

A Vulnerability Assessment for the Great Barrier Reef

Australian Government
Great Barrier Reef
Marine Park Authority



Estuaries

Information valid as of October 2016

Summary

Diversity

“Estuarine wetlands are those with marine or oceanic water, which is diluted with freshwater run-off from the land. It is usually an area where a river meets the sea, providing an important habitat for many species”.¹ Occurring in the interface between marine and riverine ecosystems, the form of an estuary is governed by competing forces of river, tide and wave energy. The relative dominance of these forces creates different estuary types. Estuaries contain many tidal and subtidal habitats.

Estuarine habitats may include: forests (mangroves), coastal saltmarshes (grass, sedge and herb swamps), saltflats and saltpans, mudflats and intertidal seagrass ecosystems. Beneath the water, estuarine habitats can include soft-bottom communities, hard-bottom communities, and ecosystems dominated by coral and seagrass.



Figure 1: Mangrove ferns growing in a mangrove forest

Susceptibility

Estuaries are located at the terminus of coastal catchments and receive run-off and contained loads of sediment, nutrients and other contaminants from contributing catchment areas. Due to these biophysical linkages, the condition of an estuary is mediated by the condition of its catchment to varying degrees.

Estuaries are therefore susceptible to catchment land use and development that alter freshwater flows or elevate loads of sediment, nutrient and other contaminants exported downstream. Different estuary types, for example wave dominated, tide dominated or river dominated, have different water flushing and mixing and sediment retention characteristics (Figure 2). This affects their susceptibility to water quality impacts associated with run-off contaminant loads.²

Estuarine ecosystems within the Great Barrier Reef catchment are exposed to extreme environmental conditions, from large freshwater flows during the wet season leading to hyposalinity, to hypersaline conditions caused by cessation of flows and evaporation during the dry season. Estuarine ecosystems have adapted to these conditions, but are dependent on connectivity and tidal exchange for ongoing health and resilience.

Changes to river flow regimes and tidal connectivity between individual habitat components can cause phase shifts in estuarine communities. Recovery time from disturbance can be as long as 20 years.³ Saltmarsh communities are generally more susceptible to human disturbance than mangrove areas.

As coastal environments, estuaries are also exposed to cyclones, associated storm surge events and rising sea levels. With the magnitude of cyclones and the rate of sea level rise projected to increase under the influence of global warming,⁴ estuarine ecosystem susceptibility to these impacts will likely increase in coming decades.

Major pressures

Estuaries are facing major existing and emerging pressures from:

- *Catchment development* — particularly development that involves the intensive use of land and water resources that results in changes in catchment run-off or development, which occurs within the immediate coastal zone and extends into estuarine ecosystems affecting functions that impact their condition (for example, tidal flushing and connectivity)
- *Catchment run-off* — conveying elevated loads of sediment, nutrients and other contaminants often via modified flows resulting in altered estuarine hydrology, water quality (turbidity, nutrients, salinity, pH, chemical residues) and geomorphology and increased susceptibility to eutrophication
- *Ports and shipping* — resulting in permanent changes to estuary function including via the removal of estuarine habitats, land reclamation and excavation, regular disturbances associated with dredging and ship traffic and cumulative contaminant load impacts
- *Commercial and recreational fishing* — generating localised impacts to target and non-target species populations
- *Recreational use* — generating impacts via high levels of boat traffic and other forms of disturbance, including uncontrolled four-wheel drive vehicle

and human access to saltmarsh and other sensitive habitats

- *Climate change* — driving multiple sources of pressure including sea level rise, extreme climate events (droughts, floods, cyclones and storm surge), elevated temperatures, ocean acidification and altered ocean currents. These exacerbate other pressures associated with catchment and estuary condition via magnified and synergistic impacts.

Cumulative pressures

While it is useful to identify individual pressures, estuarine ecosystems are more commonly exposed to multiple, cumulative sources of pressure that impact both habitats and individual species. Cumulative pressures on estuaries arise from the combination of direct site-based impacts and indirect impacts driven by land use within contributing catchment areas or modified coastal processes.

Great Barrier Reef Outlook Reports (2009⁵, 2014⁶) have described the extensive loss of coastal ecosystems across developed areas of the Reef catchment since European settlement. They also describe the replacement of these ecosystems with non-remnant vegetation and land uses that do not provide the same ecosystem services to downstream areas, including estuaries and ultimately the Reef.

The historic and continuing loss of catchment ecosystem services that provide sediment and nutrient regulation and landscape water balance are a primary source of cumulative pressures affecting estuaries.



Figure 2: Saltmarsh plants (Samphire)

Estuaries have also long been used as places of human settlement. They offer shelter from prevailing winds and are commonly used (and modified) for urban, port and coastal development. Within the Great Barrier Reef catchment, most urban and port developments occur within larger riverine estuaries.²

Their location in coastal areas where human actions and development are concentrated means estuaries also get exposed to significant cumulative pressure from activities that modify coastal processes, for example dredging, reclamation and point and diffuse source pollutant discharges.

Site physical impacts such as clearing of mangrove areas, bunding of supra tidal areas or installation of infrastructure often undermine the functional integrity and hence natural resilience of estuaries to further disturbance pressure. For example, instream infrastructure that results in reduced tidal flushing will increase an estuary's susceptibility to nutrient pollution or eutrophication.



Figure 1: Mangrove roots provide a nursery habitat for many species

Consequently, the cumulative impact to estuaries is often most severe when direct physical modification is coupled with indirect sources of impact from contributing catchment areas, such as agricultural run-off, sedimentation from soil erosion or exposure to industrial pollutants.

The relationship between cumulative pressure and estuary condition is often not linear. Once site functional integrity and/or catchment development thresholds are exceeded, cumulative pressures can operate synergistically to increase impacts exponentially. For example, a tidal barrage constructed within an estuary will simultaneously expose it to altered tidal flushing, water mixing and salinity regimes, reduced biological connectivity and productivity, and an increased susceptibility to elevated nutrient and sediment inputs that can lead to secondary impacts associated with water quality deterioration.

Where a contributing catchment to an estuary is subject to ongoing development and/or degradation pressure, there is a strong likelihood that cumulative pressures will continue to increase. More substantive impacts occur once catchment development thresholds are surpassed. Changes in catchment

conditions (such as percentage vegetation cover, intensive land or water use) result in nonlinear increases in catchment sediment, nutrient and contaminant exports and/or loss of landscape water balance.²

Climate change represents a major emerging driver of cumulative pressure on estuaries. This is because estuaries located at the interface between marine and terrestrial ecosystems are vulnerable to impacts that affect both ecosystems. It is also because climate change operates by multiple expressions of pressure including: sea level rise, extreme climate, ocean acidification and altered ocean currents.

The climatic and hydrologic regimes impacted by climate change are also the primary determinants of catchment condition and run-off behaviour. Changes in these regimes will amplify the individual and collective impact of existing catchment development and run-off pressures.^{4,7,8}

Sea level rise is perhaps the greatest threat for estuarine ecosystems, with rates increasing significantly in recent years.⁶ Projections based on current ice sheet melt contributions indicate the potential for multi-metre increases by mid-century.⁹ Such rates of sea level rise are likely to be beyond the adaptive capacity of many estuarine ecosystem habitat components.^{7,8}

Management in the Great Barrier Reef and adjacent areas in Queensland

A direct legislative management tool for the protection of marine vegetation is the requirement for notification and permission for plant removal under the *Fisheries Act 1994* (Qld).

Other planning and assessment Acts and Regulations are used to protect estuaries from potential development impacts, for example, through powers to refuse or manage particular activities, to declare protected areas, or to

place conditions on discharges or run-off. Examples of these tools are the *Environment Protection and Biodiversity Conservation Act 1999*, the *Great Barrier Reef Marine Park Act 1975* (as well its complementary Queensland Marine Parks legislation) and the *Sustainable Planning Act 2009* (Queensland). In 2017 the new *Planning Act 2016* will commence, replacing the *Sustainable Planning Act*. This Act ensures that areas at high risk of coastal erosion are maintained as development free.

Within the Great Barrier Reef catchment there are multiple Acts and other mechanisms identified as making relevant provisions in this area.

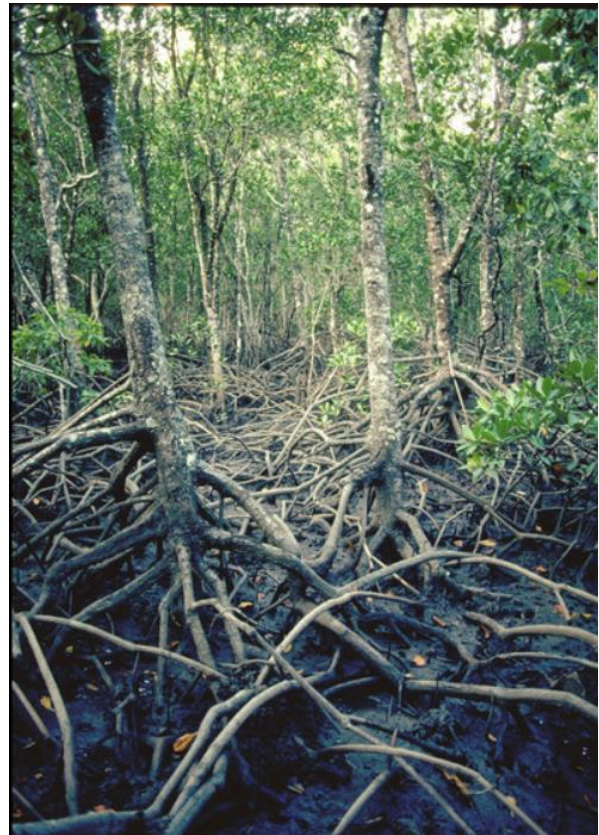


Figure 4: Mangrove forest

The primary focus of actions to protect estuaries, aside from applying those tools identified above, is to improve water quality

entering the Great Barrier Reef. The *Reef Water Quality Protection Plan 2009* (Reef Plan) sets targets for improvement and is supported by the resources of the Australian and Queensland governments, as well as significant investment by industry, to implement change and monitor progress.

Other programs include education, awareness and action plans on what individuals can do to minimise their impacts on the environment, such as the *Great Barrier Reef Climate Change Action Plan 2007–2012* and the Reef Guardian program.

Great Barrier Reef Outlook Report 2014

Assessment:

- Mangroves — good, diversity and abundance being maintained
- Saltmarsh — modified by coastal development (15 per cent reduction in area)
- Other estuary components — not assessed.

Estuaries play a significant role in the ecosystem health and resilience of the Reef. Mangrove forests are integral to the Reef ecosystem, providing essential structure and habitat for a range of terrestrial, marine and intertidal species. They play a critical role as: a source of primary production and carbon sequestration; nursery and breeding sites¹⁰; depositional areas for suspended sediments from the water; and physical barriers to storms and weather events.^{11,12,13}

Mangrove habitats are dynamic, with some localised declines and some expansions.¹⁴ In contrast to international trends, the overall condition of mangrove forests in and adjacent to the Reef is relatively stable and abundance is being maintained.^{12,13, 11,14}

Saltmarshes are an important, highly productive interface between marine and terrestrial environments in the upper intertidal

area along the length of the Great Barrier Reef coast.^{12,15} They provide feeding and breeding areas for many marine species including commercial fish and prawn species. Coastal development has modified saltmarshes, affecting more than 15 per cent of the habitat in the catchment.¹⁶ The impact is highest in areas with grazing and cropping, urban growth or large population centres.¹⁴

A national assessment of estuary condition conducted in 2002 found almost half of the estuaries within the Reef catchment were in near pristine condition and another third were in a largely unmodified condition² (see Figure 1). Less than a fifth of Great Barrier Reef catchment estuaries were assessed to be collectively modified or extensively modified, although more modified estuaries were concentrated within types more suited to port development (Figure 3).

Current policies and legislative mechanisms provide effective protection against direct impacts on the values of estuarine wetlands. Indirect impacts derived from catchment run-off and diffuse pollutant sources are less well served by existing management capacity. Legacy issues, such as bund walls installed to promote the growth of ponded pastures and exposed acid sulphate soils, require further management consideration.

In the past decade, rates of measured and projected sea level rise have increased dramatically.⁶ Accelerating sea level rise will significantly affect distributions of estuarine habitats in the future. Policies that facilitate and accommodate the landward migration of estuarine habitats need to be developed to maintain coastal buffers and connectivity between terrestrial and marine environments.

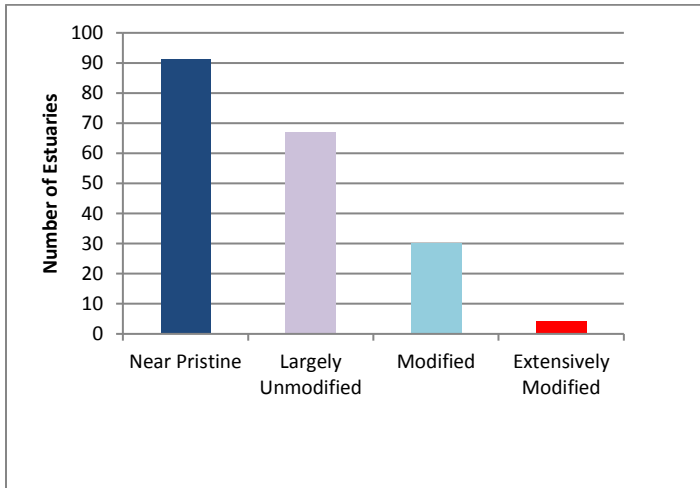


Figure 2: Condition of estuaries within the Great Barrier Reef catchment ²

Vulnerability assessment: high

The vulnerability assessment for estuaries is high, particularly for those adjacent to coastal development or those that have catchments dominated by intensive agricultural land use.

- Connectivity is important to tidal wetland functioning. Connectivity loss due to urban infrastructure and cumulative impacts of coastal development is often not considered in development planning and approvals.
- Estuaries are highly susceptible to climate change impacts, particularly sea level rise. Sea level rise mitigation activities, such as shoreline and channel armouring works to prevent infrastructure loss, are likely to further impact these ecosystems.
- Existing coastal infrastructure will prevent landward migration of estuaries as sea level rises — this will result in intertidal habitat loss in some areas.
- Legacy issues, such as saltwater intrusion bunding and a potential increase in illegal bunding (especially as sea level rise advances), may further impact some areas.
- Changing rainfall patterns from climate change are predicted to result in more

frequent droughts and failed summer wet seasons and conversely more extreme rainfall events and flooding. The former will result in reduced freshwater flows and increased exposure of estuaries to hypersaline conditions particularly in seasonally dry tropical areas, a process already implicated in extensive mangrove dieback in the Gulf of Carpentaria.¹⁷ Extreme rainfall events will exacerbate the export of contaminant loads from poorer condition catchments and drive geomorphic, habitat and water quality changes.

- There is a clear need to manage cumulative impacts on estuaries. Appropriate legislative tools or sufficient understanding do not yet support development planning within contributing catchment areas so that it avoids risks posed to estuary condition and function by surpassing catchment development thresholds.

Suggested actions to address vulnerabilities

Catchment run-off

At the scale of the Great Barrier Reef, the most significant response to improve the resilience of estuaries is to reduce water quality risks associated with catchment run-off. Continued actions under Reef Plan to reduce pollutants released to receiving waters from diffuse sources remain important.

Actions that are particularly critical include improving catchment ecosystem services that regulate the generation of contaminant loads and their transport, such as improved waterway stability, riparian and wetland condition and the maintenance of environmental flows.

For more localised (point source) and urban impacts, it is important to continue

implementing waste water management. This includes:

- tertiary treatment technology and recycling (where absent)
- urban storm water management through best practice erosion and sediment and appropriate discharge controls (where absent)
- application of water sensitive urban design techniques to new and existing urban land development.

Coastal development

In 2013, the Australian and Queensland governments produced comprehensive strategic assessments of the Great Barrier Reef World Heritage Area and the adjacent coastal zone. The Queensland Government assessment identified the significant loss of estuarine ecosystems that had occurred as a result of past land use decisions, particularly through the clearing of vegetation and agricultural development.¹⁸

The assessment also found a range of threats is continuing to impact coastal and inshore habitats such as estuaries. These threats included: extreme weather events, climate change, poor water quality from diffuse pollution sources in catchment run-off and loss of habitats¹⁸. Processes of sedimentation, nutrient cycling and connectivity were found to be in particularly poor condition despite having started to stabilise in recent years as a result of management intervention.

New coastal development was found to be concentrated within a very small area of the Great Barrier Reef coastline and subject to relatively effective planning, development assessment and impact mitigation processes. However, several key areas for improvement that would achieve better outcomes for estuarine ecosystems were nominated. These included:

- developing planning frameworks that specifically considered matters of national environmental significance and more adequately addressed cumulative impacts
- greater integration of development impact offset programs to deliver strategic outcomes
- focusing on actions that build ecosystem resilience including improving water quality
- rehabilitating critical habitat, re-establishing corridors and recovering threatened and migratory species
- implementing arrangements to concentrate new port development around existing major ports, and delivering more strategic approaches to the development and operation of marinas
- ensuring water quality guidelines support a healthy state for a broader range of habitats and species and account for cumulative impacts
- supporting research on critical ecosystem thresholds with a focus on inshore biodiversity and associated ecosystems
- strengthening engagement and facilitating actions that maintain and enhance the condition of values and reduce impacts particularly in relation to climate change, catchment run-off, degradation of coastal ecosystems and direct use.

While avoiding disturbance to estuaries should always be the first consideration, where it cannot be avoided, environmental offsets should be required and applied to reduce other threats to estuaries.

In response to the emerging threat of accelerating sea level rise, developers should consider the potential for shoreline retreat and

the need for the subsequent movement of estuarine habitat landward. This should be factored into all planning schemes to ensure the long-term viability of these habitats.

Understanding status and trends and requirements for ecosystem health

It is important to ensure management of estuaries is based on good science and underpinned by an effective research and monitoring program. Almost all the current estuarine monitoring is in close proximity to ports. Despite this focus, the limits and tolerance of estuarine ecosystems to various threats, such as increased nutrients and changes to hydrology, are still not well understood.

Very little is known about the population status, ecological roles and/or pressures and impact thresholds for estuarine flora and fauna, nor their reliance on adjacent ecosystems. Information is required at regional (basin) scales on key connectivity and hydrological mechanisms (especially groundwater recharge, discharge and extraction). There is also a need to use such knowledge to better manage cumulative impacts on estuaries.

Climate change

Broad national and global initiatives required to address climate change are not considered here. Information on cumulative impacts can be found in the Great Barrier Reef Marine Park Authority's *Climate Change and the Great Barrier Reef – A Vulnerability Assessment*.¹⁹

Efforts by the Great Barrier Reef Marine Park Authority are primarily aimed at understanding the vulnerability of the Reef's ecosystems, including estuaries. These efforts focus on maintaining them in a healthy state, which builds resilience to climate change in the broader Reef ecosystem and the communities and industries that depend on it.

There should be continued focus on actions that protect or improve the existing condition and function of estuaries, and hence the resilience of high-risk habitats and species to climate change threats. Specific adaptive management measures that will facilitate species and habitat adaption to new environmental conditions, particularly those associated with elevated sea levels and altered catchment run-off are also critical.

Background

Brief description of estuaries

“Estuarine wetlands are those with marine or oceanic water, which is diluted with freshwater run-off from the land. It is usually an area where a river meets the sea, providing an important habitat for many species”.¹ Occurring in the interface between marine and riverine ecosystems, estuaries are governed by competing forces of river, tide and wave energy. The relative dominance of these forces creates different estuary types.

Estuaries contain many tidal and subtidal habitats including: forest (mangroves); coastal saltmarshes (grass, sedge and herb swamps); saltflats and salt pans; mudflats; and intertidal seagrass habitats. Beneath the water, estuarine habitats can include soft-bottom communities, hard-bottom communities, and ecosystems dominated by coral and seagrass. Expression of groundwater (springs) are often found close to these areas, discharging in areas along the coast.

Geographical distribution

The National Land and Water Resources Audit national assessment of estuary condition² identified 192 estuaries within the 35 river basins constituting the Great Barrier Reef catchment. These estuaries fell into six geomorphic types defined by the relative dominance of river, tide and wave energy. The most common estuary types were tide dominated, reflecting the relative dominance of tidal energy within the sheltered environment of the Great Barrier Reef lagoon. There were 75 tidal flat creeks and 42 tide-dominated estuaries (Figure 2, Figure 3).

There is approximately 3969 square kilometres of combined mangrove and saltmarsh habitat remaining along the Great Barrier Reef coast (based on Queensland Government regional ecosystem mapping). This is a 10 per cent reduction from the pre-clearing extent (4339 square kilometres). The most extensive of the mangrove and saltmarsh habitat areas in relatively good condition are found within five main areas: Princess Charlotte Bay, Hinchinbrook Island, Bowling Green Bay, Broadsound/Shoalwater bays and the Fitzroy River estuary.¹²

Estuarine ecosystem status with the Great Barrier Reef catchment

Overall, approximately nine per cent of the pre-European settlement (pre-clear) area of estuarine ecosystems has been extensively modified or lost in the Great Barrier Reef catchment. Table 1 shows the pre-European settlement (pre-clear) and the 2006 extent of estuarine regional ecosystems at the catchment, natural resource management area and basin scales. These values are based on regional ecosystem mapping data and do not reflect the intrinsic health of these ecosystems.

Table 1: Pre and post-clear extent of estuarine regional ecosystems within the Great Barrier Reef catchment

Estuaries	Pre-clear extent (km ²)	Post-clear extent (km ²)	Percentage remaining
Catchment	4339	3969	91
Cape York natural resource management region	962	958	100
Jacky Jacky	255	255	100
Olive-Pascoe	48	48	100
Lockhart	94	93	99
Stewart	34	34	100
Normanby	336	335	100
Jeanie	169	169	100
Endeavour	28	27	96
Wet Tropics natural resource management region	422	383	91
Daintree	34	33	97
Mossman	19	16	84
Barron	14	10	71
Mulgrave-Russell	57	47	82
Johnstone	40	35	88
Tully	20	19	95
Murray	89	88	99
Herbert	155	137	88
Burdekin Dry Tropics natural resource management region	661	640	97
Black	11	11	100
Ross	135	128	95
Haughton	319	317	99
Burdekin	4	3	75
Don	194	183	94
Mackay–Whitsunday natural resource management region	464	443	95
Proserpine	126	122	97
O'Connell	131	127	97
Pioneer	10	7	70
Plane	199	188	94
Fitzroy natural resource management region	1602	1328	83
Styx	356	345	97
Shoalwater	528	343	65
Waterpark	275	259	95
Fitzroy	332	286	87
Calliope	88	80	91
Boyne	26	17	66
Burnett–Mary natural resource management region	230	220	96
Baffle	131	130	99
Burnett	15	11	73
Kolan	18	14	78
Burrum	27	26	96
Mary	42	41	98

The population status for estuaries varies between the two major components: mangrove communities and saltpan/saltmarsh communities.

Mangroves

Mangroves are flowering plants that inhabit inter-tidal habitats along estuaries, rivers, bays and islands²⁰. Mangrove communities are usually groups of trees and shrubs, growing in sheltered areas where fine sediments accumulate, and where they are inundated by seawater during the tidal cycle.

The mangrove forests along the Great Barrier Reef coast are very diverse, with at least 39 mangrove species and hybrids recorded.^{21,22,23} This represents about 50 percent of species worldwide. Mangrove forests in and adjacent to the Great Barrier Reef coast are some of the most healthy in the world, and are an integral part of the Reef ecosystem.

- Mangroves, once considered undesirable swamps, are now justly regarded as places of interest and beauty. An estimated 2139 square kilometres of mangrove wetlands border the Great Barrier Reef.
- Mangroves have been cleared along some sections of coast, but have successfully re-established on others.
- Mangrove communities are dynamic and have been known to die back at times (For example: Pioneer River, Shoalwater Bay). The Pioneer River die back is likely to have been caused by herbicide run-off.²⁴
- Of the 39 mangrove species on the Reef (half of the world's total species) the highest biodiversity is found in the far north.²³
- Mangroves are maintaining their biodiversity and, in most places, their abundance on the Reef, in stark contrast to most of the rest of the world where they have been cleared mainly for aquaculture and fuel.^{12,13}
- Mangrove-fringed salt flats are more prevalent in the dry tropics.¹³
- Mangrove forest extent has remained relatively stable within most estuarine systems, however significant losses have occurred in regions and river basins that host more intensive coastal development. These include the intensively developed lower Burdekin River basin (36.7 per cent loss), the Boyne River basin which hosts industrial and urban areas associated with Gladstone (31 per cent loss), the Pioneer basin which hosts intensive agricultural development and the port of Mackay (28.2 per cent loss) and the Barron River basin that hosts Cairns city, (28 per cent loss). (Table 2).

Table 2: Pre and post-clear extent of mangrove regional ecosystems within river basins of the Great Barrier Reef catchment

Mangroves		Pre-clear extent (km ²)	Post-clear extent (km ²)	Percentage remaining
Great Barrier Reef catchment		2193	2139	97.5
Cape York natural resource management region		552	550	100
	Jacky Jacky	222	222	100
	Olive-Pascoe	37	37	100
	Lockhart	75	75	100
	Stewart	10	10	100
	Normanby	97	96	99
	Jeanie	85	85	100
	Endeavour	26	25	98
Wet Tropics natural resource management region		364	340	93.5
	Daintree	33	32	98
	Mossman	15	14	93
	Barron	12	9	72
	Mulgrave–Russell	52	44	86
	Johnstone	38	34	90
	Tully	19	19	99
	Murray	79	78	100
	Herbert	116	109	94
Burdekin Dry Tropics natural resource management region		277	269	97.2
	Black	8	8	98.5
	Ross	40	38	93.3
	Haughton	146	146	99.4
	Burdekin	2	1	63.3
	Don	80	77	96.0
Mackay–Whitsunday natural resource management region		323	316	97.6
	Proserpine	93	92	99.4
	O'Connell	104	102	98.6
	Pioneer	9	7	71.9
	Plane	118	115	97.4
Fitzroy natural resource management region		534	524	98.3
	Styx	57	56	99.9
	Shoalwater	129	129	99.9
	Waterpark	199	199	99.9
	Fitzroy	94	92	97.7
	Calliope	43	40	93.1
	Boyne	11	8	69.0
Burnett–Mary natural resource management region		144	140	97.2
	Baffle	82	81	99.6
	Burnett	11	10	86.7
	Kolan	14	12	90.6
	Burrum	15	15	98.0
	Mary	23	22	97.3

Figure 3: Estuary types and their relative susceptibility to change (from National Land and Water Resources Audit 2002²)



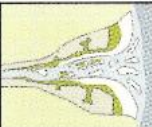



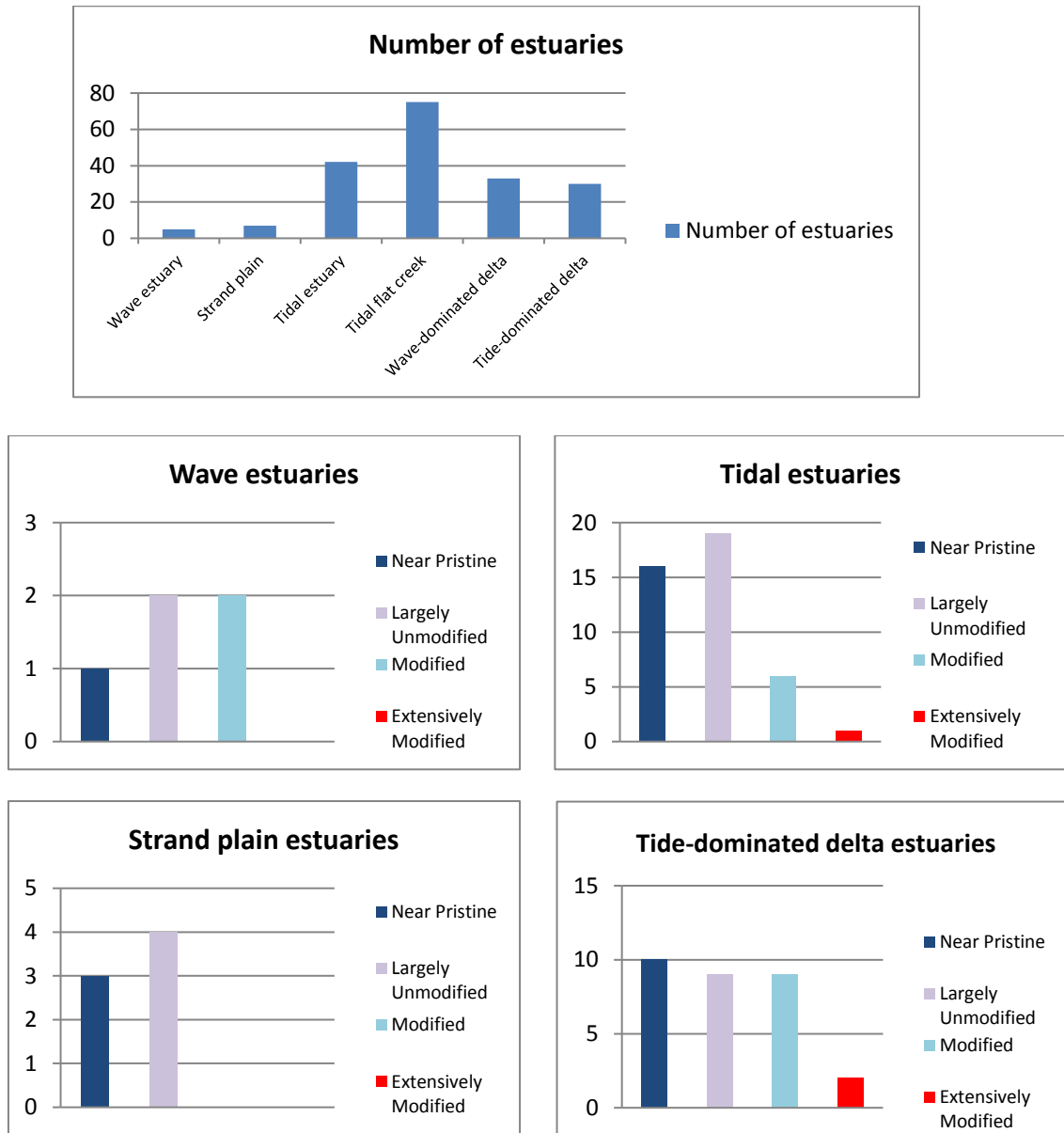
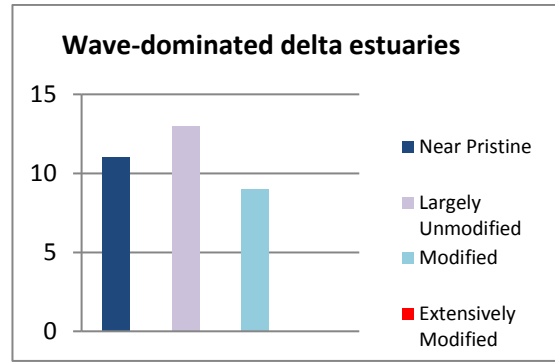
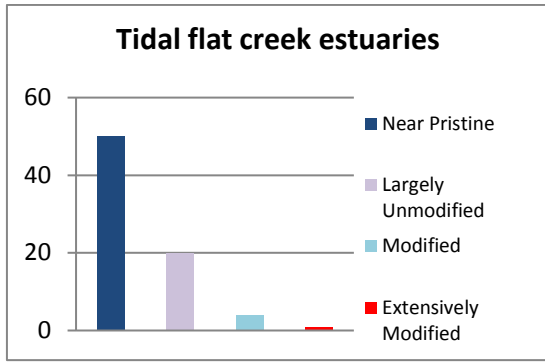
Type of coastal environment	Sediment trapping efficiency	Turbidity	Circulation	Risk of sedimentation
 Tide-dominated delta	low	naturally high	well mixed	low
 Wave-dominated delta	low	naturally low partially mixed	salt wedge/ partially mixed	low
 Tide-dominated estuary	moderate	naturally high	well mixed	moderate
 Wave-dominated estuary	high	naturally low partially mixed	salt wedge/ partially mixed	high
 Tidal flats	low	naturally high	well mixed	low
 Strandplains	low	naturally low wedge/partially mixed	negative/salt	low

Figure 4: Geomorphic estuary types within the Great Barrier Reef catchment and their condition





Saltmarshes

Saltmarshes occur discontinuously along the entire Queensland coast, with approximately 1830 square kilometres of saltmarsh habitat occurring along the Great Barrier Reef coast.¹² This represents more than 40 per cent of the combined area of mangrove and saltmarsh found along the Great Barrier Reef coast.²⁵

Coastal saltmarsh communities consist of plants and animals that grow along the upper intertidal zone of coastal waterways and host a variety of salt-tolerant herbs, grasses, reeds, sedges and shrubs. Saltmarshes are situated below the level of highest astronomical tide but well above low tide level. The most landward fringes of saltmarshes may only receive seawater inundation on the highest of tides (for example spring and king tides). Saltmarshes are typically located landward of mangroves, on flat plains.²⁶

Saltmarshes may or may not be vegetated. Non-vegetated saltmarshes are often referred to as saltpans or saltflats, due to the hypersaline conditions present and lack of vegetation. Vegetated saltmarshes fall into two categories: those vegetated by succulents and those dominated by tussock grasses.²⁶

Ecosystem services provided by saltmarshes include: water purification, high nutrient cycling and primary productivity, erosion regulation, natural hazard protection and climate regulation. Saltmarshes are the component of estuaries that have been the most significantly modified by coastal developments. As noted for mangroves, river basins hosting more intensive coastal development have experienced the greatest losses. Once tides have been excluded by constructed bunds or tide gates, saltmarsh areas have often been converted to intensive agriculture, particularly sugar cane.

River basins that have coastal plains dominated by intensive sugar cane agriculture have experienced the greatest losses of saltmarsh. This includes the Kolan Basin (63 per cent), the Burnett Basin (58 per cent), the Russell–Mulgrave Basin (52 per cent), the lower Burdekin (36 per cent) and the Mossman Basin (31 per cent) (Table 3).

Substantial areas (approximately 30 per cent) of saltmarsh were altered or destroyed by artificial bund construction and tide exclusion prior to the Queensland Policy for Development and Use of Poned Pastures¹⁶ was endorsed in 2003. Most historical impediments remain²⁷ and represent the primary cause of significant saltmarsh losses in non-cropping areas, as illustrated by the 46 per cent loss in the Shoalwater Basin (Table 3).

Table 3: Pre and post-clear extent of saltmarsh regional ecosystems within river basins of the Great Barrier Reef catchment

Saltmarshes		Pre-clear extent (km ²)	Post-clear extent (km ²)	Percentage remaining
Great Barrier Reef catchment		2146	1830	85.3
Cape York natural resource management region		410	408	100
	Jacky Jacky	33	33	100
	Olive-Pascoe	10	10	100
	Lockhart	19	18	95
	Stewart	23	23	100
	Normanby	238	238	100
	Jeanie	84	84	100
	Endeavour	2	1.8	92
Wet Tropics natural resource management region		58	42	72.7
	Daintree	0.4	0.3	82
	Mossman	3	2.1	69
	Barron	0.8	0.3	32
	Mulgrave-Russell	5	2	48
	Johnstone	0.7	0.6	79
	Tully	0	0	100
	Murray	9.6	9.4	98.4
	Herbert	39	27	71
Burdekin Dry Tropics natural resource management region		384	371	96.5
	Black	3	2.8	92.5
	Ross	95	90	96
	Haughton	172	171	97
	Burdekin	1.6	1	64
	Don	113	105	93
Mackay–Whitsunday natural resource management region		141	127	90.5
	Proserpine	33	29	89
	O'Connell	26	24	92
	Pioneer	0.6	0.5	80
	Plane	81	73	91
Fitzroy natural resource management region		1068	803	75.1
	Styx	299	288	96
	Shoalwater	398	210	54
	Waterpark	76	59	89
	Fitzroy	238	194	82
	Calliope	44	40	89
	Boyne	14	8	58
Burnett–Mary natural resource management region		85	79	92.8
	Baffle	49	48	99
	Burnett	2.9	1.2	42
	Kolan	3.4	1.3	37
	Burrum	11	11	92

Ecosystem role/function

Estuaries are ecologically important habitats that link marine, riverine and terrestrial environments. They provide habitat for aquatic and terrestrial organisms, including several threatened species. Estuaries are vital to the biological productivity of coastal waters^{20,22,28,29} and connect the catchment, river and sea. Extreme physical processes shape estuaries. The ebb and flow of the tide, episodic freshwater pulses that bring with them sediments and nutrients from the catchment, and high rates of evaporation generate constant fluxes in salinity, temperature and water level.

Estuaries are a significant sink for carbon and store more carbon per unit area than terrestrial ecosystems. The rate of carbon storage in sediments of estuarine wetlands has been estimated to exceed that of tropical forests by a factor of 50.³⁰ If left undisturbed, carbon in estuarine soils can be stored for millennia. The rate of carbon sequestration in saltmarsh in international studies has been estimated to be in the order of 2.2 tonnes of carbon per hectare per annum.³¹ Restoring tidal saltmarshes, particularly by reinstating tides to areas drained and/or bunded for agriculture, would significantly increase the world's natural carbon sinks.³¹

Unlike freshwater wetlands, estuarine wetlands do not emit methane - this is because of the inhibitory effects of sulphates on methanogenic bacteria.³² Carbon inputs are thus subject to minimal respiratory losses. Acid sulphate soils that are often found in estuarine areas are high in organic material and have been shown to lose as much as 33 tonnes per hectare of carbon per year when drained and oxidised.³³

Ecosystem goods and services

Physical, biological and ecological roles conducted by estuarine habitats provide important ecosystem goods and services for inshore Reef health.³⁴ To varying degrees, estuarine habitats regulate the physical processes in which they reside. Mangroves play an important role in sediment dynamics, estuarine hydrology and nutrient cycling. Sedimentation appears to be highest in mangroves that line rivers, which have high rates of freshwater discharge. Lower accumulation rates occur in fringing mangroves that border estuaries and open bays situated in the dry tropics. Over the long term (centuries to decades) sediment movement in mangroves in the wet tropics can be very dynamic.³⁵ Wider stands of mangroves also play a major role in preventing coastal erosion³⁶ and stabilising coastal soils from migrating seawards. The ecosystem goods and services provided by riverine, basin and fringing mangroves vary due to differing processes operating in these areas.³⁷

Mangroves regulate freshwater run-off by retaining it and acting as a biological filter for the water before it enters the Great Barrier Reef. This retention allows for greater processing of nutrients and chemicals.³⁵ Mangrove forests perform nitrification and denitrification, assimilating ammonia, nitrite and nitrate relatively quickly.³⁸ These nutrients are limited within mangrove forests.³⁵ Mangroves are suited for the uptake of chronic nitrogen inputs contained within sediments and groundwater.³⁹

Estuarine ecosystems are vital to the biological productivity of coastal waters.^{20,22,28} Mangrove and saltmarsh plants produce large amounts of organic material (for example, leaves, seeds/propagules, flowers and wood) through primary production. These intertidal ecosystems also support other primary producers such as micro- and macro-algae.³⁵ The plant and algal material (alive and dead) is used by consumer, detritivore and decomposer organisms and contributes to food webs that sustain many other animals including predatory animals, such as fish and birds. The nutrients that are cycled sustain many other primary producers.⁴⁰ Leaf-burying mangrove crabs of the family Sesamidae provide a pivotal link between mangrove productivity and coastal food chains. Recruitment of larval fish into mangrove waterways (including many targeted fishery species), peaks in coincidence with the production of zoeae by these leaf-burying crabs. This provides a direct linkage between mangrove and fisheries production.¹⁰

Mangrove prop roots also serve as a habitat for cyanobacteria and are capable of high rates of nitrogen fixation.³⁵ Adjacent benthic macroalgal mats also stimulate denitrification.^{35,41,42} Bacteria within mangroves have a faster uptake of nitrogen than terrestrial tropical forest types (due to the need for rapid growth to cope with extreme conditions).³⁵

Mangroves export particulate organic carbon to inshore coastal ecosystems, with higher rates of carbon export in areas with higher tidal ranges.³⁵ Mangroves are also a site for carbon sequestration.^{36,43} Coastal wetlands store more carbon per unit area than terrestrial ecosystems.

Mangrove forests also export silica (important for diatom growth).⁴⁴ Reductions in silica production from the loss of mangroves could result in a dominance of dinoflagellates (some of which can be toxic) over diatoms.⁴⁵

Mangroves provide nursery grounds for many pelagic and nearshore fish species and are the habitat for an extensive array of nearshore marine life, as well as birds, flying foxes and other terrestrial wildlife.¹² These animals pollinate flowers and distribute seeds within the Great Barrier Reef region.⁴⁶ The complex topography and strong-bottom friction associated with mangroves aggregates floating debris, which supports populations of bacteria, protists, zooplankton and fish. However, phytoplankton diversity in mangroves is lower than in open water.³⁵ Likewise, tree stems, roots and fallen timber (and their epiphytes) are attractive to many organisms entering the forest on the flood tide. These, along with resuspended sediments, combine to cause the low clarity typical of mangrove waters.³⁵

The mangrove forest floor is where the most essential energetic processes and trophic relations within mangroves take place. Many mangrove epibenthic, root epibiont and infaunal organisms harvest a wide range of foods. Much of the leaf litter reaching the forest floor is consumed or hidden below ground by crabs⁴⁷, thereby reducing nutrient export from the mangroves. Burrowing crabs also assist with mangrove hydrodynamics.³⁵

Mangrove detritus is needed to sustain high bacterioplankton productivity in relatively pristine mangrove waters. The bacterioplankton is subject to intense consumption by microzooplankton,³⁵ which forms the basis of the estuarine food chain.

Ecosystem goods and services category	Services provided by estuarine ecosystems
Provisioning services (e.g. food, fibre, genetic resources, biochemicals, fresh water)	<ul style="list-style-type: none"> • Provision of fish, crustacean and mollusc species that form the basis of commercial, recreational and traditional fisheries • Production of plant and animal resources used by Indigenous people
Cultural services (e.g. spiritual values, knowledge system, education and inspiration, recreation and aesthetic values, sense of place)	<ul style="list-style-type: none"> • Major habitat for culturally significant species and locations that provide a sense of identity and site linkages to cultural lore, making estuaries very important to Traditional Owner interests in sea country management • Recreational services via opportunities for nature-based recreation including boating, fishing and nature appreciation • Spiritual and inspirational services via places that provide a source of inspiration and/or community identity • Aesthetic services via places of aesthetic beauty • Educational services via opportunities for formal and informal education • Employment opportunities associated with fishing and other forms of nature-based tourism • Opportunities for transportation of goods and commerce via sites for ports
Supporting services (e.g. primary production, provision of habitat, nutrient cycling, soil formation and retention, production of atmospheric oxygen, water cycling)	<ul style="list-style-type: none"> • Primary and secondary production with food chain linkages to adjoining marine waters • Habitat, including nursery areas, for ecologically important aquatic species with connections to the Reef, and recruitment sources for freshwater and marine fishery species • Nutrient cycling • Oxygenation of water and sediments • Atmospheric oxygen and water vapour contributions • Connective pathway for food, nutrients and species from catchment to the Reef
Regulating services (e.g. invasion resistance, herbivory, pollination, climate regulation, disease regulation, natural hazard protection)	<ul style="list-style-type: none"> • Potential acid sulphate soil management • Temperature regulation of both air and water • Biogeochemical modification of chemicals and heavy metals, including by flocculation of heavy metals • Natural hazard protection, for example, coastal protection from erosion and storm wave dissipation • Water flow regulation (groundwater and surface flows) • Sediment trapping, stabilisation and assimilation • Climate regulation via carbon cycling and sequestration

Pressures influencing estuaries in and adjacent to the Great Barrier Reef Marine Park

Estuarine systems provide connectivity between land and sea, while regulating hydrological flows (both landward and seaward), recycling nutrients and engaging in primary and secondary production. Pressures that influence these connections pose the greatest threat to the health and resilience of estuaries. The key pressures affecting estuaries include:

- *Catchment development* — particularly development that involves the intensive use of land and water resources, which result in changes in catchment run-off, or development that occurs within the immediate coastal zone and extends into estuarine ecosystems, affecting functions that impact their condition (for example, tidal flushing and connectivity).
- *Catchment run-off* — conveying elevated loads of sediment, nutrients and other contaminants often via modified (reduced, peakier or shorter) flows, which result in altered estuarine hydrology, water quality (turbidity, nutrients, salinity, pH, chemical residues) and geomorphology and increased susceptibility to eutrophication.
- *Ports and shipping* — resulting in permanent changes to estuary function through the removal of estuarine habitats, land reclamation and excavation, regular disturbances associated with dredging and ship traffic and cumulative contaminant load impacts
- *Commercial and recreational fishing* — generating localised impacts to target and non-target species populations.
- *Recreational use* — generating impacts via high levels of boat traffic and other forms of disturbance, such as uncontrolled four-wheel drive vehicle and human access to saltmarsh and other sensitive habitats.
- *Climate change* — driving multiple sources of pressure, including sea level rise, extreme climate events (droughts, floods, cyclones and storm surge), elevated temperatures, ocean acidification, altered ocean currents and exacerbating other catchment and estuary condition associated pressures via magnified and synergistic impacts.

Vulnerability assessment matrix

The Great Barrier Reef Outlook Reports 2009⁵ and 2014⁶ identified a number of commercial and non-commercial uses of the Marine Park, as well as climate change, coastal development and poor water quality from catchment run-off, as key pressures that reduce the resilience of the Great Barrier Reef ecosystem, including components such as estuaries.

These pressures are key factors that influence the current and projected future environmental, economic and social values of the Great Barrier Reef ecosystem. These pressures can impact directly and/or indirectly on habitats, species and groups of species to reduce their resilience. Using the vulnerability assessment framework adapted by Wachenfeld and colleagues⁴⁸, this assessment aims to provide an integration of social, ecological, economic and governance information. For each key pressure affecting estuaries in the Reef catchment, exposure and sensitivity is assessed in relation to each other to reach a level of potential impact. The potential impact is then reassessed, having considered the level of natural adaptive capacity that estuaries have to respond to the pressure and the adaptive capacity that management has, or can apply, to reduce the potential impact from the pressure.

This provides managers and stakeholders with an understanding of key elements that each pressure can impose on the habitat to assess the overall residual vulnerability of estuaries to that particular pressure. This allows for suggested actions to be formulated, which can minimise the impact of pressures to which estuaries are most vulnerable.

Vulnerability assessment matrix summary for estuaries

Pressure	Exposed to source of pressure	Degree of exposure to source of pressure	Sensitivity to source of pressure	Adaptive capacity — natural	Adaptive capacity — management	Residual vulnerability	Level of confidence in supporting evidence
Commercial tourism	Yes — locally	Low	Low	Good	Good	Low	Good
Defence activities	Yes — locally	Low	Low	Good	Good	Low	Good
Traditional use	Yes — Great Barrier Reef catchment wide, localised higher pressure	Low	Low — can be higher where other pressures exist	Good — can be poorer where other pressures exist	Good	Low	Moderate
Climate change	Yes — entire region, multiple expressions of pressure such as sea level rise, extreme climate/storms, elevated temperatures, ocean acidification, altered ocean currents	Very high — without effective emissions mitigation that avoids dangerous climate change	High to very high — for species and habitats on terrestrial margin, at limits of tolerance ranges, and estuaries with narrow tidal range, low gradient coastal plain, landward development constraints, highly developed catchment, poor tidal flushing, higher rates of sea level rise, and other pressures.	Poor — if climate change/sea level rise is rapid, estuary condition and function is poor, catchment is highly developed, estuary is vulnerable type, subject to frequent storm disturbances, low gradient coastal plain, highly seasonal climate with biotic community at tolerance margins	Poor — if effective global emissions control not achieved, and if estuary has poor natural adaptive capacity	High to very high	Poor High uncertainty surrounds predictions of sea level rise, temperature and ocean acidity rates of change and end points. Specific community tolerance thresholds for parameters that are predicted to change are not well understood.
		High — with best case emission mitigation	Moderate — for estuaries with greater tidal range, tidal flushing, water mixing, lower sediment retention, limited catchment, landward development, steeper coastal plain, species-broad tolerances, lower rates of sea-level rise	Moderate — if pressure mitigated by emissions control, estuary/catchment condition/function good, resilient estuary type, storm disturbances infrequent, higher gradient coastal plain, less seasonal climate, biota tolerant	Moderate — where natural adaptive capacity is moderate and legislative and planning frameworks can enable shoreline retreat/landward migration of estuary	High	Analysis of potential shoreline retreat and subsequent movement of estuarine habitat inland has not been done.

Pressure	Exposed to source of pressure	Degree of exposure to source of pressure	Sensitivity to source of pressure	Adaptive capacity — natural	Adaptive capacity — management	Residual vulnerability	Level of confidence in supporting evidence
Pressure	Exposed to source of pressure	Degree of exposure to source of pressure	Sensitivity to source of pressure	Adaptive capacity — natural	Adaptive capacity — management	Residual vulnerability	Level of confidence in supporting evidence
Ports and shipping	Yes — locally (with potential for regional significance)	High — within port limits	Very high — e.g. for complete ecosystem removal or reclamation	Poor — e.g. for complete ecosystem removal or reclamation	Good — spatial confinement, conditional approvals	High — for greenfield proposals and expanding sites	Good — effects of pollutants
		Low — outside port limits	Low — e.g. distanced from activity	Moderate — e.g. for medium density sediment plumes	Moderate — some concern regarding removal and cumulative impact	Low — areas outside port limits and influence of generated plumes	Poor — cumulative effects
Recreation (not fishing)	Yes — localised greatest along urban coast and areas served by recreational infrastructure	High — in proximity to settlement and for saltmarsh habitats	Moderate — where pressure high and for more sensitive habitat (saltmarsh)	Moderate — where pressure high and sustained	Moderate — limited capacity for compliance in some areas	Low	Moderate
		Low — for remainder of coast	Low	Good — able to regrow/ recolonise	Good		
Catchment development	Yes — developed coast and river basins with more intensive development	High — basins with intensive land and water resource use and development extending into estuary ecosystem causing habitat loss and function	High to very high — where exposure high, and/or estuary is vulnerable type, existing poor condition/ function and/or development removes habitat / impacts function (e.g. tidal flushing)	Poor — where estuary stressed by other pressures, or development results in permanent habitat removal/ hydrodynamic change or the frequency of impact is greater than the recovery period.	Poor — where exposure and sensitivity high, pressure associated with existing intensive development of catchment/ estuary, numerous other pressures operating	Very high — estuaries with intensively developed catchments including within estuarine ecosystem boundary	Moderate Cumulative impacts are difficult to assess. Knowledge of ecosystem health thresholds for estuaries in relation to contaminant loads and flow requirements remain too poorly understood to inform catchment scale development planning.
		Moderate — basins with variegated land use and/or some development extending into estuarine system	Moderate — where development impacts estuary condition but not functional integrity	Moderate — e.g. estuary type resilient to pressures, limited other pressures, able to recover between disturbances	Moderate — where pressure results in periodic stress but catchment/ estuary retains regulating ecosystem services	Medium to high — much of Great Barrier Reef coast where estuaries pressured and development accommodated at cost to ecosystem service provision	
		Low — basins with low intensity land	Low — exposure low, resilient	Good — e.g. for temporary	Good — new development/		

Pressure	Exposed to source of pressure	Degree of exposure to source of pressure	Sensitivity to source of pressure	Adaptive capacity — natural	Adaptive capacity — management	Residual vulnerability	Level of confidence in supporting evidence
		and water resource use	estuary type, changes within range natural variability	disturbance, resilient estuary type with good condition/ function	contemporary assessment, estuary condition / function good	Low — for estuaries in basins with low intensity land use	
Pressure	Exposed to source of pressure	Degree of exposure to source of pressure	Sensitivity to source of pressure	Adaptive capacity — natural	Adaptive capacity — management	Residual vulnerability	Level of confidence in supporting evidence
Commercial fishing	Yes — Great Barrier Reef catchment wide, localised exclusions	Low Medium — some non-targeted individual species including some of conservation interest	Low Medium — some non-targeted individual species and estuaries stressed by other pressures	Good Moderate — where exposure and sensitivity are higher and estuaries stressed by other pressures	Good Moderate — where effort is high, or latent, and transferable and enforcement resources limited	Low	Good
Recreational fishing	Yes — Great Barrier Reef catchment wide, localised exclusions	Low Medium — near urban centres / areas of settlement and where estuaries are served by recreational infrastructure	Low Medium — where exposure is higher and/or other pressures undermine ecosystem resilience	Good Moderate — where exposure and sensitivity are higher and estuarine ecosystem stressed by other pressures	Good Moderate — where population and associated fishing pressure high, enforcement resources limited	Low	Good
Catchment run-off	Yes — Great Barrier Reef catchment wide, closely related to catchment development pattern, land use practices and entrained land degradation processes	High to Very high — catchments with intensive land and water resource use and/or extensive land degradation	High — estuary is vulnerable type and/or contaminant loads/ hydrological change are above ecosystem health thresholds and/or other pressures present, e.g. impacts to tidal flushing	Poor — where pressure is long duration, frequent, large magnitude outside tolerance levels and/or estuary is vulnerable type and/or key habitat components or functions are lost to other pressure	Poor — where exposure and sensitivity is high, intensive land and water resource use commitments in catchment are high, and/or function /condition impaired by other pressures	High — in catchments dominated by intensive land use and/or containing extensive areas of land degradation, particularly gully erosion	Moderate Knowledge of end of catchment loads good, but transport pathways unknown Knowledge of thresholds of estuarine system tolerance to

Pressure	Exposed to source of pressure	Degree of exposure to source of pressure	Sensitivity to source of pressure	Adaptive capacity — natural	Adaptive capacity — management	Residual vulnerability	Level of confidence in supporting evidence
	Pressure has both contaminant load and altered run-off hydrology components.	Moderate — catchments with mixed land use, and regulating ecosystem services, and/or low intensity land use with some established land degradation	Low — where estuary has good condition/function and/or flushing/mixing and/or contaminant loads/hydrological change are within ecosystem health thresholds	Good — if pressure only short-term stress, system has good condition/ function, estuary type resilient, changes within thresholds	Moderate — actions underway where exposure and sensitivity to run-off pressure is medium and catchment land use, condition, functional process integrity and natural adaptive management capacity good	Medium — for basins with a variegated land use pattern, which retain and support catchment ecosystems services that regulate contaminant loads and transport	contaminant loads and changes in flow, is still limited A degree of uncertainty surrounds effectiveness of strategies to minimise run-off from agricultural lands.
		Low — catchments with low intensity land use, little or no land degradation			Good — where exposure and sensitivity to pressure is low and estuary has good condition and function	Low — for undeveloped basins with low intensity land use and little or no land degradation	

Key concerns

Catchment and coastal development

Existing and proposed development remains an issue of concern for the sustainability of estuarine ecosystems. This is particularly the case for developments that involve the intensive use of land and water resources, which result in changes in catchment run-off, or those developments that occur within the immediate coastal zone and extend into estuarine ecosystems.¹⁸

Development affects estuaries through direct site-based physical impacts on estuarine habitats and through indirect impacts that are related to modified coastal processes or that are driven by land use and associated run-off from contributing catchment areas (discussed below).⁶

Where development results in direct impacts to an estuary's ecological condition or function (such as tidal flushing and connectivity), its resilience to further impacts is undermined. This is particularly the case for impacts to estuarine habitat connectivity (discussed below), which result from instream structures such as tidal barrages and tide gates, tide-excluding bunds on saltmarsh areas, and barriers created by road and rail crossings or urban infrastructure.

While contemporary catchment development assessment processes consider downstream impacts, the legacy of past land use decisions are intensive patterns of catchment land use and development established by extensive clearing of native regional ecosystems.⁶ Such patterns of development have a more limited capacity to provide ecosystem services that regulate sediment, nutrient and other contaminant loads and transport. They are also a primary source of catchment run-off pressure affecting estuaries and the Great Barrier Reef ecosystem.^{5,18} An outstanding concern for managing indirect and direct development impacts is the limited understanding of catchment and ecosystems development thresholds, and the inability of current development assessment frameworks to adequately address the risks posed by cumulative development impacts.¹⁸

Some specific concerns related to development pressure are outlined below:

- Growing urban development increases inputs such as illegal dumping, stormwater discharge, hydrocarbon inputs and pesticides. Toxicants released from vehicle traffic and illegally dumped rubbish can affect estuarine ecology.
- Mosquitoes use the brackish pools in saltmarshes for reproduction — local authorities treat those located adjacent to urban areas because of the risk of mosquito borne diseases. Mosquito control measures, such as draining canals in saltmarshes, can affect water movement over saltmarshes and affect saltmarsh ecology. Spraying of pesticides onto saltmarshes is also undertaken in many areas. More novel methods, such as runnelling (shallow enlargement of natural drainage lines), are now recommended and allowed under permit by the Queensland Government.²⁶ As urban development encroaches on saltmarshes, mosquito control via pesticides and habitat modification is becoming more common.⁴⁹
- Proximal urban development results in saltmarsh areas being used for recreational purposes (fishing, off road driving, trail bikes) and as illegal dumping grounds. Recreational off-road vehicles and trail bikes driven on saltflats and saltmarshes increase soil erosion and create barriers or channels that alter shallow water flows.²⁶ A single set of wheel track damage can

take up to one year to recover and significant saltmarsh wetlands have been destroyed by recreational vehicle use.⁴⁹

- Saltmarshes have been reclaimed as part of industrial, agricultural, port and residential development.⁴⁹ In estuarine ecosystems, saltmarshes are the components that have been modified the most — this can have potentially significant impacts of estuarine function and the health of some species.
- Altered catchment hydrology (loss of hydrological flows due to roads and other infrastructure) is causing increases in saltmarsh salinity and a reduction in sediment deposition — critical factors for saltmarsh ecology.³¹
- Coastal sediment supply and transport processes have been altered by increasing urbanisation and land use changes, and these can lead to smothering of saltmarsh habitats.⁵⁰
- Saltmarsh sediments are also usually anoxic and have large accumulations of iron sulphides and other heavy metals such as arsenic. Disturbing these acid sulphate soils can cause sulphuric acid and heavy metals to drain into coastal waterways, leading to poor health and even loss of species.⁵¹ Heavy metals can accumulate in food chains. Coastal waters are alkaline in pH, and the release of acids can have serious consequences for estuarine plants and animals that can lead to the loss of species.
- Weeds and pests can greatly affect estuaries. Some of these are native species that only become problems under certain conditions, while others are non-native species that have been brought into Australia. Rubbervine (*Cryptostegia grandiflora*) is a major introduced pest in many regions bordering the Great Barrier Reef World Heritage Area. It is a particular threat to mangroves, as it can tolerate saline conditions.¹² In saltmarsh areas that have been modified into ponded pastures, exotic pasture grasses, such as para grass and *Hymenachne*, can become a problem.²⁶
- Invasive species, trampling by livestock, pollution (herbicides and pesticides) and fertilisers. Increased nutrients can lead to eutrophication and algal blooms that can smother saltmarsh plants and animals.⁴⁹



Figure 5: Wheel ruts in a saltpan have resulted in this change in saltmarsh vegetation

Connectivity

Changes to the connectivity functions of estuarine systems are particularly detrimental to ecosystem health and have the potential for flow-on impacts to the Great Barrier Reef, particularly inshore reef communities. Any alteration to one component of an estuary will likely affect the integrity of the whole estuary.

Through spatial analysis, the Great Barrier Reef Marine Park Authority estimates that connectivity in approximately 30 per cent of saltmarsh areas (or an area of around 552 square kilometres) of the Great Barrier Reef coast has been affected by bund wall installations. These bund walls may be in place because of infrastructure (road and rail networks). In addition, they may have been created to exclude saltwater from potential grazing land, thereby allowing freshwater pasture grasses to establish and enable increased production in otherwise marginal land. This equates to a loss of potential carbon sequestration of 75,000 to 121,000 tonnes of carbon per hectare per annum.³¹

The loss of estuarine ecosystems connectivity also has the following impacts:

- Many estuarine organisms also depend on other adjacent habitats during the low tide. As the high tide moves out, they leave mangroves to shelter in nearby seagrass beds and mudflats located in deeper water.⁵² Many species move on with the tide, feeding on plants and sediments as they move. Loss of these flooding opportunities can be critical to the survival of many species. The organism's interdependency on different habitat types means the abundance and diversity of life found across these habitats is much higher when connections are maintained.⁵³
- Studies in the Caribbean have found fish populations on coral reefs are more diverse and abundant when reefs are connected to mangrove systems.⁵⁴ In some cases, the biomass of fish was found to be double that of reefs that were not connected to mangrove systems.⁵⁵ This included commercially important fish, such as snappers and sweetlips.
- In the Great Barrier Reef, the connection between mangrove habitats, seagrass beds and coral reefs is critical for the completion of some fishes' life cycles, such as the red emperor. Expanding coastal development can lead to modifications to estuary entrances, canal developments, seawalls, levee-banks, channels, block banks, weirs, roads and tidal gates, which all alter hydrological regimes of estuaries.²⁶

To address catchment and coastal development pressures, including connectivity impacts, some key identified needs include¹⁸:

- development of planning frameworks that more adequately address cumulative impacts
- greater integration of development impact offset programs to deliver strategic outcomes
- a focus on actions that build ecosystem resilience, including improving water quality and reinstating estuary function
- rehabilitation of critical habitat and re-establishment of corridors and hydrological connectivity
- implementation of arrangements to concentrate new port development around existing major ports, and delivery of more strategic approaches to the development and operation of marinas
- support for research on critical ecosystem thresholds.

Catchment run-off

Catchment run-off and associated poor water quality is identified in the *Great Barrier Reef Outlook Report 2009*⁵ as the second most significant pressure on the Reef after climate change. Catchment run-off pressure is closely related to catchment development pattern, land use practices and entrained land degradation processes. The pressure is comprised of contaminant load and altered run-off hydrology. Catchment run-off from modified catchments conveys elevated loads of sediment, nutrients and other contaminants, often through modified flows that result in altered estuarine hydrology, water quality (turbidity, nutrients, salinity, pH, chemical residues) and geomorphology. It also increases their susceptibility to eutrophication².

The vulnerability of an estuary to catchment run-off pressure is partially determined by its geomorphic type, its baseline water quality and its relative capacity for water circulation and sediment trapping (Figure 2). The primary causes of catchment run-off pressure on estuaries along the Great Barrier Reef coast are:

- intensive patterns of catchment development and/or degraded catchments that have lost the capacity to provide ecosystem services that regulate generated loads and transport of sediment, nutrient and other contaminants
- site impacts to estuary function (particularly tidal flushing and connectivity).^{2,5,18}

The following are some of the catchment run-off issues recognised across the Reef catchment:

- Increasing human demands on coastal land-based resources are leading to higher water consumption, which results in the creation of dams that can alter hydrological regimes and the sinking of bores that can lower the water table. In some areas this is changing groundwater salinity.
- Increasing urbanisation and land use changes have altered coastal sediment supply and transport processes, which can smother estuarine habitats.⁵⁰
- Nutrients are essential to estuarine processes. Increases in the rate of nutrients entering estuaries (for example, from fertiliser applications on agricultural lands) initially leads to enhanced primary production. This enhanced production is detrimental to coastal ecosystems, as this initially leads to species composition being altered and, secondarily, to toxic or nuisance blooms. Autotrophic production rates then exceed the rate of consumption, resulting in the settling of the excess organic matter, the decomposition of which leads to oxygen depletion, build-up of toxins (such as sulphides), smothering and mortality of benthic and some pelagic species. Ultimately, anaerobic conditions develop in normally oxidised surface sediments and overlying waters. This results in mass mortality (eutrophication).²⁰ As these areas increase and persist, 'dead zones', such as those observed in the Gulf of Mexico, can occur.
- The addition of nitrogen triggers the release of nitrous oxide, a greenhouse gas with 298 times the global warming potential of carbon dioxide.⁵⁶
- Tropical environments are especially sensitive to pollution due to the lower nutrient and dissolved oxygen levels generally present in these warmer waters. Areas subjected to point-source pollution favour few opportunistic species and have a lower overall level of species abundance and diversity.

To address pressures presented by catchment run-off, some key identified needs include¹⁸:

- ensuring water quality guidelines support a healthy state for a broader range of habitats and species and account for cumulative impacts
- a focus on actions that build ecosystem resilience and ecosystem service provision, including improved water quality via re-instatement of contaminant load and transport regulating functions and use of innovative treatment technologies
- rehabilitating critical habitat
- strengthening engagement and facilitating actions that maintain and enhance the condition of values while reducing impacts particularly from climate change, catchment run-off, degradation of coastal ecosystems and direct use.

Port and shipping activities

The pressure of ports and shipping can result in permanent changes to estuary function, including through the removal of estuarine habitats, land reclamation and excavation, regular disturbances associated with dredging and ship traffic, and cumulative contaminant load impacts.⁶

Issues related to ports and shipping along the Great Barrier Reef coastline include:

- port and other boating facilities often being sited within estuaries because of protection afforded by mangroves
- the potential for ballast water, used to stabilise ships, to introduce non-native species to Reef waters. Asian green and bag mussels that attach to boat hulls have been introduced to ports within the Great Barrier Reef.

Estuaries have been reclaimed as part of industrial, agricultural, port and residential development.⁴⁹ Port developments, port expansions and port infrastructure (road and rail networks) can result in direct removal of estuaries or interfere with connectivity between estuaries and other ecosystems.

Modification of coastal process by port infrastructure can have impacts on adjoining coastal ecosystems, especially estuarine ecosystems.

To address pressures from ports and shipping, some identified key needs include:¹⁸

- development of planning frameworks that specifically consider matters of national environmental significance and more adequately address cumulative impacts
- greater integration of development impact offset programs to deliver strategic outcomes
- a focus on actions that build ecosystem resilience including improving water quality
- more strategic approaches to developing and operating marinas
- supporting research on critical ecosystem thresholds with a focus on inshore biodiversity and associated ecosystems
- strengthening engagement and facilitating actions that maintain and enhance the condition of values and reduce impacts particularly from climate change, catchment run-off, degradation of coastal ecosystems and direct use.

Climate change

Climate change represents a major emerging driver of cumulative pressure on estuarine ecosystems. In the *Great Barrier Reef Outlook Report 2014*⁶, climate change was recognised as the most significant pressure on the Great Barrier Reef ecosystem.

Climate change is also a threat to estuaries located at the interface between marine and terrestrial ecosystems. These ecosystems are vulnerable because climate change impacts include a range of pressures, such as sea level rise, extreme climate, ocean acidification and altered ocean currents. The climatic and hydrologic regimes affected by climate change are also the primary determinants of catchment condition and run-off behaviour. These changes will amplify the individual and collective impact of existing catchment development and run-off pressures.^{4,7,8} Estuarine ecosystems are especially vulnerable to sea level rise; changing rainfall patterns with associated impacts to salinity regimes and catchment condition; sediment, nutrient and other contaminant loads; altered storm frequency; and changes in water and air temperature and ocean currents and acidity.^{45,4,7,8,9,57,58,59,60}

Estuarine ecosystem exposure to climate change impacts is increasing with time — current projections indicate high exposure end points. While estuarine habitat type, condition, catchment topography and development context will differentiate the sensitivity and rate of exposure of estuaries to emerging climate change impacts (see Appendix 1), exposure across the board is assessed to be high to very high over decadal timescales. This assessment is made on the basis that global greenhouse gas emissions are currently tracking⁶¹ in line with the worst-case representative concentration pathway (RCP 8.5) scenarios modelled by the IPCC.^{62,63,64} This presents the spectre of a global climate trajectory progressing beyond target levels of 1.5–2 degrees Celsius and into the realm of dangerous climate change. This would have accompanying extreme risks for estuaries and other ecosystems of the Great Barrier Reef catchment before the turn of the century.⁶⁰

Current research also suggests that IPCC projections of an approximate one metre sea level rise by 2100⁶² are overly conservative due to under-estimation of Greenland and Antarctic ice shelf melt contributions⁹. Contributions from ice shelf melt in Greenland alone are projected to add a metre of sea level rise by 2100.⁶⁵ Historical evidence from throughout the Holocene period indicates a 2.3 metre sea level rise can be expected for every degree Celsius of global warming⁶⁶ and revised projections suggest multi-metre sea level rise by mid-century.⁹

The impacts of climate change on estuaries may include:

- impacts upon trophic function, both directly and at secondary levels on habitats, species distribution, abundance and connectivity. The lack of knowledge on trophic function in estuarine systems adds uncertainty as to the level of impact that climate change will have on estuarine systems. The major vulnerabilities of these systems to climate change will occur as a result of rainfall changes, sea level rise, altered storm frequency and severity and changes in water temperature.⁴⁵
- a reduction in residence time for water during wet season flows and, in some cases, increased floods. This will cause the nutrient processing capacity of estuaries to be reduced, delivering more nutrients to the Reef.⁴⁵

- modification of estuaries as interventions (such as shoreline protection, beach nourishment) to combat erosion and shoreline retreat occur. These can result in severe localised ecological impacts.⁶⁷
- a further decline in seagrass in estuaries. Decline has been observed along coastlines subjected to increasing anthropogenic pressures⁶⁸ and severe weather events.
- landward progression of estuarine vegetation in response to sea level rise. This is often restricted by coastal development. These habitats will reduce in area and become fragmented under a changing climate.⁴⁹ Expansion in seaward habitats conducive to mangroves will result in future reduction in the extent of saltmarshes.

As coastal environments, estuaries are also exposed to cyclones, associated storm surge events and rising sea levels. With the magnitude of cyclones and the rate of sea level rise projected to increase under the influence of global warming⁴, the susceptibility of estuarine ecosystems to these impacts will likely increase in coming decades.

Changing rainfall patterns as a consequence of climate change are predicted to result in more frequent droughts and failed summer wet seasons and, conversely, more extreme rainfall events and flooding. The former will result in reduced freshwater flows and increased exposure of estuaries to hypersaline conditions, particularly in seasonally dry tropical areas. This is a process already implicated in extensive mangrove dieback in the Gulf of Carpentaria.¹⁷ Extreme rainfall events will exacerbate the export of contaminant loads from poorer condition catchments and drive geomorphic, habitat and water quality changes.

Unmitigated climate change is recognised as having the potential to ultimately generate catastrophic impacts to all contemporary ecosystems, including estuarine wetlands.^{9,60} In this context the described sensitivity of estuarine species and habitats (Appendix 1) is relative and based on the premise that national and global initiatives to address climate change risks will become effective within the next decade.

If realised, higher-end projections for sea level rise rates and heights⁹ are likely to be beyond the landward migration capacity of major components of estuarine habitat mosaics.^{7,8} Components of estuaries within sea level rise inundation zones will ultimately experience complete transformation to highly modified/novel–marine systems.

While broader national and global initiatives required to address climate change are not considered here, it needs to be reiterated that the extent and persistence of climate change impacts depends first and foremost on the success of international efforts to curb the rate of accumulation of greenhouse gases in the atmosphere. In addition, it may potentially depend on the as yet undeveloped capacity to extract emissions from the atmosphere.

The main opportunities for adaptive management of climate change pressure affecting Great Barrier Reef catchment estuaries lie in implementing actions to address other sources of pressure to enhance ecosystem resilience. It may also lie in direct interventions that enhance and facilitate the landward migration and establishment of estuarine habitat in conjunction with sea level rise.

Interventionist adaptive management capacity is likely to be less where natural adaption capacity is undermined due to existing levels of estuary modification and/or catchment land use intensity, which present existing condition impacts and limit opportunities for landward movement of estuarine habitat mosaics in relation to sea level rise. Adaptive management outcomes will be more positive where planning and legislative frameworks can factor in the potential for shoreline retreat and provide for natural or facilitated inland movement of mangroves and saltmarsh habitat. This will ensure the long-term viability of these habitats, and estuaries where catchment land use patterns, condition or protective/restorative management opportunities (including sustainable limits on water resource development) limit the extent of other pressures that affect estuary condition and function.

Management of estuaries in the Great Barrier Reef Marine Park

The Australian Government, along with state and local governments, and landholders and the wider community have responsibility for managing estuaries in the Reef catchment. Responsibilities are formalised in laws and through international obligations. Various government agencies manage estuaries by applying a range of laws, policies and programs.

Up-to date information on these laws, policies and programs can be found at *Wetland Info*:
<http://wetlandinfo.ehp.qld.gov.au/wetlands/management/policy-legislation/>



Figure 6: Coastal mangroves

Appendix 1: Vulnerability assessment matrix

Commercial marine tourism	
Exposed to source of pressure (Yes/No)	Yes — localised pressure
Degree of exposure (low, medium, high)	Low: <ul style="list-style-type: none"> Boat wake, propellers, anchors, mooring chains and rope, vessel waste discharge and small spills are possible impacts. There is high volume visitor access to Reef areas with established infrastructure rather than estuarine habitats, although there is small-scale visitation and operation in and around estuaries generally near urban centres. Associated marina development to moor vessels can have localised impacts, although most use existing port infrastructure.
Sensitivity to source of pressure (low, medium, high, very high)	Low: <ul style="list-style-type: none"> Although disturbances from anchoring and boat propellers do occur^{69,70}, it is only likely on a small scale within estuaries. Sensitivity is not attributable to any one source.
Adaptive capacity natural (Poor, moderate, good)	Good: <ul style="list-style-type: none"> Estuarine communities have the ability to regrow or recolonise small areas following disturbance.
Adaptive capacity-management (Poor, moderate, good)	Good: <ul style="list-style-type: none"> Planning, education and partnering programs are applied to minimise physical disturbance. Activities require assessment and permission, which allow conditions for management to be legislated. There is regulation of access to estuaries, and provision of mooring points. The Great Barrier Reef Marine Park Zoning Plan 2003 and complementary state plans provide some protection. There are penalties for non-compliance.
Residual vulnerability (Low, medium, high)	Low
Level of confidence in supporting evidence (Poor, moderate, good)	Good

Defence activities	
Exposed to source of pressure (Yes/No)	Yes — localised, specific locations and times
Degree of exposure (low, medium, high)	<p>Low:</p> <ul style="list-style-type: none"> • There are six designated defence training areas within or adjacent to the Great Barrier Reef World Heritage Area. The largest (with the highest intensity of use) is the Shoalwater Bay Defence Training Area; others, like Halifax Bay or Cowley Beach, are used less often. • Possible impacts are primarily on shallow coastal or intertidal habitat within those limited areas. • Exposure is most relevant in Shoalwater Bay Training Area.
Sensitivity to source of pressure (low, medium, high, very high)	<p>Low:</p> <ul style="list-style-type: none"> • Adaptive management of training areas has demonstrated a successful approach with no recognisable major environmental impacts to date⁷¹. • There are small-scale disturbances from traversing, anchoring and boat propellers possible.
Adaptive capacity natural (Poor, moderate, good)	<p>Good:</p> <ul style="list-style-type: none"> • Estuarine communities have the ability to regrow or recolonise small areas following disturbance. • There are extended time periods between activities that may cause impacts.
Adaptive capacity-management (Poor, moderate, good)	<p>Good:</p> <ul style="list-style-type: none"> • Activities are well managed, limited in extent, duration, and geographic location. • Defence has a number of policies and management plans that together contribute to a robust environmental management plan within the World Heritage Area including the Defence Environmental Policy and the Maritime Activities Environmental Management Plan⁷². • Further management could be applied as required.
Residual vulnerability (Low, medium, high)	Low
Level of confidence in supporting evidence (Poor, moderate, good)	Good

Commercial fishing	
Exposed to source of pressure (Yes/No)	Yes — localised
Degree of exposure (low, medium, high)	Low: <ul style="list-style-type: none"> Boat wake, propellers, anchors, mooring chains and rope, vessel waste discharge and small spills may have possible effects. Individual populations of estuarine species, including non-targeted species and species of conservation interest, may have greater exposure to impacts associated with netting and trapping employed by inshore finfish and crab fisheries (refer to vulnerability assessments for specific species).
Sensitivity to source of pressure (low, medium, high, very high)	Variable — low to medium: <ul style="list-style-type: none"> Disturbances from anchoring and boat wake and propellers may occur at a small scale. Sensitivity is not attributable to any one source. Netting from inshore finfish fishery may impact on local populations of estuarine species and species of conservation concern that use estuaries (refer to vulnerability assessments for specific species). Sensitivity is also influenced by the presence of other pressures (e.g. where fisheries recruitment has been impacted by loss of nursery habitat or connectivity impacts). Capacity to sustain commercial fishing pressure will be reduced where mangrove forests and riparian vegetation are impacted by development.
Adaptive capacity natural (Poor, moderate, good)	Good: <ul style="list-style-type: none"> Estuarine habitats and populations have the ability to regrow or recolonise a small area following disturbance. Natural adaptive capacity will be more moderate where pressure exposure and sensitivity is higher. Where there are significant other pressures (e.g. catchment run-off and development) operating on an estuary (particularly if these impact nursery habitats and connectivity), the capacity to naturally adapt to commercial fishing pressure will be undermined.
Adaptive capacity-management (Poor, moderate, good)	Moderate to good: <ul style="list-style-type: none"> Fishing activities are regulated with penalties for non-compliance, regulation of access to estuaries and provision of mooring points Large areas of the Great Barrier Reef are protected from fishing activity through zoning, Fish Habitat Areas, or through low level of effort in General Use zones. Most estuaries lie outside Great Barrier Reef Marine Park Authority planning jurisdiction. Inshore tropical finfish commercial fishing effort within the Great Barrier Reef catchment remains high relative to other northern Australian regions (i.e. Gulf of Carpentaria or Northern Territory⁷³). Some concerns exist regarding latent and transferable effort and for the sustainability of some targeted and non-targeted species, particularly rays and sharks.
Residual vulnerability (Low, medium, high)	Low
Level of confidence in supporting evidence (Poor, moderate, good)	Good: <ul style="list-style-type: none"> Queensland fisheries assessment <i>The effects of net fishing: addressing biodiversity and bycatch issues in Queensland inshore waters</i>.⁷⁴

Recreational fishing	
Exposed to source of pressure (Yes/No)	<p>Yes — localised</p> <p>Greatest near:</p> <ul style="list-style-type: none"> • urban centres • where areas of settlement occur within or in close proximity to estuaries • where estuaries are served by recreational infrastructure, e.g. boat ramps, camping grounds.
Degree of exposure (low, medium, high)	<p>Variable — low to medium:</p> <ul style="list-style-type: none"> • There are potential impacts associated with <ul style="list-style-type: none"> ○ bait digging, net dragging, non-sustainable take, waste, small spills and littering ○ boat wake, propellers, anchors, mooring chains and rope, other physical impacts of boating on vegetated bottom ○ site disturbance and impacts caused by four-wheel drive vehicle access tracks and informal camp sites ○ injury of targeted and non-targeted species including some of conservation interest.
Sensitivity to source of pressure (low, medium, high, very high)	<p>Variable — low to medium:</p> <ul style="list-style-type: none"> • Where exposure is low to medium, sensitivity of estuarine ecosystems as a whole is low. • Where exposure is high (i.e. high levels of recreation use, large adjoining human populations and associated disturbance regimes), sensitivity can be medium for estuarine ecosystems as a whole or even high for individual species targeted by recreational fishing activities. • Sensitivity is also influenced by the presence of other pressures (e.g. where fisheries recruitment has been impacted by loss of nursery habitat or connectivity impacts, capacity to sustain recreational fishing pressure will be diminished), or where estuarine mangrove forests/riparian vegetation are impacted by development impacts, resilience to boat wake impacts will be reduced.
Adaptive capacity natural (Poor, moderate, good)	<p>Variable — moderate to good:</p> <ul style="list-style-type: none"> • Estuarine habitats and populations have the ability to regrow or recolonise a small area following disturbance. • Natural adaptive capacity will be more moderate where pressure exposure and sensitivity is higher. • Where there are significant other pressures (e.g. catchment run-off and development) operating on an estuary (particularly if these impact nursery habitats and connectivity), the capacity to naturally adapt to recreational fishing pressure will be undermined.
Adaptive capacity-management (Poor, moderate, good)	<p>Moderate to good:</p> <ul style="list-style-type: none"> • Planning, education and partnering programs are applied to minimise physical disturbance. • The Great Barrier Reef Marine Park Zoning Plan 2003 and complementary state plans provide some protection. • Most estuaries lie outside Great Barrier Reef Marine Park Authority jurisdictions. • Fish habitat protection areas, seasonal closures and fisheries bag, size limit and no-take legislation offer protection for targeted and non-target species of conservation value. • Sustainability risks may still occur where population pressure and levels of recreational fishing activity are high.
Residual vulnerability (Low, medium, high)	Low
Level of confidence in supporting evidence (Poor, moderate, good)	Good

Ports and shipping	
Exposed to source of pressure (Yes/No)	Yes — localised, with potential for regional significance
Degree of exposure (low, medium, high)	<p>Variable:</p> <ul style="list-style-type: none"> • There are four major ports, six other trading ports and two very small operations. • Ports and shipping activities are focused on geographically discrete locations. <p>Low:</p> <ul style="list-style-type: none"> • where distanced from activity areas • possible groundings. <p>Medium:</p> <ul style="list-style-type: none"> • There is possible exposure to exotic species, oil and chemical spills (including ballast water discharged by commercial shipping), bio-fouling on hulls (and inside internal seawater pipes of commercial and recreational vessels). • Shipping traffic is generally confined to specified channels and holding areas. <p>High:</p> <ul style="list-style-type: none"> • Within port developments, there is direct loss of habitat and impacts from dredging, marinas and marine facility expansion.
Sensitivity to source of pressure (low, medium, high, very high)	<p>Variable — potential sources of pressure from port and shipping activities are varied, hence sensitivity follows suit</p> <p>Low:</p> <ul style="list-style-type: none"> • Activity generates little potential harm to estuaries (e.g. smaller port areas such as Port Douglas). • If a ship were to ground within an estuary, which has a low likelihood, it would most probably cause only minimal disturbance to the whole of the estuary. If the ship was very large, and/or toxic contaminants were spilt, the sensitivity may increase to medium or even to high. Potential ongoing impact, for example from release of antifoulant, may increase sensitivity. • Operational discharges from ships such as sewage and ballast water, as well as potential oil spills⁷⁵, can threaten water quality and introduce marine pests. Discharge release locations are limited however, and not expected to occur at levels that would be above low sensitivity. Potential sensitivity to introduced pests would depend on what the pest was. <p>High:</p> <ul style="list-style-type: none"> • Activity can cause loss of estuaries through direct removal, and also indirectly through changes to hydrodynamics, generation of sediment plumes that potentially bury mangroves and saltmarsh. Sustained spillage, e.g. of mineral products during loading operations, also has the potential to generate a cumulative contaminant impact. Large oil spill or chemical spill could be locally significant. <p>Very high:</p> <ul style="list-style-type: none"> • For example, if the whole estuary is removed or modified permanently.
Adaptive capacity natural (Poor, moderate, good)	<p>Variable — capacity depends on nature, duration and frequency of disturbance</p> <p>Poor:</p> <ul style="list-style-type: none"> • Habitat is permanently removed. • Habitat is regularly impacted. • Sediment loads smother estuaries too deeply.

	<ul style="list-style-type: none"> Sustained small load spillages contribute to a cumulative contaminant impact. <p>Variable:</p> <ul style="list-style-type: none"> Ability to resist or out-compete potential pests or invasive species is not known. <p>Good:</p> <ul style="list-style-type: none"> Impacts are temporary.
<p>Adaptive capacity-management (Poor, moderate, good)</p>	<p>Moderate to good</p> <p>Good:</p> <ul style="list-style-type: none"> New port proposals for greenfield sites are not supported in the World Heritage Area under the <i>Sustainable Ports Development Act 2015</i>. <p>Moderate:</p> <ul style="list-style-type: none"> Port expansions and major dredging proposals or other activities associated with ports generally require environmental impact assessments and permits or approvals. A combination of monitoring and modelling during dredging activity is used to minimise the risk of environmental impacts. Dredging and material placement in the World Heritage Area is prohibited and other placement is managed to ensure any adverse effects such as degraded water quality, decreased availability light, releasing toxicants and/or smothering are prevented or confined to areas away from sensitive environments or land based. Land-based disposal may pose a threat to estuaries. Issues such as operational ship-sourced pollutants, discharge and disposal of waste, exchanges of ballast water, oil spills and potential antifouling paint effects are covered by various regulations, conventions and policies applied in the Great Barrier Reef.
<p>Residual vulnerability (Low, medium, high)</p>	<p>Low:</p> <ul style="list-style-type: none"> Areas outside port limits and the influence of plumes generated primarily by dredging. <p>High:</p> <ul style="list-style-type: none"> If proposals to open new areas where estuaries exist are successful (although impacts would be local), they are likely to result in losses. <p>Note: There are also likely losses for existing port expansions that include reclamation and new berths. Cumulative impacts are also difficult to assess.</p>
<p>Level of confidence in supporting evidence (Poor, moderate, good)</p>	<p>Good:</p> <ul style="list-style-type: none"> For the effects of pollutants. <p>Poor:</p> <ul style="list-style-type: none"> For consideration of cumulative effects.

Recreation (not fishing)	
Exposed to source of pressure (Yes/No)	<p>Yes — localised</p> <p>Greatest:</p> <ul style="list-style-type: none"> • near urban centres • where areas of settlement occur within or in close proximity to estuaries • where estuaries are served by recreational infrastructure, e.g. boat ramps, camping grounds
Degree of exposure (low, medium, high)	<p>Variable:</p> <ul style="list-style-type: none"> • Principally in estuarine and intertidal coastal habitats that are impacted by <ul style="list-style-type: none"> ○ off road vehicle use, informal access tracks, camp sites, littering ○ direct human and domestic animal disturbance ○ weed introduction ○ bait digging ○ boat wake, propellers, anchors, mooring chains and rope dragging, physical impacts of boating activity on vegetated bottom, possible small spills. <p>High:</p> <ul style="list-style-type: none"> • Recreational use of saltmarsh areas can have significant local effects.²⁶
Sensitivity to source of pressure (low, medium, high, very high)	<p>Variable:</p> <ul style="list-style-type: none"> • Sensitivity is not attributable to any one source. • Saltmarshes are particularly sensitive to physical impacts such as vehicle and animal impacts.
Adaptive capacity natural (Poor, moderate, good)	<p>Moderate to good:</p> <ul style="list-style-type: none"> • Estuarine habitats and populations have the ability to regrow or recolonise small area following disturbance. <p>Good:</p> <ul style="list-style-type: none"> • Where recreational pressures on estuaries represent short-term stress rather than long-term strain (e.g. periodic use with some capacity for recovery between disturbances) and where estuary is not significantly impacted by other pressures <p>Moderate:</p> <ul style="list-style-type: none"> • Where high frequency and level of disturbance represents longer-term strain (e.g. permanent vehicle access tracks, causing erosion or changes in tidal ingress patterns; permanent camp sites preventing vegetation regeneration; sustained boating activities with wake causing bank collapse) • Also where other operating pressures limit natural adaptive capacity
Adaptive capacity-management (Poor, moderate, good)	<p>Moderate to good:</p> <ul style="list-style-type: none"> • Planning, education and partnering programs are applied to minimise physical disturbance. • Regulation and protection mechanisms constrain detrimental activities. • Compliance is limited due to limited resources.
Residual vulnerability (Low, medium, high)	Low
Level of confidence in supporting evidence	Good

(Poor, moderate, good)	
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Traditional use of marine resources

Exposed to source of pressure (Yes/No)	Yes — localised <ul style="list-style-type: none"> • Mostly on country in areas north of Cairns
Degree of exposure (low, medium, high)	Low: <ul style="list-style-type: none"> • Take of targeted species, including some of conservation interest, may have a possible effect. • Bait digging, net dragging, gathering, anchor damage, boat wakes, propeller damage, rope dragging, physical impacts of boating activity and, possible small spills may have an effect. • Vehicle access, camp sites, burning and littering in the adjoining estuary can impact supra-tidal habitats.
Sensitivity to source of pressure (low, medium, high, very high)	Low: <ul style="list-style-type: none"> • Most disturbance is small scale and sustainable in terms of recovery potential. • Sensitivity is not attributable to any one source. • Higher sensitivity may occur when targeted species / habitat have had populations /area extent reduced due to other operating pressures.
Adaptive capacity natural (Poor, moderate, good)	Good: <ul style="list-style-type: none"> • Estuarine habitats and populations have the ability to regrow or recolonise a small area following disturbance. • Capacity may be lower where other pressures are operating on species populations and/or habitat condition / extent.
Adaptive capacity-management (Poor, moderate, good)	Good: <ul style="list-style-type: none"> • Planning, education and partnering programs are applied to minimise physical disturbance. • The Australian Government, under the Caring for our Country initiative, committed \$10 million over five years towards the Land and Sea Country Indigenous Partnerships Program. • The program actively engages Aboriginal and Torres Strait Islander communities in the management and protection of the Reef's marine resources and cultural diversity.
Residual vulnerability (Low, medium, high)	Low
Level of confidence in supporting evidence (Poor, moderate, good)	Moderate: <ul style="list-style-type: none"> • Evidence of use or any associated potential impact is minimal. New information expected from the Reef Program.

Climate change	
Exposed to source of pressure (Yes/No)	<p>Yes</p> <ul style="list-style-type: none"> • There is long temporal-scale, chronic pressure across the Great Barrier Reef. • Multiple expressions of pressure, including sea level rise, extreme climate, ocean acidification and altered ocean currents.
Degree of exposure (low, medium, high)	<p>Variable — high to very high:</p> <ul style="list-style-type: none"> • If unmitigated, all habitats will be affected. • Estuarine ecosystem exposure to climate change impacts is increasing with time. • Current projections indicate high exposure end points. • Estuarine habitat type, condition, catchment topography and development context will differentiate the sensitivity and rate of exposure of estuaries to emerging climate change impacts (discussed below). • Exposure across the board is assessed to be high to very high over decadal timescales. • This assessment is made on the basis that global greenhouse gas emissions are currently tracking¹⁶ in line with the worst-case concentration pathway (RCP 8.5) scenarios modelled by the IPCC.^{63, 64, 65.} • This presents the spectre of a global climate trajectory progressing beyond target levels of 1.5–2 degrees Celsius and into the realm of dangerous climate change, with accompanying extreme risks for estuaries and other ecosystems of the Great Barrier Reef catchment before the turn of the century.⁶¹ • Current research also suggests that IPCC (2014) projections of ~1m rise by 2100 are overly conservative due to under estimation of Greenland and Antarctic ice shelf melt contributions⁸, with contributions from the former projected to add a metre of sea level rise by 2100.⁶⁶ • Historical evidence from throughout the Holocene indicates 2.3 metre sea level rise can be expected for every degree Celsius of global warming⁶⁷ and revised projections suggest multi-metre sea level rise by mid-century.⁸
Sensitivity to source of pressure (low, medium, high, very high)	<p>Variable — low to very high:</p> <ul style="list-style-type: none"> • Potential climate change pressures are varied and so sensitivity is also variable. • As described for degree of exposure (above), sensitivity to exposure will ultimately depend upon the level of pressure generated by climate change before, if and when mitigation efforts become effective. • Unmitigated climate change is recognised as having the potential to ultimately generate catastrophic impacts to all contemporary ecosystems, including estuarine wetlands.^{8, 61} • In this context, described sensitivity is relative and based on the premise that national and global initiatives to address climate change risks will become effective within the next decade. • The major vulnerabilities will be to <ul style="list-style-type: none"> ○ sea level rise ○ changing rainfall patterns (with associated impacts to salinity regimes) and catchment condition ○ sediment, nutrient and other contaminant loads ○ altered storm frequency ○ changes in water and air temperature ○ ocean currents and acidity.^{45, 4, 57, 58, 76, 6, 60, 9} <p>Low:</p> <ul style="list-style-type: none"> • For estuaries that have good tidal flushing, water column mixing and low sediment retention* (e.g. tidal- dominated deltas, tidal flat creeks²). <p>Moderate:</p> <ul style="list-style-type: none"> • Where species or estuary characteristics lie between those described for low (above) and high to very high (below).

	<p>High to very high:</p> <ul style="list-style-type: none"> • For estuaries/species that <ul style="list-style-type: none"> ○ use the terrestrial margin and upper inter-tidal habitat types (including as a food source e.g. mangrove leaves) will be most impacted by sea level rise and climatic disturbance (e.g. saltmarsh, supratidal mangroves, intertidal sea grass) ○ that survive close to the limits of their tolerance range for environmental parameters predicted to change (i.e. temperature, salinity, pH, dissolved oxygen, turbidity^{31 58} and/ or have sex ratios determined by temperature⁵⁸) ○ occur in coastal zones with smaller tidal ranges³¹ and/or low gradient coastal plains⁶ and/or are constrained by landward development^{49, 2,4,8,58,67,77} ○ occur in catchments with high levels of intensive development and/or are estuary types that have poor tidal flushing, water column mixing and high levels of sediment retention and/or are exposed to higher rates of sea level rise / climate change. • Increased sediment retention/ deposition can create geomorphic and functional impacts but can also benefit mangrove colonisation /survival during sustained sea level rise. ⁴⁵
<p>Adaptive capacity natural (Poor, moderate, good)</p>	<p>Poor to moderate:</p> <ul style="list-style-type: none"> • The capacity for adaptation is not well understood and capacity can only be described in a relative sense within the premise that climate change mitigation will become effective within the nearer term to avoid its full catastrophic potential. • The capacity for adaptation to sea level rise is dependent on the rate and extent. The upper boundaries for these are not yet resolved, though increasing evidence suggest rates and heights much greater than existing IPCC projections. • Components of estuaries within sea level rise inundation zones will experience transformation to highly modified / novel – marine systems <p>Poor:</p> <ul style="list-style-type: none"> • For estuaries that <ul style="list-style-type: none"> ○ experience sea level rise and climate change impacts rapidly ○ have an existing poor condition / intensively developed catchment and is a type vulnerable to increased contaminant loads^{70, 57} ○ occur on low gradient coastal plain subject to rapid inundation ○ are bound by landward development ○ have instream structures restricting tidal flushing and habitat migration opportunities ○ are subject to cyclonic storms at intervals shorter than required recovery periods ○ occur in a highly seasonal climate where environmental extremes (e.g. temperature, salinity, dissolved oxygen) are already at the margins of biotic community tolerances. <p>Moderate:</p> <ul style="list-style-type: none"> • If rates of sea level rise and climate change reduces/plateaus due to effective implementation of emission mitigation, and/ or estuary <ul style="list-style-type: none"> ○ has good condition / undeveloped catchment ○ is a type less vulnerable to increased contaminant loads ^{70, 57} ○ occurs on higher gradient coastal plain subject to lower rates of landward sea water incursion ○ lacks landward development and instream structures that restrict tidal flushing and habitat migration opportunities ○ is subject to infrequent cyclonic storms at intervals greater than required recovery periods ○ occurs in a less seasonal climate where environmental extremes are seldom experienced ○ has a biotic community comprised of species with wider tolerance ranges than others for the parameters predicted to change and conditions remain tolerable ○ ocean currents and other recruitment pathways allow for changes of species distributions and new community compositions that tolerate new conditions.

<p>Adaptive capacity-management (Poor, moderate, good)</p>	<p>Poor to moderate:</p> <ul style="list-style-type: none"> • Extent and persistence of impacts from climate change will depend on the success of international efforts to curb the rate of accumulation of greenhouse gases in the atmosphere, and on the resilience of the estuarine ecosystem to climate change impacts that manifest over coming decades. • Given current trajectories of greenhouse gas emissions, strategies that build resilience and reduce vulnerabilities of estuaries will be increasingly crucial to their prognosis. • While the main opportunities for management lie in ongoing implementation of actions to address other sources of pressure to enhance ecosystem resilience, direct adaptive management (e.g. enhanced landward migration/ establishment of estuarine habitat) may help mitigate some direct impacts of sea level rise. <p>Poor:</p> <ul style="list-style-type: none"> • Where natural adaption capacity is low due to existing levels of estuary modification, and catchment land use intensity limits opportunities for landward movement of estuarine habitat mosaics in relation to sea level rise. <p>Moderate:</p> <ul style="list-style-type: none"> • Where planning and legislative frameworks can factor in the potential for shoreline retreat and provide for natural or facilitated inland movement of mangroves and saltmarsh habitat.
<p>Residual vulnerability (Low, medium, high)</p>	<p>High to very high:</p> <ul style="list-style-type: none"> • It is particularly high along the developed coast and in relation to sea level rise. • If higher end projections for sea level rise rates and heights (e.g. Hansen <i>et al</i> 2016) are realised, they are likely to be beyond the landward migration capacity of major components of estuarine habitat mosaics.
<p>Level of confidence in supporting evidence (Poor, moderate, good)</p>	<p>Poor:</p> <ul style="list-style-type: none"> • High uncertainty surrounds predictions for the effects of climate change particularly sea level rise, temperature and ocean acidity rates of change and end points. • Specific thresholds for parameters that are predicted to change are not known. • Analysis of potential shoreline retreat and subsequent movement of estuarine habitat inland is not done.

Catchment development	
Exposed to source of pressure (Yes/No)	<p>Yes — long temporal scale chronic pressure*</p> <ul style="list-style-type: none"> • Greater pressure is associated with areas of more intensive development (i.e. within river basins from Daintree south). • Development pressure is associated with direct site impacts (where development abuts or extends into estuarine wetlands including instream infrastructure) and indirect impacts associated with <ul style="list-style-type: none"> ○ catchment land and water resource use intensity ○ patterns that disturb biophysical processes altering flows ○ contaminant loads received by estuaries in catchment run-off (described separately).
Degree of exposure (low, medium, high)	<p>Variable – low to high</p> <p>Low:</p> <ul style="list-style-type: none"> • Where estuary occurs in catchment dominated by low intensity land and water resource use (i.e. protected areas, forestry, rangeland grazing on unimproved pastures), and areas of more intensive land use are not proximal to the estuary, and estuary is free of structures or modification affecting tidal movement. <p>Medium:</p> <ul style="list-style-type: none"> • Where estuary occurs in catchment with variegated land use pattern, including some areas with more intensive patterns of land or water resource use that affect catchment hydrology, and contaminant loads and/or development has extended into the boundary of the estuarine ecosystem (resulting in some habitat loss), including via structures that measurably affect tidal flushing and ingress. <p>High:</p> <ul style="list-style-type: none"> • Where estuary occurs in catchment dominated by intensive land use (including major water resource development) that affects catchment hydrology and contaminant loads, and/or development has encroached significantly within the boundary of the estuarine ecosystem (resulting in significant habitat loss), including via structures that significantly alter tidal flushing and ingress.
Sensitivity to source of pressure (low, medium, high, very high)	<p>Variable — low to very high</p> <p>Low:</p> <ul style="list-style-type: none"> • Where estuary exposure is low and/or development activity generates little potential harm to estuaries, for example <ul style="list-style-type: none"> ○ a change to land use that does not involve removal of estuarine vegetation or affect the quality, quantity or timing of water that runs off the land beyond natural variability ○ estuary type has inherent resilience to increases in sediment / nutrient loads (e.g. good mixing and flushing) ○ estuary retains good condition and function including representation of all habitat types comprising estuarine ecosystem mosaic and connectivity between them. <p>Moderate:</p> <ul style="list-style-type: none"> • Where estuary characteristics lie between those described for low (above) and high to very high (below) <p>High to very high:</p> <ul style="list-style-type: none"> • Where development activity results in the loss of estuarine vegetation through direct removal

	<ul style="list-style-type: none"> • Where changes to water mixing and tidal flushing drives the quality, quantity or timing of water that runs off contributing catchment areas beyond natural variability ranges. • Where the estuary type is inherently vulnerable to increasing sediment and/or nutrient loads (e.g. poor mixing and flushing, high sediment trapping, naturally low turbidity) • Where the estuary has existing poor condition and function (indicated by loss of original habitat types comprising estuarine ecosystem mosaic and/or connectivity between them), which is exacerbated by further development
<p>Adaptive capacity natural (Poor, moderate, good)</p>	<p>Variable — poor to good</p> <p>Poor:</p> <ul style="list-style-type: none"> • If development results in long-term system strain compared with short-term stress, for example <ul style="list-style-type: none"> ○ the habitat is permanently removed ○ hydrodynamic changes (tidal flushing, water mixing, flow mediated salinity regime) make habitat unsuitable for the existing community ○ if the impact frequency is greater than habitat recovery periods ○ if water flow, quality or quantity changes are outside ecosystem health tolerance levels and/or are significantly altered from system baseline conditions ○ if the estuary type is vulnerable to changes in water quality/contaminant loads (due to poor mixing/flushing²) ○ if key habitat components and functions including connectivity have already been impacted by other stressors (weeds, fire, storms, sea level rise, extreme climate, feral animals, grazing stock). <p>Good:</p> <ul style="list-style-type: none"> • If development impacts represent short-term stress compared with long-term system strain, for example <ul style="list-style-type: none"> ○ if disturbance is temporary ○ if sediment loads do not smother estuaries completely ○ if water flow, quality or quantity changes are within ecosystems health tolerances ○ where impact frequency is less than required habitat recovery periods ○ where the estuary type is resilient to changes in water quality/contaminant loads (due to good mixing, flushing) ○ all key habitat components and functions including connectivity still remain and have not been impacted by other stressors (weeds, fire, storms, sea level rise, extreme climate, feral animals, grazing stock).
<p>Adaptive capacity-management (Poor, moderate, good)</p>	<p>Poor to good:</p> <ul style="list-style-type: none"> • Developments are subject to assessment, licensing and conditions that can protect marine plants. • Waste water discharge quality is legislated. • Codes of practice and water sensitive urban design are in place to manage stormwater in many local areas. • Erosion and sediment control plans are legislated requirements during construction phases of development. • Penalties exist for non-compliance. • Cumulative impacts are however difficult to assess. <p>Poor:</p> <ul style="list-style-type: none"> • Where exposure and sensitivity to pressure is high and natural adaption capacity poor (e.g. where pressure is primarily associated with existing intensive development that have extended into the estuary ecosystem boundary) • Where dominant contributing catchment areas are beyond thresholds required to retain catchment ecosystem services, resulting in permanent sustained impacts to estuary condition and function (e.g. due to loss of key habitat components, connectivity, tidal exchange, flushing, flows) • Where other pressures have manifested (e.g. weeds, feral animals, fire, human/ cattle disturbance, chronic water quality, storms, sea level rise)

	<ul style="list-style-type: none"> Where land tenure and competing estuary use commitments limit opportunities for adaptive management intervention <p>Good:</p> <ul style="list-style-type: none"> Where exposure and sensitivity to pressure is low, estuary condition and function remain good, and natural adaption capacity has been retained Where development pressure is primarily associated with new development subject to contemporary assessment processes and contributing catchment is not intensively developed (and retains catchment ecosystem services supporting estuary condition and function) Where other pressures have not established Where land tenure and estuary use commitments provide opportunities for adaptive management intervention (including asset protection, threat management and ecosystem restoration)
<p>Residual vulnerability (Low, medium, high)</p>	<p>Low:</p> <ul style="list-style-type: none"> For estuaries that are within basins with low-intensity land use, including estuaries within protected areas <p>Medium to high:</p> <ul style="list-style-type: none"> For much of the Great Barrier Reef coast, particularly where existing levels of catchment development require further development be accommodated within estuarine ecosystem boundaries and/or within catchment areas currently providing ecosystem services to downstream estuaries <p>Very high:</p> <ul style="list-style-type: none"> For estuaries in urban areas with contributing catchment areas dominated by intensive development that extends into estuarine ecosystems boundaries There are issues with capacity to control population growth to coastal areas and urban sprawl. Cumulative impacts are difficult to assess and catchment development thresholds are not recognised in formal planning processes.
<p>Level of confidence in supporting evidence (Poor, moderate, good)</p>	<p>Moderate:</p> <ul style="list-style-type: none"> Cumulative impacts are difficult to assess. Knowledge of ecosystem health thresholds for estuaries in relation to contaminant loads and flow requirements remain too poorly understood to inform catchment scale development planning.

Catchment run-off

Exposed to source of pressure (Yes/No)	<p>Yes — Great Barrier Reef catchment wide</p> <ul style="list-style-type: none"> • Pressure temporal dimension varies from long chronic strain to periodic stress. • Pressure closely related to catchment development pattern, land use practices and entrained land degradation processes. • Catchment run-off pressure is comprised of contaminant loads and altered run-off hydrology.
Degree of exposure (low, medium, high)	<p>Variable — low to very high</p> <p>Low:</p> <ul style="list-style-type: none"> • Where estuaries occur in protected or relatively un developed catchments • Where land use intensity is low • Where land management practices retain adequate ground cover • Where alluvial gully and waterway bank erosion is absent • Where there is no proposed intensification of land use <p>Medium:</p> <ul style="list-style-type: none"> • In estuaries that occur in catchments with <ul style="list-style-type: none"> ○ mixed land uses ○ areas of settlement but overall land use pattern is variegated ○ areas of less intensive land use ○ relatively low exposure but are being subject to land use intensification ○ predominantly extensive land use but extreme weather events significantly impact catchment condition ○ alluvial gully and waterway bank erosion is evident ○ poor condition as a result of cumulative impacts that are changing hydrological flows. <p>High to very high:</p> <ul style="list-style-type: none"> • In estuaries that occur in catchments with <ul style="list-style-type: none"> ○ a mostly extensive land use pattern, but there has been significant land degradation and some impairment of regulatory ecosystems services controlling contaminant load retention/ transport ○ land use practices result in significant off-site export of contaminant loads and regulatory ecosystems services controlling contaminant load retention/transport have been impaired ○ a more intensive monotypic land use, with remnant vegetation areas occurring as isolated patches, drainage lines as narrow discontinuous and/or degraded riparian vegetation corridors ○ medium exposure to run-off pressures, but are being subject to: (i) land use intensification or (ii) occur in catchments receiving point source waste water discharges or (iii) extreme weather events significantly impact catchment condition or (iv) the cumulative impact of catchment condition changes results in major sustained hydrological changes in receiving estuaries. <p>The estuaries most at risk of poor water quality extend from Cooktown south to around the Burnett River. This area was estimated by combining flood flow frequency⁷⁸ with a ranking of catchment contaminant loads (refer to Figure 5).^{79,80} Within this area contaminants are found at different loads and levels. For example, waters off the Wet Tropics and Mackay Whitsunday regions receive higher nutrient levels, while waters off the Dry tropics (Burdekin and Fitzroy) receive higher loads of sediment.^{78,81,82,83,84} Hence, the degree of exposure is parameter specific.</p>

<p>Sensitivity to source of pressure (low, medium, high, very high)</p>	<p>Variable — low to high:</p> <ul style="list-style-type: none"> • Dependent upon exposure to pressure and temporal dimension of associated impacts (e.g. short-term stress versus longer-term strain). • Sensitivity is also influenced by wetland type and contrast between baseline conditions and those created by catchment run-off pressure (e.g. clearwater system versus turbid, oligotrophic versus eutrophic etc.) and by the occurrence and frequency of extreme weather events (droughts/floods). • Sensitivity may also vary in relation to the different components of run-off pressure including contributions to altered flow/hydrology and individual contaminant types (e.g. sediment, nutrients and others such as agrichemical residues). • The response of mangroves to nutrients varies depending on the season and the species. Additional nutrients sometimes favour mangrove growth and in other cases have negative effects (e.g. eutrophication). • Different estuarine species can tolerate different sediment, and salinity regimes. Few studies have been done, however, to determine the tolerance ranges or thresholds. <p>Low:</p> <ul style="list-style-type: none"> • For estuaries that <ul style="list-style-type: none"> ○ are characterised by good flushing and mixing (e.g. tide- dominated delta or estuary² and/or contaminant loads and hydrological changes are within the range of background variability / ecosystems health guidelines and result in only short-term stress but not long-term strain to the system) ○ retain good condition and function and is not impacted by secondary pressures (e.g. altered flushing) ○ occur in a catchment with distributed rainfall and sustained base flow and/or estuarine community is predominantly comprised of species with broad environmental tolerances for attributes affected by run-off (e.g. turbidity, salinity, dissolved oxygen, nutrients etc). <p>High:</p> <ul style="list-style-type: none"> • In estuaries that <ul style="list-style-type: none"> ○ are characterised by poor flushing and mixing (e.g. wave- dominated delta or estuary², and/or contaminant loads and hydrological changes are outside the range of background variability/ecosystem health guidelines and result in long-term strain to the system (and generation of secondary pressures, e.g. weed infestation, low dissolved oxygen) ○ have poor existing condition and function (including impacts to tidal flushing) due to secondary pressures (e.g. barriers, bunds) ○ occur in a catchment with highly seasonal rainfall and flow and naturally periodically stressed water quality conditions ○ are within a seasonal climatic zone and receive run-off as aseasonal flows (e.g. irrigation tailwater) during dry season^{45,85} ○ Have a community composition that is predominantly species with narrow environmental tolerances for attributes affected by run off (e.g. turbidity, salinity, dissolved oxygen, nutrients etc.).
<p>Adaptive capacity natural (Poor, moderate, good)</p>	<p>Variable — poor to good:</p> <ul style="list-style-type: none"> • Natural adaptive capacity to catchment run-off pressure depends on estuary exposure and sensitivity including the duration, frequency and magnitude of run-off events, and the level of individual and collective impact contributed by contaminant loads and flow alteration. <p>Poor:</p> <ul style="list-style-type: none"> • If catchment <ul style="list-style-type: none"> ○ run-off pressure results in long-term system strain or if the impact frequency is greater than habitat recovery periods ○ water flow, quality or quantity changes are outside ecosystem health tolerance levels (e.g. losses of mangroves in the Fitzroy River have been attributed to catchment run-off) ○ is significantly altered from system baseline conditions ○ type is vulnerable to changes in water quality/contaminant loads (due to poor mixing/flushing²)

	<ul style="list-style-type: none"> ○ habitat condition/components and functions, including connectivity, have already been impacted by other stressors (weeds, fire, storms, sea level rise, extreme climate, feral animals, grazing stock). <p>Good:</p> <ul style="list-style-type: none"> ● If catchment <ul style="list-style-type: none"> ○ run-off pressure delivered by short-term stress (e.g. disturbance is temporary) and impact frequency is less than habitat recovery periods ○ estuary type is resilient to changes in water quality/contaminant loads (due to good mixing, flushing²). ○ key habitat components and functions (including connectivity) still remain and have not been impacted by other stressors (e.g. bund walls, weeds, fire, storms, sea level rise, extreme climate, feral animals, grazing stock).
<p>Adaptive capacity-management (Poor, moderate, good)</p>	<p>Poor to good:</p> <ul style="list-style-type: none"> ● Through integrated coastal management decision making, policies and legislation, there is potential to explicitly recognise the intrinsic value of estuarine habitat and implement protection and/or restoration. ● Significant actions are already underway to halt and reverse the decline in water quality entering the Great Barrier Reef (including implementation of the Reef Water Quality Protection Plan, development and implementation of Healthy Waters Management Plans and precursor products). ● Implementation of water quality guidelines into permitting and decision making processes. ● Waste water discharge quality is legislated. <p>Poor:</p> <ul style="list-style-type: none"> ● Where exposure and sensitivity to run-off pressure is high (including due to estuary type being vulnerable to run-off pressure²) and impacts to estuary condition and function have emerged as a result of long-term chronic strain. ● Adaptive management capacity is particularly limited where <ul style="list-style-type: none"> ○ contributing catchment areas are dominated by existing intensive development that is associated with high contaminant loads (e.g. irrigated agriculture) ○ natural catchment buffers (e.g. vegetated drainage lines/detention areas associated with the provision of ecosystem services that regulate the retention and transport of contaminant loads) have been lost or degraded ○ development beyond sustainable catchment thresholds has generated permanent changes in catchment run-off hydrology (e.g. hard panning, laser levelling) ○ land tenure is predominantly freehold and development density presents limited spatial opportunities for reinstatement of buffer and detention functions. ● In less intensively developed basins, widespread land degradation (e.g. subsoil exposure/ gully erosion) can also contribute to poor adaptive management capacity. ● Other constraints include where <ul style="list-style-type: none"> ○ secondary pressures (e.g. loss of estuary habitat types and connectivity between them due to high value development commitments within estuary boundaries) have become entrenched ○ natural adaptive management capacity has been lost ○ cultural practice and economic pressures are an impediment to adoption of best management practices on farm ○ the climate is highly seasonal and tending toward more frequent extreme events. <p>Moderate:</p>

	<ul style="list-style-type: none"> Where exposure and sensitivity to run-off pressure is medium and catchment land use, condition, functional process integrity and natural adaptive management capacity lies between that described for poor (above) and good (below) <p>Good:</p> <ul style="list-style-type: none"> Where exposure and sensitivity to run-off pressure is low Where any existing impacts to estuary condition and function have emerged as a result of short-term or spatially limited stress, rather than long-term strain or where run-off pressure is associated with proposed rather than existing development Adaptive management capacity is best where <ul style="list-style-type: none"> contributing catchment areas have limited intensive development associated with high contaminant loads natural catchment buffers remain (or are capable of being repaired/reinstated) catchment run-off hydrology behaves similar to baseline conditions in terms of flow duration curves land degradation is limited. Management capacity is also enhanced when <ul style="list-style-type: none"> there is an absence of entrenched secondary pressures affecting condition and functions natural adaptive management capacity remains there are economic and/or legislative incentives to support adoption of best management practices on farm the climate is less seasonal and extreme events infrequent.
<p>Residual vulnerability (Low, medium, high)</p>	<p>Low to high</p> <p>Low:</p> <ul style="list-style-type: none"> For undeveloped basins that are dominated by extensive land use (grazing) that is not associated with significant soil erosion, and other low intensity land use e.g. protected areas, traditional use. <p>Medium:</p> <ul style="list-style-type: none"> For basins with a variegated land use pattern and which retain catchment ecosystems services that regulate contaminant loads and transport. <p>High:</p> <ul style="list-style-type: none"> For catchments dominated by intensive land use and or containing extensive areas of land degradation particularly gully erosion. <p>Addressing the poor water / high contaminant loads and altered hydrology associated with Great Barrier Reef catchment run-off is not a short-term problem with a simple solution. It will take many years to improve practices that generate contaminant loads and also to allow for the targeted repair and reinstatement of catchment ecosystems services that regulate their transport and retention.</p>
<p>Level of confidence in supporting evidence (Poor, moderate, good)</p>	<p>Moderate:</p> <ul style="list-style-type: none"> Knowledge of end of catchment loads good but transport pathways uncertain. Knowledge of thresholds of estuarine system tolerance to contaminant loads and changes in flow is still limited A degree of uncertainty surrounds effectiveness of strategies to minimise run-off from agricultural lands.

* Coastal habitats (reefs, foreshores, rivers and estuaries) are under increasing pressure from human activities. More than 85 per cent of Queensland's population lives on the coastal fringe. Predicted strong population growth means the intensity of activity and development in coastal zones is likely to persist or increase.

The purpose of this vulnerability assessment process is to provide a mechanism to highlight key concerns and make assessments of the vulnerabilities of species, groups of species or habitats to sources of pressure within the Great Barrier Reef. The purpose of the vulnerability assessment matrix is not to produce a comprehensive ecological risk assessment, but to identify and document key pressures that influence a species, species group or habitat, using a standardised and transparent process.

To achieve this objective, it has been necessary to apply a linear relationship (e.g. $a=b$, or exposure=sensitivity) to comparisons that are sometimes non-linear by nature. For example, when applying the exposure/sensitivity matrix[♦] to create a combined score for the two, if a species, group of species or habitat has a very high level of exposure to a pressure but low sensitivity to it (using the *Great Barrier Reef Outlook Report 2009* risk assessment process outlined below), it is scored as having a medium–high exposure/sensitivity score. This medium–high score may be the same as determined for another assessment where there may be a low level of exposure but a very high level of sensitivity. This implies a linear relationship between the sensitivity of a species or habitat and a given level of exposure, which may not necessarily be the case. However, it does provide managers with the required level of resolution on these relationships for the purpose of vulnerability assessments and *Great Barrier Reef Biodiversity Conservation Strategy 2013*.

Criteria for determining the degree of exposure or sensitivity against each source of pressure are based on those published in Appendix 4 of the *Great Barrier Reef Outlook Report 2009*. For each pressure, once the likelihood and consequence of exposure (or sensitivity) has been established using Appendix 4, the risk (or in the context of the pressure assessment matrix, the degree of exposure or degree of sensitivity being assessed), is calculated using the matrix of Figure 8.1 on page 166 of the Outlook Report.⁵

[♦] The exposure/sensitivity matrix is described on the vulnerability assessments page on the Great Barrier Reef Marine Park Authority website.

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