TOWNSVILLE PORT EXPANSION PROJECT

Additional Information to the Environmental Impact Statement

APPENDIX A5

Cumulative Impacts Assessment Supporting Information

TOWNSVILLE PORT EXPANSION PROJECT

AECOM BMT WBM

1.0 Supporting Information to the Revised Cumulative Impacts Assessment

1.1 Introduction

This report provides relevant information that was used to develop the revised cumulative impact assessment prepared as part of this AEIS as outlined in Chapter 25.0 of the AEIS. Information presented below includes:

- identification of the potential stressors that may impact upon Sensitive Ecological Receptors
- characterisation of the likelihood of occurrence of these stressors
- consideration of how the distribution and condition of the Sensitive Ecological Receptors varies over time
- the risks of these individual stressors on Sensitive Ecological Receptors in Cleveland Bay.

Consistent with recently released guidelines, including the Great Barrier Reef Marine Park Authority (GBRMPA) *Framework for Understanding Cumulative Impacts Supporting Environmental Decisions and Informing Resilience-Based Management of the Great Barrier Reef World Heritage Area* (GBRMPA Guidelines) (Anthony, Dambacher, Walshe, & Beeden, 2013), the focus of this assessment has been on two particular Sensitive Ecological Receptors; namely coral reefs and seagrass meadows.

1.2 Identified Potential Stressors on Sensitive Ecological Receptors

The stressors considered in this cumulative impact analysis are categorised into:

- large-scale external drivers, including climate change derived ocean warming and ocean acidification
- strong synoptic weather events, especially cyclones
- contribution of sediments, nutrients and pesticides, from land-use changes, urban development and sediments re-mobilised by dredging activities
- fishing, tourism and marine transport stressors.

The key cause-effect relationships discussed in this assessment can be seen in the influence diagram presented in Figure 1. This figure shows the main cause-effect or risk propagation linkages (risk pathways) between stressors and ecological endpoints (Sensitive Ecological Receptors).

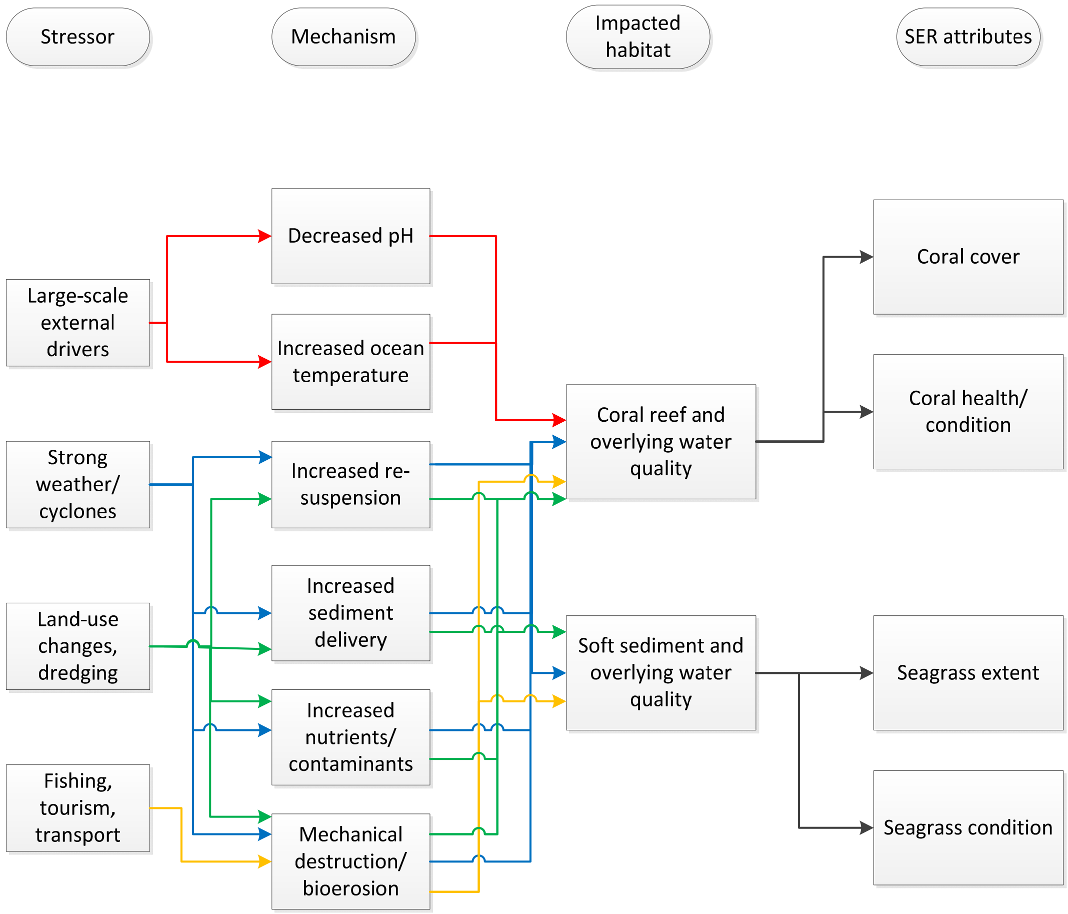


Figure 1 Influence diagram showing key cause-effect risk pathways considered in this analysis.

As outlined in detail in Chapter B.6 (Marine Ecology) of the EIS and further discussed in Section 8.0 of the AEIS, the main risk to the Sensitive Ecological Receptors are:

- reduced water clarity (increased turbidity)
- increased sedimentation rates in the vicinity of the Sensitive Ecological Receptors.

Both seagrasses and corals have shown sensitivity to periods of elevated turbidity and sedimentation rates. Increased turbidity reduces light availability to these Sensitive Ecological Receptors . Increased sedimentation rates can smother seagrass beds and lead to a requirement of coral colonies to expend energy clearing fine sediments. Therefore any mechanism that mobilises fine sediments must be considered to be a stressor for the Sensitive Ecological Receptors in the study area. This includes both project related and non-project related mechanisms, and as such, capital dredging impacts from the proposed Project need to be considered in the context of other stressors operating on these Sensitive Ecological Receptors .

The key project related stressor is the capital dredging campaign; in particular when the TSHD (Trailer Suction Hopper Dredger) is operating. Capital dredging can break up consolidated sediments and along with losses from dredger hopper overflow, additional fine sediments effectively enter the water-column during and post dredging operations. These fine sediments generated by dredging activities can contribute to the overall fine sediments budget that enter from catchments following flooding events and existing fine sediments that have entered the lagoon over geological timescales and are routinely re-suspended. These project related stressors are discussed in detail in the Section 6.0 and Appendix A1.

Key non-project stressors include turbidity which can be increased through the presence of either suspended fine mineralogical sediments, or floccs produced through primary biological production. 'New' fine sediments predominantly enter the Great Barrier Reef (GBR) lagoon from catchment sources and are primarily deposited within tens of kilometres of major river mouths (Lewis *et al*. 2014). Wet season cyclone events can disturb and redistribute these fine sediment across the shelf as well as import new fine sediments into the system through land based runoff associated with heavy rainfall.

However fine sediments have been entering the GBR lagoon over geological timescales and in the case of Cleveland Bay, the majority of fine sediments that are routinely re-suspended are ‘old’ sediments that were deposited during the Holocene period (Lewis *et al*. 2014).

It has also been recognised that the supply of fine sediment since European colonisation in the 1800s has increased up to six-fold by comparison to pre-European periods (Kroon *et al*. 2012). Whilst this increase is substantial, the relative increase is small by comparison to the similar post-European settlement increases in sediment delivery in other more urbanised Queensland catchments such as the catchments that flow into Moreton Bay (Dr Tim Stevens-Griffith University. Pers. Comm.).

The input of these ‘new’ fine sediments from catchments can also form a vector for the delivery of nutrients from catchment sources and these additional nutrients can stimulate primary production in the inner shelf region, which can further contribute to increases in turbidity over near-shore Sensitive Ecological Receptors.

The stressors described above can also be intensified by non-project sources of anthropogenic origin. In particular, other infrastructure projects underway near or within the study area need to be considered.

The proposed PEP is located in an established and existing port which has been identified in the Queensland Ports Strategy as one of the Priority Port Development Areas. The port has grown over last century in response to the regional development of North Queensland, underpinned by the strategic role Townsville has played in the Australian Defence capability.

Over the same period the biodiversity values of the GBR have increasingly been recognised and managed through the establishment of multiple conservation management zones including the GBR Marine Park zones and declared Fish Habitat Areas. The Port is located within declared port limits situated adjacent to conservation and management areas.

The Sensitive Ecological Receptors in the study area are also potentially impacted by other activities occurring within the region. These can be classified into the following categories:

- general urban development of the Townsville region
- other projects occurring within the Port boundaries
- land-use activities occurring within the regional catchments
- development of other GBR ports.

Impacts from urban development, including discharges from wastewater treatment plants are generally managed through:

- sediment, erosion and nutrient release measures for point source discharges
- through recommended measures by the Townsville City Council in relation to erosion and sediment control.

Relevant assessments (where available) for these activities concluded these activities are not having substantive far-field impacts on the Cleveland Bay or GBR-wide ecosystem. The other main activity occurring within the port boundaries are ongoing maintenance dredging activities. These are considered in Section 6.0 and Section 8.0 of the AEIS.

Land-use activities occurring within the broader region and wider GBR catchments are considered in detail in the remainder of this cumulative impacts assessment.

1.3 Characterisation and Likelihood of Stressors

This section characterises the identified stressors, and their variability. In risk assessment terminology this would be described as characterising the stressors and determining the likelihood that these stressors could lead to impacts in any given year.

As highlighted above, four stressors or general sources of risk have been considered in line with the GBRMPA Cumulative Impacts Framework (Anthony, Dambacher, Walshe, & Beeden, 2013).

1) Intense weather events (i.e. cyclones).
2) Large scale externalities.
3) Dredging and catchment land use practices.
4) Fishing, marine tourism and transport.

The risk characteristics of these sources, in terms of how they can impact Sensitive Ecological Receptors and how often they typically occur, are described below.

1.3.1 Intense weather events (cyclones)

Mechanisms and risk pathways

Intense weather events, including cyclones and other strong wind and rain events can be a source of risk through the following risk pathways.

- Over synoptic time-scales (i.e. hours, days), large storm-induced waves can lead to direct mechanical destruction of Sensitive Ecological Receptors , including coral colonies.
- Over synoptic and seasonal time-scales, large rainfall events and wetter wet seasons can mobilise large volumes of sediments within catchments. This sediment, and attached nutrients can enter the inner shelf, reduce light levels and increase short term sedimentation rates on Sensitive Ecological Receptors.
- Over synoptic and seasonal time-scales, large rainfall events can lead to extensive freshwater plumes that can impact freshwater intolerant and light sensitive species.
- Over geological time-scales, cyclones act to control the inflows of new sediments in the GBR lagoon and the cross-shelf distribution and allocation of existing sediments within the lagoon and shorelines.

The majority of investigations of the impacts of cyclones on Sensitive Ecological Receptors in the GBR mostly focus on short term synoptic events (events occurring over periods of days). By contrast, the most important role of cyclones occurs over geological timescales where repeated cyclones cumulatively act to control the inflow of new sediments into the lagoon through seabed erosion, reef breakage (bio-erosion) and river flooding, and importantly control and maintain partitioning of sediments and restrict development of new reefs in the inner shelf sediment prism (Larcombe & Carter, 2004).

Reoccurrence and likelihood

Figure 2, extracted from Puotinen (2004) and Figure 3 from BoM (Bureau of Meteorology) data, shows the tracks and number of cyclones that entered Queensland waters during the 20th century. Details of these cyclones can be found in Section 2.0.

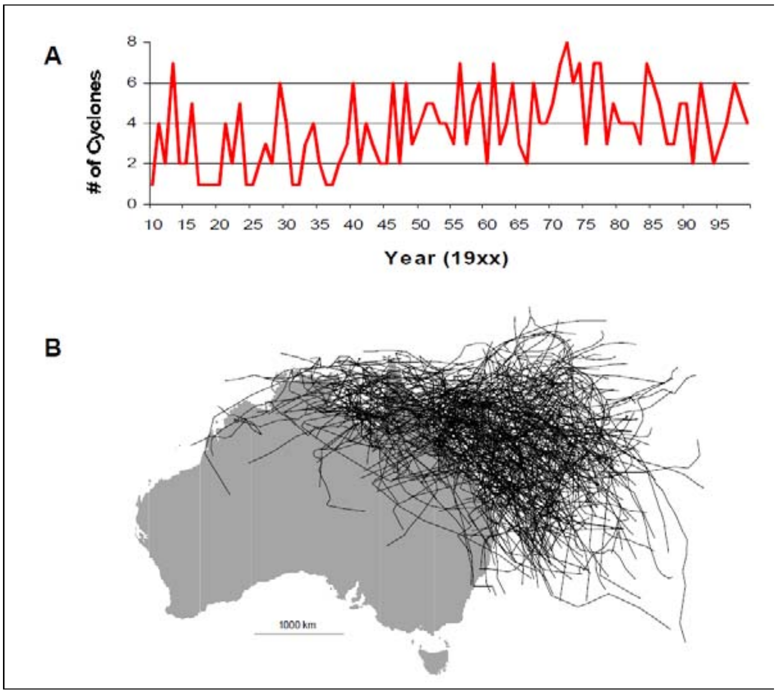


Figure 2 Number (A) and paths (B) of tropical cyclones that entered Queensland Australia from 1910 to 1999. Tracks were generated from the tropical cyclone database (Puotinen M. , 2004).

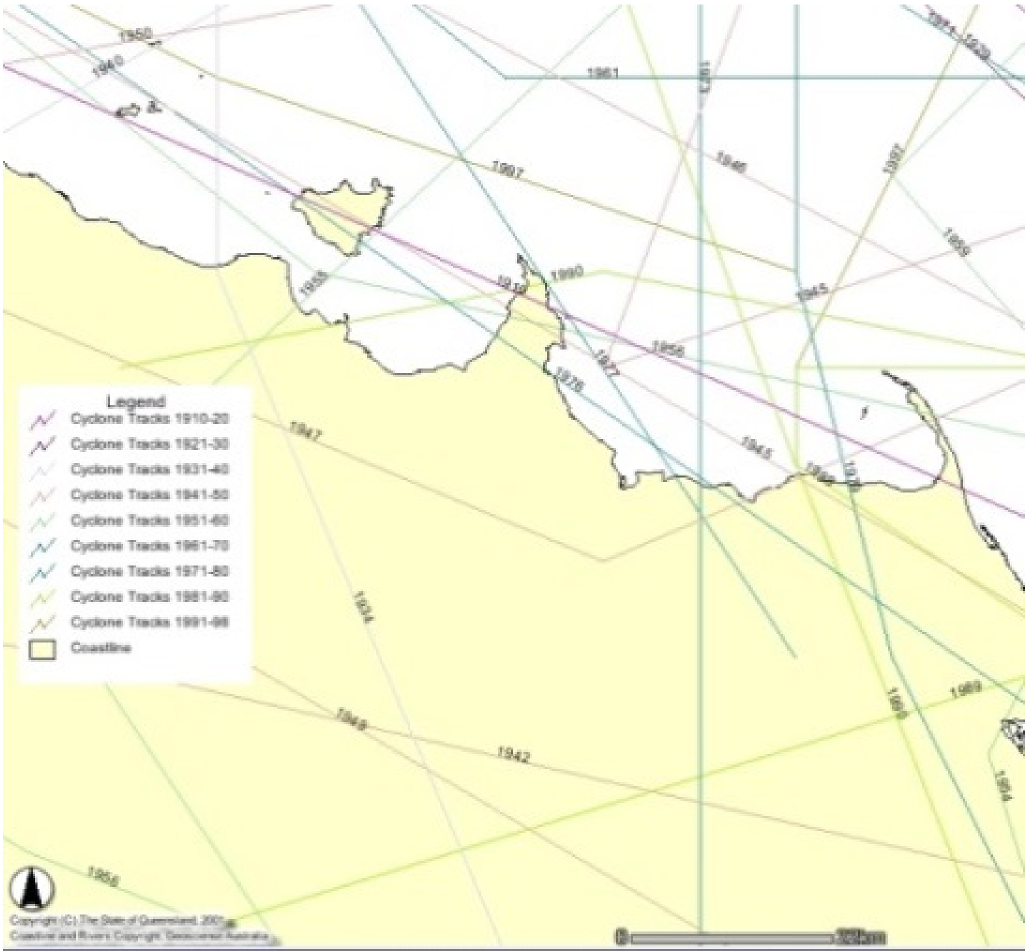


Figure 3 Major cyclones near Cleveland Bay. Data provided by the BoM.

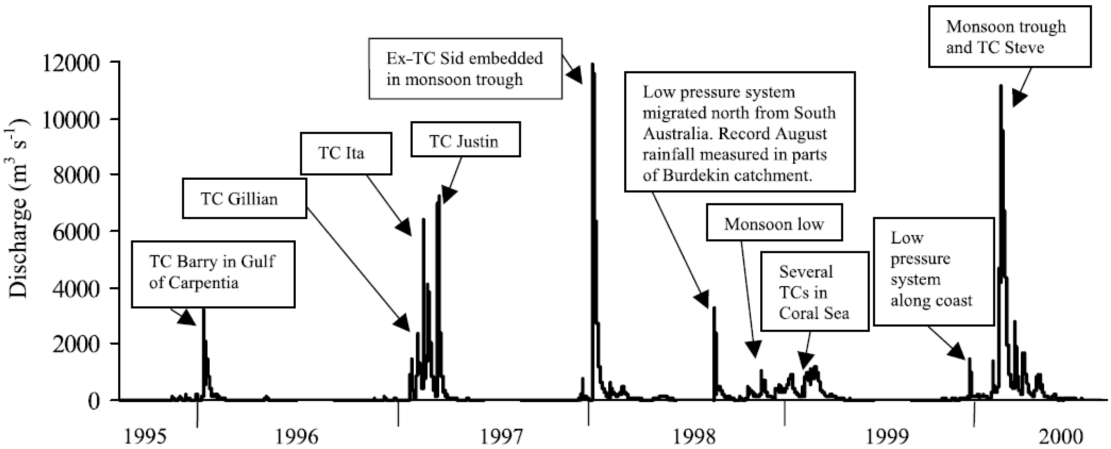


Figure 4 Hydrograph from the Burdekin River (extracted from (Amos, Alexander, Horn, Pocock, & Fieldings, 2004)).

The hydrograph data shown in Figure 4 demonstrates that cyclones are an integral part of the GBR climatology. This is evident in the central GBR where the PEP is proposed.

Deriving likelihood from first principles, given that the length of the GBR is approximately 2,300 km, and that on average four named cyclones cross the GBR every year, if it is assumed that catastrophic damage occurs 25 km either side of each cyclone and that any cyclone will cross perpendicular to the coast, then, as a result, every time a cyclone crosses the GBR it will impact at least one of 46, 50 km-wide sections. Therefore, on average 4 of these 46 sections are impacted every year, as a long term average, which is close to a 10% likelihood that any given 50 km section of reef will be impacted by cyclone damage in any given year. This would equate to every reef within the GBR being impacted by one major cyclone event every ten years.

A refined version of this calculation was performed by Puotinen (1994; 1997). Assuming cyclones can create destructive conditions 100 to 200 km away from the centre (Done T. , 1992), and given known distributions of coral reefs, Puotinen (1994; 1997) estimate that for the period 1969-1997 every reef in GBR was influenced by at least one cyclone.

Similarly, based on a minimum destructive wind speed of around 25 m s^{-1} for periods of 20 hours, Puotinen (1994; 1997) estimate that for the latitude of Townsville, reefs were impacted by a cyclone on average every other year between the years of 1969-2003. Figure 5 shows recent cyclones that have crossed the GBR.

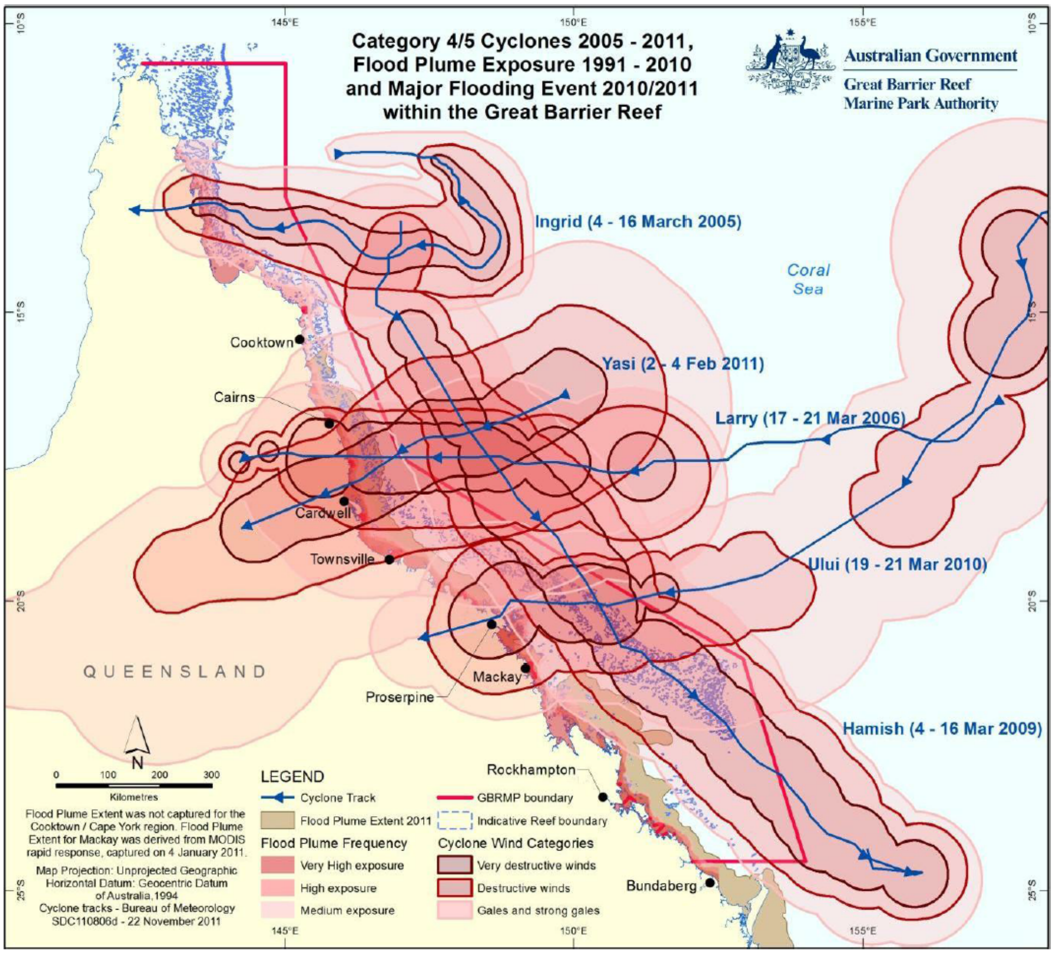


Figure 5 Area of the Great Barrier Reef affected by the cumulative impacts of major cyclones over six years overlaid with the major flood plume extents over the last two decades.

These estimates support that on average, reefs in the central GBR will be impacted by cyclonic activity somewhere between every other year and once every decade. Given the relatively short return period in terms of all cyclones, and even for major cyclones, studies show that cyclones play a major role in controlling the regional and local reef community structure, reef-scale, growth rates of reefs and general recovery periods of 1-20 years. This also implies that many, if not most reefs do not get time to fully recover from cyclonic activity. In summary, evidence of past cyclones exist on most if not all reefs in the central GBR. Nott and Hayne (2001) also use coral core records to suggest that every 2 or 3 centuries a 'super cyclone' impacts the GBR.

It is also important to factor that fewer cyclones cross the coast during El Niño years. This implies that both major inputs of sediments during flood events (that are often associated with cyclones) and mechanical destruction from cyclones are often reduced during El Niño years.

Major cyclonic events rarely if ever completely destroy all coral colonies or seagrass meadows within the path of the cyclone (Lukoschek, Cross, Torda, Zimmerman, & Willis, 2013). However, the idea that coral reefs in the Townsville area only experience destructive cyclone events rarely, and have time to fully recovery in between these events is not supported by the available evidence.

Despite common speculation on the potential impacts of climate change on cyclones, there is no compelling evidence to suggest that long-term averages of either the frequency or intensity of cyclones crossing the coast at or near Cleveland Bay has changed significantly over the last century; although this may be a result of lack of data. An increasing number of ecological research papers have speculated that climate change will increase the frequency and/or intensity of cyclones in Queensland. The Intergovernmental Panel on Climate Change (IPCC) in the most current assessment report (AR5) notes that (Intergovernmental Panel on Climate Change, 2013):

"Globally, there is low confidence in attribution of changes in tropical cyclone activity to human influence. This is due to insufficient observational evidence, lack of physical understanding of the links between anthropogenic drivers of climate and tropical cyclone activity, and the low level of agreement between studies as to the relative importance of internal variability, and anthropogenic and natural forcings."

And that:

"Projections for the 21st century indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rain rates".

The best evidence suggests the possibility that less, but more intense cyclones may be a result of global warming during this century. However, these projections are inherently uncertain. Furthermore, as highlighted by the IPCC AR5 studies, current datasets do not indicate any significant trends in global tropical cyclone frequency over the past century. Therefore the best estimates of near future cyclone return intervals are the historical records.

1.3.2 Large-scale externalities

Mechanisms and risk pathways

Large-scale externalities encompass sources of risk that are essentially external to the GBR and wider Queensland region. The major source of the externalities is through climatological processes, especially global warming and ocean acidification.

The cause-effect or dose-response mechanism whereby increased ocean temperatures lead to coral bleaching has been well-established, although it is believed to be complicated by other factors including variability in nutrient and sediment concentrations and incoming solar radiation. Bleaching occurs when coral colonies reject or expel endosymbiotic zooxanthellae typically in response to a combination of high incoming irradiance and elevated sea surface temperatures when sea surface temperatures remain several degrees above typical seasonal ambient conditions. This bleaching threshold is commonly around 30°C for the GBR (Wooldridge, 2009) (Figure 6). Coral bleaching resulting from heat stress has been observed in Hawaii (Jokiel & Coles, 1990), the Caribbean (Winter, Apeldoorn, Bruckner, Williams, & Goenaga, 1998), the Indian Ocean (Wilkinson, Linden, Cesar, Hodgson, Rubens, & Strong, 1999) and Panama (Glynn & D'Croz, 1990).

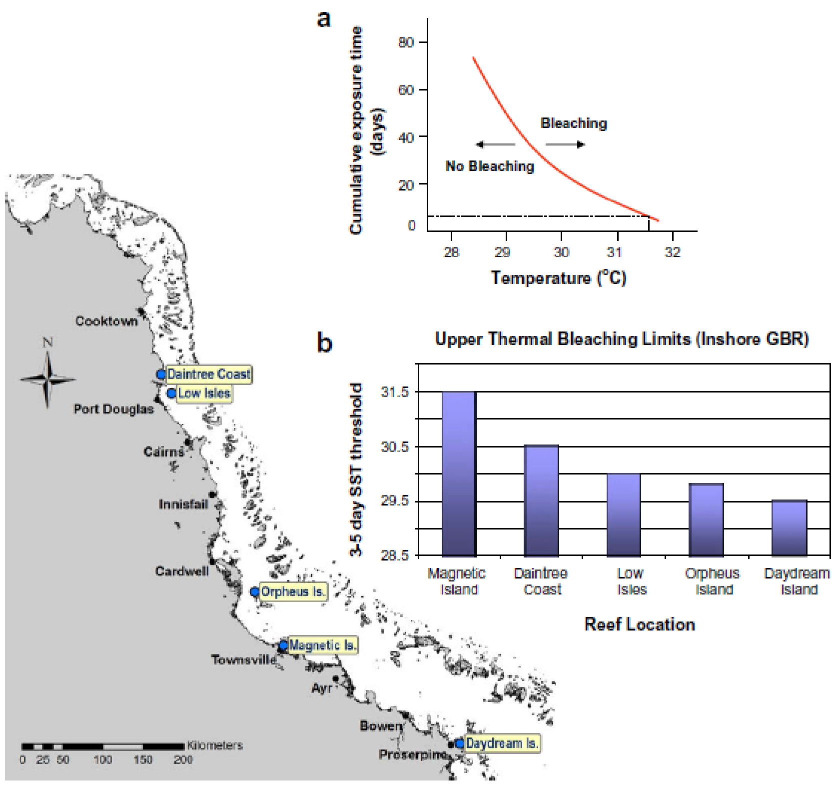


Figure 6 Time-integrated thermal bleaching threshold curve for a hypothetical reef (after Benkelman's, 2002). Temperature and exposure time combinations to the right of the thermal bleaching curve are predicted to induce a bleaching response. (b) Regional-scale variability in the upper thermal bleaching limits of the inshore reefs of the GBR (after Berkelmans, 2002: Berkelmans, 2008). Extracted from Wooldridge (2009).

Similarly, ocean acidification resulting from a rise in partial pressure of carbon dioxide can reduce calcification and accelerate bio-erosion rates in coral reefs (Wisshak, Schonberg, Form, & Freiwalk, 2012). As highlighted by Veron (2011), rates of coral calcification are partly determined by the availability of carbonate ions via the level of aragonite saturation. Furthermore, geological analyses highlight the correlation between previous mass reduction in coral reefs and acidification (i.e. (Veron J. , 2008).

Recurrence and likelihood

In the GBR, major coral bleaching events were observed in 1998, 2002, and 2006 in parts of the GBR (Berkelamans, De'ath, Kininmonth, & Skirving, 2004). During the 2002 event around 41% of reefs surveys showed signs of bleaching.

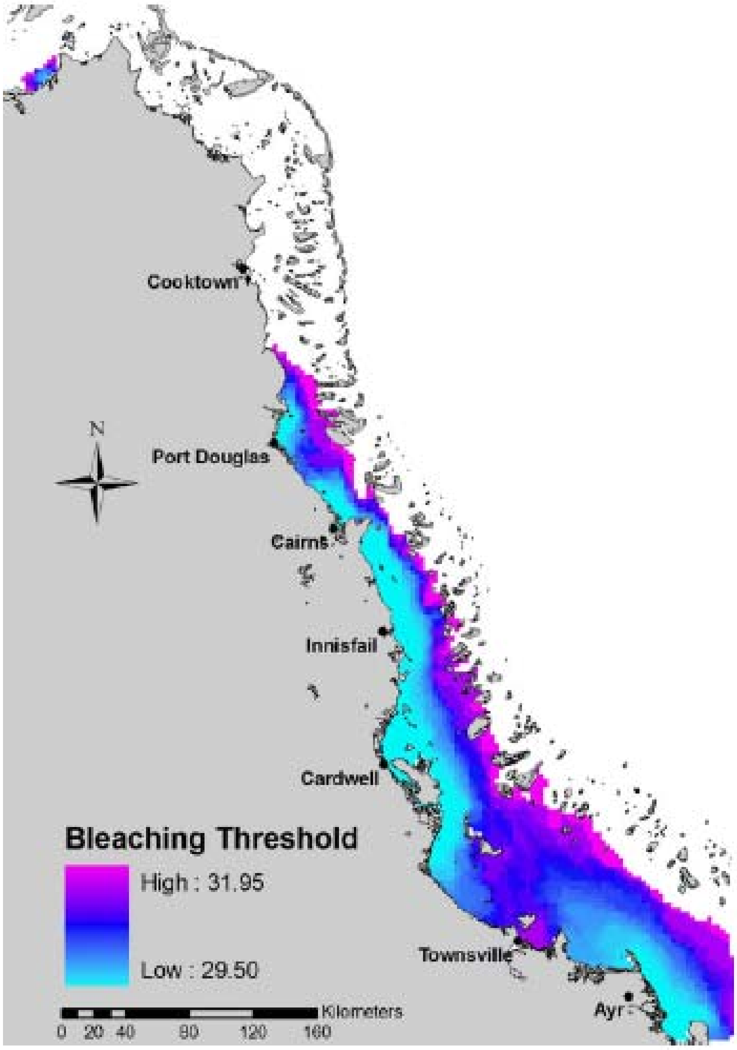


Figure 7 Spatial extrapolation of the quantitative relation between degree of exposure to nutrient enriched terrestrial water and the upper thermal bleaching thresholds of inshore reefs of the central GBR. Extracted from Wooldridge (2009).

Wooldridge (2009) estimated the spatial distribution of bleaching thresholds for the GBR and these are shown in Figure 7. Of relevance, this figure indicates that Cleveland Bay has an equivalent bleaching threshold or vulnerability to the outer shelf reefs.

IPCC AR5 projections continue to support the view that under most emissions scenarios there will be continued warming of the upper-ocean, and acidification of the global oceans. However as expected the projected rate of increase is strongly determined by future emissions scenarios, which are unknown.

Figure 8 shows estimated bleaching probabilities for coral bleaching at Heron Island, extracted from the study of Yara *et al* (2014) that used projections from 23 climate models using the IPCC A1B emissions scenarios. These projections suggest that over the next two decades the most likely return period for bleaching events remains between 5 and 10 years. By contrast, by the end of the century it is projected that bleaching events will be occurring every year on average.

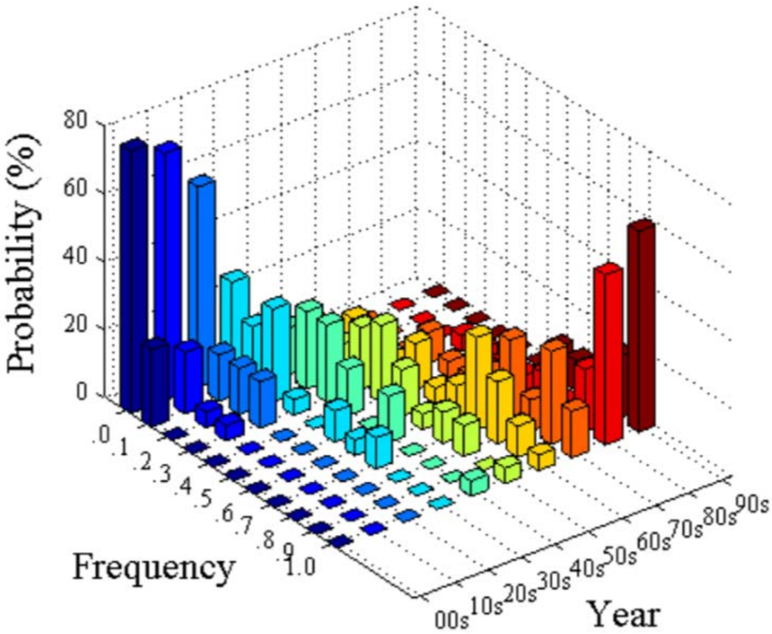


Figure 8 Projected bleaching events (Extracted from Yara *et al* (2014)).

The likelihood that acidification will impact specific Sensitive Ecological Receptors , especially corals, in any given year is difficult to even characterise at present. Whilst the mechanisms through which acidification could impact coral are becoming clearer, whether they are actually occurring at present and how much is far from clear.

1.3.3 Dredging and catchment land use practices

Mechanism and risk pathways

Changed catchment land-use practices and coastal development have led to a change in the rate of delivery of nutrients, pollutants and contaminants, and fine and coarse sediments entering coastal regions worldwide. For example, the damming of large rivers on many continents has curtailed the downstream delivery of coarse sediments resulting in increases in coastal erosion as a result of shutting off the supply of coarse sediments to the coastal zone.

Similarly, world-wide, coastal water quality has been impacted by agricultural runoff and urban development in many receiving catchment environments. This can lead to increased eutrophication from elevated nutrient loads, and increased concentrations of contaminants in sediments and in the water-column, especially around heavily industrialised coastal regions.

Fine sediments in tropical waters can reduce light levels to coral colonies and seagrass beds, and increased sedimentation rates can smother seagrasses and corals and lead to requirements for increased energy expenditure for clearing fine sediments in coral colonies.

Increased nutrient loads into the GBR lagoon has also been strongly linked with outbreaks of Crown of Thorns Starfish (CoTS; *Acanthaster planci* – Fabricius *et al* 2010).

Dredging operations have the potential to generate fine sediments when the cutting head is operating. These fine sediments can temporarily reduce the water clarity (increase the turbidity) within the footprint of the dredge plume. The characteristics of expected plume can be found in Section 6.0 of the AEIS (Marine Water Quality).

1.3.3.1 Recurrence and likelihood

Land-use changes occurring within the GBR catchments (total catchment area 424 000 km^2) can influence coastal marine Sensitive Ecological Receptors through the delivery of nutrients, pesticides and fine sediments which enter the GBR lagoon mainly during ‘wetter’ wet seasons. These inflows or waterway discharges vary both through and over time.

Figure 9 shows the relative discharges from the major waterways that drain into the GBR lagoon. The Burdekin River is the single-largest point source by volume in the GBR catchment. The Burdekin enters the GBR upstream (south) from Cleveland Bay where river plumes typically flow northwards as result of near-shore wind-driven flows forced by the predominant south-easterly trade winds.

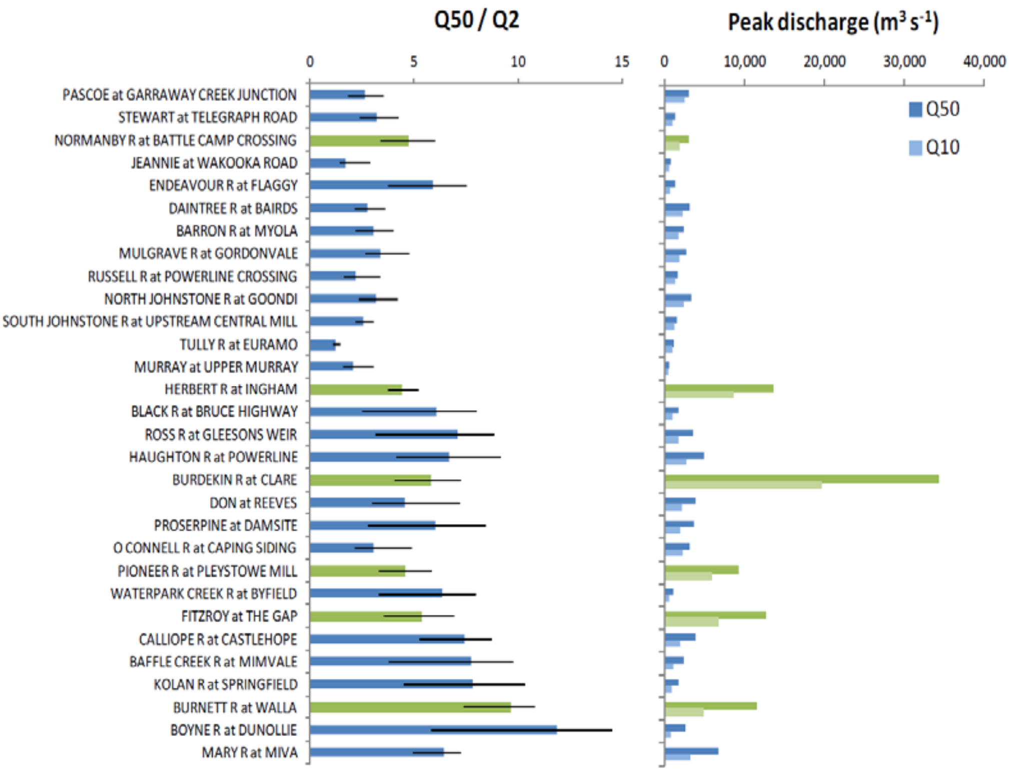


Figure 9 Left: Flood variability at selected GBR river gauges, represented by the ratio of the peak discharge of the flood with 50 years recurrence interval relative to peak discharge of the flood with two-year recurrence interval (Rustomji, 2009) Rivers indicated in green are the largest for their respective resource management region.

Information on discharges over recent years from rivers that flow into the GBR are shown in Figure 10, Figure 11 and Figure 12. The prolonged dry period, followed by the intense floods during 2010/11 can be seen in Figure 10. For a number of catchments the 2010/11 flows were the largest in the historical record.

In the GBR system there is strong agreement that post-European clearing in the catchment has increased the annual average delivery of contaminants, nutrients and fine sediments several-fold by comparison to pre-European settlements periods (Kroon, et al., 2012). Therefore whilst large flood events have always occurred in the catchments, over recent decades the volumes of pesticides, sediments and nutrients associated with these flood events have increased.

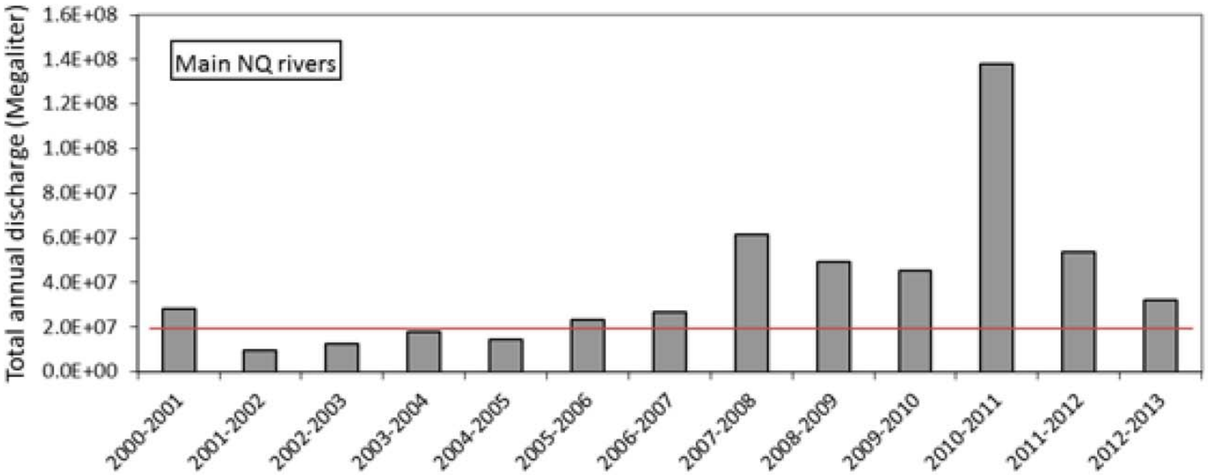


Figure 10 Total discharge from main GBR rivers showing above median flow since 2007-2008. Units are in Megalitres (Reproduced from http://watermonitoring.derm.qld.gov.au).

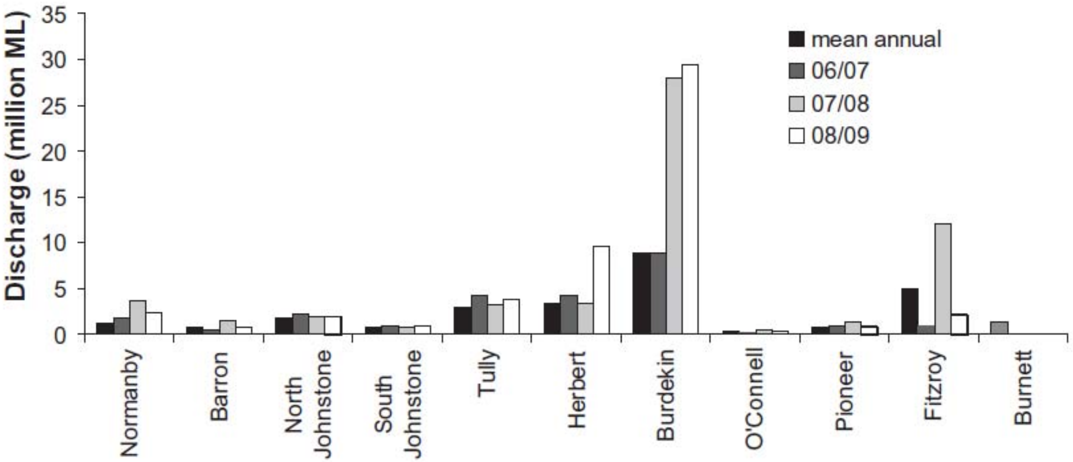


Figure 11 Annual discharge volume (2006-09) and long term mean annual discharge (table) in the major catchments of the GBR. Units are in millions of megalitres (Reproduced from Joo *et al* (2012)).

Combined flow standardised TSS and nutrient loads (mean annual concentrations) at the monitored EOS sites.

Monitoring year	Discharge (million ML)	TSS (mg/L)	TN (µg/L)	TP (µg/L)	NO_x-N (µg/L)	NH_4-N (µg/L)	FRP (µg/L)
2006/07	25	308	744	190	158	13	17
2007/08	57	334	1029	289	100	11	35
2008/09	53	242	709	176	73	20	22
Mean	45	295	827	218	110	15	25

Figure 12 Combined flow standardised TSS (total suspended solids), Total Nitrogen (TN), Total Phosphorus (TP) and nutrient loads (mean annual concentrations) at the monitored in major GBR rivers (see Joo *et al*., 2012 for details).

1.3.4 Fishing, marine tourism and transport

Mechanism and risk pathways

The potential and probable impacts of fishing activities have been well-researched over numerous decades, and a considerable research effort has been directed towards understanding the impacts of fishing on the GBR during the 1980s and 1990s. Impacts have included direct habitat destruction of soft-sediment habitats as a result of trawling activities, and changes to predator-prey relationships when reef fishes are exploited.

Marine tourism and transport, principally dive and fishing charters, and commercial shipping and ferry services all involve the passage of vessels that create noise and in the case of shipping and other vessels, can release fine sediments into the local marine environment. Diving tourism has also had significant impacts on reefs through mechanical destruction associated with vessel anchors and divers themselves.

Recurrence and likelihood

Fishery values, baseline conditions and use of Cleveland Bay were addressed in Section 8.0 of the EIS. Below is a summary of the key findings.

C & R Consulting (2007) compiled records of soft sediment habitat associated demersal fish species in Cleveland Bay. These records identified 253 species from 65 families in Cleveland Bay and the lower reaches of Ross Creek and Ross River. Around one-third of these species are migratory, including over 40 species that migrate between marine and freshwaters (amphidromous), 23 species that migrate in marine waters, 12 species that migrate between marine and freshwaters for breeding, and two species that migrate in freshwater environments.

Commercial fisheries operating in Cleveland Bay include:

- Queensland Mud Crab fishery
- East Coast Otter Trawl
- Queensland Blue Swimmer Crab fishery
- Queensland East Coast Spanish Mackerel fishery
- Queensland East Coast Inshore fin fish fisheries.

The Queensland Spanner Crab fishery includes waters adjacent to Cleveland Bay.

Analysis of the Department of Agriculture and Fisheries (then DEEDI) catch data indicates that Cleveland Bay is not considered to represent a key production area for mud, spanner, and blue swimmer crabs, but does produce regionally important catches for the East Coast Otter Trawl, the East Coast Spanish Mackerel fisheries, and localnet fishery (focusing on barramundi, but also threadfin salmon and grey makerel).

Cleveland Bay and surrounds are not known to represent regionally important areas for the aquarium fish or sea cucumber fisheries.

Restrictions to commercial fishing activities in Cleveland Bay include a Dugong Protection Area (netting restrictions), Cleveland Bay Fish Habitat Area (trawling restrictions), and commercial fishing closures of Ross River, Ross Creek, Alligator River and Crocodile Creek.

Cleveland Bay also supports recreational fisheries, and a number of inshore, reef and pelagic species are targeted. Recreational fishers generally target similar species to commercial fishers including barramundi, mullet, whiting, bream and mud crabs in inshore areas; and reef fish such as coral trout (*Plectropomus* spp.), snapper (*Lutjanidae*), sweetlip *(Lethrinidae*) and trevally (*Caranx* spp.) when further from shore (Ludescher, 1997). The value of recreational fishing is likely to be greater than the commercial fishing industry.

Most line-based recreational fishing tends to occur around artificial structures such as navigation structures and breakwaters, as well as reef environments around Middle Reef and Magnetic Island. Some crabbing occurs in coastal creeks throughout the bay.

Estuarine areas in the south-east of Cleveland Bay (e.g. Ross River, Alligator and Crocodile Creeks) are commonly used for targeting species such as barramundi, mangrove jack, flathead, whiting and mud crabs. Cast netting for prawns and herring occurs extensively along Ross Creek, the Ross River mouth and along foreshore areas; and yabbie pumping occurs on the eastern side of Ross River (Sinclair Knight, 1991).

The breakwaters around the Port of Townsville are popular recreational fishing locations, primarily for fishing from small boats (CPL, 2007). The only Port of Townsville breakwater that recreational anglers have access to for land-based fishing is the western breakwater. Reef and deep-sea recreational fishing is focused around Cape Cleveland, Middle Reef, the shipping channel, Pallarenda Point and Magnetic Island (Sinclair Knight, 1991).

Although some limited recreational fishing data are collected by DEEDI (2011) for the wider region, little is known about the catch and value of recreational fishing in Cleveland Bay and surrounds. It is also difficult to quantify the overall market value of the recreational fishing industry because it supports a wide network of businesses and tourism-related operations in Townsville and on Magnetic Island. It is likely to be considerably more than the commercial fishing industry, as previous estimates of the economic value of recreational fishing in the area (Sinclair Knight, 1991) are high. At that time that this report was compiled approximately 70,000 kg of bait was sold annually at a retail value of ~$200,000. It was also estimated the annual retail value of bait and tackle sales to be $2.5 million, whilst outlay on boats, motors and chandlery was estimated to be a further $2 million.

There is little information about the amount of Indigenous fishing conducted, however it is likely to be small when compared to the general recreational and commercial sectors.

The GBRMPA Strategic Assessment identifies that tourism is strongly focused offshore of Cairns, Port Douglas and the Whitsunday Island. It is evident from the Strategic Assessment that tourism within Townsville and Magnetic Island holds a lesser value than other key areas within the GBR Marine Park area but is comparable to other locations outside of the key tourist areas (GBRMPA, 2014).

1.4 Sensitive ecological receptors and variability

The extent and condition of Sensitive Ecological Receptors in the study area are outlined in Chapter B.6 (Marine Ecology) of the EIS. In response to comments on the EIS this assessment has been reviewed and updated as part of this AEIS. This revision involved both undertaking a new survey and field data collection. A summary of these findings with a focus on the relevance of these findings to potential cumulative impacts is presented in the following sections. This analysis also includes considerations of how the distribution and condition of the Sensitive Ecological Receptors vary between years.

1.4.1 Corals

Coral reefs within Cleveland Bay are located between Magnetic Island and the mainland (for example Middle Reef), or fringing reefs on Magnetic Island, for example in Nelly Bay.

Browne at al (2010) examined the condition and community structure of Middle Reef, and observed changes to the community structure over years, including an average increase in coral cover over the windward slope for the period 1993-2008 Figure 13.

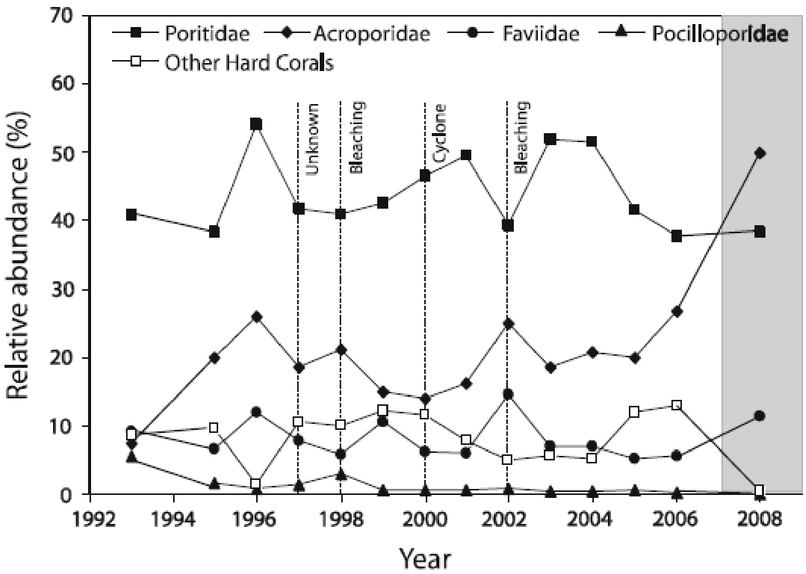


Figure 13 Changes in the relative abundance of the dominant hard coral families. Data collected by the long-term monitoring research teams at AIMS from 1993 to 2007. Shaded area represents data collected as part of this study in 2008. (Browne, Smithers, & Perry, 2010).

Lewis *et al* (2012) conducted a detailed examination of the geological history of the fringing reefs at Nelly Bay and concluded:

> "*Our integrated approach provides insights into natural compositional variability of fringing reefs and demonstrates that in the past the coastal fringing reefs in the GBR region were exposed to considerable turbid conditions and yet managed to grow rapidly and form extensive reef flats. This suggests that turbidity levels may not seriously limit reefal growth*".

Coral monitoring conducted in 2012 for the Reef Rescue Program monitored sites at Middle Reef and Geoffrey Bay on Magnetic Island. This monitoring noted that the deeper communities at Middle Reef were not heavily exposed to cyclone damage for recent cyclones including Cyclone Yasi. However, bleaching during the period 1998 and flood plumes during 1994, 1997, 1998 and 2008 following the Millennium Drought were also thought to have impacted reefs in the Burdekin region.

Figure 14 shows time series of percentage cover for hard corals from the Reef Rescue program at Middle Reef and Geoffrey Bay. These data show some evidence in a declining trend in coral cover at the shallower sites, but little change at the deeper parts of the reef (5 m) where measured.

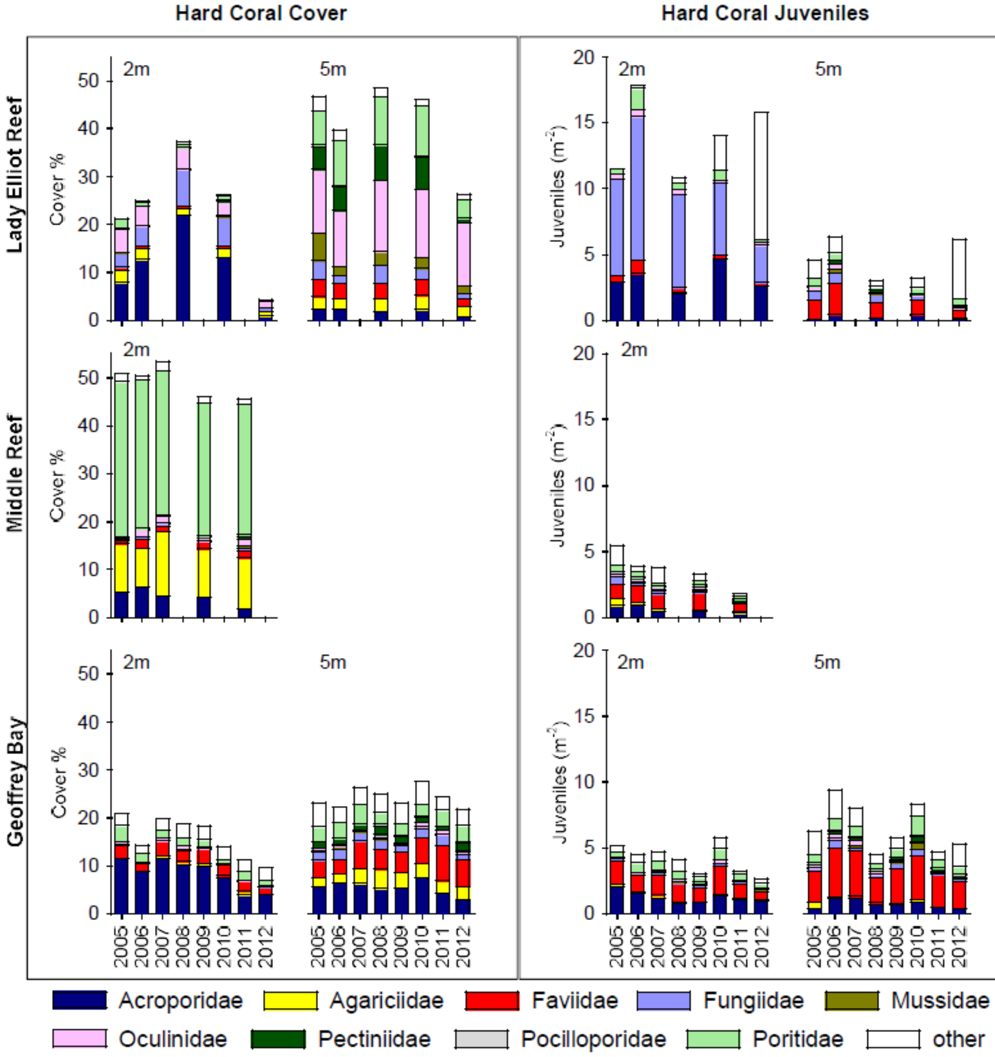


Figure 14 Extracted from Figure 29 of Thompson *et al* (2013).

The most comprehensive time series of GBR coral cover is contained in the AIMS long-term monitoring dataset; some of which is used in the Reef rescue program. Figure 15 shows results from this monitoring program. The Burdekin region (H) identified in this figure is relevant for this study.

The first years from 1995 of the record show an increasing trend in coral cover. By contrast, the coral cover decreased during the majority of the record. The reason for this decrease is suggested to be a series of closely spaced events including bleaching events and major storm events (refer to the dots in Figure 15).

Two main conclusions can be drawn from these data:

- in the absence of major weather events it is plausible that coral condition could have continued to increase
- the identified external stressors (storms and bleaching) were likely to be of sufficient frequency and magnitude to reverse the trend in recovering condition.

These results are consistent with the data collected during the baseline monitoring for this Project, as presented in the Appendix A1 (Additional Field Studies for the Townsville Port Expansion Project AEIS) of the AEIS.

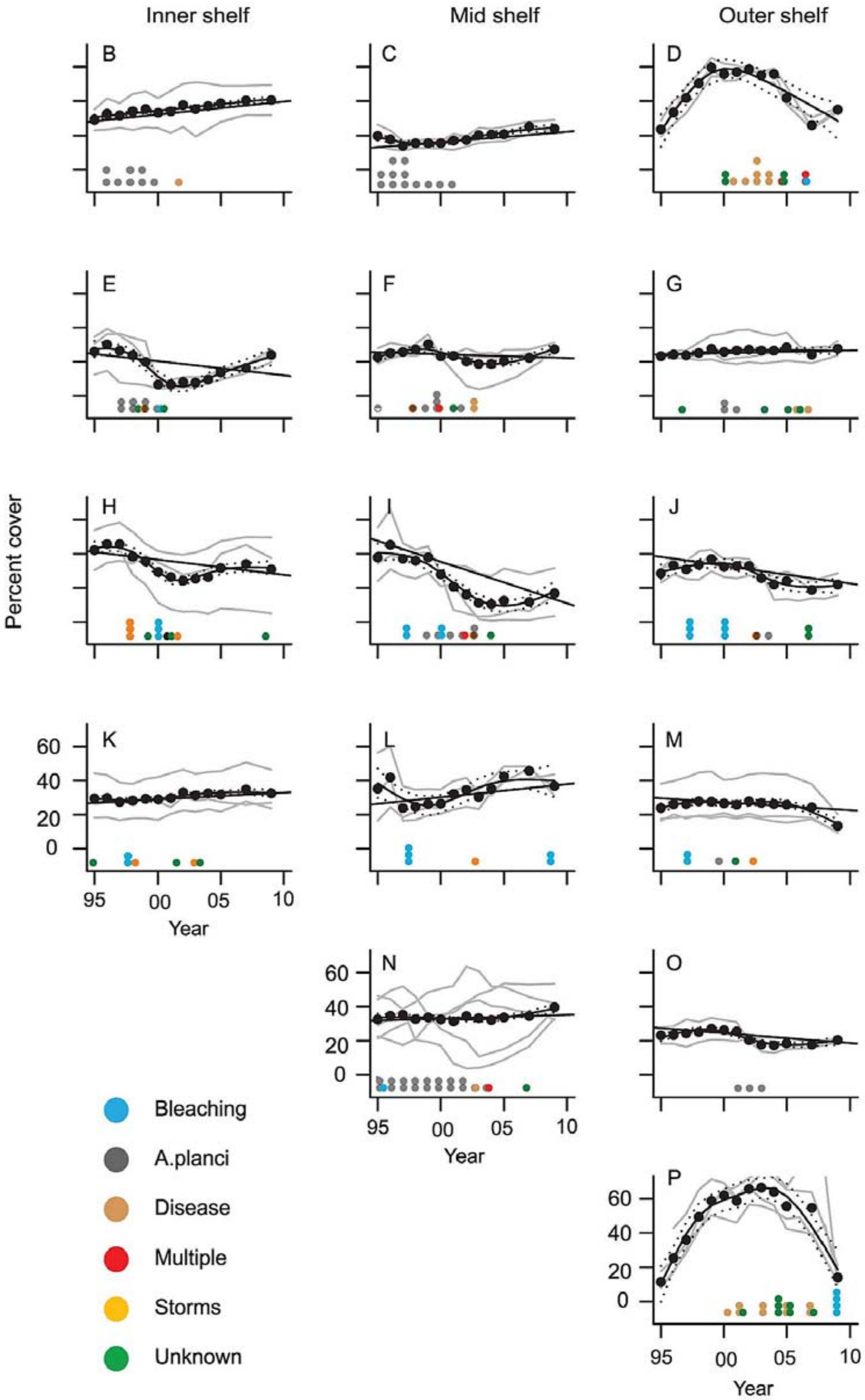
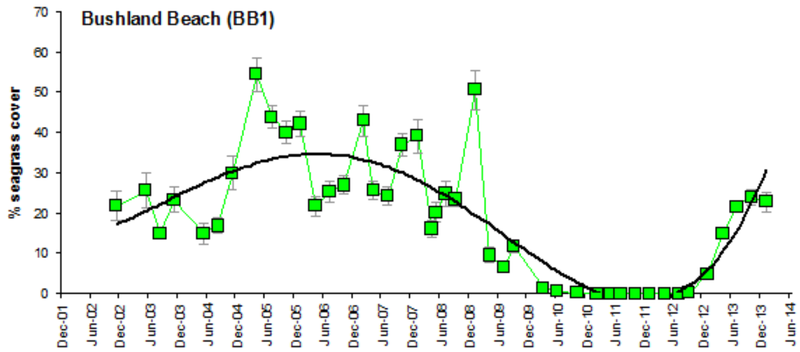


Figure 15 Temporal trends in percent cover of hard coral on the GBR (1995 - 2009). From Osborne *et al*. (2011)

1.4.2 Seagrass

The distribution and density of seagrass meadows within Cleveland Bay can show great variation over a range of temporal scales. At seasonal scales, there is a typically a seasonal growth cycle of intertidal and shallow subtidal seagrass meadows (Waycott, Longstaff, & Mellors, 2005), with higher percentage cover in late spring/summer (Johnson, Brando, Devlin, Kennedy, McKenzie, & Morris, 2011). This is the typical seasonal pattern of seagrass meadows in near-shore waters of the GBR region (Waycott, Longstaff, & Mellors, 2005; Unsworth, McKenna, & Rasheed, 2010), with higher water temperatures during summer periods promoting seagrass growth rates (Collier & Waycott, 2010).

Large inter-annual changes in seagrass meadow extent and community structure resulting from synoptic and climate-driven disturbances have been observed in the Port's annual seagrass monitoring program (McKenna & Rasheed, 2011). For example, a major reduction in seagrass above-ground biomass and extent (at the deepest boundaries of the meadows) was recorded in Cleveland Bay between 2007 and 2011. Similar declines in seagrass cover were recorded by Seagrass Watch at Cape Pallarenda and Magnetic Island over the measurement period (Figure 16). Johnson, *et al*. (2011) found that there was declining trends in seagrass cover at the mainland sites (i.e. Cape Pallarenda) since 2005, whereas those around Magnetic Island only began to decline in 2008.


Bushland Beach (BB1)
% seagrass cover
70
60
50
40
30
20
10
0
Dec-01
Jun-02
Dec-02
Jun-03
Dec-03
Jun-04
Dec-04
Jun-05
Dec-05
Jun-06
Dec-06
Jun-07
Dec-07
Jun-08
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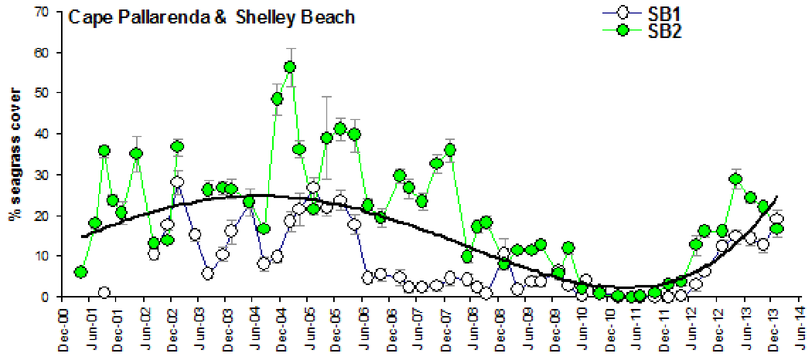
Cape Pallarenda & Shelley Beach
SB1
SB2
% seagrass cover
70
60
50
40
30
20
10
0
Dec-00
Jun-01
Dec-01
Jun-02
Dec-02
Jun-03
Dec-03
Jun-04
Dec-04
Jun-05
Dec-05
Jun-06
Dec-06
Jun-07
Dec-07
Jun-08
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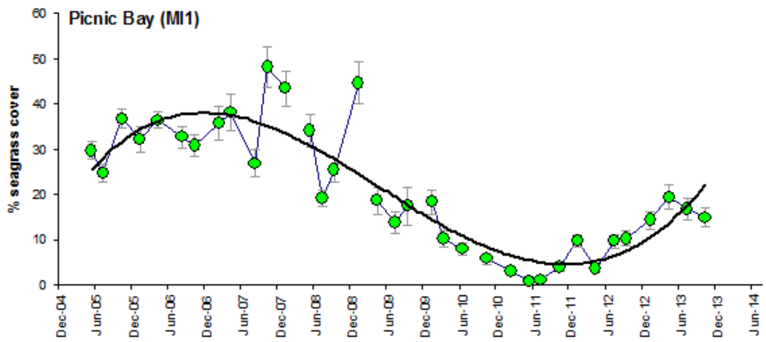
Dec-13
Jun-14


Picnic Bay (MI1)
% seagrass cover
60
50
40
30
20
10
0
Dec-04
Jun-05
Dec-05
Jun-06
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
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Dec-13
Jun-14

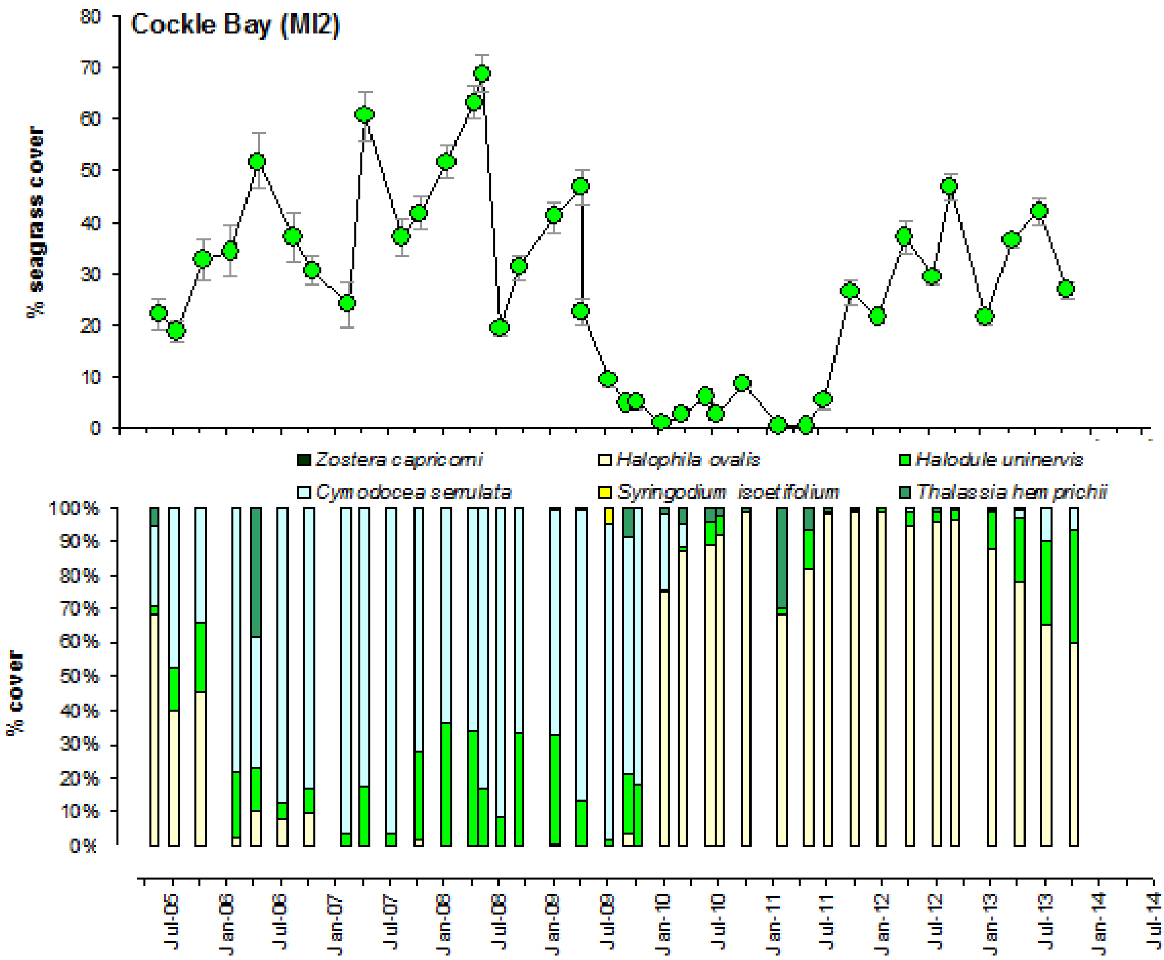

Figure 16 Seagrass monitoring data

The Reef Rescue Marine Monitoring Program (Johnson, Brando, Devlin, Kennedy, McKenzie, & Morris, 2011) assessed the condition of seagrass meadows, and found that seagrass meadows of the Burdekin-Townsville region were classified as being in a 'poor state' throughout the 2009/10 monitoring period (Johnson, Brando, Devlin, Kennedy, McKenzie, & Morris, 2011).

By contrast, more recent monitoring indicates recovery at all sites within and close to Cleveland Bay (Figure 17 and Figure 18). This most recent survey indicates that the degradation that occurred following the 2010/11 major flood plume events has been followed by a subsequent recovery to the 7-year average of seagrass habitat area.

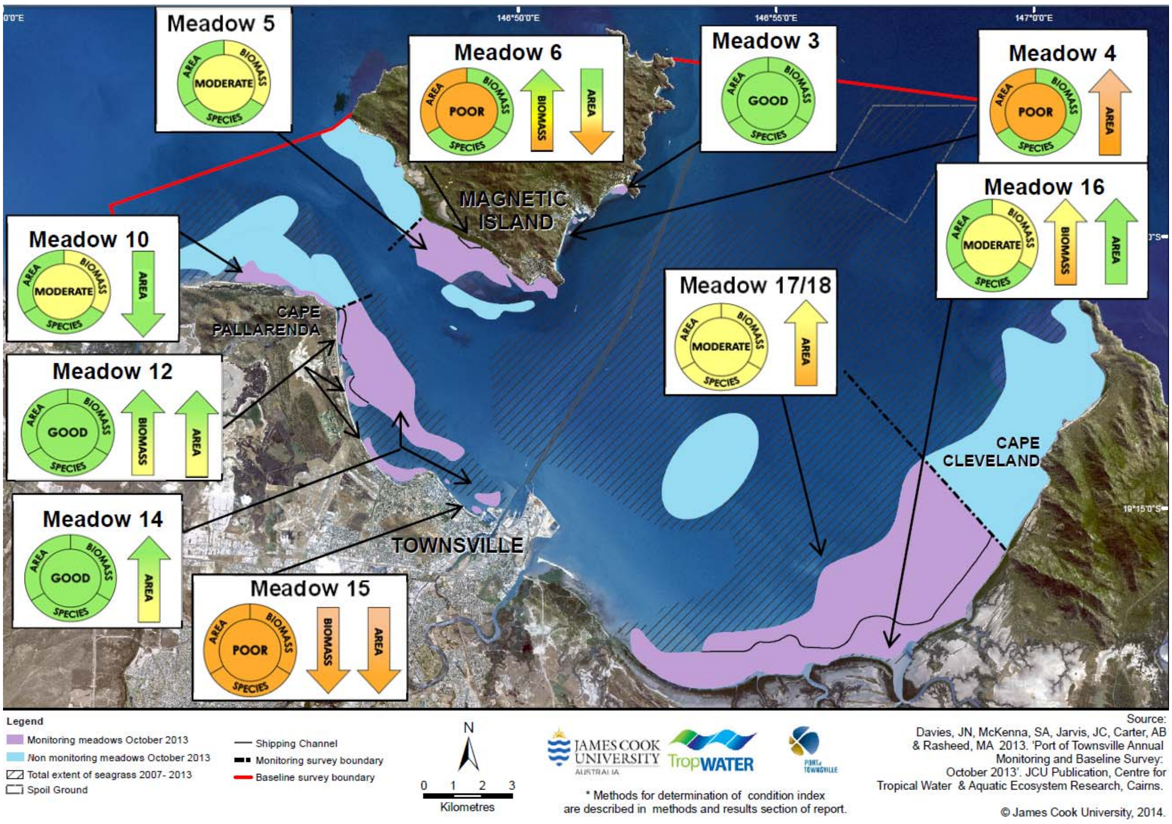

Figure 17 Results of 2013 seagrass monitoring (Extracted from Port of Townsville Annual Monitoring and Baseline Survey 2013 - TropWATER Report No. 14/02)

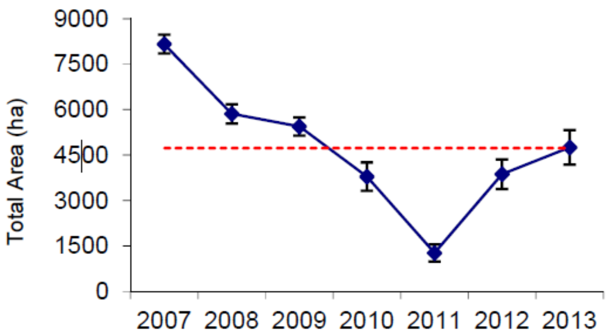

Figure 18 Total area of seagrass within the Townsville monitoring meadows from 2007 to 2013 (error bars = "R" reliability estimate). Red dashed line indicates 7-year mean of total meadow area

1.5 Impacts and Risks of Individual Stressors on Sensitive Ecological Receptors in Cleveland Bay

The previous sections characterised the stressors, considered the variability or likelihood of occurrence of stressors and the changes in condition of the Sensitive Ecological Receptors. This section investigates the impacts and risk of impact of the identified stressors on the Sensitive Ecological Receptors . The estimation of risk is determined by both the likelihood of occurrence (discussed above) and the consequences of occurrence.

1.5.1 Cyclones

Impacts on corals

The most obvious impact from large storm events is the direct mechanical destruction of coral communities (Figure 19). Van Woesik *et al* (1991) observed large scale destruction of the upper 2 m of impacted reefs and identified considerable damage to coral colonies at depth of 30 m following Cyclone Ivor in 1990. Similarly, Bongaerts *et al*. (2013) identified storm damage to reefs in the mesophotic zone down to depths of 60 m, presumably as a result of the passage of Cyclone Yasi around 100 km to the north of the study site at Myrmidon Reef.

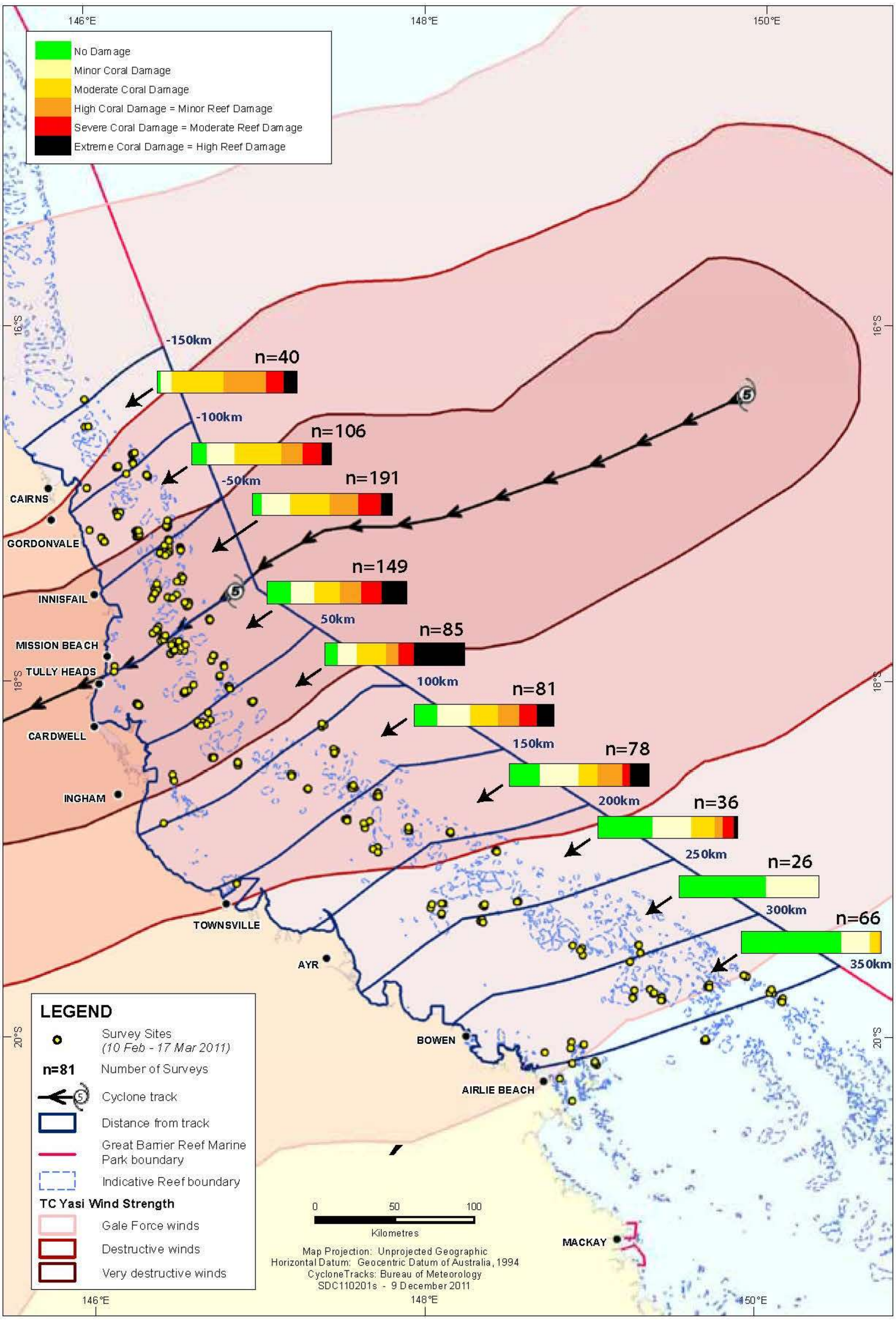

Figure 19 From GBRMPA report: extreme weather and the GBR report 2010 – 2011.

Fabricius et al (2008) recorded severe impacts including an 800% decrease in hard coral cover for inshore reefs within 70 km of a cyclone path. These reefs experienced wind speeds in excess of 33 m s^{-1} (119 km/h).

For outer shelf reefs, De'ath *et al* (2012) estimated that cyclones accounted for 48% of direct mortality of coral colonies during the period 1985-2012.

Severe and moderate direct damage has been attributed to within around 50 km either side of cyclone paths (Puotinen M. , 2004; Connell, Hughes, & Wallace, 1997) although damage has been observed 100-200 km from cyclone paths (Puotinen M. , 2004; Done T. , 1992). Major disturbance and damage is very common 25 km either side of a cyclone path (Puotinen M. , 2004).

Loss of coral cover during major storm events is variable and dependent upon the exposure and vulnerability of individual reefs. This in turn depends on their location and orientation with respect to the cyclone track, the community structure and successional stage of development of the individual reef (Fabricius, De'ath, Puotinen, Done, Cooper, & Burgess, 2008).

For example, Figure 20 below, extracted from Fabricius *et al* (2008) demonstrates the patchy nature of loss of coral cover. These data were derived from observations of coral condition and cover following the passage of Cyclone Ingrid in March 2005. Prior to the passage of the storm, some reefs were around 40% cover and reduced to 8% in places.

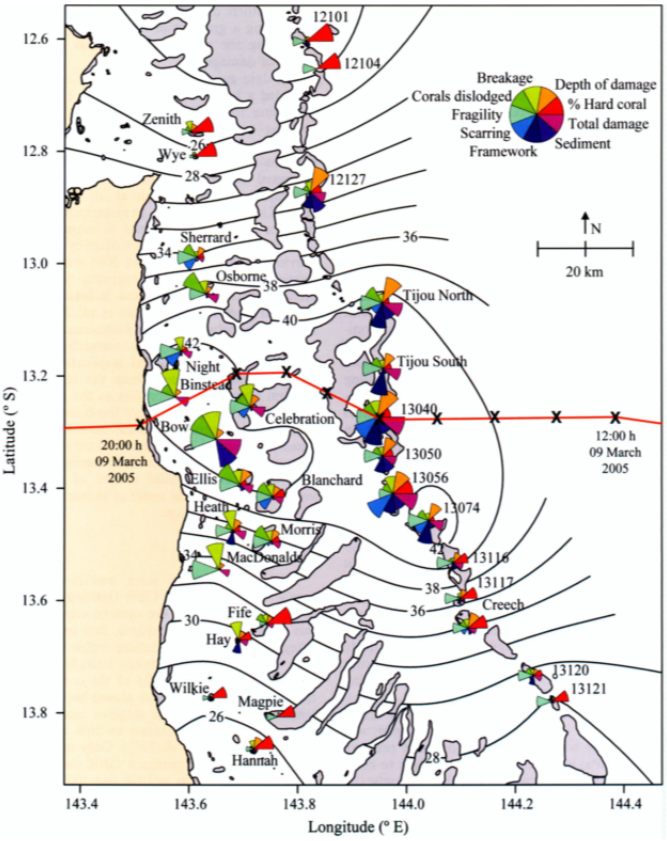

Figure 20 Distribution of coral damage for Far North Queensland. Extracted from from Fabricius *et al* 2008.

Fabricius *et al*. (2008) also identified that the best predictor variable for cyclone damage is the maximum 10-min averaged wind speed. Furthermore, various forms of damage were only observed at winds above a certain threshold. Inshore, sites suffered catastrophic destruction at >33 m s^{-1} winds (category 3 or more) and storm duration of >12 h. Threshold thought to be 28 m s^{-1}.

Figure 21 below shows estimates of local damage resulting from different categories of cyclones.

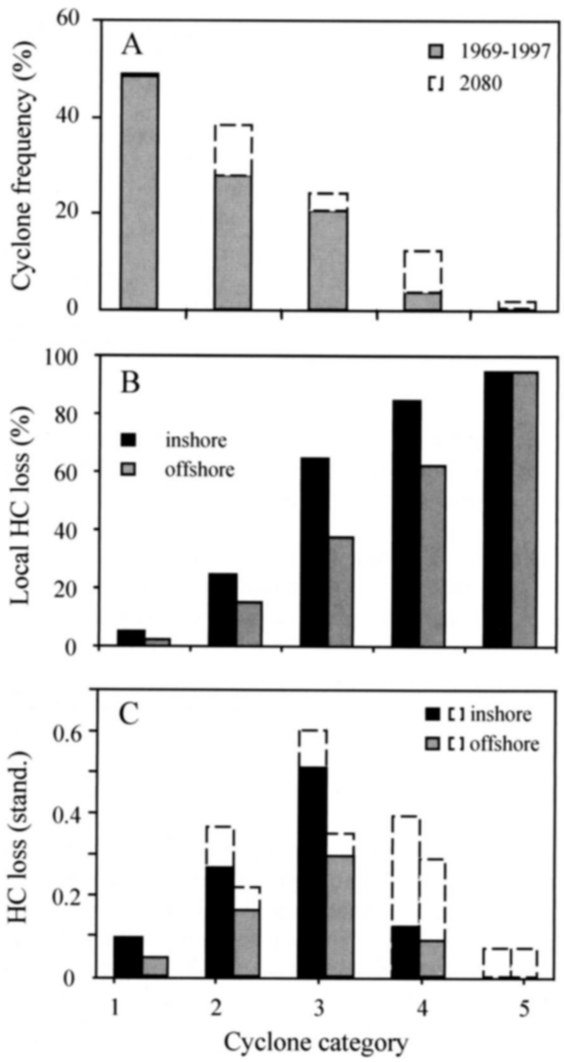

Figure 21 Observed and predicted cyclone intensity distribution, and changes in coral cover by tropical cyclones on the GBR. (A) Frequency distribution of tropical cyclones on the GBR as observed between 1969 and 1997, and with a increase in cyclone intensity of half a category as predicted for 2080; (white dashed bars). (B) Observed local loss in coral cover in response to cyclone intensity on inshore and offshore reefs. (C) GBR-wide loss of coral cover on inshore and offshore reefs, at cyclone intensity distributions as observed 1969 – 1997 (black and grey bars), and as predicted for 2080 (white dashed bars). Values are standardized to cumulative present-day losses on undisturbed inshore reefs (black bars) as 1.0. (Figure 7) from Fabricius *et al* 2008, Note: Hard Coral = (HC).

Jones and Berkelmans (2014) also identified that the freshwater plume from Cyclone Tasha in 2010 bathed shallow reefs 12 km offshore causing 40-100% mortality of fringing reefs in Keppel Bay down to a depth of 8 m. Of relevance, the mortality from salinity stress was thought to far outweigh any mortality from pollutants.

Given that recovery periods from large cyclones events can be of the order 10-20 years (Lukoschek, Cross, Torda, Zimmerman, & Willis, 2013) and often led by recovery of *Acropora* colonies, and that return periods of major cyclones can be of the same order or less, then it is not unreasonable to assume that on average many if not most of the coral reefs in the Townsville region are commonly in some degree of recovery from a major cyclone event, all of the time.

Impacts on seagrass

Seagrass beds are particularly susceptible to impacts from flood plumes as they mostly occur in shallow depths (< 20 m) and rely on consistently high levels of incoming irradiation for survival. During repeated or extended flood plumes incoming light levels can be reduced to the point of mortality. For example, Preen *et al* (1995) report that around 24% of the entire seagrass population along the Queensland Coast was lost during a three week period in 1992 following a cyclone and two major floods. Substantial recovery was observed two years later for the deeper bed (> 10 m depth) but some beds in shallow depths had failed to substantially recover. Similarly, following the widespread flood-related loss of seagrass meadows in the Great Sandy Strait in February 1999, Campbell and McKenzie (2004) report that recovery periods were of the order 2–3 years (Campbell, 2004).

1.5.2 Large scale externalities

Impacts on corals

Most projections of future climactic conditions suggest that there will be continued warming and acidification of surface ocean waters although the rate of increase cannot be accurately predicted as a result of a number of factors, not the least of which is uncertainty over future greenhouse gas emissions.

Similarly, there is also a range of predictions over the impacts in the form of bleaching and reduced availability of carbonate to coral reefs in both Queensland and globally. Predictions that irreversible declines in the distribution of coral reefs will occur at a global scale within decades have been made (for example, Hoegh-Gulberg (1999)). By contrast, other researchers highlight that these estimates commonly discount plasticity and adaptability of reef systems. For example Pandolfi *et al* (2011) state that:

> *"recent work highlighting the role of phenotypic plasticity in evolution and the potential for rapid adaptation indicate that this view about the time scale of reef response may not adequately take account of reef organisms' capacity for coping with stress and their potential for adaptation".*

Bleaching events do lead to mortality and loss of condition of coral colonies in the GBR, and there is a strong likelihood that such bleaching events will not reduce in frequency or magnitude over this century. Yara *et al* (2014) estimate that at Heron Island the average return period for bleaching events over the next decade is less than once every ten years, which is a similar return period for category 4 and 5 cyclones.

This annual likelihood is strongly influenced by the ENSO cycle, in particular with increased likelihood of bleaching conditions occurring during strong El Niño years.

Estimates of loss of coral cover resulting from bleaching events on the GBR were derived from studies of the 1998 and 2002 bleaching events.

Marshall and Baird (2000) report bleaching on Magnetic Island reefs during 1998 (Figure 22). They estimate that six weeks after first reports of bleaching 53% of colonies were affected, including 13% moderately affected, 30% severely and 6% dead. Fast growing species such as acroporids and pocilloporids were most affected.

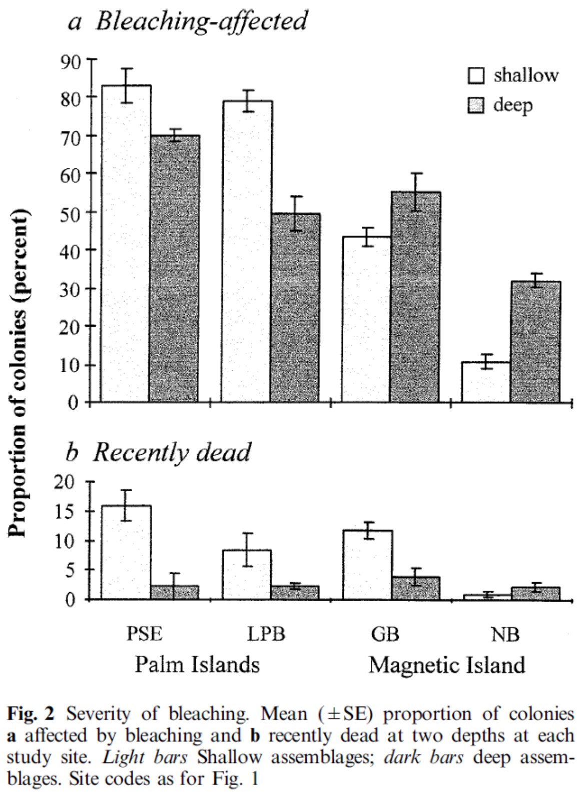

Figure 22 Severity of bleaching for PSE (Pelorus, Little Pioneer Bay, Geoffrey Bay and Nelly Bay). Extracted from Marshall and Baird (2000).

Similarly, Berkelmans *et al* (2004) estimated that around 42% of reefs bleached to some extent during the 1998 event (18% strongly bleached) while in 2002, 54% of reefs bleached to some extent (Figure 23). These statistics and the fact that nearly twice as many offshore reefs bleached in 2002 compared to 1998 (41% as compared to 21%) suggests that the 2002 event was more severe than the 1998 event.

The first field evidence of coral bleaching in 2002 was identified on 7 January 2002 at Magnetic Island (Berkelamans, De'ath, Kininmonth, & Skirving, 2004) (Figure 23, 24). By 8 February 2002, bleaching had intensified and up to 30% of hard corals on the reef crest were estimated to be white with another 50% pale. Osborne *et al* (2011), used a value of 30-35% coral cover loss during bleaching events, based on Berkelmans *et al* (2004).

Fig. 2 Raw aerial survey results of coral bleaching in 1998 and 2002 overlaid on the maximum 3-day SST for every pixel during the warmest austral summer months (December–March)

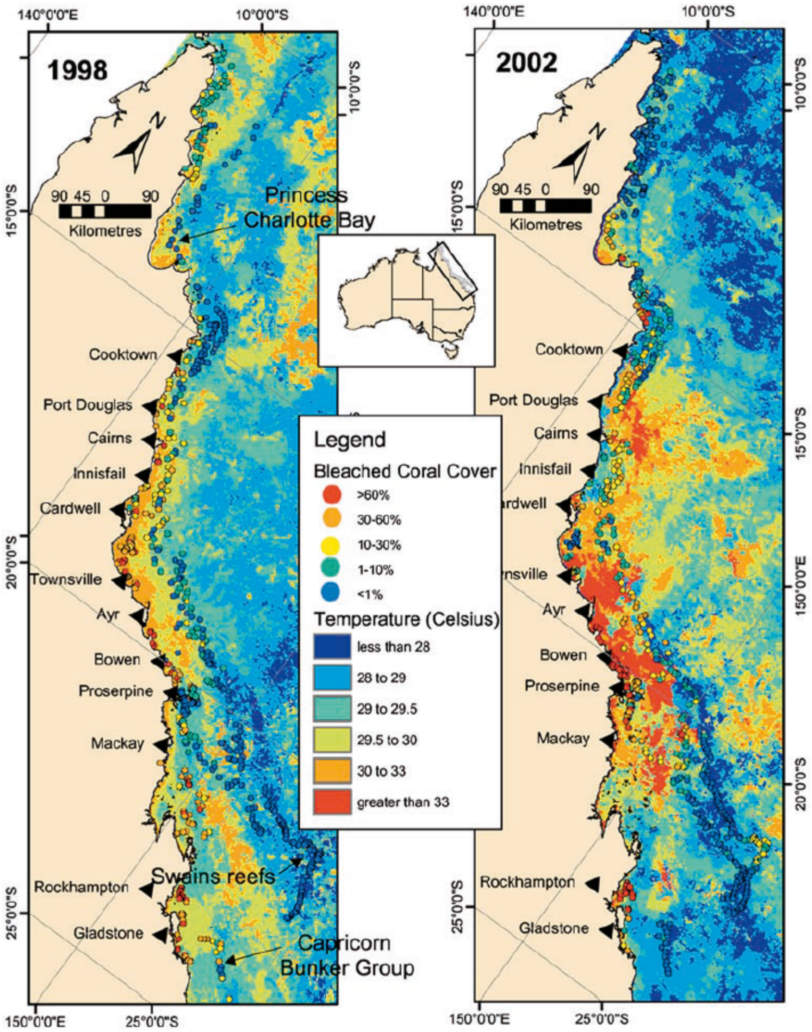

Figure 23 Distribution of bleaching. from Berkelmans *et al* (2004).

Fig. 3 Temperatures and timing of onset of bleaching at **a** Magnetic Island (Nelly Bay) and **b** Davies Reef in early 2002. Magnetic Island temperatures measured with an in-situ temperature logger and the mean calculated over a 10-year period with a 14-day smoothing function applied. Davies Reef temperatures from an automatic weather station and the mean calculated over a 15-year period with a 14-day smoothing function applied

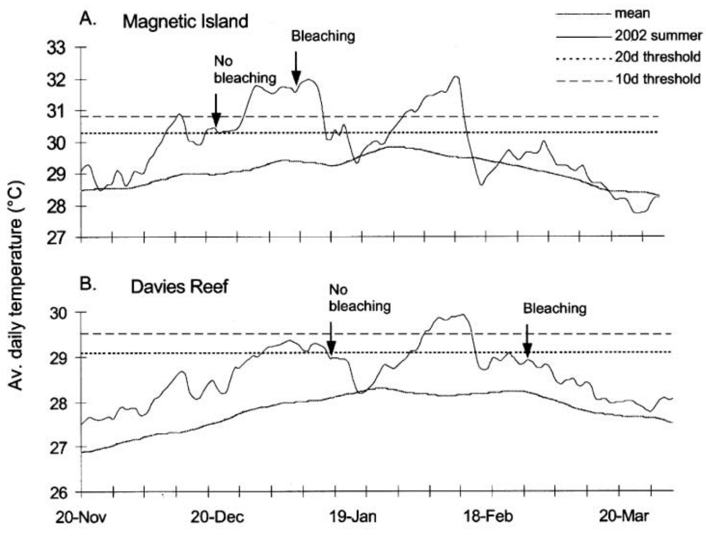

Figure 24 Evidence of bleaching. From Berkelmans *et al* (2004).

Whilst it is widely suspected that acidification is already impacting coral species, there is at present little reliable observations of direct and measurable impacts of acidification to specific reefs. Rather it is considered as a more general 'press' type effect that is acting to reduce the resilience of reefs worldwide.

Impacts on seagrass

Large-scale externalities, especially ocean warming are likely to somewhat alter the species and spatial distributions of seagrasses along the Queensland coast. For example the southward extension of the distribution of *Halophila minor* into Moreton Bay has been assumed to be a result of strengthening of the East Australian Current (Rod Connolly, Griffith University Pers. Comm). However, there is expected to be little likelihood that changes to mean global ocean temperatures alone will lead to the long-term loss of seagrass meadows in the study area. Rather, impacts from changes to runoff and storms are likely to dominate impacts. This is because the study area is not located near the latitudinal edge of the present or projected future distribution of common species in Queensland.

1.5.3 Dredging

The estimates of the direct impacts from capital dredging are derived from the modelling studies presented in the Chapter B.4 (Marine Water Quality) and B.6 (Marine Ecology) in the EIS and updated in Section 6.0 and 8.0 of the AEIS.

The most relevant example of an assessment for direct impacts from dredging in Cleveland Bay is the monitoring of the previous major capital dredging program was undertaken in 1993. The subsequent review of the environmental monitoring of this campaign concluded that the monitoring was clearly able to identify the dose-responses of the identified Sensitive Ecological Receptors to suspended sediment generated by the dredging. It is therefore helpful to revisit the results from the reactive and longer term monitoring of this campaign in order to give insight into the probable impacts of the proposed capital dredging campaign of the PEP.

The Eastern Reclaim Port Development involved the reclamation of 100 ha in the port precinct for the development of an outer berth, rail balloon loop and a cement handling facility. The Platypus and Sea channels were lengthened and deepened in order to accommodate entry of Panamax class vessels.

The capital dredging campaign involved relocating 0.75 Mm^3 with a suction dredge during the period 19 January to 6 April 1993. The capital dredging program was intensely monitored and the monitoring and dredging was overseen by an independent Technical Advisory Committee (TAC). In addition, the Queensland Department of Environment and Heritage deployed a site supervisor (seconded from GBRMPA) who convened the Initial Response Group and had oversight over day to day operations.

Both a reactive monitoring program and a longer-term monitoring program were established and these programs monitored changes to oceanographic parameters including suspended sediment concentration and impacts to Sensitive Ecological Receptors in the form of coral colonies and seagrass meadows. The reactive monitoring program involved 30 marine scientists from a range of institutions and featured at least weekly monitoring of the condition of 20 of each of the four coral species (*Acropora latistella, Merulina ampliata, Montipora aequituberculata, Pocillopora damicornis*). Extensive monitoring of regional seagrass beds in Cleveland Bay was also performed. The longer-term monitoring covered a broader suite of indicators including ten taxonomic groups and a Before-After Control-Impact (BACI) survey design able to detect changes to the 20% detectability level.

The overall conclusion from the intensive monitoring programs was:

> *"Seagrass beds in Cleveland Bay were unaffected and not one of the hundreds of monitored coral colonies on Magnetic Island fringing reefs died as a result of dredging".*

No major changes in community structure were observed and the only coral colony that suffered full mortality was a colony of *Merulina ampliata* at Geoffrey Bay that was considered to have perished as a result of other factors. Of relevance is that considerably more variability in condition of the colonies was observed than is commonly thought.

The 1993 campaign was undertaken during a seagrass recovery period (see Figure 17), similar to the current situation where seagrasses are believed to be recovering from the 2010/11 wet season.

Given the high level of governance, independence and scientific scrutiny of the monitoring program, it is reasonable to conclude that the results from the monitoring programs are defensible. Therefore, in conclusion, for the duration of the dredging program, intensity of dredging and the pre-condition of the Sensitive Ecological Receptors, it is considered that the proposed dredging operations of similar magnitude can be undertaken without undue adverse impacts, such as substantial short-term mortality or obvious long term loss of condition.

1.5.4 Catchment modification

The impacts from changed land-use practices since European colonisation in the mid-1850s in the catchments adjoining the GBR remain somewhat contentious. The literature demonstrates there have been two main hypothesis on these impacts.

The first focuses on the role of synoptic-scale (large scale) events and hypothesises that the increased sediment, nutrient and pesticide runoff following post-European land-use changes have led to changes to the near-shore turbidity regime, which has then led to anthropogenic-derived reductions in condition of Sensitive Ecological Receptors in the near-shore zone such as Middle Reef.

The second is marine geological or sedimentological based rather than synoptic-based. This second hypothesis focuses on marine sediments built up over geological timescales and proposes that these sediments are repeatedly and routinely re-suspended during wind events. The long term distribution of sediments is thought to be largely controlled by cyclones. This implies little change to long-term condition of Sensitive Ecological Receptors as they have always been exposed to reduced turbidity.

Both of these hypothesis are supported by different, but incomplete sets of evidence. The first is supported by widespread agreement, based on a series of studies, that there has been a multiple-fold increase in the delivery of fine sediments, nutrients and pesticides into the GBR lagoon post European settlement (Kroon, et al., 2012). A number of studies have also demonstrated that flood plumes following major wet season floods can be observed considerable distances downstream (commonly to the North) of major river mouths such as the Burdekin (Sandstrom, 1988; Schroeder, et al., 2012; Devlin, et al., 2012).

There is also some evidence that water quality in inshore regions near the mouths of major rivers declines following major flood events (Figure 25), and that resulting reduction in underwater light attenuation can lead to at least temporary changes to the condition of some Sensitive Ecological Receptors. This is perhaps best evidenced by the changes in seagrass cover.

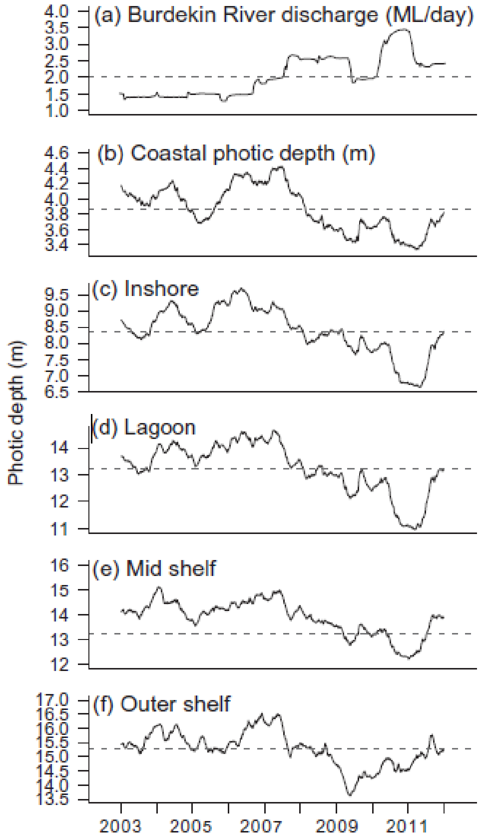

Fig. 6. Ten-year long-term trend in daily Burdekin River discharge (a) and daily mean photic depth from 2002 through 2012 for the five bands across the continental shelf within the central GBR (b–f). The horizontal dashed lines indicate the mean value of each data set.

Figure 25 Long-term trends in river discharges. Fabricius *et al* 2014.

By contrast, there is little direct evidence that there has been a long-term or chronic 'press' effect directly attributable to the 'new' sediments resulting from changes in catchment land uses leading to a reduction in coral reefs. However this may be a direct result of the lack of consistent long-term monitoring data.

The second hypothesis is also supported by a number of studies that have focused on Cleveland Bay (Maxwell, 1968; Johnston & Searle, 1984; Way, 1987; Carter, Johnson, & Hooper, 1993; Belperio, 1983; Orpin, Brunskill, Zagorskis, & Woolfe, 2004; McIntyre, 1996; Larcombe & Carter, 1998; Lambeck & Woolfe, 2000). This evidence is more sedimentological in nature and demonstrates, through marine geological surveys, that the inshore region of the GBR lagoon features a sometimes very thick (20 m) lens of sediments, and that this source of 'old' sediments far outweighs the input of 'new' sediments.

Assuming the GBR coastline length is 2,000 km (the actual coastline length is considerably longer), and this prism extends 5 km seaward and is up to 20 m thick (Figure 26 and Figure 27), then this represents a volume of at least $2{,}000{,}000 \times 5{,}000 \times 20$, or 200,000 Mm^3 of accumulated fine sediments. In reality this is likely to be an underestimate as the actual fine-scale coastline length is considerably longer than 2,000 km.

If the average annual inflow of fine sediments into the GBR lagoon from the Burdekin (the dominant source) is 4 Mt, (equivalent to around 4 Mm^3 dry weight) this then implies that on average since the 1850s, every year an additional 0.002% is added to the near-shore sediment prism from the Burdekin.

Importantly, the recent study by Lewis *et al* (2014) highlights that almost no sediment has been supplied to Cleveland Bay during the last 1,000 years. This study indicates that the majority of the sediment presently within Cleveland Bay was laid down during the Burdekin Holocene alluvium when the Burdekin entered the GBR somewhere close to what is now Cleveland Bay.

It is also widely accepted that the majority of the variability in near-shore turbidity can be explained by re-suspension associated with routine and common wind events that occur through the year. Lewis *et al* (2014), Woolfe and Larcombe, (1998), Larcombe and Woolfe (1999) and Orpin and Ridd (2012) all made the same conclusion in relation to the overall suspended sediment during these events. This conclusion was that the majority of sediments suspended during common or routine wind events through the year were existing marine sediments that had been deposited over geological timescales from previous cyclones and were resuspended by waves during the routine or common wind events.

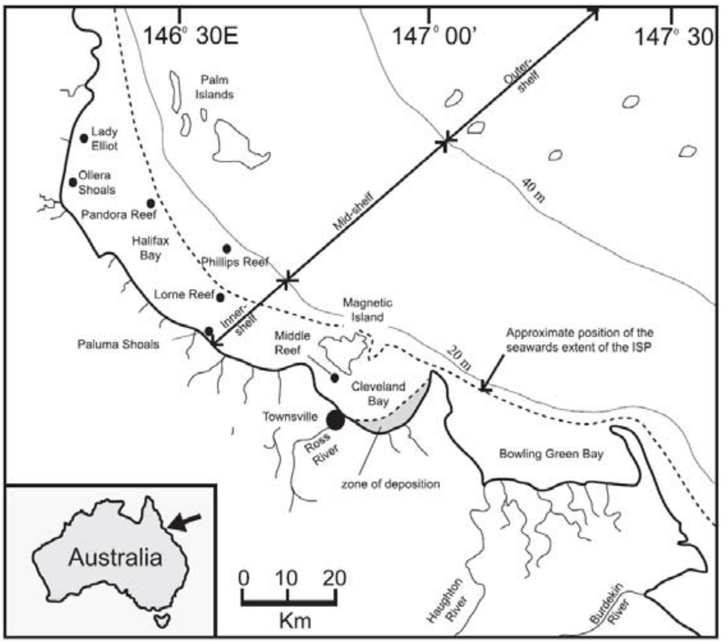

Figure 26 Sedimentary zones in the GBR (Extracted from (Browne N. , 2012).

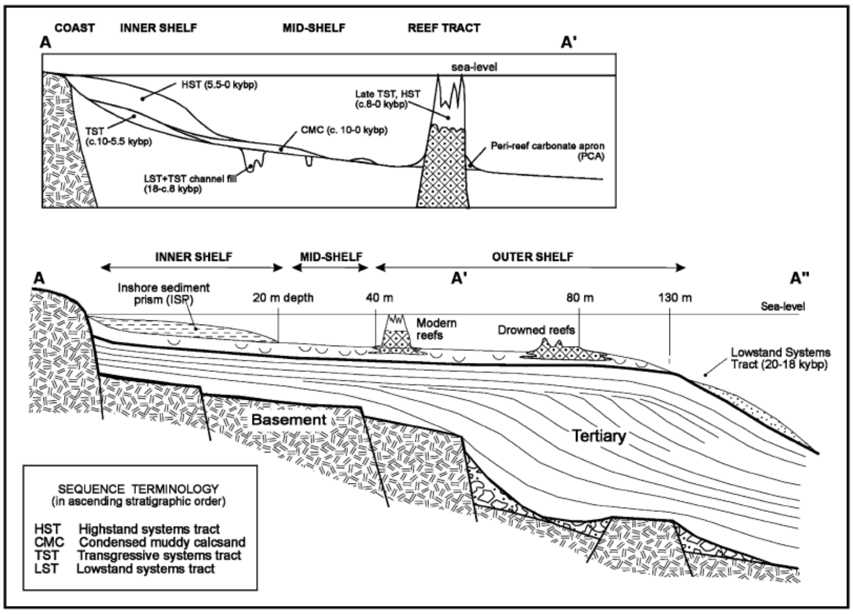

Figure 27 Typical geological cross section on the GBR (from Larcombe and Carter, 2004).

This implies that the near-shore fine sediment and hence turbidity regime may have largely remained unchanged over recent centuries, and hence there is little reason to believe that there is a long-term 'press' effect that would result in long term reduction in the condition of Sensitive Ecological Receptors. Once again a lack of long-term data on the condition of inshore Sensitive Ecological Receptors is unhelpful, as are the lack of long term water quality data.

However both schools have recently identified a possible explanation that would satisfy both hypotheses. Lewis *et al* (2014) identify that no 'new' sediments have been entering Cleveland Bay over the last 100 years, and that the majority of sediments are deposited within 50 km of major river mouths. Concurrently Bainbridge *et al* (2012) identified that river plumes following major events become organic rich floccs as they move downstream of river mouths. Fine sediments contained in river plumes mix with seawater. These fine sediments and the associated nutrient flocculates join to form larger particles or floccs. These floccs, that are by now large exopolymer particles can then also combine or associate with mineral particles to form marine snow that can be 'stickier' than sand particles. 'Marine snow' when settled on coral, can force coral colonies to expel more energy clearing these particles in comparison to sand particles (Ayukai & Wolanski, 1993, Fabricius *et al*., 2003; Passow, 2001).

This transformation from mainly mineralogical or physical particles to more consolidated floccs takes place as river plumes are transported away from river mouths. By the time Burdekin flood plumes are offshore of Cleveland Bay, the majority of the fine sediment particles have thought to have settled out and hence particles at the entrance to Cleveland Bay are likely to be very porous floccs. Increases in turbidity following major river plumes that occurred in 2011, were caused from larger flocc particles as opposed to mineralogical fine sediments alone.

Both are sources of variability in turbidity in the near-shore zones such as Cleveland Bay:

- routine re-suspension of old sediments by frequent wind events
- reductions in turbidity resulting from increased intensity of floccs during the season following major flood events.

Unfortunately it can be difficult to separate the two sources as most measurements using electronic sensors simply measure the total turbidity. As a result it can be difficult to unravel the importance or relative contributions of 'new' sediments derived from catchments and dredging operations, from the re-suspension of 'old' sediments.

Feedback from the EIS suggested that the impacts from the proposed capital dredging would have to be greater than predicted in the EIS on the basis that the dredging would create new suspended sediments on the same scale as sediments released from catchments; which were assumed to be the major source of fine sediments impacting Sensitive Ecological Receptors.

Superficially this can appear to be a valid comparison. However all of the fine sediment washed out through waterways are immediately available to increase turbidity. By contrast, whilst less than 10% of fine sediments are mobilised during dredging operations, the vast majority are contained within the reclamation site. This is illustrated schematically in Figure 28.

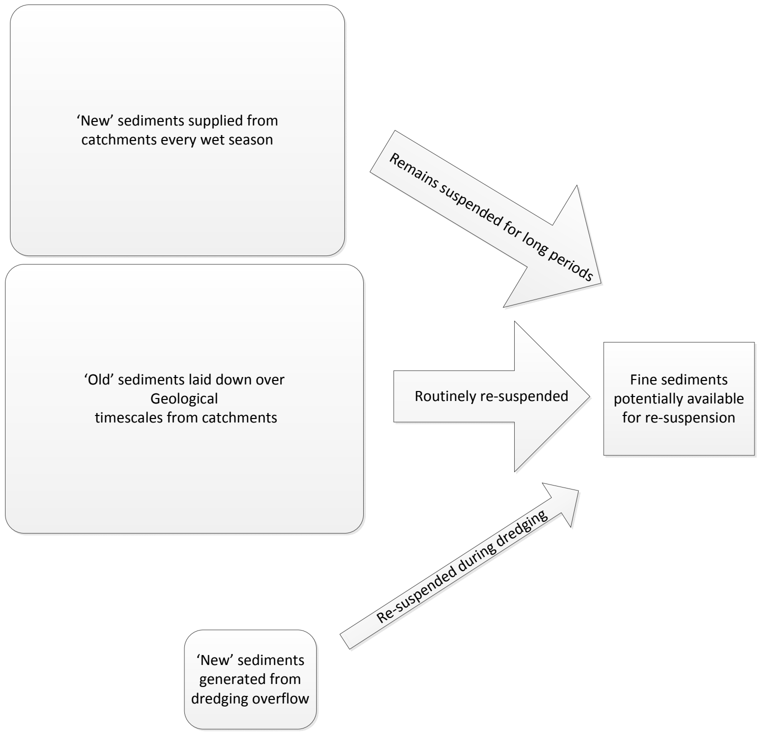

Figure 28 Schematic of sediments inputs into Cleveland Bay. Not to scale.

In light of these assumptions, increased turbidity is primarily a result of the routine re-suspension of 'old' sediments in Cleveland Bay, it becomes clear that these comparisons do not support the conclusion that sediments mobilised during dredging operations are a major contributor to the overall suspended sediment budget.

1.5.5 Effect of Nutrient Inflows on CoTS

Nutrient inflows from catchment sources (through controlling phytoplankton availability; Fabricius *et al*., (2010) Figure 29) have also been postulated to underpin outbreak of the coral-consuming Crown of Thorns (CoTS) starfish (*Acanthaster planci)*; (Brodie, Fabricius, De'ath, & Okaji, 2005).

Bell *et al* (2014) have argued that the role of point source nutrient inputs, such as wastewater treatment plants has been greatly under-estimated and by implication that the emphasis on the impacts of suspended sediments as the primary determinant on the ability of Sensitive Ecological Receptors to recover from events such as cyclones is over-emphasised. However, this result has been questioned by Furnas *et al* (2014).

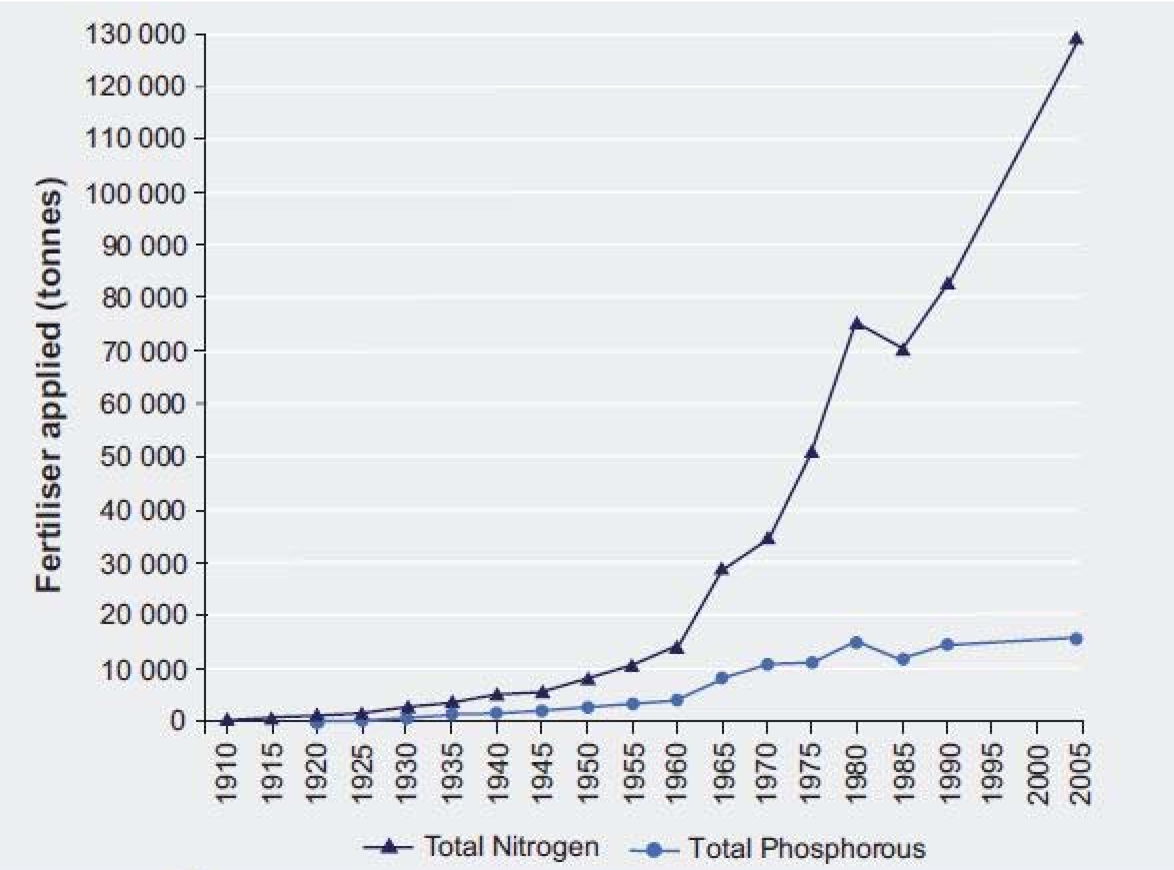

Figure 29 Fertilized inflows into the GBR lagoon (Extracted from (Great Barrier Reef Marine Park Authority, 2011))

CoTS outbreaks have been observed in the GBR since the 1960s, although there are suggestions that outbreaks have occurred previously. Major outbreaks were recorded in 1966, 1979 and 1994 and these were preceded by large discharge events from GBR catchments. Each cycle appears to have begun near Cairns. The first outbreak was observed at Green Island in 1962 (Barnes, 1966), the second also at Green Island in 1979 (Endean, 1982) and the third detected firstly by tourist operators at Michaelmas Cay (a reef neighbouring Green Island) in 1993 and then at Lizard Island (Wachenfeld, Oliver, & Morrissey, 1998).

Fabricius *et al* (2010) suggest that outbreak of the Crown of Thorns starfish are causally linked to river plumes and phytoplankton availability in the GBR lagoon (Figure 30).

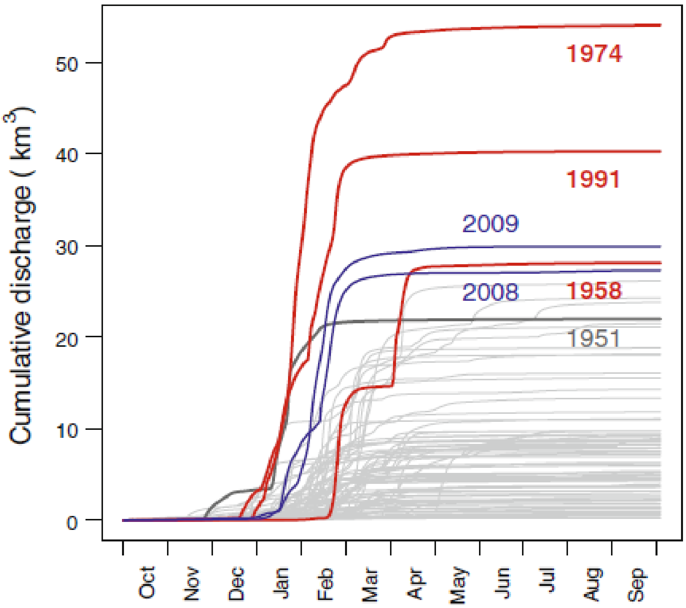

Figure 30 Burdekin discharges and CoTS (Extracted from Fabricius *et al* 2010)

Fabricius *et al* (2010) also estimated between 1985 and 1997, CoTS were observed on 32% of monitored reefs on the GBR. Coral cover on these reefs with CoTS averaged 9% 1 year after the outbreak; as compared with a mean of 28% coral cover on reefs that had not experienced an outbreak in the same period (Lourey, Ryan, & Miller, 2000). These estimates imply a GBR-wide reduction in coral cover of 0.5% year-1 due to CoTS during this 12-year period. CoTS outbreaks can result in large reductions in coral cover over multiple years. This is equivalent to an average reduction on coral cover of around 19%. Lourey *et al* (2000) estimate just under 50% of inner shelf reefs in the central GBR experienced CoTS outbreaks between 1985 and 1997.

1.5.6 Fishing, marine tourism and transport

Given the estimated low level of recreational and commercial fishing and tourism activity particularly directed at the Sensitive Ecological Receptors in the study area by comparison with popular reefs in the middle and outer shelf regions, it is expected that impacts from these activities will be minimal.

2.0 Cyclones to have impacted Queensland, Australia from 1864 – 2004

The following table presents, in chronological order, cyclones that have occurred in Queensland since 1964. The grey highlighted cells indicate the events which have occurred in the vicinity of the Townsville area.

Date	Event
2 - 3 March, 1867.	Gale winds at Bowen with buildings damaged. Boats smashed. Townsville hit with every third building blown down.
30 January, 1870.	Floods and damage in Bowen. Clermont and Peak Downs flooded. 15 lives lost.
20 February, 1870.	Nearly every house in Townsville damaged with some completely unroofed. Flooding and ships sunk.
24 February, 1875.	Steamer *Gothenberg* wrecked off Cape Upstart near Ayr with 102 lives lost.
17 February, 1876.	17 February, 1876. Severe gales at Townsville.
21 March, 1876.	Heavy winds at Townsville. SS *Banshee* wrecked at Hinchinbrook Island with 17 people drowned.
8 March, 1878.	Cairns suffers huge damages. Ships *Louise, Merchant, Kate Conley* and *Hector Miss* were sunk with no survivors.
2 February, 1882.	Cardwell suffers considerable damage.
30 January, 1884.	Bowen township all unroofed. Heavy flooding to Mackay.
17 February, 1888.	Cyclone hits east of Mackay. Ships and houses damaged.
24 March, 1890.	Cyclone hits Townsville. Ravenswood has 431mm rain in 24 hours.
29 March, 1890.	Ingham suffers damage from cyclone.
1 February, 1893.	Tropical cyclone hits Yeppoon causing extreme damage. Severe floods in Ipswich and Brisbane with Indooroopilly railway bridge and Victoria bridge washed away. More than 12 deaths.
26 January, 1896.	Cyclone Sigma. Hits Townsville causing damage and severe flooding in suburbs for around 5 kilometres. 17 drowned and a sailor killed.
4 February, 1898.	Cyclone Eline. Considerable damage around Mackay.
5 March, 1899.	Cyclone Mahima. Crosses coast at Princess Charlotte Bay. 307 fatalities of Asian and Island origin. Over 100 Aborigines were swept out to sea. Over 150 ships were sunk. Storm surge at Barrow Point was 14.6 metres. On Flinders Island, porpoises were found 15.2 metres up on the cliffs.
9 March, 1903.	Cyclone Leonta. Hurricane force winds hit Townsville. The Townsville Hospital was wrecked and the brick Grammar School was destroyed. 10 lives lost.
28 January, 1906.	Cairns devastated.
19 January, 1907.	Cooktown buildings severely damaged.
12 March, 1908.	Widespread damage to buildings, trees, fences and telegraph lines near St Lawrence.
28 January, 1910.	Heavy seas and tremendous gales at Cairns.
11 January, 1911.	Tropical cyclone passes from the Gulf of Carpentaria Inland and causes severe destruction at Marburg in south west Queensland. Areas suffer gale force winds.
10 February, 1911.	Crops and buildings damaged at Port Douglas.
16 March, 1911.	Port Douglas left with only 7 out of 57 houses standing. Mossman and Cairns also hit.
23 March, 1911.	Cyclone wrecks *Yongala* east of Townsville with 120 lives lost.
7 April, 1912.	Cairns and Innisfail have damage to structures with 40% of banana and sugar crops lost.
31 January, 1913.	Cyclone crosses near Cairns. Damage and flooding also to Innisfail. 4 lives lost.
9 February, 1915.	Bowen gets damaged.
10 December, 1915.	Tropical cyclone his north of Mackay.
27 December, 1916.	Whitsunday Island damaged. Flooding at Clermont causes loss of 62 lives.
15 December, 1917.	Heavy rain and gales at Bowen.
21 January, 1918.	Mackay hit by cyclone with almost every building damaged. A storm surge of 7.6 metres saw almost 3 metre waves breaking in the town centre. Huge flood at Rockhampton. 30 lives lost.
10 March, 1918.	Of 3500 residents in Innisfail only 12 houses remained. Mission Beach to the Atherton Tableland suffered destruction. Almost 100 dead.
3 March, 1919.	Cyclone crosses coast at Maryborough. Serious washouts.
3 February, 1920.	Cyclone crossed north of Cairns. Every house at Mt Molloy and Kuranda unroofed or destroyed. Widespread flooding and enormous cattle losses inland.
1 April, 1921.	Tropical cyclone crosses Cape York sinking boats. Heavy flooding.
28 March, 1923.	Cape York and the Gulf have severe wind forces.
26 February, 1925.	Damage to buildings at Cooktown and Mossman.
9 February, 1926.	Cyclone crosses near Townsville. Floods in Herbert and Tully Rivers.

Date	Event
9 February, 1927.	Tropical cyclone hits north of Cairns. Structural damage.
23 & 29 February, 1929.	Two cyclones. One at Townsville the other at Mossman. Flooding.
5 January, 1930.	Serious flooding after cyclone crosses at Princess Charlotte Bay. Luggers in Torres Strait are sunk.
20 January, 1930.	Cyclone action over large part of the State finally crossing at Mossman. 6 deaths due to flooding. Huge stock losses.
1 - 8 February, 1931.	Travels from Cooktown down to Hervey Bay causing state-wide flooding.
19 January, 1932.	Townsville hit. Flooding from Cairns to Mackay.
22 January, 1934.	Cairns suffers damage and flooding.
12 March, 1934.	At sea many luggers and 75 lives lost as cyclone crossed coast near Cape Tribulation.
18 February, 1940.	Crosses near Cardwell. Substantial wind damage in Townsville.
6 March, 1940.	Crosses north of Cooktown. Flooding.
23 March, 1940.	Crossed Cape York. Tremendous Gulf flooding.
7 April, 1940.	Townsville and Ayr suffer damages costing $1 million (at 1940 value).
2 March, 1946.	Cairns to Townsville had damage with some loss of life.
7 January, 1948.	Heavy floods between Cooktown and Cardwell as cyclone crosses Cape York.
10 February, 1948.	Extensive structural damage and widespread flooding when cyclone passes north of Cooktown.
15 January, 1950.	Cyclone near Cooktown with gales and floods in several areas.
16-19 January, 1950.	Tracked from the Gulf to Sydney. 7 lives lost in NSW. 2 metre waves in Moreton Bay with houses evacuated at Sandgate.
19-24 January, 1951.	Cyclone hits south east Gulf region. Major flooding to Burdekin.
7 February, 1954.	Tropical cyclone crosses south of Townsville producing heavy flooding.
7 March, 1955.	Widespread structural damage and flooding at Sarina. Lugger *Barrier Princess* lost with 8 people.
6 March, 1956.	Cyclone Agnes. Passed over Townsville. Widespread damage from Cairns to Mackay. Recorded wind gusts to 79 knots.
20 February, 1958.	Cyclone crossed the coast south of Ayr then moved back to sea. Heavy floods to Mackay with 3 lives lost.
1 April, 1958.	Cyclone and 2 metre storm surge hit Bowen. Wind gusts over 98 knots. Considerable damage to houses and other buildings. Other areas hit by induced tornadoes.
20 January, 1959.	Cyclone moved from the Gulf to cross between Cooktown and Cairns. Flooding.
16 February, 1959.	Cyclone Connie. Severe wind damage at Ayr, Home Hill and Bowen where wind gusts up to 100 knots were recorded over a two hour period. Other damage in Mackay and Rockhampton.
13-14 January, 1964.	Cyclone Audrey. Tracked from Gulf to Coffs Harbour causing extensive wind damage in the western areas such as St George (74 houses damaged) and Goondiwindi where over 50 buildings suffered. Glen Innes and Grafton, NSW also had wind damage.
15-16 April, 1964.	Cyclone Gertie. Hits the Whitsunday Islands with heavy coastal rain. Floods.
6 December, 1964.	Cyclone Flora. Innisfail to Cardwell reported damage.
30 January, 1965.	Cyclone Judy. Near Innisfail causing floods south to Townsville.
17 January, 1970.	Cyclone Ada. Passed through the Whitsunday Islands to hit Airlie Beach. Tourist resorts destroyed and 80% of buildings at Airlie Beach damaged. 14 lives lost. Floods around Bowen and Mackay.
20-22 February, 1971.	Cyclone Fiona. Tracked from the Gulf to Rockhampton. Some damage to infrastructure.
24 December, 1971.	Cyclone Althea. $50 million damage (at 1971 value) caused to Townsville. 90% of houses damaged or destroyed on Magnetic Island. 3.66 metre storm surge recorded just north of the area. 3 deaths. Hundreds of homes damaged (including over 200 Housing Commission homes).
4 March, 1973.	Cyclone Madge. Hit Cooktown. Considerable flooding to Townsville.
19 December, 1973.	Cyclone Una. Crossed near Townsville. Some damage and flooding. 4 deaths.
16 January, 1975.	Cyclone Gloria. Stayed offshore but caused flooding from Lucinda to Mackay.
19 January, 1976.	Cyclone David. Passed near St Lawrence after extending from Papua New Guinea to Lord Howe Island. Buildings damaged at Yeppoon and Mt Morgan. Wind gusts were recorded at 84 knots with wave heights peaking at 9.2 metres at recording stations.
1 February, 1976.	Cyclone Alan. Crossed the North Queensland coast near Bloomfield River mission. Became an intense monsoon travelling through Tennant Creek in the Northern Territory before heading back to sea through Byron Bay, NSW.
10 March, 1977.	Cyclone Otto. Crossed at Cape Tribulation and again at Bowen. Aggravated flood damage in Cairns.
31 January, 1977.	Cyclone Keith. Hit east of Cairns and the crossed again at Cape Cleveland near Townsville. Extensive crop damage.
1-2 January, 1979.	Cyclone Peter. Record rainfall south of Cairns (1140mm in 24 hours) caused serious flooding estimated at $10 million (at 1979 value). 2 deaths.

Date	Event
11 January, 1979.	Cyclone Greta. Crossed Princess Charlotte Bay.
1 March, 1979.	Cyclone Kerry. Passed the coast near Proserpine. Some damage around Mackay and resort islands. Wind gust recorded at 76 knots. $1 million damage (at 1979 value) to boats in harbour.
7-8 January, 1980.	Cyclone Paul. Near St Lawrence causing record floods around Bowen. Wave peaks recorded at Brisbane station at 9.8 metres.
10 February, 1981.	Cyclone Eddie. Crossed at Princess Charlotte Bay.
26 February, 1981.	Cyclone Freda. Developed near Cooktown and moved away from the coast.
3-4 March, 1983.	Cyclone Elinor. Hit near Carmilla causing minimal damage to houses.
8 March, 1984.	Cyclone Jim. Crossed the Peninsula Coast near Cape Grenville with foliage damage.
19 March, 1984.	Cyclone Kathy. Crossed the Peninsula Coast near the Pascoe River.
22 February, 1985.	Cyclone Pierre. Hit Shoalwater Bay. Minor flooding.
1 April, 1985.	Cyclone Tanya. Crossed the Peninsula Coast at Coen. Vegetation damage.
1 February, 1986.	Cyclone Winfred. Crossed near Innisfail with an eye diameter of 41km. A wind gust was calculated at 145 knots. Houses damaged. Cost was $130 million (at 1986 value). 3 deaths.
1 March, 1988.	Cyclone Charlie. Made landfall at Upstart Bay near Ayr. Wind gusts recorded to 80 knots. Some structural damage and flooding at Ayr.
4 April, 1989.	Cyclone Aivu. Building damage costs were $40 million while agriculture costs were $40 million and $10 in infrastructure (at 1989 values). Major flooding. One death.
19 March, 1990.	Cyclone Ivor. Passed the coast near Princess Charlotte Bay with some damage in Coen. As a monsoon moved south to cause extensive flooding at Yeppoon.
22-25 December, 1990.	Cyclone Joy. Travelled past Cairns to weaken in intensity crossing at Townsville. 97 knot wind gusts recorded. Structural damage south of Cairns. Induced tornado hit Mackay damaging buildings and causing floods. 6 lives lost. Cost $62 million (1990 value).
20 January, 1994.	Cyclone Rewa. Stayed 100km off the coast but caused flash flooding around Brisbane which resulted in 4 deaths.
9 January, 1996.	Cyclone Barry. Moved down from the Gulf past Sarina to Hervey Bay causing structural and vegetation damage.
27 January, 1996.	Cyclone Celeste. Came close to Bowen with an eye of 40km. wind gusts to 64 knots and some damage to buildings.
12 March, 1996.	Cyclone Ethel. Crossed at Cape Melville. 60 knot winds reported.
22 March, 1997.	Cyclone Justin II. Crossed near Cairns. Wind damage to buildings from the Atherton Tablelands to Townsville. Considerable flooding and evacuations. Cost almost $200 million.
10-11 January, 1998.	Cyclone Sid. Moved from Gulf across Cape York and intensified into a monsoon low near Townsville. Severe flooding and landslides. Peak wave height recorded at 5.41 metres. Total damage cost over $100 million (at 1998 value).
11 February, 1999.	Cyclone Rona. Made landfall near the mouth of the Daintree River. Considerable vegetation damage. Maximum wind gust was 85 knots and the peak wave height recorded was 6.3 metres. Cost of crop and infrastructure damage estimated at $150 million.
27 February, 2000.	Cyclone Steve. The cyclone passed the coast at the northern beaches of Cairns causing structural damage and flooding. Wind gusts up to 85 knots were recorded and the peak wave measurement was 5 metres at Cairns Wave Recording Station. Prominent buildings were unroofed. Mareeba reached a record flood level of 12.4 metres and evacuations were conducted.
17 March, 2000.	Tropical low created gales around Lucinda. Record flooding occurred at Giru.
2 April, 2000.	Cyclone Tessi. Crossed north of Townsville causing extensive crop damage and to some isolated buildings in the area. Townsville then suffered wind damage to buildings and widespread flooding. 70 knot winds recorded.
15 - 16 February, 2001.	Cyclone Wylva. Hovered around Mornington Island but caused very little damage. Maximum wind gust recorded was 64 knots.
23 - 27 February, 2001.	Cyclone Abigail. Crossed north-west of Cairns at Ellis Beach before entering the Gulf and reforming before crossing the coast again near the Queensland / Northern Territory border. Some damage was sustained on Mornington Island where the wave surge was 1.3 metres and the Maximum wind gust was 64 knots. Both Cairns and Green Island had considerable winds to 50 knots.
11 February 2004.	Cyclone Fritz This crossed the coast at Cape Melville. Flash flooding occurred around the Innisfail/South Johnstone area with 74mm of rainfall in one hour. 309mm was recorded over 24 hours.
19 - 24 March 2004.	Cyclone Grace Flooding between Cairns and Cooktown. 372mm of rainfall in 24 hours. Wind speeds up to 54 knots were recorded. Estimated US$20M damage to Cairns region.