

Additional Information to the Environmental Impact Statement



SECTION 25

Revised Cumulative Impacts

Assessment



25.0 Revised Cumulative Impacts Assessment

25.1 Introduction

This section provides information to address submissions received in response to the Port Expansion Project (PEP) Environmental Impact Statement (EIS) regarding cumulative impacts. This information supplements the assessment provided in Chapter B.24 (Cumulative Impacts) of the EIS.

Submissions sought more information on the relative role of projected impacts from the PEP in light of other stressors acting on the Cleveland Bay and the greater Great Barrier Reef (GBR) environment. Submissions also sought information over the present resilience of the GBR and how the Project may impact upon this resilience. Further information was also sought on how the Project may impact Outstanding Universal Value (OUV) of the GBR World Heritage Area (WHA) which is addressed in Section 26.0 of the Additional Information to the Environmental Impact Statement (AEIS).

Submissions also sought further information on whether project-related effects may impact eco-tourism operations. Other submissions sought specific information on other stressors such as cyclones, bleaching, and catchment runoff.

In relation to cumulative impacts, two questions were commonly posed:

- given recent natural hazards such as floods and cyclones in the GBR, whether potential impacts from the Project will further reduce the resilience of key GBR ecosystems to unacceptable levels
- what the relative role of the project impacts will be by comparison to impacts from these other stressors.

A number of submitters also questioned:

- the compatibility of dredging and material placement within the boundaries of the WHA
- the role of climate change in influencing the condition of the GBR.

A revised cumulative impact assessment was undertaken to address matters raised. This assessment was undertaken in accordance with the *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).*

25.2 Response to Submissions

245 submissions (including form letter submissions) related to the cumulative impact assessment. Possible impacts from the proposed dredging operations need to be viewed in light of other processes and activities (jointly referred to as stressors) acting upon sensitive ecological receptors in the region. The resultant cumulative impacts can include the following types of impacts:

- additive (linear or non-interacting) or multiplicative (non-linear and interacting) cumulative impacts of either:
 - different aspects of the same project combining to amplify impacts
 - multiple similar human/anthropogenic activities acting in the same region (for example, multiple capital dredging activities occurring in close proximity over the same relevant impact time periods)
- far field (in a geographic or food web cascading impacts sense) impacts of a single activity
- potential project impacts in the context of other natural and anthropogenic impacting processes. For example, the impacts of dredging needs to be considered in the context of cyclones, reduced water quality from runoff, bleaching and other factors that influence sensitive ecological receptors.

It is common for cumulative impact assessments to primarily focus on the first category (additive and multiplicative impacts) that typically consider other similar major infrastructure projects that are planned nearby. However, these 'nibbling' impacts caused by multiple similar activities occurring in the same region encompass only a small subset of potential cumulative impacts.

The impacts arising from other projects or different stages of this Project are considered in Section 6.0 (Marine Water Quality) and Section 8.0 (Marine Ecology) of the AEIS. The responses to submissions, contained in the revised cumulative impact assessment presented in this Section primarily focus on investigating the potential impacts of the proposed dredging on identified sensitive ecological receptors in the context of other major processes impacting on the same sensitive ecological receptors.

Consistent with recently released guidelines, including the GBRMPA Cumulative Impacts Framework (Anthony, Dambacher, Walshe, & Beeden, 2013), the focus of this assessment has been on two particular sensitive ecological

receptors; namely corals and seagrasses. More distant impacts (i.e. cascading effects through the food web) are not assessed in detail in this section as these have been considered in other sections, such as Section 8.0.

Given that the assessment of cumulative environmental impacts in Australia continues to remain an emerging concept with limited policy guidance, the approach applied in this assessment draws on existing accepted cumulative impact approaches, including the methodology developed by the United States Council on Environmental Quality (i.e. *Considering Cumulative Effects Under the National Environmental Policy Act*) and the Canadian Environmental Assessment Agency (i.e. *Cumulative Effects Assessment Practitioners' Guide*).

The structure of this section is largely based upon the GBRMPA Cumulative Impacts Framework. This framework uses qualitative and quantitative modelling to provide a systems-level understanding of how cumulative stressors may affect coral reef and seagrass ecosystems in the GBRWHA that underpin Matters of National Environmental Significance (MNES), including the OUV of the GBRWHA.

The cumulative impacts approach applied as part of the AEIS is fundamentally risk-based and as such is consistent with the international risk standard ISO 31 000.

The assessment approach involves determining the characteristics and impacts of major stressors (both project and non-project) acting on the sensitive ecological receptors, and then investigating the individual and combined impacts of all of these stressors.

The specific steps of this cumulative impact assessment methodology (and the corresponding references within this AEIS) are listed below.

- 1. Select a set of appropriate sensitive ecological receptors as identified in the GBRMPA Cumulative Impacts Framework (Section 25.3.1).
- 2. Identify all likely stressors acting on the selected sensitive ecological receptor (Appendix A5, Section 1.2).
- 3. Characterise project stressors acting on sensitive ecological receptors (Appendix A5, Section 1.3).
- 4. Characterise the non-project stressors on sensitive ecological receptors (Appendix A5, Section 1.3).
- 5. Determine the frequency of occurrence and impacts or consequences to sensitive ecological receptors of these stressors acting individually (Appendix A5, Section 1.4 and 1.5).
- 6. Investigate how these stressors acting together may impact the sensitive ecological receptors , and identify the relative role of project related impacts in the context of impacts from the non-project related stressors (Section 25.3.3).
- 7. Identify possible worst-case combinations of both project and non-project stressors (Section 25.3.3.1).

The outcomes from this analysis provide an informed understanding of the relative role of project-related impacts, in the context of the impacts of other stressors acting within the study area. It also identifies the particular combinations or timing of stressors that should be considered when planning the implementation of the Project. The assessment is included in Section 25.3 below.

Background information to support this assessment is included in Appendix A5 of this AEIS

25.3 Revised Impact Assessment Approach

25.3.1 Sensitive ecological receptors

This cumulative impact assessment focuses on two key sensitive ecological receptors identified in the GBRMPA Cumulative Impacts Framework: coral reefs and seagrass beds, which were identified to be at a higher risk in Section 8.0 of the AEIS. This focus is consistent with the submissions on the EIS and the GBRMPA Cumulative Impacts Framework (Anthony, Dambacher, Walshe, & Beeden, 2013).

The following sections summarise the known distributions of these two key sensitive ecological receptors. The study area used is consistent with the sections of the AEIS (refer Section 8.0 of the AEIS).

Corals

Cleveland Bay supports a network of near-shore reefs which form part of an extensive system of near-shore reefs within the *Coastal Central Reefs Bioregion* (GBRMPA, 2012). The location of coral reefs within Cleveland Bay are shown in Figure 25.1.

Reef habitats in Cleveland Bay include shallow fringing reefs and rocky shores around Magnetic Island, the reef platform of Middle Reef, and smaller reef areas between the mainland and Magnetic Island (e.g. Virago Shoal).

Figure 25.3 Stafford-Smith and Veron (1992) recorded at least 258 species of hard corals on reefs in Cleveland Bay and surrounds. This represents over half of the total number of hard coral species recorded in the GBR (405 hard coral species) (Fabricius K., 2009). On a GBR wide scale, the species richness recorded on Cleveland Bay reefs is considered to be moderate (DeVantier, De'ath, Done, Turak, & Fabricius, 2006).

The fringing reefs of Magnetic Island typically have the highest hard coral cover along the reef slopes, whereas the reef flats are also colonised by macroalgae and seagrass (particularly at Cockle Bay Reef). C & R Consulting (2007) classified reefs as follows based on the relative cover of hard corals and macroalgae.

- Middle Reef, Nelly Bay West and Arthur Bay very high live coral cover and low algal cover
- Nelly Bay East and Florence Bay feature live coral cover and relatively low algal cover
- Picnic Bay, Geoffrey West and Geoffrey East, relatively low live coral and algal cover.



Figure 25.1 Distribution and Extent of Reefs within Cleveland Bay

Seagrass

Cleveland Bay contains extensive and diverse seagrass meadows (Figure 25.2). Eight species of seagrass have been recorded in Cleveland Bay (Rasheed & Taylor, 2008), namely Zostera muelleri, Halodule uninervis, Syringodium isoetifolium, Cymodocea serrulata, Halophila spinulosa, Halophila ovalis, Halophila decipiens and Thalassia hemprichii.

Seagrass is not known to occur in the Port's inner or proposed outer harbour areas, although shallow water and intertidal seagrass beds occur near the mouth of the Ross River and Townsville (Strand) waterfront.

More details can be found in Chapter B.6 (Marine Ecology) of the EIS and Section 8.0 of the AEIS.



25.3.2 Summary of relevant background information

Relevant background information that advised the preparation of this revised cumulative impact assessment is contained in Appendix A5.

The background information presented includes:

- identification of the potential stressors that may impact upon sensitive ecological receptors (Appendix A5, Section 1.2)
- characterisation of the likelihood of occurrence of these stressors (Appendix A5, Section 1.3)
- consideration of how the distribution and condition of the sensitive ecological receptors varies over time (Appendix A5, Section 1.4)
- the risk of impacts of these individual stressors on sensitive ecological receptors in Cleveland Bay (Appendix A5, Section 1.5).

Consistent with recently released guidelines GBRMPA Cumulative Impacts Framework (Anthony, Dambacher, Walshe, & Beeden, 2013), the focus of this assessment has been on two particular sensitive ecological receptors; namely corals and seagrasses. As outlined 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. 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 stressors considered in this Cumulative Impact analysis included:

- 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 and sediments re-mobilised by dredging activities
- fishing, tourism and marine transport stressors.

These stressors were summarised into the following categories as per 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.

Key-cause effect relationships were identified to define links (risk pathways) between these four stressors and ecological endpoints (sensitive ecological receptors) (Appendix A5, Figure 1.1). Each of these stressors is then described in terms of their variability and likelihood of occurrence and risk of impact on the condition of sensitive ecological receptors and the corresponding consequences of this occurrence.

The background and historic data provided in Appendix A5 has been used to advise the cumulative assessments that are detailed below.

25.3.3 Cumulative and interactive impacts

This section describes the assessment of risks to sensitive ecological receptors by considering the likelihood of occurrence and consequences of the stressors firstly acting individually, and then in combination.

The GBRMPA Cumulative Impacts Framework recommends the use of Bayesian Belief Networks for undertaking some of the risk assessment tasks. Networks based on theoretical principles developed and provided in the Framework have been considered and discussed in this analysis. However the networks provided in the guidelines are not based on data, primarily due to a lack of available data. Therefore, as a result of the same lack of available data, two additional modelling tasks were performed to provide insight into the individual and cumulative impacts of all the stressors acting on the sensitive ecological receptors .

25.3.3.1 Comparison of damages

When considering, comparing and assessing the damages of episodic natural hazards a standard actuarial approach is to annualise the potential damages so that the total or long-term average annual damages (AADs) can be compared. This approach forms the basis of flood damage planning in most states in Australia (for example the Queensland Government Guidance on the Assessment of Tangible Flood Damages (Department of Natural Resources and Mines, 2002).

Estimates of average annual damages for the sensitive ecological receptors were developed by using the collated data on the return interval (frequency) of cyclones, bleaching events, capital and maintenance dredging, and estimated damages from historical events described in the scientific literature (Appendix A5, Section 1.3).

Direct damage estimates from the Project were based on the estimates presented in Section 8.0 of the AEIS and in this analysis it has been assumed that capital dredging has in the past taken place on average every 25 years. Damages from all stages were combined in these calculations and are assumed to be worst-case scenarios.

The data used to develop the average annual damages curves are shown in Table 25.1. It is noted that CoTs refers to outbreaks of Crown of Thorns Starfish (*Acanthaster planci*).

Corals

Descriptor	Return Interval (years)	AEP (Annual Exceedance Probability)	Estimated % Sensitive Environmental Receptors damaged within study area	References
Cyclones				
Category 5	100	0.01	90	Lukoschek <i>et al</i> (2013) GBRMPA (2011) Nott and Hayne (2001) [Cyclone Yasi]
Category 4	50	0.02	63	Ayling (1991) [Cyclone Joy, included sites over 200 km away from path].
Category 3	20	0.05	20-75	Done <i>et al</i> (1991) Puotinen (2007) [Cyclone Ivor] [Cyclone Hamish] Woolsley <i>et al</i> (2012)
Category 2	10	0.10	40	Puotinen (2007)(2005) [Cyclone Justin]
Category 1	5	0.18	~20	Connell <i>et al</i> (1997) [multiple cyclones- see Appendix A5 in Connell <i>et al.</i> (1997)]
Bleaching				
Projected	100	0.01	>90	Hoegh-Guldberg (2011) Yara <i>et al</i> (2014)
2002 event	20	0.05	54	Equivalent to 18% strong bleaching, 54% some bleaching over whole GBR in 2002 event. Berkelmans <i>et al</i> (2004)
1998 event	10	0.10	42	Berkelmans et al (2004)
Annual	1	0.63	0	Bleaching does not presently occur annually in Cleveland Bay.
Increased turbidity	from floods			
Extreme floods	200	0.005	80	Extrapolated from (Ayling, A.M. and A.L. Ayling, 1998).
2011 floods	100	0.01	22	Osborne et al (2011).
Typical wetter La Nina flows	7	0.13	3	Nominal value representing 'press' effect.
Typical (El Nino)	1	0.63	1	Nominal value representing 'press' effect.
CoTS				
Extreme event	100	0.01	30	Nominal value.
Major event	15	0.064	19	Lourey, Ryan & Miller (2000).
Minor event	1	0.63	0.5	Fabricius <i>et al</i> (2010) estimate an average annual GBR average loss from CoTS of 0.5% per year.
Dredging				
Capital	25	0.04	2	From PEP AEIS and POTL 1993 campaign.
Maintenance	1	0.63	0	From maintenance dredging PEP EIS.

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The results from the average annual damages estimates are shown in Figure 25.3 to Figure 25.7. In each of these figures the Annual Exceedance Probability (AEP) is plotted on the x-axis and the % mortality on the y-axis. Note that different x-axis scales are used.



Figure 25.3 Damage plots for coral reefs based on the damage estimates - Cyclones.



Figure 25.4 Damage plots for coral reefs based on the damage estimates – Bleaching.







Figure 25.6 Damage plots for coral reefs based on the damage estimates – CoTS.



Figure 25.7 Damage plots for coral reefs based on the damage estimates - Dredging.

The average annual damages for each stressor are estimated by calculating the integral or area beneath each average annual damages curve. These values are shown in Table 25.2. The results shown in this table indicated that on average, the largest source of stress for the coral reefs in the study area is bleaching, followed by CoTS and cyclones.

Source of stressor	Estimated average annual damages (%/yr)
Cyclones	7
Bleaching	15
Floods	2

10

>0.1

Table 25.2 Estimated average annual damages for stressors on coral reefs

Seagrass

Dredging

Floods CoTS

Table 25.3 shows the parameter values used for the seagrass damage model. Once again the damage estimates from dredging are based on information provided in the Section 8.0 (Marine Ecology).

Table 25.3 Parameter values used for the average annual damages estimates for seagrasses in the study area

Descriptor	Return Interval (years)	AEP (Annual Exceedance Probability)	Estimated % sensitive ecological receptors damaged within study area	References
Cyclones				
Category 5	100	0.01	95	(Poiner Ian, 1993) (Rasheed M. M., 2014)
Category 4	50	0.02	63	(Sachithanandam, 2014)) [Cyclone Lehar- category 4]
Category 3	-	-	-	Insufficient data available
Category 2	-	-	-	Insufficient data available
Category 1	5	0.18	10	Seagrass Watch
Increased turbidity	from floods			
Extreme floods	200	0.005	60	Preen <i>et al</i> (1995) Campbell and Mckenzie (2004)
2011 floods	100	0.01	30	Seagrass Watch monitoring data. Rasheed <i>et al</i> (2014) (McKenzie, 2014)
Typical wetter La Nina flows	7	0.13	5	Nominal value representing 'press' effect.
Typical (El Nino)	1	0.63	1	Nominal value representing 'press' effect.
Dredging				
Capital	25	0.04	3	From PEP AEIS and POTL 1993 campaign.
Maintenance	1	0.63	1	From maintenance dredging PEP EIS.

The results from the average annual damages estimates are shown in Figure 25.8 to Figure 25.10. In each of these figures the Annual Exceedance Probability (AEP) is plotted on the x-axis and the % mortality on the y-axis. Note that different x-axis scales are used.



Figure 25.8 Damage plots for seagrass meadows based on the damage estimates - Cyclones.







Figure 25.10 Damage plots for seagrass meadows based on the damage estimates – Dredging.

The average annual damages for each stressor are estimated by calculating the integral of area beneath each average annual damages curve. These values are shown in Table 25.4. For seagrass meadows, the largest stressors considered in this analysis are associated with cyclones and floods.

Table 25.4 Estimated average annual damages for each stressor for seagrass meadows

0	0
Source of stressor	Estimated average annual damages (%/yr)
Cyclones	7
Floods	3
Dredging	0.2

The average annual damage calculations demonstrate the very minor role that dredging plays in impacting coral cover and seagrass cover by comparison with the other major stressors.

25.3.3.2 Possible interactive effects

There has been considerable recent attention given to the condition of the sensitive ecological receptors in the GBRWHA and concerns that the overall resilience of many parts of the reef is low. For example, Figure 8.2 from the most recent Outlook Report (GBRMPA, 2014) shows the downward trend in coral health index from inshore reefs see Figure 25.11. The Burdekin region shown in this figure includes Cleveland Bay.



Figure 25.11 Changes in coral health of inshore reefs, 2008-2013; GBR Outlook Report Figure 8.2 (GBRMPA, 2014).

The reduced resilience in the GBR has commonly been attributed to the cumulative or combined impacts of a number of stressors. For example, the most recent 2014 Reef Outlook Report identifies that:

"as a result of chronic disturbances such as poor water quality and outbreaks of coral disease, as well as a recent series of acute disturbances such as crown-of-thorn starfish outbreaks, coral bleaching events and cyclones, which have left insufficient time for many coral colonies to recover between events".

Of these, the overall greatest risks are seen to be posed by large scale external stressors (Figure 9.1 from the 2014 Outlook Report); especially ocean warming leading to bleaching. This is consistent with the analysis of individual stresses presented above.

The average annual damages analysis presented above led to the ranking of the individual stressors based on their probable impacts and average recurrence. However this assessment did not consider he combined action of these stresses acting either concurrently or close together.

Two possible classes of interaction were considered:

(a) co-incident occurrence of multiple stressors

(b) incidence of a stressor whilst the sensitive ecological receptors are recovering from a previous stressor event.

Figure 25.12 shows the occurrence of major cyclones and bleaching events by latitude over recent decades in the GBR.



Figure 25.12 Spatial-temporal location of cyclone (left) and bleaching (right) events on the GBR. Each point represents a reef sampled at a particular latitude and time. Grey Symbols indicate no impact to coral communities, while black symbols indicate impacted reefs (Thompson & Dolman, 2010).

The results shown in Figure 25.12 demonstrate that both bleaching and cyclones are common features of the GBR. However it also demonstrates the differences in spatial scales whereby bleaching events often impact more reefs in comparison to cyclones. These results also show that bleaching events and cyclones do not often co-occur at the same time and the same place.

To examine the potential relationship between cyclones and bleaching events, category 4 and 5 cyclones and major bleaching events are plotted along with the ENSO (El Nino Southern Oscillation) signal (Figure 25.13). This shows that there is mostly no overlap between cyclone and bleaching events.



Figure 25.13 ENSO cycles, bleaching and major cyclones for the Great Barrier Reef. Figure produced from collating available data. Y-axis shows ENSO Index.

This then implies that co-occurrence of cyclones and bleaching are unlikely to be common, despite both stressors individually being common. However, given the recovery period of either event is in the order of years to decades, there is likely to be considerable overlap in either a cyclone or a bleaching event to occur during the recovery period of either event.

Carrigan and Puotinen (2014) also highlight another source of interaction. This study highlights that cyclones can actually reduce the impact of bleaching events when they follow bleaching events. The mechanism for this is that

cyclones can upwell cooler water that acts to mix with the warmed water that was causing the bleaching. This study estimated that at some reefs in their study area in the Caribbean, the likelihood of co-occurrence of thermal stress and cyclone cooling was as much as 31%.

Given the return periods estimated above, it implies at present, on average reefs and seagrasses in Cleveland Bay are likely to experience large cyclone events and /or a bleaching event reasonably routinely. However, the recovery period for either of these events is 10-20 years and therefore on average, at present, the reefs and seagrass meadows are recovering from either or both a cyclone event or bleaching event.

This same argument applies to major rain events, that are at the highest intensity during La Nina conditions. For example, following the large floods in 2011, seagrass beds in Cleveland Bay only returned to average distributions in 2013, two years after the event.

Given the relatively long recovery periods (multiple years) and the frequency of natural hazards (on average a few years), it is clear most, if not all reefs on the GBR rarely reach any sort of ecological successional plateau.

25.3.3.3 Coral and seagrass cover models

Consistent with the weight of evidence approach, the cumulative impacts assessment uses a range of models in order to understand how the different stressors can impact on the sensitive ecological receptor in the study area. For example, the average annual damages model detailed above seeks to quantify the relative impacts of the different stressors averaged over periods of years. From this, the relative importance or ranking of the different stressors can be determined.

The coral cover model, presented here, investigates the relative timing of impacts and recovery of different stressors on coral cover. This model seeks to understand the potential impacts of co-occurrence of dredging operations and other external stressors such as bleaching and cyclones.

The principle underpinning this model is to use the least complicated population dynamics formulation to capture the fundamental impact and growth of corals. Whilst more complicated models have been developed, these require data and parameter values that are largely unavailable for the inshore reefs in the study site.

The model formulation is based on the Schaefer logistic population growth model. The fundamental population model is used for the study of marine populations and this formulation supports classical marine fisheries stock assessment science. In this application the model is applied to investigate changes to coral cover and seagrass cover. Once again more complicated models can, and have been developed that consider for example different taxa of corals, or growth of coral and macro-algae. However, coral cover is perhaps the most robust and commonly used indicator for this application, as described in Osborne *et al* (2011).

Whilst it is recognised that perhaps the greatest source of uncertainty surrounding the decline of coral reefs globally is the relative roles of global as opposed to local disturbances (Knowlton & Jackson, 2008) it does not preclude that the present resilience of sensitive ecological receptors can be investigated by considering the likelihood, impacts and importantly recovery times from individual stressors. It has been suggested that reduced coral cover resulting from local effects reduces the ability of coral reefs to recover from globally-induced bleaching events. However Knowlton and Jackson (2008) highlight that there is no evidence to support this. By contrast, corals that have suffered exposure from acidification resulting in weaker structural skeletal strength are likely to become more impacted by mechanical destruction from cyclones.

There has also been speculation that coral reef systems exhibit alternate stable states consisting of a system dominated either by coral (demonstrating high coral cover), or a system dominated by turf macroalgae. Whereby once a system is in the turf microalgae dominated state, it is difficult to revert back to the coral dominated state. If this were the case, the logistic growth model may not be the most appropriate population trajectory function as it does not account for hysteresis that can occur when the system changes over time in a way not described by this model.

It is clear that reefs dominated by live coral colonies (>20% coral cover), can co-exist close to reefs dominated by algal turf (< 5% coral cover); Lecchini *et al* (2011), however what is not clear is whether GBR inshore reefs can seamlessly transition between these two states, or if once they fall into the algal turf state that it is difficult to revert back to a coral dominated state. Such hysteresis (whereby ecological communities do not seamlessly transition back and forth between different states) can be triggered by Allee effects (particular stresses on small population sizes) when coral cover is reduced to very low levels, the ability to recover becomes difficult. Allee effects in coral reefs can be triggered when coral populations get very low and reproduction success becomes very low as a result of lack of critical mass of gametes (i.e. reproductive failure). Therefore, this is most likely to occur when a number of reefs are simultaneously impacted. An example of this was when some eastern Pacific reefs went extinct during the 1982-1983 El Nino event (Glynn & De Weerdt, 1991; Glynn & Colgan, 1992).

As there are no alternative credible population growth functions available, the logistic formulation is used here as the most acceptable formation for the increase and decrease in coral cover.

Based on the studies of Osborne *et al* (2011) and others, GBR-wide storms, especially cyclones, and outbreaks of CoTS have had the largest impact on coral colonies; accounting for around one-third of damage each. Storms such as large cyclones tend to cause high intensity impacts over a very short period of time through mechanical damage as opposed to CoTS outbreaks that can inflict damage over periods of 2 - 3 years.

Over recent decades the impacts caused by coral bleaching and disease have been less by comparison to impacts from storms and CoTS. However, as described above climate change projections suggest, over this century the incidence of bleaching events will increase both in frequency and scale so that sometime later this century bleaching will be the dominant impacting process on coral colonies on the GBR.

As discussed above, past studies have claimed the post-European settlement (mid-1800s) fine sediment inflows into the GBR lagoon in some wet seasons will be at least five-fold greater than the inflows from the same catchments that will have occurred prior to large-scale land clearing. It has also been argued that these additional inflows will reduce the number of days available for benthic productivity. Chronic loss of productivity can lead to loss of condition, which in turn can lead to increase in disease (Haapkyla, Melbourne-Thomas, Flavell, & Willis, 2013).

In this model chronic impacts from increased number of days of reduced turbidity is represented through increased disease. The seagrass model also uses a logistic or Schaefer formulation for the seagrass cover trajectory through time. Based on the lack of recovery of some seagrass beds in the North Atlantic (De Jonge, De Jong, & van Katwijk, 2011), it has been speculated that seagrass beds can reach critical population thresholds where recovery either never occurs, or is unexpectedly slow. In such cases populations can form into one of two alternate stable states (healthy and almost non-existent). Dredging impacts used in this assessment are taken as the worst possible case impacts as described in Section 8.0.

In such cases once a population level has fallen below a critical population state and it falls into the other stable state, it can be almost impossible for population recovery to occur. However, the Seagrass Watch data collected to date demonstrated for the meadows in Cleveland Bay, the extreme 2011-2013 wet seasons led to almost complete loss of cover. Following this event these meadows recovered to similar % cover levels that were observed prior to the event. This demonstrates that for these meadows the population contraction and recovery is well estimated by the logistic model.

Corals: Baseline and Model Findings

The coral cover model parameters are presented in Table 25.5. The values shown in Table 25.5 are discussed below. The model domain consists of the study area, which stretches along the coast approximately 25 km.

Over a GBR-wide scale, Osborne *et al.* (2011) note that there are on average a disturbance around every four years. In addition, the same study highlighted that the inner and mid-shelf regions of the GBR experienced periods of almost continuous disturbance up to around 2002, following which recovery has been underway. Furthermore, the same study suggests that the major stressor on this recovery has been outbreaks of CoTS.

It is suggested that across the whole GBR the mean baseline coral cover is around 27-33% (Osborne, Dolman, Burgess, & Johns, 2011). For the inshore reefs in the central region, the baseline is 32% (Figure 25.14, Figure 25.15).

Parameter	Value	Reference
Maximum coral cover (carrying capacity)	80%	Osborne et al. (2011); Knowlton and Jackson (2008).
Current level of coral cover	32%	Osborne et al. (2011).
Intrinsic recovery rate following storms	0.15	Osborne et al. (2011).
Intrinsic recovery rate following disease	0.16	Osborne et al. (2011).
Intrinsic recovery rate following bleaching	0.12	Osborne et al. (2011).
Intrinsic recovery rate following CoTS	0.22	Osborne <i>et al.</i> (2011).
Intrinsic recovery rate following floods	0.20	Assumed.
Intrinsic recovery rate following dredging	0.15	Assumed.
Loss of coral cover during major storms	80%	Fabricius et al. (2008).
Loss of coral cover during disease	variable	Haapkyla, Melbourne-Thomas, Flavell, & Willis, (2013).
Loss of coral cover during bleaching	35%	Marshall & Baird (2000); Carrigan & Puotinen (2014).
Loss of coral cover CoTS	19%	Lourey et al. (2000).
Loss of coral cover during floods	5%	Wooldridge, S. (2009).
Loss of coral cover during dredging	2%	Section 8.0 (Marine Ecology) of the AEIS (Stage 1 TSHD).

Table 25.5 Parameters used in the coral cover model



Figure 25.14 Temporal trends in percent cover of hard coral on the GBR (1995-2009) (Osborne, Dolman, Burgess, & Johns, 2011)



Figure 25.15 Temporal trends in percent cover of hard coral on the GBR (1995-2009) (Osborne, Dolman, Burgess, & Johns, 2011) Note: A.planci also known as CoTS

Figure 25.16 shows the base case using the available monitoring data. The blue points represent the observed coral cover estimates derived from the monitoring program. The red points show the modelled trajectory of coral cover. A lack of availability of more recent comprehensive monitoring data constrains the development of up-to-date projections, although surveys completed during this assessment (refer Section 8.0 of the AEIS) suggest the rate of decline has slowed down, if not halted.

The future state of coral cover assessed under three separate scenarios (Table 25): Scenario 1 considers a recovering coral cover in the absence of repeated major hazards followed by the project capital dredging. Scenario 2 considers no intervening recovery and Scenario 3 considers ongoing degradation. The results for these scenarios are shown in Figure 25.17 to Figure 25.19.



Figure 25.16 Base case for the coral cover model

Fable 25.6 Coral cover modelling scenarios			
Scenario post project capital dredging	Coral cover trajectory		
1 – No repeated major hazards	Few major stressors between 2009 and commencement of capital dredging in 2017. Coral cover increasing.		
2 – No intervening recovery	Some stressors between 2009 and commencement of capital dredging in 2017 Coral cover constant prior to dredging.		
3 – Ongoing degradation	Multiple stressors between 2009 and commencement of capital dredging in 2017. Coral cover declining prior to dredging.		



Figure 25.17 Scenario 1 coral cover model



Figure 25.18 Scenario 2 coral cover model



Figure 25.19 Scenario 3 coral cover model

All of the simulations show that dredging, if the worst-case impacts were to arise, could result in a reduction in coral cover during the year of dredging. However what this means to the coral population depends on the recent trajectory, which in turn is dependent upon the stressors occurring in preceding years. For example, if coral cover consistently declined for multiple years preceding a capital dredging campaign, then it will be expected that the decline will continue for another year (Scenario 3).

By contrast, in Scenarios 1 and 2 even a capital dredging campaign should not result in a precipitous decline in the coral cover.

Seagrass: Baseline and Model Findings

The seagrass cover model parameters are presented in Table 25.7. The values shown in Table 25.7 are discussed below.

Parameter	Value	Reference
Maximum cover (carrying capacity)	50%	James Udy (Healthy Waterways Partnership).
Current level of cover	30%	Seagrass watch and POTL/JCU monitoring.
Intrinsic recovery rate following storms, floods	1.3-0.35. Closest fit using 0.4	Observed recovery of Cleveland bay seagrasses [= In (2)/(time for population to double)].
Intrinsic recovery rate following dredging	1.3-0.35	Assumed to be same as for floods.
Loss of seagrass cover during major storms, floods	10-30%. Closest fit using 15%	2011 event (Seagrass Watch).
Loss of seagrass cover during proposed dredging	3%	Section 8.0 (Marine Ecology) of the AEIS (Stage 1 TSHD).

Table 25.7 Parameters used in the seagrass cover model

The model implicitly assumes that the major impacting factor on seagrass cover is the underwater light environment, although the recovery parameter values used actually implicitly incorporate other factors. It is recognised that extreme temperatures also play a role in mortality (Collier & Waycott, 2010), however these impacts are presently considered to be small by comparison to changes in the light environment (Erftemeijer, 2006); (Waycott, Longstaff, & Mellors, 2005).

The distribution of seagrass beds typically follow a seasonal onshore-offshore migration with increased incoming irradiation allowing seagrass meadows to extend into deeper waters during the summer seasons. This migration can be somewhat independent of the density of seagrass cover used in most monitoring programs, and forms the basis on the logistic model used here.

The parameter value for the maximum percent seagrass cover was derived from the Seagrass Watch field guidelines (<u>http://www.seagrasswatch.org/Methods/2012/Fieldbooklets</u>). The intrinsic growth rate parameter was estimated by averaging the post-2011 flood recovery rates from the Townsville regional sites covered by Seagrass Watch (Rasheed M. M., 2014).

The worst-case impacts of dredging were estimated from the work presented in Section 8.0 of the AEIS. The data were derived from the Picnic Bay site and hence it is assumed that all the meadows in the study area will follow the same trajectory. Figure 25.20 shows the base case model.



Figure 25.20 Base case seagrass model

The following figures show the future state of seagrass meadows in three separate scenarios (Table 25.8). Scenario 1 considers a recovering cover in the absence of repeated major hazards followed by capital dredging. Scenario 2 considers no intervening recovery and Scenario 3 considers ongoing degradation. The following Figure 25.21 to Figure 25.23 present the results of these scenarios.

Scenario 3 could only occur if continuous stressors occurred in the years leading up to the capital dredging. In such a case seagrass cover could return to similar low levels as experienced following the 2011 floods.

The coral cover and seagrass models presented here assumed the dredging activities will not have any mitigation applied, and are the worst-case.

Scenario	Seagrass cover trajectory
1	Few major stressors between 2009 and commencement of capital dredging. Seagrass cover increasing.
2	Some stressors between 2009 and commencement of capital dredging. Seagrass cover constant prior to dredging.
3	Multiple stressors between 2009 and commencement of capital dredging. Seagrass cover declining prior to dredging.

Table 25.8 Seagrass cover model scenarios



Figure 25.21 Scenario 1 results







Figure 25.23 Scenario 3 results

25.3.3.4 Bayesian modelling

The approach taken in this cumulative impact assessment is one of 'weight of evidence' whereby evidence is developed using multiple approaches.

An increasingly common approach to integrating cause-effect relationship between multiple stressors and ecological endpoints, in this case the identified sensitive ecological receptors, is to develop a Bayesian Belief Network model (Gibbs M. T., 2006). Bayesian Belief Network encapsulate a range of knowledge of cause-effect linkages into one model in which relationships between stressors and sensitive ecological receptors are described by conditional probability distributions. Such a model has been developed by CSIRO and AIMS and details can be found in the GBRMPA Guidelines. This model from the Guidelines is considered, along with a discussion on other models that are presently under development but not yet available for use.

The GBRMPA Cumulative Impacts Framework for assessing cumulative impacts provides details of the Bayesian Belief Network developed for seagrass meadows and coral reefs. The Bayesian Belief Network developed by CSIRO (Figure 25.24 and Figure 25.25) are novel as the model structure and key internal model relationships (probability distributions) are generated from directional loop analyses that consider binary interactions between different parts of the system.

In the CSIRO models, as shown in Figure 25.24 and Figure 25.25, the grey boxes represent input conditions set by the user. The yellow boxes represent the probability of a change in coral/seagrass conditions base resulting from these input conditions. These Bayesian Belief Network models, that are based on theoretical relationships, were interrogated to confirm the structure of the influence diagram (Appendix A5, Figure 1) and confirm that the key stressors used in this analyses are the dominant drivers of the sensitive ecological receptors in the study area. However, these models do not represent models or networks for a specific, existing location. Hence the exact

magnitudes of the resulting probabilities are indicative only and should not be compared with data modelling from any specific location.

Specific Bayesian Belief Network using observed data are presently being generated by both AIMS, and under a research program being led by Professor Bob Pressey from James Cook University. These models are presently in the proof of concept stage and hence are not available for use in this assessment. However it is expected that they will be a key tool in future cumulative impact assessments.



Figure 25.24 Coral Bayesian Belief Network



Figure 25.25 Seagrass Bayesian Belief Network

25.4 Conclusion

A large number of submitters sought more information on how the predicted project impacts will compare to impacts from other stressors acting within the study area and GBR in general, and what consideration should be given to the timing of the Project with respect to other stressors impacting sensitive ecological receptors.

The cumulative impacts assessment presented here is consistent with the GBRMPA guidelines. Specifically, it has identified the key other stressors acting on sensitive ecological receptors, assessed their relative roles and impacts and investigated the relative timing of different stressors.

The key results from this revised Cumulative Impact Assessment are as follows.

- Research suggests that the near-shore environment of the GBR, including Cleveland Bay has featured relatively
 high turbidity over geological timescales (pre European settlement). The availability of large relic sediment stores
 in the study area resulting in frequent periods of elevated turbidity as local winds and tidal currents routinely resuspend these 'old' sediments.
- Post European settlement has seen significant development of the GBR catchment. This has resulted in
 increased loads of fine sediments entering the GBR lagoon. The majority of these sediments are thought to fall
 out of the water column and be deposited near river mouths. Ongoing sediment transport can transport some of
 these away from river mouths although these volumes are thought to be small by comparison to the existing
 sediment stores.
- The near-shore environment of the GBR, including the sensitive ecological receptors in the study area, are
 routinely impacted by stressors, including cyclones, CoTS outbreaks and bleaching events.
- The impacts predicted by the PEP are generally considerably less than impacts occurring from other stressors.
- The timing of capital dredging using a TSHD should consider major events such as bleaching or cyclones that impact the study area and occurred over the previous wet seasons.

The main recommendation from this revised Cumulative Impact Assessment is consideration should be given to the state of sensitive ecological receptors in the study area prior to capital dredging being undertaken. The risk management actions outlined in the Dredge Management Plan (Appendix B1) should be undertaken prior to capital dredging being undertaken. In particular trigger levels for managing the impacts of dredging need to be cognisant of the bio-condition of sensitive ecological receptors at the time of dredging activities.

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