world.[1176]

The extreme rainfall event in early 2019 resulted in widespread flooding, inundating homes, businesses and local sports clubs, such as the Townsville and James Cook University Rowing Club. © Chloe Schauble

6.3.2 Vulnerability of the ecosystem to climate change

The Region is particularly vulnerable to the pervasive influence of a rapidly changing climate.[1150] The primary concern is impacts on habitat-forming species, such as corals, seagrasses and mangroves, in the Region. Severe impacts that reduce the abundance or condition of habitats have flow-on effects to dependent species and communities in the Region.[1177,1178,1179]

Increasing temperatures are threatening most species and habitats in the Region

Coral reefs and coral-dependent species are the most vulnerable to **sea temperature increases**[1180] (Figure 6.7), as evidenced by the 2016 and 2017 mass bleaching events (Sections 2.3.5 and 2.4.4). Cascading effects have already resulted in the decline of coral-associated fish and invertebrates.[244,273] As the climate continues to change, the capacity of hard corals to survive, grow and reproduce is increasingly compromised[96], with resulting consequences for other species dependent on coral reefs (Section 2.3.5).

Seagrass meadows are less vulnerable to temperature increases than are coral reefs (Figure 6.7).[1181,1182] However, extreme water temperatures (greater than 40 degrees Celsius) can be fatal to seagrasses.[1181,1183] Recent evidence has linked seagrass decline in Western Australia[1184] and more than 7400 hectares of mangrove dieback in the Gulf of Carpentaria[1185] to severe marine heatwaves due to global warming. Severe cyclones Ita (2014) and Nathan (2015) resulted in 400–600 hectares of mangrove forest dieback near the Starcke River, Cape York.[52] These mortality events highlight the susceptibility of these ecosystems to the effects of climate change. Loss of seagrasses and mangroves will potentially release stored carbon back into the atmosphere, contributing to further rises in atmospheric carbon dioxide concentrations.[51,61] Projections of the future distribution of seagrasses suggest a poleward shift due to increasing sea water temperatures.[1186]

Bleached hard and soft corals at Low Isles, March 2017.
© Jenni Fox 2017

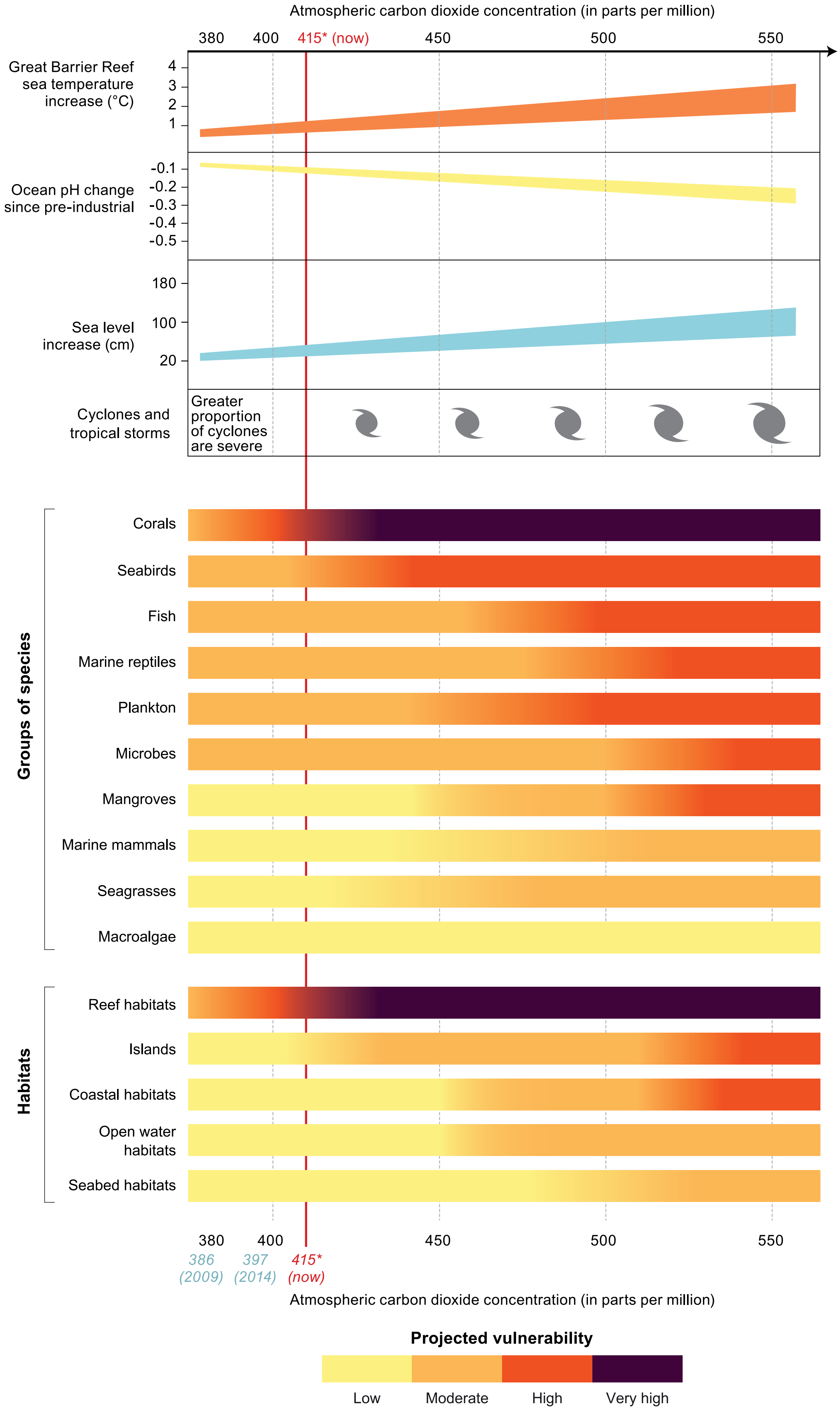
Calcifying organisms, including corals, echinoderms and algae, are most vulnerable to **ocean acidification**.[231,508,1187] Even relatively small decreases in ocean pH reduce the capacity of corals to build skeletons, which in turn reduces their capacity to create habitat.[1188,1189] As ocean acidification rates are highest on inshore reefs, which account for approximately 20 per cent of the total number of reefs in the Great Barrier Reef, the rapid decline of these inshore reefs is of great concern.[162] When calcifying organisms are weakened they are less able to resist and recover from physical damage caused by tropical cyclones.[1190]

Since 1975, a 27–49 per cent decrease in net calcification by the coral community has been observed on Lizard Island reefs.[1191] Another study demonstrated that net community calcification under pre-industrial conditions was significantly higher than it is today.[1192] This may indicate that ocean acidification could already be impairing coral reef growth. Over 55 million years ago, under high atmospheric concentrations of carbon dioxide, a reduction in calcification occurred.[105,1193,1194] It took tens of thousands of years for those changes to reverse[543], which means the emerging risks associated with ocean acidification will be essentially irreversible on human timescales.[1195]

Sea-level rise is projected to place significant pressure on coral reefs[488], mangrove forests[1185] and seagrasses[47], as well as on salt marshes and islands.[1196] For these habitats to persist, growth must keep pace with sea-level rise, however few coral reefs have the capacity to do this.[488] More frequent coastal inundation will lead to hyper-salinisation of coastal habitats and shifts in intertidal species distributions.[510]

Most marine organisms are ectotherms and are unable to regulate their body temperature. Increases in temperature affect their performance and fitness.[1197,1198] Temperature impacts due to global warming are evident on many species in the Region (Section 2.4), with mass mortality of fish and invertebrates in shallow northern reef lagoons in 2016.[90] Temperature experiments involving coral trout found declines in survivorship, metabolism and swimming activity with relatively moderate increases in temperature[277,1023,1199] (Section 2.4.7). Feminisation of green turtle hatchlings originating from Raine Island nesting beaches has been an ongoing trend for more than two decades, due to increasing sand temperatures caused by global warming (Section 2.4.10).[319] Thermal stress reduces reproductive rates and alters behaviour in crustaceans (Section 2.4.5).[243,636] Although the sub-lethal effects of temperature are often inconspicuous, they can potentially de-stabilise how the ecosystem operates.[243,636,1200]

Indirect effects of increasing temperatures are also a concern for the Region. Latitudinal shifts in species distributions and changes in the timing of biological events have already been shown for a number of plankton, bony fish and invertebrate species in response to temperature increases.[1201] Effects of increased sea surface temperatures, such as changes in timing of breeding and body size of breeding adults and loss of adequate food supplies, have been observed in many bird populations within the Region.[361,1202,1203,1204]



* For the first time since human existence, the planet's atmosphere has reached 415ppm

Figure 6.7 Projected vulnerabilities of components of the Reef ecosystem to climate change
Vulnerability differs for a number of ecosystem components and depends on total atmospheric carbon dioxide concentrations. Changes in sea temperatures, ocean pH and sea level are indicative only, based on the latest climate projections.
Source: Adapted from values presented in Gattuso *et al.* 2015[1159] and Hoegh-Guldberg *et al.* 2018[487]

As the East Australian Current strengthens and moves warmer water further south, some tropical species are expanding southwards along the southeast coast of Australia.[1205,1206] As southern waters continue to warm, particularly during winter, these species may persist and establish new populations, representing a range expansion and the tropicalisation of temperate marine ecosystems.[691,1207] Different species compositions could result in a reorganisation of ecosystem functions, particularly if displaced species are habitat-forming and lose their dominant position in the ecosystem.[1208,1209] Overall, range shifts and changes in the timing of biological events can desynchronise ecological interactions and thereby threaten ecosystem function.

The Region's key habitats, such as coral reefs, seagrass meadows and mangroves, have a natural resilience against acute physical disturbances, such as tropical cyclones, intense rainfall, freshwater flood plumes and heatwaves. However, climate change is exacerbating both acute and chronic disturbances in the Region, shrinking recovery windows and overwhelming resilience capability.[99,439,1152,1172] In the past four decades, warming due to climate change has resulted in a five-fold increase in severe coral bleaching events globally[99], and it will amplify the effects of other influencing factors, such as direct use, coastal development and land-based run-off (Sections 6.4 and 6.5).

6.3.3 Implications of climate change for regional communities

Climate change is the primary driver increasing threats to communities living in, or adjacent to, the Region, through an increase in climate extremes (record-breaking temperatures, floods and droughts) and declining Reef condition. This then affects health and wellbeing, food security and economic benefits. The ecological and economic benefits regional communities derive from the Region are diverse, and include income from fisheries and tourism, coastal protection, habitat provision for valuable species and cultural values.[1210] Climate change has already reduced fisheries productivity[1211], positive tourism experiences[1212], and coastal protection by mangroves, seagrasses and coral reefs.[1213,1214] For example, it is estimated that global marine fisheries catches will decline by three million metric tonnes for every degree Celsius of global warming, with serious regional impacts.[1215] Human health will also be affected by climate change, through increased disease outbreaks[1216], heat stress[1217] and reduced food security.[1218]

The threat of climate change is particularly pronounced for Reef-reliant communities

The vulnerability of reef-reliant industries largely depends on their exposure and sensitivity to the associated impacts, as well as their ability to anticipate and adapt to change. Surveys indicate people in the tourism industry are very concerned about the impacts of climate change on their businesses and livelihoods. Approximately one third of commercial fishers surveyed expressed similar concern, but many others still felt they needed more evidence to be convinced of the problem[785] (Section 6.2.3). Building stronger and more resilient communities will be critical for the future sustainability of reef-reliant industries.[24] Actions taken to improve community knowledge of climate change will enable communities to better prepare for, and mitigate, the impacts of climate change.

6.4 Coastal development in the Catchment

Coastal development includes all development activities, construction and land uses along the coastline as well as inland areas within the Catchment and development on islands (Section 2.3.1). The broad range of intensive land use in the Catchment exerts individual and cumulative pressures on coastal and inshore ecosystems.[718] It is broadly accepted that to support the condition and resilience of the marine ecosystem, priorities must continue to focus on reducing agricultural sources of pollutants from contributing land uses.[462,1219] Using land for agriculture is an aspect of coastal development. Trends in agricultural land management practices that affect water quality are examined in the land-based run-off section of this report (Section 6.5).

New and legacy barriers to the flow and modification of coastal ecosystems continue to affect Reef health

Approximately one million people live in the Catchment.[1126] In 2016, an estimated 885,000 people were living in the 18 local government areas with direct coastline access to the Region[1054,1220], approximately four per cent more than in 2011. Around 4100 new dwellings were constructed in these local government areas between 2014 and 2017, representing a slower housing market of approximately eight per cent in the same period. Population growth drives coastal development, concentrating mainly around urban areas. In turn, infrastructure demands intensify (for example, more roads and larger stormwater networks) and expansion into previously remote areas of the Catchment may occur (for example, Cape York). Pressure to produce and export food will also drive demand for agricultural land in the Catchment. Since 2014, the greatest expansion of any land use in the Catchment has been in conservation and natural environments, including wetlands (Figure 6.8). The expansion has specifically involved the conversion of one land use to another, and occurred predominantly in the Cape York and Mackay–Whitsunday natural resource management (NRM) regions.

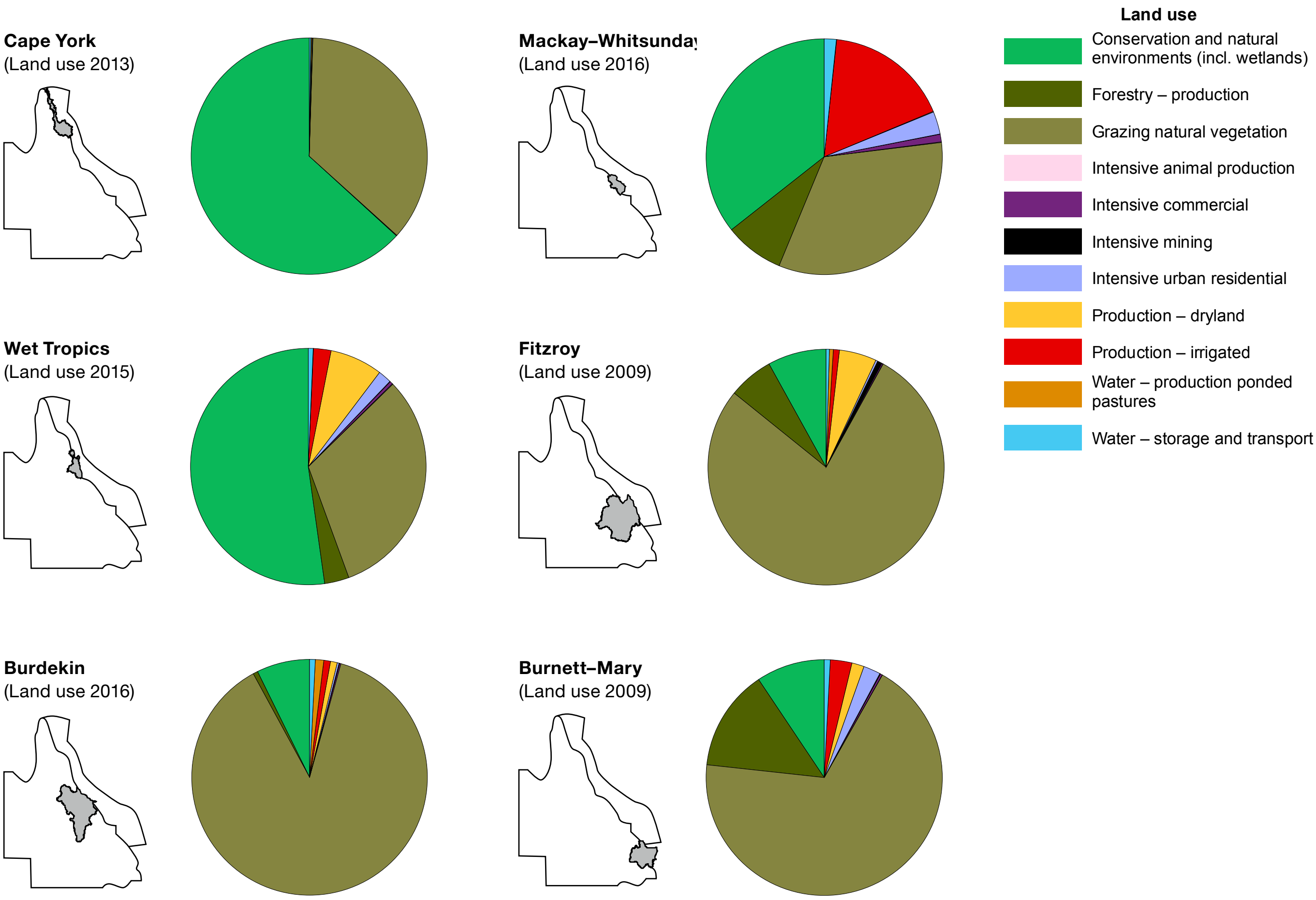


Figure 6.8 Proportion of land uses in the Catchment
Catchment land uses are grouped according to similarities in the ecological functions they provide to the Reef. The graphs identify the latest data capture between 2009 and 2016 for each natural resource management region. Source: Adapted from Department of Science, Information Technology, Innovation and the Arts (Qld)[1221]

6.4.1 Trends in coastal development

Agriculture Most land in the Catchment (about 72 per cent) supports some form of agricultural use (grazing, dryland or irrigated production and intensive animal production).[1221] As with other sectors of the Queensland economy, the primary industry sector has experienced growth in the value of production since 2014. In 2017–18, the total value of Queensland's primary industry commodities (combined gross value of production and first-stage processing) was forecast to be $19.45 billion — nine per cent greater than the average for the previous five years.[1222]

Most land in the Catchment supports some form of agricultural use

© Department of Environment and Science (Qld)

Agriculture is the main pollutant source affecting the condition of the marine ecosystem, via land-based run-off from the Catchment (Section 6.5).[527] Diffuse source pollution (not from a single discharge point) is run-off from agricultural land uses. The magnitude of the threats to the Region from poor water quality are influenced by activities, soil type and topography in the Catchment. Relevant activities include modifying coastal ecosystems (Section 3.5); the construction of barriers to flow (such as roads, rail lines, ponded pastures and weirs); and subsequent agricultural land practices (such as fertiliser use, irrigation and crop-rotation). New and legacy vegetation clearing and infrastructure, such as ponded pastures, continue to be significant human-induced threats to the Reef.[9,1219,1223] How the land can be managed to minimise the threat is considered in the assessment of land-based run-off in Section 6.5.

Mining and resources Queensland's richest resource provinces are located within the Catchment. The resource sector contributed $29.1 billion (including direct spending on royalties, tax and wages) to Queensland's economy in 2017–18.[1224] Coal mining was the largest contributor, accounting for approximately $19.9 billion (68.3 per cent of the total spending). While coal exploration activities in Queensland have declined (with a 25 per cent drop in granted exploration tenure in 2015–16 compared with the previous year), new projects are still in progress.[1225] Statewide coal production (coking and thermal net output) remained generally steady between 2014–15 and 2016–17 at approximately 240 million tonnes per annum.[1224]

Urban run-off is a lower threat than run-off from other major land uses

Urban and industrial development Urban and industrial development occupies a small proportion of the Catchment (less than 0.7 per cent) and minimal expansion has occurred since 2014.[1221] Population growth exerts pressure to develop land, construct new or upgrade infrastructure (such as roads and utilities, which impede flow) and encroach on coastal and inshore ecosystems.[1226] Gaps remain in our understanding of cumulative impacts from new and legacy development. Given the established regulatory framework for urban and industrial development, the impact of urban run-off (or point source pollution channelled to a single discharge point; Section 6.5) on water quality and Reef condition is considered localised and a lower threat than run-off from other major land uses. Instead, the influences of agriculture (particularly cane farming and cattle grazing land management practices) continue to be the focus of ongoing water quality management.[462] In 2018, urban, industrial and public lands were incorporated into new water quality targets.[527] The increasing impact of land-based marine debris is an emerging concern for Australian residents[785] (Section 6.5). The extent of artificial light pollution from coastal development (urban areas, industry, ports, marinas and ships in anchorages) remains a data gap.

Sewage treatment plants An example of point source pollution is sewage treatment plants. These facilities have been progressively upgraded over the last 25 years.[9] In 2017, an industry analysis estimated that 76 sewage treatment plants were located within 50 kilometres of the coastline.[1227] Of these, 27 had achieved best practice for the reduction of nitrogen and phosphorus loads to the Region ('tertiary' treatment standard). Achieving this standard may not always be feasible in some locations.[1219,1227] Overall, the contribution of sewage treatment plants to anthropogenic nutrient loads to the Region is minor[467], however, comprehensive evidence about these facilities is limited.[1223]

Barriers to flow Waterways within the Catchment have been affected by barriers to flow since European settlement. Structures of all sizes that impede water flow have an influence on waterway condition and function. Data are limited on the extent of these structures across the Catchment, however, statistics are available for the Mackay–Whitsunday and Wet Tropics NRM regions. River basin assessments for 2013–14 in the Mackay–Whitsunday region consider barrier density on freshwater waterways, estuary barrier density and in-stream habitat modification.[1228,1229,1230] For example, overall the Plane River rates poorly and the Don River is considered good. The Wet Tropics analysis from 2015–16 continues to evolve, and several indicators have not yet been developed or monitored.[1231] However, the Wet Tropics region had more waterways free of barriers in 2015–16 than the Mackay–Whitsunday region in 2013–14.

Tidal works Sea walls, groynes and reclamation are tidal works that present barriers to flow. The Region is susceptible to impacts from tidal works mainly near built-up areas. Tidal works have occurred in, and adjacent to, the Region since European settlement. While quantifiable extent data are available for some works, comprehensive data on all tidal works and their cumulative impacts are lacking. A recent study estimated nine per cent of the Region's mainland shoreline has been modified by engineered structures.[1232] Most structures occur in marina and port developments, with 60 per cent located within the lower three kilometres of estuaries.

Linear infrastructure Privately and publicly owned roads, rail and tracks are types of linear infrastructure that present barriers to flow. They are not confined to built-up areas and are present across the Catchment. New or upgraded roads make marine and coastal areas more accessible and can increase direct use of the Reef. Erosion from linear infrastructure has been identified as a significant sediment source within particular parts of the Catchment[467] and a vector for pests and weeds into remote coastal ecosystems. For example, in the Normanby–Stewart catchment of Cape York, linear road infrastructure represents the largest direct human-induced disturbance of all intensive land uses in this area.[1233] Access to quantitative data on the state of existing linear infrastructure remains a challenge for condition and trend reporting.

Linear road infrastructure represents the largest anthropogenic disturbance in some areas of the Catchment

Aquaculture Aquaculture is a comparatively minor land use in the Catchment, covering an estimated 30 square kilometres. However, six land-based aquaculture development areas identified in the Catchment are proposed to promote the growth of this sector.[1234,1235,1236] Since 2014, the statewide production value has been varied but overall it has declined (less than five per cent, from $120 million in 2014–15 to $114 million in 2017–18).[1237] No marine-based aquaculture facilities are currently operating in the Region.

Port development Port development undertaken directly in the Region is described and assessed in Section 5.5. Land-based aspects of port activities (above low water mark, including reclamation) form part of the coastal development assessment. However, coordinated data on the extent of new and legacy port reclamation remains a data gap. New reclamation is thought to be minimal since 2014. Point source pollutants from ports are regulated and impacts on the Region are largely localised. However, coordinated data across all ports in the Region are limited.

Marine access infrastructure Marine access infrastructure and launch facilities (boat ramps, pontoons and marinas on islands, in rivers and on the mainland coast) support local, recreational and tourism access to the Region. While some of these facilities are outside the Region, impacts from dredging and disposal of these facilities may flow into and affect the Region. The threat is assumed to be minimal and localised, given the small volumes and permit conditions. Since 2014, approximately 323,000 cubic metres of material in total was dredged (capital and maintenance) at these facilitates in and adjacent the Region.[1238]

Island development Development on some of the Region's islands supports permanent residential populations and tourism resorts. The principal residential islands include Palm Island and Magnetic Island, with stable populations of about 2400 and 2300, respectively.[1054] Islands of the Reef form part of the property's outstanding universal value. The property's aesthetic heritage value has been affected by a number of deteriorating island destinations on state-owned land (including national parks).[1239] While many island resorts have remained closed following cyclones in 2011 and 2017, Daydream Island Resort reopened in early 2019. At the time of writing, a proposed redevelopment on Great Keppel Island had not progressed and a proposal at Lindeman Island was amended, removing marine infrastructure elements. A development at Hummock Hill near Gladstone, approved in 2018, also amended its plans to remove marine infrastructure.

Deteriorated island resort infrastructure affects aesthetic heritage values

6.4.2 Vulnerability of the ecosystem to coastal development

The Region's ecosystem remains vulnerable to the effects of legacy, current and future coastal development, as well as cumulative impacts. The primary pressure from coastal development is from agricultural land use. By comparison, pressure from urban, industrial and mining development is minor. Modifying coastal ecosystems and barriers to flow increases the risk posed by poor water quality entering the Region.

The Region's ecosystem remains vulnerable to the effects of legacy, current and future coastal development

Modifying coastal ecosystems for coastal development limits their ability to provide ecosystem function and services that benefit the values of the Reef[102] (Section 3.5). For example, modifying wetlands can limit their effectiveness in absorbing and transforming pollutants, slowing overland flow and providing nurseries for freshwater and marine species.[43,102,707,719] Intact coastal ecosystems can prevent major erosive processes (like gully erosion) and abundant ground cover may decrease sediment and nutrient loads entering the Region.[467] As an indicator of modification, between 2015–16 and 2017–18, the Catchment accounted for a consistently high proportion (about 38–47 per cent) of woody vegetation clearing in the state (Section 3.5 Figure 3.12).[703,704]

Land-based pollutants from the Cape York NRM region are not recognised as posing a high threat to coastal or marine ecosystems.[1240] Even so, proactive management actions are being taken. For example, in 2016 the Queensland Government purchased Springvale Station (a 560 square kilometre cattle property) with an aim to reduce sediment into the Normanby River catchment. The property is in the state's protected area estate and contributes to the 73 per cent of area added to conservation and natural land use across the Catchment.[1233,1241] Data are not yet available on the performance of the remediation activities on Springvale Station (such as destocking and erosion management[1242]; Figure 6.9) or any improvements in water quality entering Princess Charlotte Bay. By contrast, the Cape York region falls within the 20-year plan to invest and support economic expansion of northern Australia.[1243] This initiative may result in expansive new barriers to flow and further modification of coastal ecosystems in this area.

Agricultural land use is the primary pressure on the Reef from coastal development

Barriers to flow, such as tidal barrages and tidal works, have historically been installed to prevent the ingress of saline tidal waters and often to provide road access to the foreshore. As a result ponded pastures are created, impounding fresh water or forming an area to expand cropping and grazing land (Section 3.5.1). Where barriers reduce freshwater flow and connectivity between marine and freshwater systems, fisheries productivity can be reduced.[1244,1245,1246] Long-standing legislative arrangements mean the Region's exposure to impacts from new ponded pastures infrastructure should be limited.[712,713]

Figure 6.9 Gully erosion, West Normanby River catchment, Springvale Station © Kerry Trapnell 2017

Barriers to flow have been linked to the mobilisation of acid sulfate soils. Activities that may disturb **acid sulfate soils** have been regulated in Queensland since the early 2000s, reducing the exposure of the Region to such impacts. Acid, metals and other contaminants in these soils can affect many species at a local scale, both immediately and through accumulation in the food chain. This occurred in the Trinity Inlet (Cairns) where a seven kilometre bund wall was constructed in the 1970s to enable sugar cane production.

The Queensland Government purchased and created the East Trinity Environmental Reserve in 2000, undertaking active remediation. By 2016, the area returned to a functioning mangrove ecosystem and wildlife habitat.[1247,1248]

Tidal works, such as foreshore seawalls and groynes outside, and encroaching on, the Region, can affect inshore marine habitats by altering local marine hydrology, permanently removing inshore marine habitats and diminishing local aesthetic attributes. The presence of **artificial light** adjacent to the Region is an inferred increasing risk as regional communities expand in the coastal zone. It is known that emerging marine turtle hatchlings have a reduced ability to find the sea in the presence of artificial light (Section 2.4.10).[331]

Mining and other resource activities cover a comparatively very small proportion of the Catchment, but they can expose the Region to impacts that are hard to reverse. Contaminated tailing water flowing into the Region or water table is a current and future threat. Threats are regulated through new environmental protection legislation.[1249,1250,1251] Resource-based activities can affect the Region's natural, Indigenous and historic heritage value in two main ways.[1252,1253] Firstly, the historical export of resources and agriculture has been the major driver of port, linear infrastructure and urban expansion along the Region's coast. Secondly, continued global use of fossil fuels is the primary driver of climate change and ocean warming (Section 6.3).

Atmospheric pollution (excluding the contribution to climate change of gases, such as carbon dioxide) is not currently a significant threat to the condition of the Reef. While some recent studies have considered the impacts of pollutants like coal dust particles on the Reef (Section 5.7)[1078,1079], limited data are available for other atmospheric pollutants.

6.4.3 Implications of coastal development for regional communities

Coastal development occurs in areas of the Catchment where the bulk of the population reside. While rural areas have low populations, coastal development in the form of agriculture (specifically grazing) is the dominant land use in the Catchment and is the primary source of poor water quality entering the Region. As such, human-induced land-based run-off remains one of the greatest impacts and threats to the Reef — and one of the most manageable.

In urban areas and small communities, coastal development provides broad economic and social benefits via employment, economic activity, housing and places for recreation. While some data and monitoring gaps exist, urban activities are considered well regulated and their impacts on the Region are largely minor and localised.[462,1219] However, modifying coastal ecosystems for further urban or agricultural development remains a threat to the condition of the Region. The pressure exerted by modifying coastal ecosystems is more pronounced in rural areas, resulting in poor water quality entering the marine environment.[1219] Poor water quality more broadly can affect the economic and social benefits regional communities derive from the Region (Section 6.5.3). The effects of climate change (Section 6.3) are likely to amplify the effects of coastal development (urban, industrial and rural) on the Region. The implications of coastal development, therefore, cannot be considered in isolation.

Implications of coastal development cannot be considered in isolation from other influencing factors

6.5 Land-based run-off

Land-based run-off comprises freshwater flow (Section 3.2.3) from the terrestrial environment and what is carried with it into receiving waterbodies, including sediments, nutrients, pesticides and other pollutants (Sections 3.2.4 and 3.3.1). Land-based run-off can be both point source and diffuse source. A point source is a single, identifiable, discharge point, such as a pipe. Diffuse sources are inputs occurring over a wide area, not easily attributed to a single source, such as land-based run-off.

As water flows through the Catchment to the marine environment, the uses of the land it passes through and over have a strong influence on its volume, velocity and quality. Activities, such as the application of fertilisers, livestock management, pest control, stormwater and sewage management, aquaculture, mining and fracking, and earthworks can all affect the resulting water quality.[1254]

Diffuse source land-based run-off occurs naturally and has always delivered sediments and nutrients to the Region. However, changes in land use within the Catchment since European settlement have increased the loads of sediments, nutrients and other pollutants (including pesticides, herbicides, heavy metals and plastics) entering the Region. The expansion of Catchment development (particularly agriculture) has been a primary contributing factor (Section 6.4).

The 2017 Scientific Consensus Statement determined that *'current initiatives will not meet the water quality targets'* and *'progress towards water quality targets has been slow'*.[462,1223] The *Reef Water Quality Protection Plan 2013*[720] was updated in 2017, and transitioned into the *Reef 2050 Water Quality Improvement Plan 2017–2022* (Reef 2050 WQIP).[527]

The Reef 2050 WQIP was released in 2018. Actions and progress towards Reef 2050 WQIP targets are assessed annually. The whole-of-Reef water quality targets in the Reef 2050 WQIP to be achieved by 2025, include:

- at least 60 per cent reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads
- at least 20 per cent reduction in anthropogenic end-of-catchment particulate nutrient loads
- at least 25 per cent reduction in anthropogenic end-of-catchment fine sediment (less than 16 micrometres) loads
- protect at least 99 per cent of aquatic species at the end-of-catchments.[527]

6.5.1 Trends in land-based run-off

Freshwater flowing from the Catchment is the main mechanism for transporting pollutants into the Region. The condition and trend of specific pollutant loads and water quality parameters most relevant to land-based run-off (nutrients, sediments, pesticides and other pollutants) are detailed below. Freshwater inflow, nutrient cycling, sediment exposure and salinity are discussed in Chapter 3.

Since 2014–15, annual freshwater discharge to the Region has been below the long-term median due to below-average rainfall (Section 3.2.3). As a result, annually monitored sediment, nutrient and pesticide loads discharged into the Region have been relatively low, particularly in comparison to the previous Outlook reporting period, in which several large-scale floods influenced the Region.[469] However, extreme rainfall and flooding occurred between the Cape York and Mackay–Whitsunday regions in February 2019 (Section 3.2.3). Research into the impacts of this large freshwater flow is underway but results fall outside this reporting period.

Catchment modelling is used to estimate the long-term annual average load reductions expected as a result of the reported adoption of improved land management practices (Box 10 and Figure 6.12). This modelling factors in significant inter-annual variability of climate conditions when assessing improvements. Although the models used involve certain assumptions and limitations[1255,1256], they draw on the best available science and the information produced is generally well regarded. Modelled results for 2014–2017 indicate that Region-wide progress in load reductions ranged from very poor to good, depending on the pollutant being measured.[463] The rate of progress slowed for all pollutants after 2013 compared with the improvement rate between 2008 and 2013.[1219]

It takes a significant period of time for improved land practices to influence the condition of inshore ecosystems

After 15 years of monitoring, it is still not clear whether reduced land-derived pollutant loads have made a measureable change in the trend of land-based run-off in the Region.[155] The lack of certainty is due to most parameters fluctuating over the monitoring period and annual variation in rainfall and run-off.[463,469,1257] Sufficient time series are required to differentiate annual variation from long-term trend in the quality of the receiving water.[462,469,472] In addition, it can take a long time for improvements in land management practice to show up as measured improvements in the water. The time lag can be years (for pesticides) to decades (for nutrients and sediments).[472,1258] For instance, it has been estimated it will take 50 years to detect load reductions at the end-of-catchments of both the Burdekin and Tully rivers.[1258] The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program is designed and adapted frequently to specifically detect changes well within these timeframes and inform management actions as needed.

Overseas studies have detected measurable reductions in river pollutant loads and associated coastal water quality and ecosystem condition, ranging between eight to 20 years for nutrients and 28 years for sediments.[1259] The small improvement in trend of water quality entering the Region suggests that Catchment land use changes have not yet been implemented at a sufficient scale or timeframe to result in a measurable difference. Confounding factors, including extreme weather events, also complicate this process.

Nutrients Nutrients occur naturally in the environment in relatively low concentrations. They include dissolved inorganic and organic nutrients (such as nitrogen, phosphorus and carbon) and particulate nitrogen and phosphorus (Section 3.3.1).[467] Modelling indicates that total nitrogen loads exported to the Region via land-based run-off have more than doubled since European settlement, from approximately 20,000 to 46,500 tonnes per year. This ranges from 1.2-fold to 4.7-fold increases for individual catchments. The largest nutrient loads come from the Wet Tropics (46 per cent) and Burdekin (21 per cent) regions.[467] This is largely due to land use changes in the Catchment, particularly fertiliser use in agriculture (predominantly sugarcane).[43,154,467,537,1260] Urban areas also contribute small amounts of nutrients to the Region, such as through wastewater discharges, which are important at a local scale.[467]

Nutrient concentrations across the length and width of the Region are highly variable; they are affected by the proximity of rivers, water circulation patterns and upstream land use. Concentrations of chlorophyll-*a* (an indicator of nutrient enrichment) across the Region hover near, or slightly above, the annual Great Barrier Reef Water Quality Guideline[1261] values, except in the Mackay–Whitsunday region where chlorophyll-*a* concentrations have exceeded guideline values since monitoring began in 2005 (Section 3.3.1).[155] All monitored inshore regions show increased concentrations of dissolved organic carbon since 2005, suggesting biogeochemical cycling is changing.[155,469]

Catchment modelling indicates very poor progress against nutrient reduction targets

Models suggest that investments to improve agricultural land management practices from 2009 to 2016 reduced the dissolved inorganic nitrogen load leaving the Catchment by 20.9 per cent. Reduced levels of chronic environmental stress are expected to follow for the Region's inshore ecosystems.[461,1262,1263] However, the lag between improved practices and environmental benefits is likely to mean that nutrient concentrations will continue to affect the ecosystem for years to decades.[43,167,470,1259] Current Catchment modelling reports very poor progress towards the dissolved inorganic nitrogen target of 60 per cent reduction for the whole Reef by 2025 under the Reef 2050 WQIP.[527] From 2009 to 2018, load reduction was only 21.2 per cent.[1264]

The largest loads of particulate nitrogen originate from the Wet Tropics (27 per cent) and Fitzroy (20 per cent) regions.[467] Particulate nitrogen primarily comes from land used for grazing.[467] As at June 2018, overall progress against the new Reef 2050 WQIP target of 20 per cent reduction by 2025[527] was 13 per cent.[1264] Particulate and dissolved organic nutrients are a major contributor of loads to the Region, but understanding of their sources and transformations remains a significant knowledge gap.[467]

Phosphorus often binds to sediments, particularly fine sediment, which may cause it to be more readily available once in the marine environment.[467] Modelling estimates that the Region's particulate phosphorus loads have increased 2.9-fold from pre-development conditions (with increases ranging from 1.2-fold to 5.3-fold for individual catchments).[467] The largest phosphorus loads come from the Fitzroy (33 per cent) and Burdekin (22 per cent) regions.[467] In the Wet Tropics and Mackay–Whitsunday regions, the main source of phosphorus is sugarcane farming. Grazing activities contribute the most in other regions. Cape York is the exception, contributing minimal anthropogenic phosphorus.[467] The Reef 2050 WQIP target for particulate phosphorus is a 20 per cent reduction in loads[527] entering the Reef by 2025. As at June 2018, a reduction of 16.2 per cent had been achieved.[1264]

Sediments Since European settlement, fine sediments entering the Reef lagoon are estimated to have increased five-fold, and in some regions up to eight-fold.[154,467] Land use south of Port Douglas is generally more intensive and adjacent inshore marine areas are more frequently exposed to greater sediment loads than those further north.[463]

Catchment modelling indicates moderate progress against suspended sediment reduction targets

The Burdekin region is the major contributor (approximately 40 per cent) of the total anthropogenic sediment load to the Region, followed by the Fitzroy (18 per cent), Wet Tropics and Burnett–Mary regions (15 per cent each).[467] The main sources of sediment loads from land are from grazing lands, erosion on hillslopes and sub-surface erosion from gully and streambank.[467] Sediments from urban areas can be important at local scales.[467]

Sediment loads are exacerbated by highly variable rainfall patterns across the various river catchments.[153,467,473] Sediments delivered from flood plumes settle relatively close to river mouths (within 50 kilometres).[470,471] However, fine sediment is carried further in suspension.[467,472] Delivery and resuspension of new sediments from run-off and dredging, and resuspension of existing sediments, combine to affect water quality condition.[467,471,475] Concentrations of total suspended solids in the marine area are either below or at the annual Great Barrier Reef Water Quality Guideline values in the Johnstone–Russell–Mulgrave sub-region (Wet Tropics) and Burdekin region.[155,1261] However, in the Tully–Herbert sub-region (Wet Tropics) and Mackay–Whitsunday region, concentrations are either on or slightly above guideline values.[155] Water clarity has decreased in the Mackay–Whitsunday region since monitoring began in 2005.[155,469]

A key target of the Reef 2050 WQIP is to achieve a 25 per cent reduction in sediment loads entering the Region as a result of human activities by 2025.[527] Overall progress, as of June 2018, shows a reduction of 14.4 per cent.[1264] A significant lag time is likely before reductions in suspended sediment load in the Region will be measurable and water quality improvements are ecologically significant; sediment effects will continue for years or decades.[43,167,470,1258,1259] In addition, sediment exposure is expected to increase with the predicted increase in severity of extreme weather events due to a changing climate.[43]

Turbid river plume emerging from the Mulgrave–Russell river system, February 2015. © Dieter Tracey

Pesticides Pesticides, including herbicides, insecticides and fungicides, are used to control pests and weeds in agricultural and urban environments. These compounds were absent from the Region's environment before European settlement.[1265,1266,1267]

The current pesticide target aims to protect at least 99 per cent of aquatic species from all pesticides, as measured at the end-of-catchments. To date, pesticide reduction has mainly focused on reducing the loads of five photosystem II (PSII) herbicides (ametryn, atrazine, diuron, hexazinone and tebuthiuron).[1268] However, with advances in understanding of the toxicity of a broader range of pesticides, the assessment has expanded to 22 pesticides (PSII herbicides, other herbicides and insecticides) with a focus on reducing concentrations (that directly relate to species protection) rather than loads of pesticides.[1268]

Sugarcane cropping contributes more than 95 per cent of the total load of photosystem II (PSII) herbicides entering the Region

Up to 56 different types of pesticides and pesticide metabolites have been detected in the Region's freshwater, estuarine, wetland and marine ecosystems.[1269] These most often occur in mixtures and can have a joint toxic impact on organisms (Section 6.5.2). Since 2009, there is no clear reduction in nearshore marine pesticide concentrations linked to improved land management practices.[1254,1270] Diuron, atrazine and hexazinone are the most consistently detected and abundant PSII herbicides at most sites, reflecting land use in sugarcane, horticulture and grain cropping industries.[1268] The concentrations of pesticides in marine waters in the Region remains generally low.[1268] The highest pesticide concentrations are generally found at the Mackay–Whitsunday sites (Round Top Island).[1268] The spatial pattern of pesticide concentrations in the marine environment reflects the dominant land use in the adjacent Catchment, and highest concentrations are found closest to the source.[1269] Sugarcane cropping contributes more than 95 per cent of the total load of PSII herbicides entering the Region and is the dominant land use in the Wet Tropics.[1269] The cumulative effects of long-term exposure to the mixture of pesticides is not well understood, and there is the potential that exposure may reduce resilience of inshore seagrass and coral habitats.[1268,1270,1271]

Marine debris Marine debris, in particular plastic, causes environmental, economic, aesthetic and human health impacts.[36,159,467,580] The most common marine debris found in the Region are plastic remnants (including lids, wrap and containers), rope and net scraps, cigarette butts and rubber footwear.[42,1272]

Plastic remnants dominated marine debris loads collected in more than 261 beach clean-ups within the Region in 2017.[37] However, single-use plastics only constituted a small proportion (approximately one to two per cent) of the overall marine debris collected.[37] The three most prevalent types of single-use plastic were plastic drink bottles, plastic bags and straws (Figure 6.10). More single-use plastic items were found washed up on islands than at coastal or inland locations.[1273]

Global plastic use has increased twenty-fold since the 1960s and is expected to double again in the next 20 years[1274], so the potential for global environmental harm is significant. The distribution and volume of marine debris are highly influenced by the amount washed into the Region, its size and buoyancy, and the effects of currents, winds and the shape of the coastline and offshore islands. Marine debris enters the Region from the Catchment (from industrial and urban sources) and from local and international ocean-based activities (ship-sourced waste, abandoned fishing gear from recreational and commercial fisheries, and recreational uses and tourism).[43,1275] The distance marine debris travels depends on its source and weight. Marine debris from rivers in the Region is estimated to travel an average of 19 kilometres from its source, whereas marine debris from shipping is estimated to travel approximately 225 kilometres.[36] Predicting plastic movement can be difficult given the uncertainty around how a diverse range of particles will respond to hydrodynamics and wind. Understanding and quantifying the source and volume of marine debris in the Region is improving, but remains a significant knowledge gap that requires ongoing effort.[43]

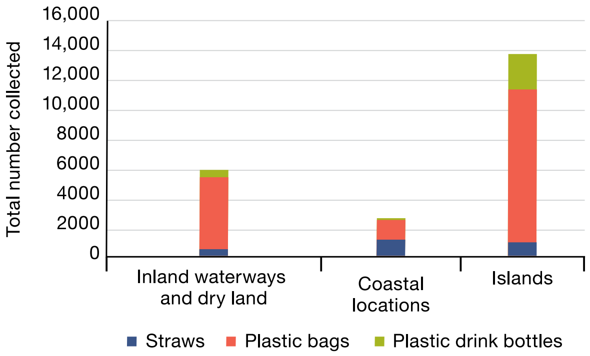


Figure 6.10 Three of the most prevalent types of single-use plastic collected from across the Region, 2017
The data represents 134 coastal beach, 92 island and 35 waterway and dry land clean-ups. Source: Australian Marine Debris Initiative 2018[37] GBRMPA acknowledges the Australian Marine Debris Initiative and the community organisations and individuals involved in the collection and provision of data used in this report.

The type of marine debris washing up on coastlines and islands across the Region between 2014 and 2018 differed from north to south and from the coastline out to islands (Figure 6.11).[37] Over that time, marine debris initiatives recorded 6645 clean-up days (recorded by the Tangaroa Blue Foundation 2018), which is likely to be an underestimate, especially for activities in isolated areas.[37] Plastic remnants (hard plastic and film fragments) were the most prevalent marine debris type in 2014-2018 in all regions, on both the coast and islands.[37] Less local litter originates from the Cape York coast in the northern sector compared with the more populated central (adjacent to Townsville) and southern (adjacent to Bundaberg) sectors.[37]

At a smaller scale, a separate study on islands in the Capricorn Bunker Group (offshore Gladstone), found marine debris had probably come from local sources, such as tourism and fishing.[1276] Cape York and the Wet Tropics received the highest proportion of garbage being washed ashore from sources at sea (for example, from South East Asian sources).[42,43] Cape York's exposure to both oceanic sources and local shipping activity is of particular concern.[43] Debris sourced from shipping and recreational fishing over this same time period was relatively low in all other areas.

Other pollutants Other pollutants, including metals and metalloids, antifouling paints, pharmaceuticals and personal care products (such as cosmetics and soaps) can be found in the Region.[1240] Chronic contamination from antifouling paints and exposure to personal care products have been assessed as a risk in regions south of Cape York.[1240] These pollutants are associated with land-based run-off and high levels of human occupation locally and globally.[43,1075] Pharmaceuticals and personal care products have been found in treated sewage (for example, paracetamol in the Fitzroy region)[1277,1278], although monitoring information on spatial and temporal variation of these pollutants is limited.[1075]

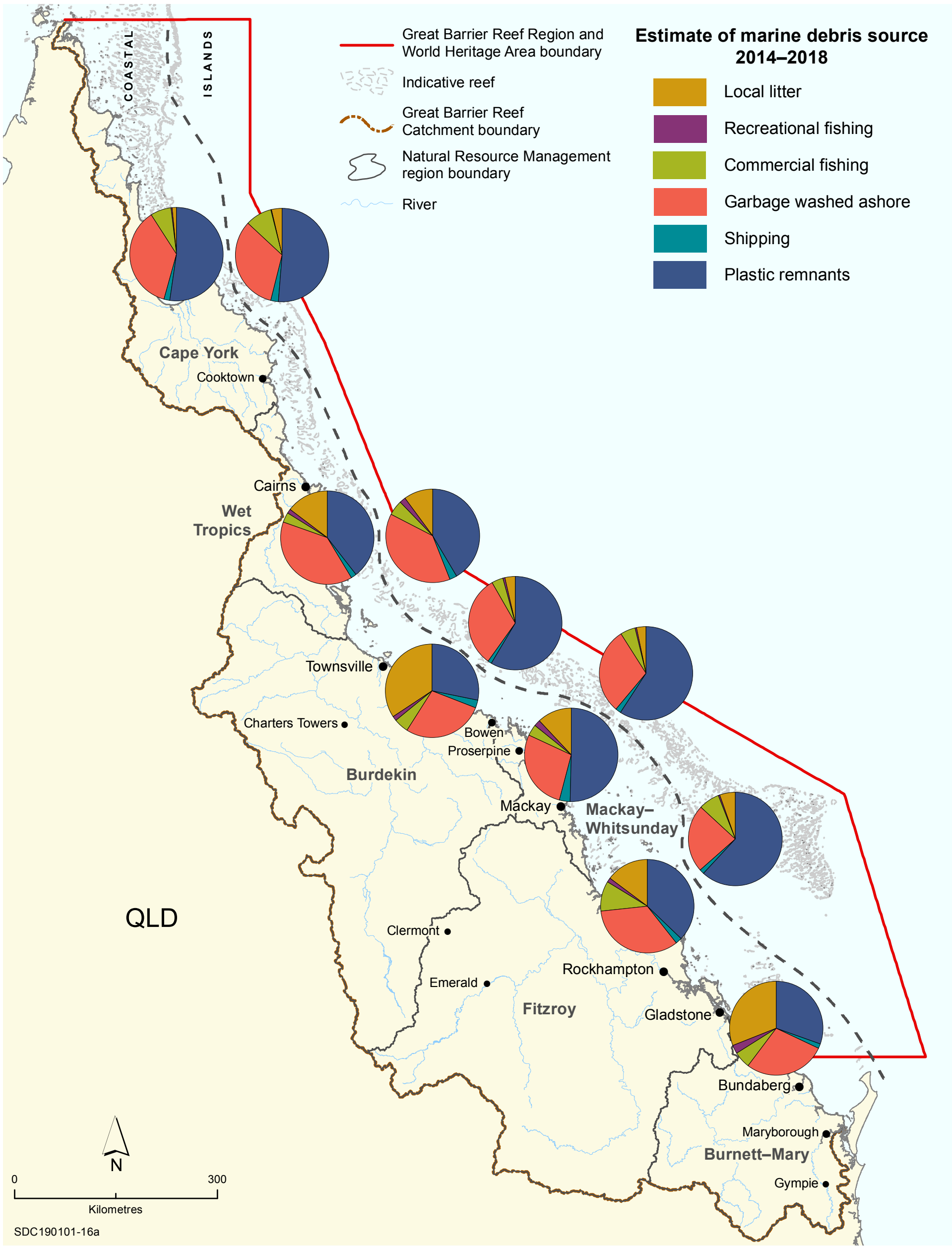


Figure 6.11 Estimate of the main source of marine debris, 2014 to 2018
Data shown cover marine debris collected from coastlines and islands adjacent to six natural resource management regions from 2014 to 2018. Plastic remnants are from unidentified sources.
Source: Australian Marine Debris Initiative[37] GBRMPA acknowledges the Australian Marine Debris Initiative and the community organisations and individuals involved in the collection and provision of data used in this report.

Although artificial chemicals were expected to be in very low concentration, a test of inshore areas in 2016–17 detected eight pharmaceuticals, two personal care products, one illicit drug, 13 endogenous chemicals, two fungicides and one herbicide metabolite.[1270] The cumulative effects of the mixture of chemicals are unknown and little monitoring information exists for non-agricultural chemical pollutants.[1270]

Metals and metalloids naturally occur in rock and soils, and can enter the marine environment via weathering, erosion and atmospheric deposition. Human activities have increased concentrations entering the marine environment through run-off and point-source discharge from most land uses in the Catchment, such as from mines and ports.[1279] Most studies have been conducted in and around ports, including Gladstone, Hay Point, Abbot Point, Townsville, and Cairns. Concentrations in these areas are relatively low, although water quality guidelines were exceeded in some instances.[1279,1280] Metals and metalloids accumulate and remain in the system for years to decades.[1279,1280] Mines within the Catchment have released metals and metalloids into the Region, including arsenic (associated with tin mining) and mercury (associated with past gold mining).[1279] Disposal of waste water from contemporary mining and refining activities continues to pose a risk to the Region, particularly after high-rainfall events.[1279]

Per- and poly-fluoroalkyl substances (PFAS) are artificial chemicals used widely and mass produced since the 1950s.[1281,1282] These chemicals are now considered possibly damaging to human health and the environment. Historically in Australia, PFAS were used in high volumes in firefighting foams and in waterproofing and stain-resistance treatments for products, such as textiles, carpet and paper. Because PFAS help reduce friction, they are also used in a variety of other industries, including aerospace, automotive, building and construction, and electronics.[1283,1284,1285,1286]

Firefighting foams containing PFAS as active ingredients are used extensively worldwide and within Australia, including at Defence bases, ports and other industries for both emergency firefighting and training. Past practices have resulted in high levels of PFAS contaminating the environment, particularly near firefighting training sites.[1284] As landfills and wastewater treatment plants consolidate waste containing PFAS from a broad range of industrial, commercial and consumer products, they are also potential point sources for PFAS emissions.[1283] PFAS can enter the ocean from a variety of sources, including contaminated rivers, groundwater and effluent, where they will persist and become part of the food chain.[1287] In 2004, the Department of Defence began phasing out the use of firefighting foams containing PFAS.[1284] More recently, high concentrations of PFAS have been found in the Catchment around the Townsville RAAF base[1288], and the ports of Gladstone and Townsville.[1289,1290] Low levels have been found in the Port of Mackay.[1291] The distribution and effects of PFAS in the marine environment are not well understood.

View towards the junction of the Russell and Mulgrave rivers over flooded sugarcane fields. © Dieter Tracey

Agricultural land management practices

While agricultural land use is a type of coastal development, agricultural land management practices form part of the assessment of land-based run-off. Several initiatives have been established to drive and encourage best practice agricultural land management throughout the Catchment.[527,1292,1293,1294] In March 2019, strengthened Reef protection regulations were proposed.[1295,1296] 'Best practice' is not a regulated standard; it varies across industry sectors and is reported using industry-specific management practice frameworks[1297,1298] or an alternative benchmark applied independently by industry. Rationalising the varying definitions, targets and measurements of best practice from different programs applying agricultural land management practices is difficult.[1295,1299]

After a period of early uptake, the rate of adoption of agricultural best practice has slowed. This is partially a consequence of modified targets but also reflects improved measurement frameworks.[462,1297,1298] Evidence from farm trials suggests that sustainable agricultural practice improves productivity, increases profitability and protects the Reef.[1295] Over several years, the targets for measuring the uptake of best practice have evolved from measuring the number of landholders who adopted improved management practice[1300] to measuring the total land area managed using best management practice systems.[527,720]

In mid-2018, the Reef 2050 WQIP introduced new land and catchment management targets, as part of the five-year review and update process.[527] Since monitoring began in 2009, industry sector adoption of best management practices has been observed in some NRM regions (for example, grazing in Cape York).[1264] Changes to how the data are assessed have occurred as part of improvements in program evaluation. The changes mean data from 2016 onwards cannot be compared with previous years. However, the new data for 2016 provide a more accurate benchmark against which to measure future progress. Overall, progress against the new Reef 2050 WQIP targets remains slow (Figure 6.12).[1264] Further improvement will depend on increasing commitment by land managers to make long-term changes in agricultural land management practices.[707,1257,1301] The effectiveness of management tools to address potential impacts from land-based run-off and coastal development is discussed further in Chapter 7.

Cattle grazing is one of the key agricultural land uses in the Catchment. © Department of Environment and Science (Qld) 2013

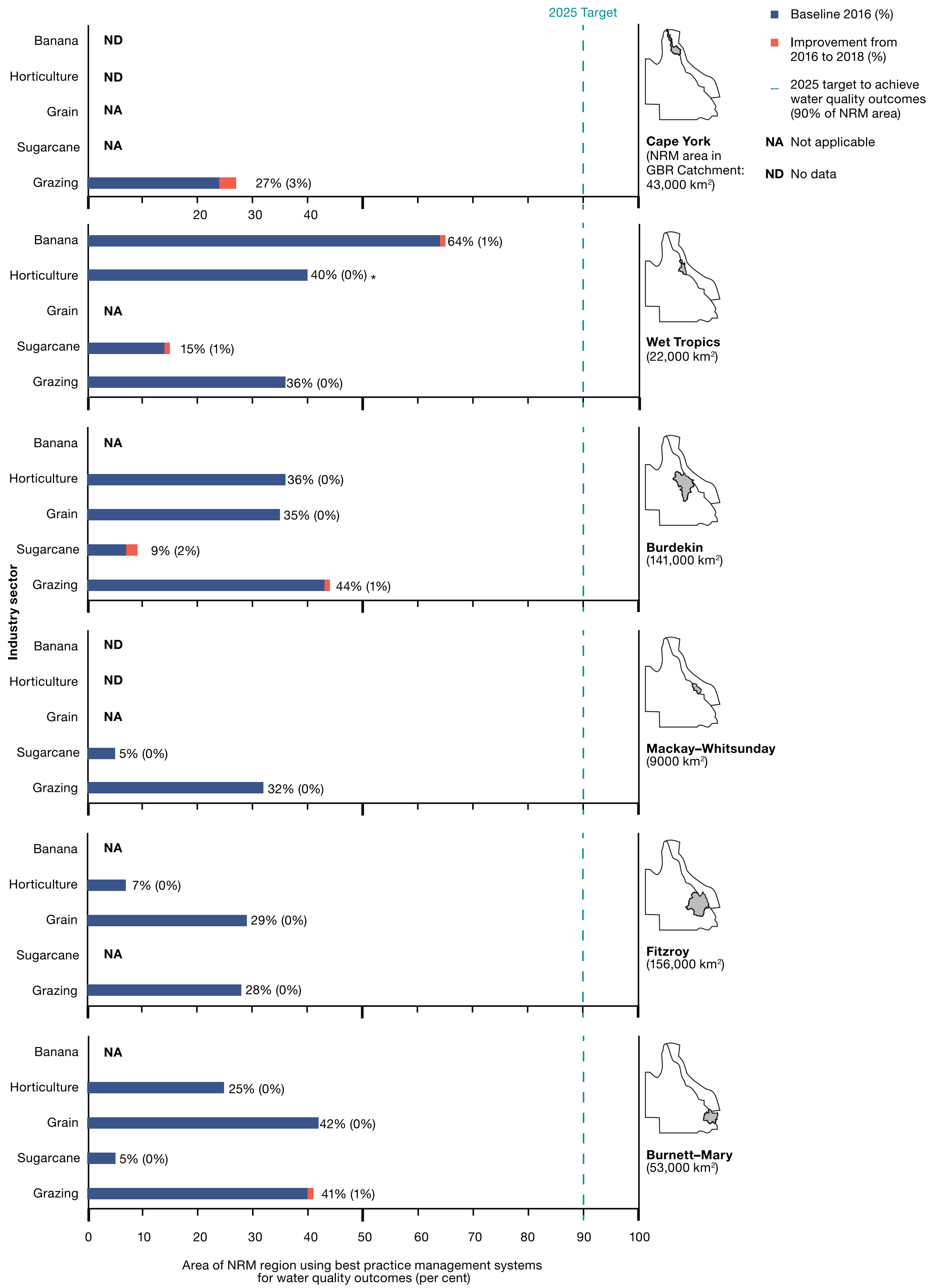


Figure 6.12 Proportion of area managed using best management agricultural practice systems in the Catchment, 2016–2018
Monitoring agricultural land management practices began in 2009; the baseline was reset in 2013 and again in 2016 to align with the next reporting period. New land and catchment management targets were introduced in mid-2018 to achieve water quality targets by 2025.[527] *The dotted blue line represents the Reef 2050 WQIP target for 2025. The percentage shows the proportion of land under best management agricultural practice systems as of 30 June 2018 (percentage point increase since 2016 is included in brackets). (*) Indicates significant new data capture since 2016.* Source: Commonwealth of Australia and State of Queensland[1264]

6.5.2 Vulnerability of the ecosystem to land-based run-off

Thirty-five major river catchments drain into the Region, with varying flow frequency and intensity. The greatest water quality risks to the Region and its coastal ecosystems are land-derived inputs from nutrients, fine sediments and pesticides.[1240] Mid-shelf and offshore areas are less influenced by land-based run-off because of their distance from river mouths. The water quality in these areas is considered generally in better condition.[43,469] However, in some locations between Lizard Island and Townsville, mid-shelf reefs are affected by land-based run-off, which are adjacent to regions that have a high dissolved inorganic nutrient load.[1240] In contrast, inshore areas are highly influenced and degraded by land-based run-off[43,1302] (for example, coral resilience is lowered due to poor water quality).[1303]

Following periods of comparatively low sediment, nutrient and pesticide loads, inshore ecosystems have demonstrated some ability to improve, provided they do not experience extra stresses. The observed recovery of seagrass meadows in inshore areas between 2012 and 2018 for example, was partly due to an absence of severe cyclones and below-average rainfall and freshwater discharge.[462,463] In the Mackay–Whitsunday region, inshore coral condition improved significantly in 2015–16, similar to levels when monitoring first began in 2005–06, highlighting the recovery potential of these reefs. However, after cyclone Debbie impacted this area in 2017, the recovery gains were reversed and coral condition decreased.[193] Recovery of these corals is likely to take several decades even if future agricultural inputs are eliminated.[1304] Future recovery of inshore ecosystems will depend on a number of factors, including good water quality, sufficient recruitment, regrowth of surviving corals, and a suitable recovery window free from other major stressors, especially thermal extremes.

Understanding the exposure of the Region's ecosystems to pollutants in land-based run-off is important for identifying the most vulnerable areas.[469] Of the six NRM regions in the Catchment, the inshore areas adjacent to the Cape York region are considered the least affected by land-based activities. The other five NRM regions are more developed (80 per cent used for agriculture[1305]) and contribute high pollutant loads to the Region through river discharges.[707] Best practice land management has been identified as the activity having the greatest potential to improve water quality entering the Region.[462]

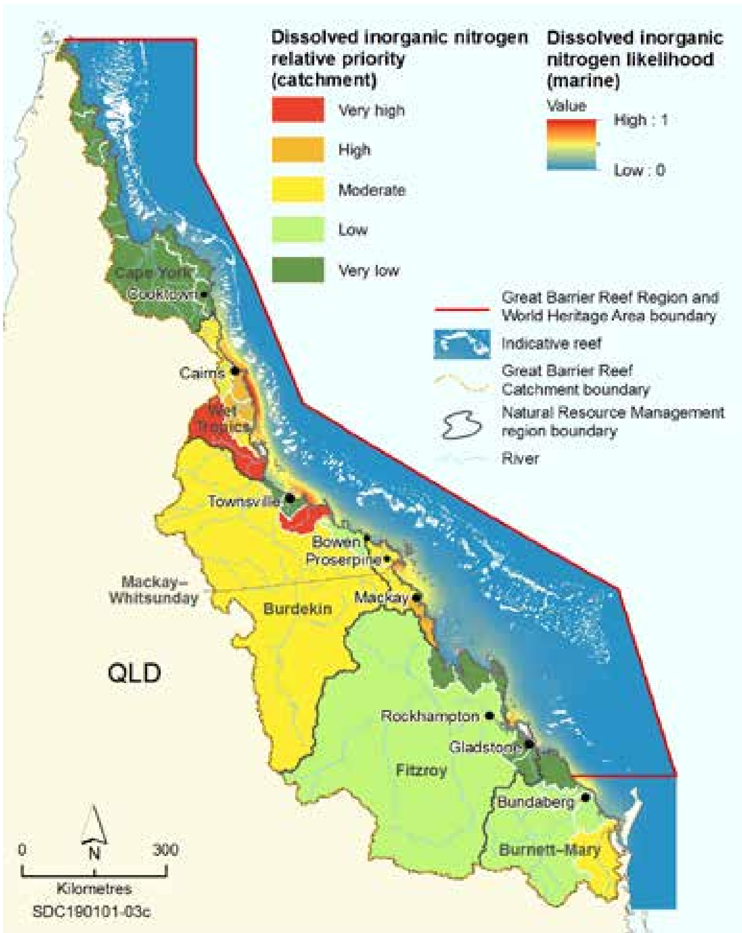


Figure 6.13 Relative catchment priorities and likelihood of exposure of Reef ecosystems to dissolved inorganic nitrogen
Assessment of the relative priority of each of the Region's 35 catchments according to their contribution to the modelled likelihood of exposure of Reef ecosystems to anthropogenic dissolved inorganic nitrogen (illustrated by shading in marine areas). Source: James Cook University adapted from Waterhouse *et al*. 2017[1240]

Understanding the impacts from multiple pollutant sources is critical to protecting the Region's values. Depending on the pollutant (nutrients, sediment and pesticides), different areas in the Region are subject to high anthropogenic loads (Figure 6.13, Figure 6.14, Figure 6.15). Areas adjacent to the Wet Tropics, Burdekin and Mackay–Whitsunday NRM regions are of particular concern, given high modelled loads of dissolved inorganic nutrients and suspended sediments. That makes the species, habitats, ecological processes, and community benefits in those regions particularly vulnerable to land-based run-off.

All ecosystems and species in the Region require some nutrients to facilitate growth, either through direct ingestion or absorption.[1223] However, **increased nutrients** from land-based run-off can overwhelm natural processes and negatively affect Reef ecosystems.[537] Dissolved inorganic nutrients (and fine particles) can travel large distances[43,458,537] during high-flow river discharge events (Figure 6.13), where they become available to phytoplankton, bacteria, macroalgae and seagrasses further offshore.[59,537,1306] Elevated concentrations of dissolved inorganic nutrients within the water column, derived from land-based run-off and offshore upwelling within the Reef system, can fuel the abundance of some phytoplankton species and benefit crown-of-thorns starfish larvae.[757,1307] (Section 3.6.2) This effect on larval food supply may be one of the factors that influence **outbreaks of crown-of-thorns starfish**, along with the availability of coral cover, abundance of predators, and connectivity (Section 3.6.2). Increases in dissolved inorganic nutrients can also increase benthic algae growth, potentially increasing competition with corals for

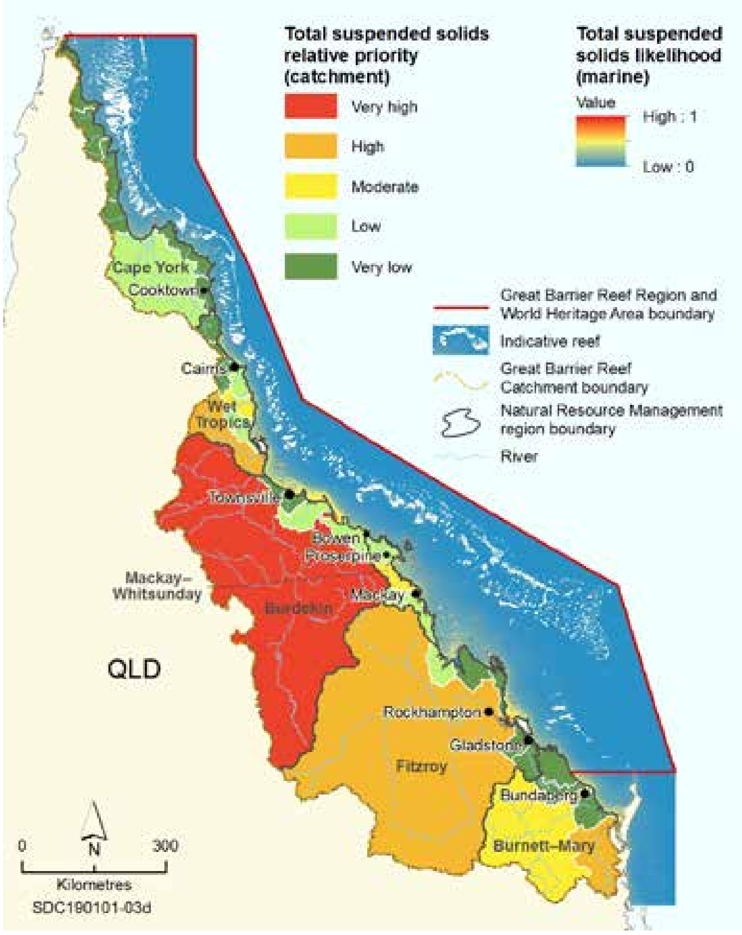


Figure 6.14 Relative catchment priorities and likelihood of exposure of Reef ecosystems to total suspended solids
Assessment of the relative priority of each of the Reef's 35 catchments according to their contribution to the modelled likelihood of exposure of Reef ecosystems to anthropogenic total suspended solids (illustrated by shading in marine areas). Source: James Cook University adapted from Waterhouse *et al.* 2017[1240]

space.[43,59,158,1308] Dissolved inorganic nutrients may also exacerbate the effect of other stressors, such as high temperature anomalies and increase the susceptibility of hard corals to bleaching and disease.[537,539,540] The effects of high levels of dissolved inorganic nutrients (including sediments binding) on seagrasses vary. Initially seagrass growth is promoted[70], but light availability may decline with increased growth of phytoplankton in the water column and epiphytes that coat seagrass.[1240]

The receiving waters and ecosystems in the Wet Tropics region and, to a lesser extent, the Burdekin and Mackay–Whitsunday regions, are the most likely to experience high levels of dissolved inorganic nutrients (Figure 6.13). The basins that deliver the greatest contribution of loads to these areas and are, therefore, a high priority for management are the Herbert, Haughton, Mulgrave–Russell, Johnstone, Tully and Plane catchments (Figure 6.13).[1240]

Suspended **sediment in run-off** entering the Region can have far-reaching effects on Reef ecosystems, particularly following extreme weather events. Fine sediments are of most concern for areas with shallow seagrass meadows and inshore coral reefs, because they are lighter, remain suspended for longer, travel further and are resuspended with winds and tides.[1240] These factors perpetuate the impact of fine sediments over long periods. Sediments reduce light availability required for photosynthesis, essential for food chain dynamics and the growth of corals and seagrass meadows.[43,153,473] High concentrations of suspended sediments from dredging and natural resuspension events can negatively affect coral spawning events and coral settlement, which generally occur from October to December.[1309]

Coral reproduction is also highly vulnerable to suspended sediments, which can entangle and entrap small coral spawn and also reduce their settlement success.[1309,1310] Fine sediments can settle and build up on benthic turfing algae, deterring herbivores from grazing.[603,1311] Adult corals can also die or be partially smothered from high levels of sediment exposure.[514] Turbid waters can also affect fish species, doubling larvae development time[1312], reducing growth rates[1313], reducing the ability to find suitable habitat[1314], changing predator–prey interactions[477,1315], and damaging gill structure.[1063,1316] Mangroves and wetlands are also vulnerable to pressures from increased sediments along with other pollutants and nutrients, affecting biodiversity and their ability to provide ecosystem services to the Reef.[473]

The likelihood of exposure of marine habitats to fine sediment is greatest in receiving waters adjacent to the Burdekin and Fitzroy regions (Figure 6.14).[1240] The catchments that deliver the greatest contribution of loads to these areas and are, therefore, higher priority for management are the Burdekin, Herbert, Fitzroy and Burnett–Mary catchments (Figure 6.14).[1240]

Pesticide run-off poses a toxicity risk to freshwater ecosystems in the Catchment and some inshore coastal habitats, particularly within the southern Mackay–Whitsunday and the lower Burdekin regions, where the highest end-of-catchment concentrations occur (Figure 6.15).[254,462,1254,1317,1318] Potential impacts from pesticides include: reduced growth as a result of photosynthetic inhibition in seagrass, coral and algae; reduced fertilisation and metamorphosis in invertebrates[473,1269]; disruption of ecological processes, such as nutrient cycling and recruitment[1254,1271,1319]; and potential endocrine disruption in fish.[1320,1321,1322]

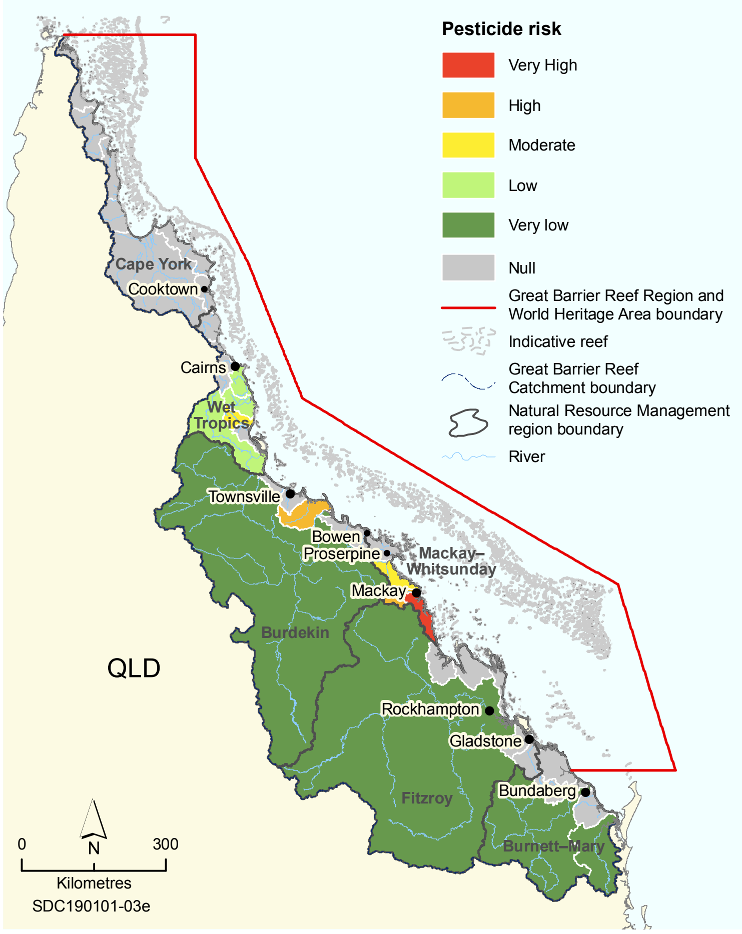


Figure 6.15 The risk of pesticides to freshwater and estuarine ecosystems

Assessment of the risk of pesticides to freshwater and estuarine ecosystems for each of the Reef's 35 catchments. Assessment was not conducted in catchment areas shaded grey due to limited or no data availability. Pesticides are important at different scales and different locations in the Region and the risk differs between the individual pollutants, source catchments and the distance from the coast. Source: James Cook University adapted from Waterhouse *et al.* 2017[1223]

Pesticides used today have shorter half-lives (that is, they breakdown faster) than those used in the past (for example, DDT).[473,1269] However, they can still persist (and accumulate) in the marine environment for a significant period, ranging from a month to nine years.[1323] Low concentrations of pesticides have been detected in offshore sediments.[1269] The potential impact of pesticides on ecosystems and species in the Region is not well understood.

Due to its high use, the herbicide diuron dominates toxic-load assessments and has been shown to reduce the productivity and photosynthetic efficiency of marine plants and corals.[43,1324] Alternative herbicides (including 2,4-D and glyphosate) were expected to cause less environmental harm than PSII herbicides.[1325] However, several studies have found that some alternative herbicides pose a similar risk to the environment as PSII herbicides.[1254,1266,1267,1269] The frequency of alternative herbicides at greater concentrations than PSII herbicides have been observed in the Wet Tropics.[1254]

Except for a few specific locations, concentrations of pesticides in the Region are below levels expected to cause significant risk to marine organisms.[1254] However, the effect of ongoing low-level pesticide exposure on the inshore Reef area remains a key knowledge gap.[472] The threat from pesticides is likely to be higher in some regions than others, especially when present in combination with other pollutants and stressors (for example, thermal stress).[473,1254,1269] The cumulative effects of multiple pollutants and stressors on ecosystem health remain poorly understood.[473,1254,1269]

Other pollutants (in particular, marine debris and specifically single-use plastic) are likely to be more widespread than previously reported, due to the continual breaking up of macroplastics into microplastics. The impact of plastic marine debris can persist and amplify when it degrades over time to create microplastics (plastics smaller than five millimetres long). These smaller plastic particles can be ingested by marine organisms, accumulate through the food chain and have the potential to affect human health.[43,159,444,1326,1327]

Marine debris can enter the Region via **terrestrial discharge** of stormwater. It has the potential to affect a wide range of species and habitats, including but not limited to marine turtles, fish, cetaceans, dugongs, seabirds, corals, microorganisms and invertebrates through direct entanglement or by being mistaken for food.[43,1275,1327,1328,1329,1330] For example, on Heron Island, 21 per cent of wedge-tailed shearwater chicks were fed plastic fragments by their parents.[365] Furthermore, 52 per cent of marine turtles may have ingested debris[1331] with the youngest turtles being the most susceptible to plastic pollution.[336] Loggerhead turtle hatchlings travelling down the East Australian Current and feeding at the surface are more likely than adults turtles to be exposed to, and ingest, floating macroplastics (such as plastic bottles and take-away container fragments).[336,649,1331,1332] Ingested marine debris can result in digestive blockages, toxin absorption and death.[1275,1333] There is growing concern about microplastic accumulation on nesting sites and the negative affects it can have on incubating environments for marine turtles.[1096] Recent evidence indicates low concentrations of microplastic particles have been found in corals within the Region.[159] Corals that come into contact with marine debris are 20 times more susceptible to disease, although this is minimal in the Region.[580] Debris can also block out light and smother coral.[36,43] Microorganisms and invertebrates have been detected on floating plastic in the Region, highlighting a dispersal pathway for invasive species.[36,43,1328,1334]

Metals and metalloids have been detected in the water, sediment and biota of marine ecosystems in the Region.[43,1279] They can exert toxic and sub-lethal effects on marine species, which include impairing fertilisation of corals and entering the food web by being absorbed by microorganisms and ingested by filter feeders (oysters and mussels) and fish.[1279,1335] Elevated levels of metals and metalloids in green turtles can cause acute inflammation and liver dysfunction.[1336,1337] The longer term effects of bioaccumulation within the ecosystem are not well understood.[43]

Some compounds in PFASs are highly persistent and therefore tend to bioaccumulate in organisms and move up the food chain. Some PFASs are known to have impacts on the environment (affecting offspring, survival and growth of freshwater fish and invertebrates)[1338,1339] and human health (such as PFOS).[1281,1284,1288,1340] Though PFAS are being phased out, they are expected to persist in the environment for long periods of time.[1284] The deep ocean is a potential sink for PFAS, which can be released through resuspension.[1288,1341] More research is required to determine the potential consequences of long-term exposure to aquatic organisms and the risk to human health.[880]

6.5.3 Implications of land-based run-off for regional communities

Australians regard the Reef as a significant contributor to their national identity and in many cases place more value on that aspect than its economic values.[1299] A survey of stakeholders in 2017, concluded the Reef is highly valued for a range of socio-economic reasons, including that it supports a variety of life (fish and coral reefs), has aesthetic beauty and is a World Heritage Area (Section 4.5.1).[785] Pollution of marine and island environments in the Region from land-based run-off and degradation of ecosystems reduces heritage and natural values and threatens Reef-dependent industries, especially marine tourism. It can also affect people personally though their health and wellbeing, personal connections, and enjoyment and appreciation of the Reef. Catchment residents surveyed in 2017 rated pollution as one of the greatest threats to the Reef.[785] Similarly, 1545 Catchment residents surveyed in 2015 found they placed great importance on seeing no visible rubbish on beaches and islands.[849]

Reef-dependent industries are affected when poor water quality degrades ecosystems

Observed reduction in water clarity has been greatest in regions with the highest nutrient and sediment loads adjacent to the most intense agricultural land use.[158] Poor water clarity affects visitor experiences through reduced underwater visibility and diver safety.[1342] Reduced water clarity may also indirectly reduce economic return, through a decrease in expenditure by divers and snorkellers.[1343] Local businesses are most supportive of initiatives to improve water quality in areas that have high levels of use and are also affected by agriculture, such as the Whitsundays. Government and community members, particularly farmers, have invested significantly in reducing the input of excess nutrients, sediment and pesticides from broadscale agriculture into the Region. Many actions to improve coastal habitats, minimise erosion and improve the efficiency of fertiliser applications on farms can improve the quality of water entering the Region.[707] Within urban areas, actions by local governments and schools to revegetate terrestrial habitats and reduce waste entering waterways are contributing to improved water quality entering the Region.

6.6 Direct use

Direct use of the Region includes commercial marine tourism, defence activities, fishing, recreation, research and educational activities, ports, shipping and the traditional use of marine resources. The current and projected trends in direct use are based on the relevant sections in Chapter 5. The analysis of the vulnerability of the Region's values to ongoing direct use as a whole (Section 6.6.2), and its implications for regional communities, align with the evidence and assessments presented in Chapters 2 to 5.

6.6.1 Trends in direct use

Commercial marine tourism remains the highest contributing Reef-dependent industry to the Region's economy (Section 5.2). Since 2014, the number of visitors to the Region has generally increased. The Marine Park Authority's high standard tourism program remains in place, although uptake has slowed. Interpretive products about the Region's values and training for Reef tourism guides have increased.

Declining ecosystem condition reduces the benefits Reef-dependent industries and people derive from the Reef

Defence activities, specifically training, are expected to be maintained or increase in frequency and intensity (Section 5.3). While modern defence training activities have negligible impacts on the Region, balancing defence activities with conservation in sensitive habitats remains a high priority. As cumulative stressors increase, the risk of not achieving appropriate balance will increase.

Amphibious landing as part of defence training exercises.

Fishing is the largest extractive use of the Region (Section 5.4). Trawl, net, line and pot remain the most significant commercial fishing methods. Recreational fishing remains one of the most popular activities on the Reef and in estuaries. Some species continue to be a concern and information remains limited for some species. Illegal fishing (recreational and commercial) persists as an issue. No-take zones are exhibiting a variety of benefits for fisheries' sustainability and ecosystem health. Given this, and the growing pressure on the Reef's ecosystem generally, fishers' compliance with zoning requirements is increasingly important. The expansion of vessel tracking systems into more commercial sectors is expected to substantially improve commercial fishing compliance rates.

Recreational use (not including fishing) is one of the major direct uses of the Region. It encompasses short trips to the beach through to longer journeys to the Reef (Section 5.5). Between 2014 and 2018, the number of recreational vessel registrations in the Catchment was the highest recorded. The broad cultural value of the Reef has significantly increased for residents since 2013, despite coral condition decreasing.[1009]

Research and educational activities occur in many parts of the Region, often around research stations. Understanding of cumulative effects of the impacts associated with research and educational activities remains limited (Section 5.6). Since 2014, research on the effects of climate change, reef restoration technologies and socio-ecological connections in response to multiple stressors (such as crown-of-thorns starfish predation and mass coral bleaching) has continued to grow.

Ports in the Region have experienced mixed economic outputs since 2014, with a minor decline in combined trade throughput at the priority ports in 2016–17 (Section 5.7). While port operations and their impacts have remained constant since 2014, regulatory changes for ports in 2015 have reduced some threats and increased management effort. Port maritime development has slowed since that time.

Shipping traffic through the Region is relatively limited compared with busier international locations (Section 5.8), although the number of cruise ships transiting the Region is increasing. Advances in technology, regulation, inspections and the level of monitoring of shipping traffic have improved shipping safety. Shipping and its impacts in the Region have remained constant since 2014. However, knowledge and management gaps remain around the impact of ship anchoring, resuspension of sediments from ship propellers and light pollution from ships at anchor.

Traditional use of marine resources is a key part of the Reef's Indigenous culture and the ongoing connection of Traditional Owners to their land and sea country (Section 5.9). Since 2014, new Traditional Use of Marine Resource Agreements have been accredited bringing the cumulative area covered by these agreements to approximately a quarter of the Region's coastline.

6.6.2 Vulnerability of the ecosystem to direct use

The eight identified direct uses of the Region expose the Reef's values to a variety of impacts at a local scale and cumulatively. When coupled with the highest and most immediate threats to the Reef (such as sea temperature increase and altered weather patterns), the impact of direct use is amplified. Some activities (tourism, defence, ports and research) tend to be localised, while other uses (fishing, recreational use and shipping) are more widespread. The effectiveness of the current management tools for the main types of direct use in, and adjacent to, the Region are assessed in Chapter 7.

Damage from direct use can be permanent or temporary. Permanent change is usually a result of modifications to coastline and island habitats from coastal development, or port and marine infrastructure activities. By contrast, direct use impacts that can kill and injure coral, such as anchoring, are usually temporary and smaller in scale. Damaged areas can return to a pre-disturbance state if recovery times are adequate. Handling and manipulation of benthic organisms can lead to localised damage to the reef structure and increase the prevalence of **outbreaks of disease**.[1344]

Commercial marine tourism, fishing and recreation activities in some locations may interact with other uses — **incompatible uses** (with incompatible values) can affect or displace another user group. Displacement concerns have been raised between commercial marine tourism and Traditional Owners, as well as resource allocation between recreational and commercial fishers.

Marine debris clean up by Tangaroa Blue.

Legacy defence activities, such as unexploded ordinance, and other activities in the Catchment and Region involving PFAS, continue to be detected in, and adjacent to, the Region. The impact of PFAS chemicals on plant and animal communities is still unknown. **Marine debris** is a threatening process for wildlife[1096] and an emerging threat to the Region as the global human population increases (Section 6.2.1). Direct uses have the potential to add marine debris to coastal, island and marine habitats. A comprehensive understanding of the quantity of, and ecological effects from, microplastics in the Region is lacking (Section 6.5).

The number of reported **vessel strikes** on species of conservation concern is generally low.[1015] Surface-breathing marine animals (such as marine turtles, dugongs, dolphins and whales) are most often struck by vessels, with the collision often resulting in injury or death. Population growth in regional communities is a driver of human-induced impacts on the Region. More vessel use, larger ships and expansion of direct use activities are likely to increase **wildlife disturbance** across the Region.

Even though procedural controls are in place to respond to **oil spills** and some **chemical spills**, the Region remains vulnerable to **vessel groundings** and large spills of other foreign material (diesel and other cargo). For example, large volumes of sugar released into a coral reef environment could make the water anoxic (devoid of oxygen) affecting a large number of species. Shipping (and other vessels greater than 50 metres in overall length), international fishing and recreational vessels (predominantly yachts) are vectors for introduced **exotic species**. If introduced and persistent, introduced species can have widespread effects on the ecosystem. While limited pest incursions have occurred at ports and marinas since 2014, islands remain vulnerable to pest incursions.

Dredging and **disposal of dredge material** in inshore areas contribute to sedimentation by disrupting and resuspending sediments. A growing shipping fleet and increased coastal development (including from ports) continues to intensify the intrusion of artificial light into the Region. The effect of **artificial light** on marine turtles is well known[331,332,1345], and exposure has increased since 2014.

Fishing is the single largest extractive activity in the Region. Target and non-target species from various trophic levels are directly removed from the ecosystem. Indirectly, other species and habitats may also be affected through anchor damage and **damage to the seafloor** (from trawling). Across the range of threats and impacts from fishing, **incidental catch of species of conservation concern** (dugongs, inshore dolphins and some species of sea snakes, marine turtles, sharks and rays) still persists. Dugong and green turtle populations are still depleted following past commercial harvesting and are further threatened by climate change. These species remain at risk of entanglement and drowning when they interact with legal fishing gear, or **illegal fishing and poaching**. Illegal fishing in no-take zones and harvest of fish smaller or larger than relevant size limits can be perceived by fishers as a one-off, short-term impact. However, illegal fishing can have long-term impacts on biodiversity given some species take many years to reach sexual maturity (Section 8.3.4).

Climate change, habitat loss and delayed recovery of critical fisheries habitats make the ecosystem more vulnerable to direct effects from fishing and other direct use. Conversely, deterioration of habitat that fisheries species rely upon will increase the vulnerability of the fishing industry through reduced catches, increased disease prevalence and a potential shift in fisheries species. This social-ecological vulnerability also applies to all other Reef-dependent uses.

6.6.3 Implications of direct use for regional communities

The Region is not a pristine ecosystem and it exists in a dynamic state.[781] The dynamic state involves interactions with people and how they use the Region's natural heritage values and connect with Indigenous heritage values. Since European settlement, use of the Region has changed and intensified.

For uses that depend on the Reef, the condition of the ecosystem remains fundamental to the longevity of their various industries, economic prosperity and social wellbeing. The social and economic implications flowing from the unprecedented back-to-back coral bleaching events in 2016 and 2017 and several cyclones since 2015 are partly known. The social-ecological implications are particularly obvious where the damage to the environment or resort infrastructure affected tourists' choice of destination. However, the indirect effects are not yet fully known. The direct economic cost of climate change and ecosystem disturbance on Reef-dependent communities has not been fully quantified and remains a knowledge gap.

Recreational use provides enjoyment and social benefits.
© GBRMPA, photographer: Pine Creek Pictures

Non-Reef-dependent uses (defence activities, ports and shipping), which are not directly connected to the Region's natural values, are affected by external factors. The economic significance of ports and shipping is largely driven by global and domestic demand for resources and commodities. As an interconnected system, however, changes to the climate that affect the health and usability of the Region are likely to affect the suitability of the Reef as a transit corridor for ships.

6.7 Vulnerability of heritage values to influencing factors

Of the four main factors influencing the Region (climate change, coastal development, land-based run-off and direct use), climate change remains the greatest threat to the Region's heritage values. The outstanding universal value of the Reef and how Traditional Owners interact with the natural environment, are highly vulnerable to the factors influencing the Region.

Pressures exerted on the Region's natural heritage value (ecological and biological processes and habitats assessed in Chapters 2 and 3) equally apply pressure on the Region's Indigenous heritage value. Therefore, even the slightest change in the Region's processes or habitats may have far-reaching consequences on the natural and Indigenous heritage value of the Region. While the impacts of climate change have been assessed for many of Australia's world heritage properties, including the Reef (Sections 6.3 and 7.3.9), limited adaptive planning has been undertaken for other Indigenous and historic heritage places in the Region.[1346] Spatial and temporal impacts of climate change vary between places and properties, so each will have different vulnerabilities and adaptive capacity. Adaptive responses can ameliorate risk by early identification of specific impacts and instigation of targeted conservation measures.[1347] Broad social and cultural values of Traditional Owners, regional communities and Reef users will make an important contribution to developing vulnerability assessments and interventions.[1348]

The cultural sensitivity of some Indigenous heritage values and the vast geographical expanse of the Region make investigation, monitoring and management of these values difficult. Island and mangrove systems are highly valued by Traditional Owners and some Indigenous cultural sites, such as middens, are still recovering from several recent severe cyclones (Section 4.3). Some traditionally valued species (marine turtles and dugong) remain under pressure from climate change, habitat loss and degradation, fishing-associated impacts[811], and marine debris. Conversely, humpback whales, which are important to the Woppaburra Traditional Owners, are recovering strongly but remain at risk from wildlife disturbance (people approaching too close) and vessel strike. Direct use of the Region may restrict Traditional Owners' access to country, which may **fragment cultural knowledge** and reduce the capacity of Traditional Owners to pass on their culture (a **foundational capacity gap**). Without access and connection to country, Traditional Owner groups cannot manage their land and sea country. Distance and separation from country may also result in loss and fragmentation of knowledge of tangible and intangible Indigenous heritage values.

An inherently difficult aspect of maintaining resilience of historic heritage values, is identifying and protecting sites, and monitoring their condition and integrity. Where heritage values are known (for example, lightstations), ongoing maintenance reduces the asset's vulnerability. Historic heritage values (lightstations, shipwrecks and aircraft wrecks) continue to be vulnerable to natural degradation, severe weather events and illegal activities. The location of heritage values can influence their vulnerability and resilience.[1348] Under predicted climate change scenarios, sea-level rise (Section 3.2.5) will endanger Indigenous and historic heritage components situated at or just above sea level in intertidal areas and on Commonwealth islands.

Indigenous and historic heritage is irreplaceable, therefore, where possible, impacts should be avoided or mitigated.[1349] Irreversible damage or loss of Indigenous and historic heritage values can arise from direct use (for example, through intentional or unintentional removal of, or damage to, significant artefacts or sites of Indigenous significance).[1007] **Inappropriate behaviour** or presence of people at certain sites can also affect Indigenous heritage values. Poor water quality, coupled with climate change impacts, natural processes and encroaching coastal development (ports, marinas, revetment walls) will place pressure on inshore and coastal natural and Indigenous heritage values. Overall, a changing climate is imposing strong current and predicted impacts on all the Region's heritage values.

Many heritage values are vulnerability to the same threats as the ecosystem. Sediment laden water affects habitats of culturally significant species. © Matt Curnock 2019

6.8 Assessment summary — Factors influencing the Region's values

Paragraph 54(3)(g) of the *Great Barrier Reef Marine Park Act 1975* requires '… *an assessment of the factors influencing the current and projected future environmental, economic and social values* …' of the Great Barrier Reef Region.

Paragraph 116A(2)(e) of the *Great Barrier Reef Marine Park Regulations 1983* requires '… *an assessment of the factors influencing the current and projected future heritage values* …' of the Great Barrier Reef Region.

The assessment is based on four assessment criteria:

- impacts on ecological values
- impacts on heritage values
- impacts on economic values
- impacts on social values.

Grades for all components and attributes examined in the assessment, as well as the grade for the criterion, are allocated according to the statements in the table below.

6.8.1 Impacts on ecological values

Grading statements — impacts on ecological, heritage, economic and social values

Very low impact
Few or no impacts have been observed and accepted predictions indicate that future impacts on the Region's ecological, heritage, economic or social values are likely to be minor.

Low impact
Some minor impacts have already been observed and there is concern that, based on accepted predictions, there will be significant but localised impacts on the Region's ecological, heritage, economic or social values.

High impact
Current and predicted future impacts are likely to significantly affect the Region's ecological, heritage, economic or social values. Concern about serious ecosystem, heritage, economic or social effects within next 20–50 years.

Very high impact
Current and predicted future impacts are likely to irreversibly destroy much of the Region's ecological, heritage, economic or social values. Widespread and serious ecosystem, heritage, economic or social effects likely within next 10–20 years.

Borderline
Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.

Trend since last report

- ↑ Increased
- ↔ Stable
- ↓ Decreased
- ▬ No consistent trend

Future trend

- ↑ Increasing
- ↔ Stable
- ↓ Decreasing
- ▬ No consistent trend

Confidence

- ● Adequate high-quality evidence and high level of consensus
- ◐ Limited evidence or limited consensus
- ○ Inferred, very limited evidence

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
[High impact]	[High impact] ↑ (future ↑)	[Very high impact] ↑ (future ↑)			**Impact on ecological values:** Climate change has had a widespread effect on ecological values fundamental to the Region's identity. High coral mortality due to thermal bleaching events has transformed the Reef. Evidence of cascading effects of coral loss on fish and invertebrate abundance and diversity are emerging. Negative impacts on ecological values, associated with coastal development, land-based run-off and direct use are being amplified under the strong signal of climate change.
[Very high impact]	[Very high impact] ↑ (future ↑)	[Very high impact] ↑ (future ↑)	●	●	**Climate change:** Climate change has had far-reaching effects on the Reef, with record-breaking sea surface temperatures resulting in widespread mortality of shallow-water corals. Flow-on effects to dependent species, habitats and heritage values are also occurring. Impacts of climate change are becoming more severe and widespread.
[High impact]	[High impact] ↑ (future ↑)	[High impact] ↔ (future ↑)	◐	◐	**Coastal development:** The extent of new coastal development has been minor, although the impact of legacy development remains high. Projected future populations will increase development pressure on the Region. Economic expansion in northern Australia will intensify access to currently remote parts of the Catchment.

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
	↓ ↓	↔ ↓	●	●	**Land-based run-off:** Poor water quality continues to affect inshore areas. The rate of reduction of pollutant loads has been slow as a result of modest improvements in agricultural land management.
	↑ ↑	↑ ↑	◐	◐	**Direct use:** The cumulative effects of extraction and damage to the Reef by direct use, coupled with smaller recovery windows, erode ecosystem resilience. More frequent acute disturbances (cyclones, flood plumes, coral bleaching) will exert more pressure on a degraded system.

6.8.2 Impacts on heritage values

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
	↑	↔ ↑			**Impact on heritage values:** The Region's natural heritage value is already impacted by climate change, transforming the reefscape through reductions in species and habitats and altered ecological processes. This status, coupled with Traditional Owners' connection to sea country, places Indigenous heritage values of the Region under growing pressure. Historic heritage values remain vulnerable to a changing climate and impacts from human interaction.
	↑	↑ ↑	◐	◐	**Climate change:** The interconnectedness of the natural and Indigenous heritage values exacerbates the vulnerability of the Region to the impacts of a changing climate. Some Indigenous and historic heritage values are irreplaceable if lost or damaged. Historic heritage components remain exposed to altered weather patterns.
	↑	↔ ↑	◐	◐	**Coastal development:** Encroachment from coastal development into the Region (ports, marinas, revetment walls) will place pressure on inshore and coastal natural and Indigenous heritage values. Altered weather patterns resulting from increased global emissions are a major threat to heritage values.
	↓	↔ ↓	◐	○	**Land-based run-off:** Culturally significant species (dugongs, marine turtles) that rely on inshore seagrass continue to be vulnerable to land-based run-off. A changing climate is imposing strong current and predicted impacts on natural and Indigenous heritage values.
	↑	– –	◐	◐	**Direct use:** Direct use has limited impacts on historic heritage values, except shipwrecks that can be damaged by various activities. Even though many threats associated with direct use are generally well managed, an imbalance persists between traditional use and ecological and economic benefits to the Region.

6.8.3 Impacts on economic values

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
	↑ ↑	↔ –			**Impact on economic values:** The economic value of Reef-dependent uses relies on a healthy Reef ecosystem. For non-Reef-dependent uses, economic value is aligned with market forces and population growth in the Catchment. Effects of ecological declines may become apparent over the next few years.
	↑ ↑	↑ ↑	●	●	**Climate change:** Climate change effects on the Regions' natural heritage are expected to have major economic consequences for Reef-dependent industries, including tourism and fisheries. Economic effects of climate change may lag behind ecological effects and to date the full impact of ecological damage sustained since 2014 has not yet been fully realised. The loss of coastal protection as the Reef degrades and more frequent severe weather occurs poses a significant economic and social risk to the Queensland community.
	– –	– –	◐	◐	**Coastal development:** Population growth, poorly managed land use, development and infrastructure in the Catchment may affect the marine ecosystem. Indirectly, this would place pressure on the profitability of Reef-dependent uses.

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
	↓ ↓	↔ ↓	◐	◐	**Land-based run-off:** The Region is vulnerable to the effects of poor water quality. Resulting declines in ecosystem health will affect the economic growth of Reef-dependent industries. However, if practice change continues impacts may decrease in future.
	↔ ↓	↔ −	●	◐	**Direct use:** Direct use of the Region continues to be a significant contributor to regional and national economies. Visitation showed minor declines coinciding with severe cyclones, but by 2018 was showing signs of recovery. Future economic value of many Reef-dependent activities is intrinsically linked to the condition of the Reef.

6.8.4 Impacts on social values

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
	↑ ↑	↑ ↑			**Impact on social values:** Ecosystem decline as a result of climate change and land-based run-off will affect community health, wellbeing and enjoyment derived from the Region. An increased concern for the Region and its ecosystems has been recorded. However, across the broad spectrum of influencing factors, evidence is limited about the effect of disturbances on social values.
	↑ ↑	↑ ↑	◐	◐	**Climate change:** Climate-related changes to the ecosystem have affected patterns of use of the Reef and visitor satisfaction. People's awareness of the current and future effects of climate change is increasing their concern about the ecosystem. The loss of coastal protection will have effects on social values. The vulnerability of Reef-dependent individuals and businesses depends on their ability to anticipate and adapt to change.
	↔ ↔	↔ −	◐	◐	**Coastal development:** Coastal development provides broad economic and social benefits to regional communities adjacent the Region through employment, commerce and places for recreation. Expansion into remote parts of the Catchment may provide social benefit from further access to the Region.
	↓ ↓	↔ ↓	◐	◐	**Land-based run-off:** Ecosystem declines from poor water quality, particularly in inshore areas, can affect wellbeing and enjoyment of stakeholders through degraded aesthetics.
	↔ ↔	↔ ↔	◐	◐	**Direct use:** The Reef continues to be valued by national and international communities. Employment opportunities, knowledge, recreation and access contribute to the social benefits derived from the Reef. Traditional Owners' connections to land and sea country are fundamental to the Indigenous cultural values of the Region.

6.9 Overall summary of factors influencing the Region's values

The Reef is undergoing significant social, economic and environmental change. The main drivers increasing pressure on the Reef's values are economic and population growth; management will become more challenging if growth outpaces the implementation of protective management measures (such as setting limits on use of sensitive locations). Drivers of change can also positively affect the Region's values. For example, technological developments (another key driver) can lead to changed behaviours, such as use of renewable energy.

The Reef is undergoing significant social, economic and environmental change

Influenced by these underlying drivers of change, climate change, coastal development, land-based run-off and direct use are the major factors affecting the Region's values. Each of these factors is assessed in terms of its impact on ecological, heritage, economic and social values. Understanding of the current condition and trend of these factors has improved since 2014.

Of the four major factors, climate change is having the greatest impact on the Region's values, and the signals of climate change, such as increasing water temperatures, are accelerating. Furthermore, climate change will amplify the impacts of other threats. The impacts of climate change will become more frequent, severe and widespread. The resultant trend is one of increasing cumulative effects on the Region's ecological, heritage, economic and social values. For example, two consecutive years of mass coral bleaching caused the loss of at least 30 per cent of the Region's shallow-water coral cover, and this is having cascading effects on coral-dependent species.

Overwhelmingly, climate change is the primary factor affecting the Reef, and its influence is increasing faster than previously predicted

Coastal development has a high impact on ecological and heritage values. Legacy effects of past coastal development, primarily agricultural land uses, mining and urban development, are still significantly affecting coastal ecosystems adjacent to the Reef. The future trend is increasing, and existing and further modifications to coastal ecosystems and barriers to flow will encroach further upon natural and heritage values in the future.

The Region continues to be vulnerable to exposure to pollutants (mainly sediments, nutrients and pesticides) transported from land-based run-off resulting from unsustainable agricultural land management practices. Land-based run-off can seriously threaten the Region's natural and Indigenous heritage values and, therefore, the success of Reef-dependent industries such as commercial fishing and marine tourism. Poor water quality can also affect social attributes, such as people's health and wellbeing, personal connections, enjoyment and appreciation of the Reef.

Land-based run-off from agriculture in the Catchment remains the greatest contributor to poor water quality in the inshore area

Across the multitude of direct uses of the Region, the Reef's values are exposed to a variety of pressures, including local and widespread impacts. The cumulative effects of multiple direct uses occurring in one location, coupled with broad influences of climate change, remain a significant issue and management challenge. Knowledge and understanding has continued to improve for marine debris and its impacts on species and ecosystems. It is essential that management actions that effectively address direct use impacts and maintain resilience continue, in particular, effective spatial planning, compliance and crown-of-thorns starfish control.

Cumulative impacts to ecological values from the factors influencing the Region's values are amplified under the strong signal of climate change

Some structures within waterways provide mechanisms to assist fish to move upstream.