Synthesis of current knowledge of the biophysical impacts of dredging and disposal on the Great Barrier Reef

Report of an Independent Panel of Experts

Published by the Great Barrier Reef Marine Park Authority
ISBN 978 1 922126 57 3

This publication should be cited as:

McCook, L.J.; Schaffelke, B.; Apte, S.C.; Brinkman, R.; Brodie, J.; Erftemeijer, P.; Eyre, B.; Hoogerwerf, F.; Irvine, I.; Jones, R.; King, B.; Marsh, H.; Masini, R.; Morton, R.; Pitcher, R.; Rasheed, M.; Sheaves, M.; Symonds, A.; Warne, M.St.J. 2015, *Synthesis of current knowledge of the biophysical impacts of dredging and disposal on the Great Barrier Reef: Report of an Independent Panel of Experts,* Great Barrier Reef Marine Park Authority, Townsville.

National Library of Australia Cataloguing-in-Publication entry

Synthesis of current knowledge of the biophysical impacts of dredging and disposal on the Great Barrier Reef: Report of an Independent Panel of Experts / L. McCook, B. Schaffelke, S. Apte, R. Brinkman, J. Brodie, P. Erftemeijer, B. Eyre, F. Hoogerwerf, I. Irvine, R. Jones, B. King, H. Marsh, R. Masini, R. Morton, R. Pitcher, M. Rasheed, M. Sheaves, A. Symonds, M.St.J. Warne.

Includes bibliographical references.

Dredging—Environmental aspects—Queensland—Great Barrier Reef.
Dredging spoil—Queensland—Great Barrier Reef.
Fishes—Effect of dredging on—Queensland—Great Barrier Reef.
Aquatic plants—Effect of dredging on—Queensland—Great Barrier Reef.
Environmental monitoring—Queensland—Great Barrier Reef.
Great Barrier Reef (Qld.)—Environmental conditions.

627.7309943

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Acknowledgements

The Great Barrier Reef Marine Park Authority and the Australian Institute of Marine Science would like to thank:

- The Expert Panel participants
- Mr Tim Moltmann (Australia's Integrated Marine Observing System)
- CSIRO's Land and Water Division
- CSIRO's Marine and Atmospheric Research Division
- James Cook University
- Jacobs Group (Australia) Pty Ltd
- The UWA Oceans Institute, University of Western Australia
- Southern Cross University
- Pollution Research Pty Ltd
- RPS APASA Pty Ltd
- Office of the Environmental Protection Authority, Western Australia
- RMC Pty Ltd
- Royal Haskoning DHV
- Queensland Department of Science, Information Technology, Innovation and the Arts.

The Great Barrier Reef Marine Park Authority and the Australian Institute of Marine Science also acknowledge the invaluable contributions of Traditional Owners and stakeholders consulted during the development of the project.

The Great Barrier Reef Marine Park Authority and the Australian Institute of Marine Science acknowledge the continuing sea country management and custodianship of the Great Barrier Reef by Aboriginal and Torres Strait Island Traditional Owners whose rich cultures, heritage values, enduring connections and shared efforts protect the Reef for future generations.

Preface

The issue of port development in the Great Barrier Reef Region has been a significant issue for government, industry and the wider community over the past few years. This review was commissioned by the Australian Institute of Marine Science and the Great Barrier Reef Marine Park Authority to assess the available information relating to the effects of dredging activities in the Region.

The work of the Expert Panel was largely completed in late 2014. Since those deliberations there have been changes in the publicly available forecasts of dredge material volumes and disposal locations.

In November 2014 the Federal Minister for the Environment committed to a ban on the disposal of capital dredge material in the Great Barrier Reef Marine Park, which forms 99 per cent of the Great Barrier Reef World Heritage Area. In February 2015, the new Queensland Government committed to legislate to restrict capital dredging for the development of new or expansion of existing port facilities to within the regulated port limits of Gladstone, Hay Point/Mackay, Abbot Point and Townsville, and to prohibit the sea-based disposal of dredge material from these sites in the Great Barrier Reef World Heritage Area.

These changes have been incorporated into this report as clearly identifiable updates, as of March 2015. All changes made to the Report due to this March 2015 update are indicated by blue shading of the text. These changes also take into account updated estimates of river loads of sediments.

Notwithstanding these changes in development and management, dredging and the disposal of dredge material continues to be an important pressure in the Great Barrier Reef.

The Australian Institute of Marine Science and the Great Barrier Reef Marine Park Authority are very grateful to the members of the Expert Panel for producing this synthesis of current knowledge about the impacts of dredging. Our wish is that this synthesis report will spark further inquiry that will increase understanding of our coastal systems and the way our communities and industries are affecting the natural coastal systems of the Great Barrier Reef.

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Executive summary

This report provides an independent synthesis of the current knowledge of the effects of dredging and sediment disposal on the physico-chemical environment and the biological values of the Great Barrier Reef World Heritage Area (World Heritage Area), as assessed by an Expert Panel.

Dredging and sediment disposal can change the physical and chemical environment and affect the biological values of the World Heritage Area. Many of these effects will be context dependent and will differ between locations, types and extent of dredging and sediment disposal activities. The Expert Panel's evaluation identified the following key direct and indirect effects:

- *Removal by excavation during dredging operations*. Most current and proposed dredging activities are carried out within soft-sediment seafloor habitats, sometimes supporting seagrass, and do not involve excavation of coral reefs. The area directly affected by excavation is generally only a small proportion of relevant habitats. Although this effect is severe within that footprint, and could be significant regionally, the overall ecological significance of direct removal to the Great Barrier Reef was considered to be small. There is evidence of very low levels of mortality of marine turtles during dredging excavations, which is reduced by the use of turtle deflection devices.
- *Burial at marine dredge material disposal and reclamation sites*. Current and proposed disposal of dredge material does not take place on coral reefs, but may affect a range of soft-sediment seafloor habitats, sometimes including seagrass. The area directly affected by burial is generally a small proportion of relevant habitats, so although the effects are severe within that limited footprint, and could be significant regionally, the overall ecological significance to the Great Barrier Reef was considered to be small.
- *Changes to bathymetry and hydrodynamics by excavations.* These changes were considered to be localised in the Great Barrier Reef and sufficiently predictable by modelling.
- *Increased artificial lighting* (at night) *and underwater noise* may have significant impacts on marine wildlife. It is difficult to distinguish to what extent, if any, effects are due to dredging *per se*, as distinct from the effects of other port, urban and industrial infrastructure and activities.
- *Release of fine sediment*. Both dredging and marine disposal create significant plumes of suspended sediment, causing increased turbidity and sedimentation and reducing light available to marine organisms. Maintenance dredging and disposal creates plumes that are shorter in duration, and more localised, than capital dredging. The extent and duration of these plumes appear to have been underestimated in previous assessments, although the panel held a range of views about this.

- *Potential contributions to chronic suspended sediments:* Importantly, both disposed sediments and dispersed sediments from dredge plumes have the potential to be resuspended and transported by waves and ocean currents, and to contribute to the long-term, chronic increase in fine suspended sediment concentrations in the inshore Great Barrier Reef. The extent to which this occurs and affects biodiversity was not agreed by the Expert Panel. In particular, panellists had differing views on whether any additional contribution from dredging was significant compared to background levels of resuspension and inputs of fine sediments in run-off from catchments.
- It is difficult to compare sediment released from dredging with inputs from terrestrial run-off, as there are limited data and many differences in the physical and chemical properties, the delivery to and the transport and fate in the waters of the Great Barrier Reef and the methods for measuring these processes. In particular, significant but unknown proportions of fine sediments in dredged material will not be available for resuspension. Acknowledging these difficulties, the Expert Panel compared overall amounts, and the amounts of fine sediments, from recent and proposed dredging activities in the Great Barrier Reef with the amounts estimated from rivers under natural and current conditions. Although some members of the panel had differing views on the validity and methods of these comparisons, the results show that dredging is a potentially significant source of sediments, and fine sediments in particular, being at least similar in magnitude to estimated natural inputs from rivers and potentially similar to anthropogenic inputs from catchment land uses.
  March 2015 update: The Panel re-analysed this comparison, based on updated projections for future disposal of dredged sediments in the Great Barrier Reef, provided by the Great Barrier Reef Marine Park Authority, along with updated estimates of average river loads. The updated projections for dredge disposal reflect the recent policy commitments to ban disposal of capital dredge material in marine environments (see Preface). The Panel recognized that implementation of these policies will mean that dredging will contribute much less fine sediment in the future (potentially about 5-10 percent of the estimated long-term average input from rivers in the comparison).
  It must be emphasised that this comparison is only intended to provide broad context for dredging and that dredge amounts released to the ecosystem will only be a proportion of these amounts; the comparisons should not be interpreted beyond that context.
- Any contribution from dredging to large-scale, chronic increases in suspended sediments could affect coral reefs, seagrass habitats, some other seafloor biodiversity, pelagic (open water) and estuarine habitats, fish populations and wildlife. As the magnitude of that contribution is not clearly determined nor agreed, the extent to which dredging activities have contributed to the known, sediment related declines in ecosystems is not clear. Some panellists considered these effects likely to be minor, but some felt the effects may be significant given the above conclusion that dredging related inputs are significant.
- Although coral reef organisms are sensitive to dredging-related pressures, the exposure of coral reefs on the Great Barrier Reef to dredging pressures is generally low to medium,

as the majority of dredging and disposal in the Region takes place at some distance from coral reefs. Available monitoring does not suggest that recent dredging projects in the Great Barrier Reef have directly resulted in significant, short-term coral mortality but sublethal effects are uncertain, as are effects of long-term contributions to suspended sediments. In particular, suspended sediments may have serious impacts on recovery of reefs from other disturbances (reducing resilience); such impacts would not be detected in most environmental impact assessments and are potentially important given the degraded condition of many inshore reefs in the regions where dredging takes place.

- Seagrass meadows near dredging activities in the Great Barrier Reef have a high exposure and sensitivity to dredging pressures, although some also have high capacity for recovery. Monitoring provides no evidence for long-term impacts of maintenance dredging on seagrass, although it cannot preclude short-term impacts. Direct and indirect impacts on seagrasses of past capital dredging have been documented, albeit generally inside predicted areas. Losses were a relatively small proportion of local seagrass populations, but even small losses are more critical in the context of the overall degraded condition of Great Barrier Reef seagrass populations.

Disposal of dredge material on land or in reclamation. The Expert Panel identified a number of potential impacts and challenges involved in disposing of dredge material on land or in reclamation. These include:

- Loss of coastal habitats, many already under considerable pressure, due to the large areas required to process dredged sediments.
- Run-off of seawater from the dredge material, which may contain large amounts of fine sediments, into freshwater or coastal ecosystems.
- Potential acid sulphate soils, with associated risks of production of sulphuric acid and the release of quantities of potentially toxic metals such as iron and aluminium.

Although the Expert Panel prioritised synthesis of existing knowledge, its evaluation identified significant areas of insufficient knowledge. Of particular importance is the need for improved understanding of long-term sediment dynamics in the World Heritage Area. There is also a need for more extensive, long-term and better integrated monitoring and assessment of dredging and disposal effects in the World Heritage Area, and a need for that information to be more readily accessible to the public and the research community. Further, there is a need to quantify the sensitivity of a wider range of marine species, including but not limited to a wider range of coral and seagrass species, to the effects of increased turbidity, suspended sediments and sedimentation. Other information needs are outlined in the body of this report.

Most panel members agreed this statement is just one step toward better management of dredging and sediment disposal in the World Heritage Area. Other key steps would include:

- similar syntheses of available knowledge on the social, economic, cultural and heritage aspects of dredging and sediment disposal, including Indigenous culture and heritage
- ongoing review and enhancement of policies, governance, planning and assessment procedures for dredging activities in the World Heritage Area, to ensure better outcomes for both the environment and users, including ports
- better acquisition, integration and accessibility of knowledge and information
- targeted research to address the key knowledge gaps identified in this statement, to allow ongoing improvement of the science-base for management.

Introduction

The Great Barrier Reef is a national treasure, and World Heritage Area, but the recently released Great Barrier Reef Region strategic assessment report[1] and Outlook Report 2014[2] show that the Great Barrier Reef is in decline, especially in the inshore areas of the southern two-thirds of the region. In this context, it is critical that we understand and reduce the cumulative impacts of all pressures on this iconic ecosystem.

This report has been prepared by an Expert Panel of independent scientists to synthesise information and knowledge of the actual and potential pressures posed by dredging and dredge material disposal on the physical, chemical and biological environment of the World Heritage Area (detail below and in Appendix A).

Dredging is the excavation or removal of sediment and/or rock from the seabed and is a routine part of port operations and of coastal and marine infrastructure developments (for detailed technical information see[3]). The recent resources boom in Australia has led to demand for more and larger ports, especially along the subtropical and tropical coast, with many current and planned port developments involving the dredging of millions of cubic metres of sediment, especially in Western Australia[3]. In the Great Barrier Reef, major dredging operations are currently underway or planned for the expansion of existing ports (Figure 1). While some of these expansions may not occur, the proposed volumes are significant by global standards[4].

There are two major types of dredging operations: *capital dredging* is carried out to open up new shipping channels, marina or port basins or berth pockets, or to deepen or widen existing areas. *Maintenance dredging* keeps previously dredged areas at the required depth. Large capital dredging campaigns (volumes of 500,000 m^3 and larger) occur infrequently, are generally of longer duration (weeks to months or years), and generally remove seabed material with a wide range of particle sizes (gravel, sands, silts and clays). Maintenance dredging campaigns are undertaken at regular intervals (years) or as required, are typically of short duration (days to weeks), and generally remove sediments with a higher proportion of finer particles.

The sediment removed by dredging can be disposed in the marine environment, used for reclamation, or disposed on land. Figure 1 gives a summary of actual volumes of dredged sediment disposed in the World Heritage Area marine environment to date and a forecast of future volumes (see also Appendix B for detailed data).

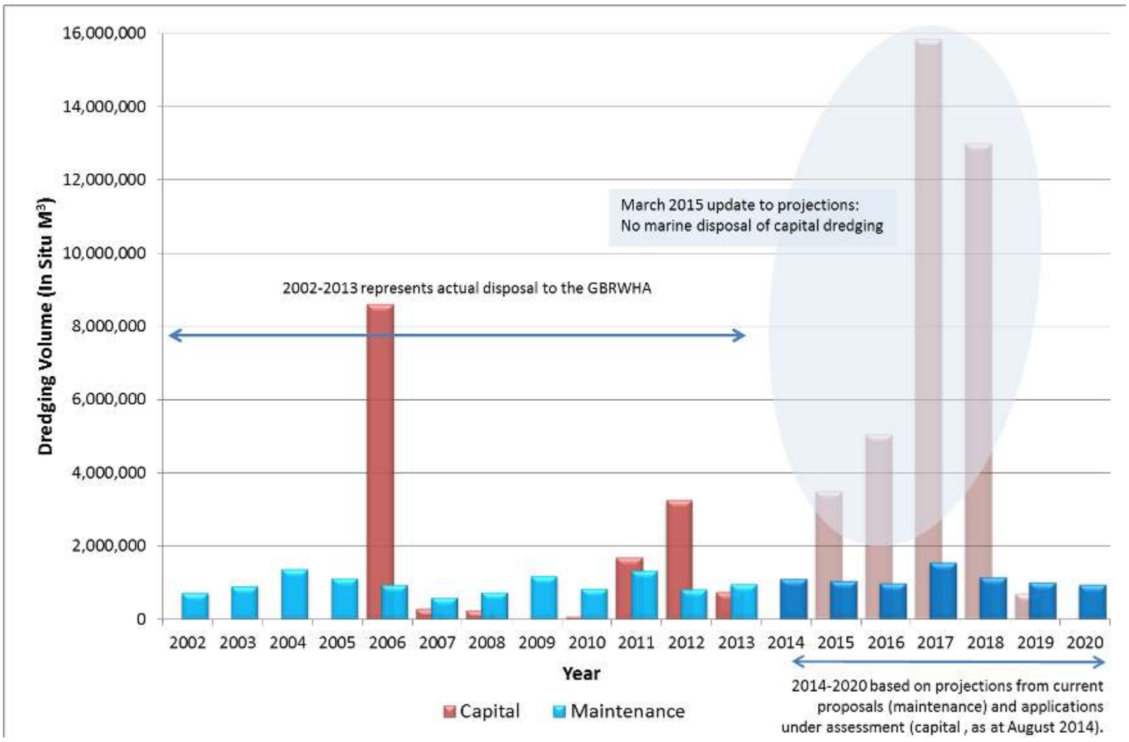

Figure 1: Actual historical and projected future volumes of dredge material disposed in marine environments of the Great Barrier Reef World Heritage Area.
Source: Great Barrier Reef Marine Park Authority (GBRMPA) and Department of the Environment (see Appendix B, Table B-6).
Future projections assume all referred projects being approved and proceeding as proposed (August 2014).
Update March 2015: Advice from GBRMPA indicates that volumes projected for future disposal (2014 -2020) of capital dredging will be zero (see explanation below).

Disclaimer: *Actual disposal volumes (2000-2013, capital and maintenance) were collated based on annual reporting requirements to the Great Barrier Reef Marine Park Authority and the Department of the Environment (as part of annual reporting requirements to the International Maritime Organisation under the Sea Dumping Act) and on historical disposal information provided by port operators. Maintenance dredge disposal volumes forecasted for future years were based on historical averages of actual disposal volumes supplied to the Great Barrier Reef Marine Park Authority and the Department of the Environment. Where increase in future maintenance dredging is anticipated as a result of capital expansion, forecasts are based on publicly available information contained in proposals referred under the EPBC Act as of 25 August 2014. Capital dredge volumes forecasted for future years were based on publicly available information contained in proposals referred under the EPBC Act as of 25 August 2014. They reflect the proposed volume to be disposed.*

Update March 2015: *Since the original analyses in August 2014, there have been a number of significant changes in the policy context around projected volumes of capital dredged material. These changes include:*

- *withdrawal of proposed capital dredging at Hay Point*
- *anticipated delay in proposed capital dredging at Gladstone*
- *commitment to disposal of capital dredged material from Abbot Point on land*
- *Commitment by the Australian Government[a] to a permanent ban on disposal of capital dredged material in the Great Barrier Reef Marine Park (note that many existing spoil disposal grounds are outside the*

[a] p.2, Australian Government 2015, State Party Report on the State Of Conservation of the Great Barrier Reef World Heritage Area (Australia) Property Id N154 in response to the World Heritage Committee Decision WHC 38 Com 7b.63 www.environment.gov.au/heritage/publications/state-party-report-gbr-2015 (viewed 12 March 2015).

Marine Park boundary- see Appendix C)

- *Commitment by newly elected Queensland State Government to restrict major capital dredging to the ports of Townsville, Abbot Point, Hay Point / Mackay and Gladstone and to prohibit the disposal of dredge material from these sites in the Great Barrier Reef World Heritage Area. This would suggest that there will be no marine disposal of capital dredge material in the forecast period to 2020 (the World Heritage Area does include existing spoil grounds).*

On this basis, and to ensure the ongoing relevance of the entire Report, the Expert Panel agreed to update relevant sections of this Report (Fig. 1, Executive Summary and Sections 1.4 and 1.5), on the basis of updated projections for disposal of dredge material in the marine environment, provided by GBRMPA on 6 March 2015. For transparency, all such updates are indicated by blue shading behind new text; no material or content has been removed for this update. The Expert Panel also notes that i. the benefits of these new policy commitments will depend on their effective implementation; and ii. the disposal of capital dredged material on land instead of in the marine environment brings an attendant set of environmental and other challenges (Section 3).

Dredging has occurred in the Great Barrier Reef since ports were established. For example, dredging began off Townsville in 1883 and off Cairns in 1888. Historical data for Port of Townsville dredging operations report regular (monthly to annual) maintenance dredging and occasional capital dredging operations in Cleveland Bay from 1889 to 1988[5].

Dredging and the disposal of dredge material within and adjacent to the Great Barrier Reef Marine Park and the World Heritage Area have recently become contentious issues for the government, stakeholder groups and the general public. It is widely recognised that dredging activities need to be carefully managed as they may impact areas of conservation value through degradation of water quality, changes to the hydrodynamic regime, smothering of benthic biota, translocation of species and removal of habitat. Management measures to reduce these impacts include planning, environmental impact assessment, avoidance, minimisation and compensation measures[6].

The recently released Queensland Ports Strategy[7] prescribes four ports in the World Heritage Area (Abbot Point, Gladstone, Hay Point and Mackay, and Townsville) as Priority Port Development Areas (PPDAs) and states that “the Queensland Government will prohibit dredging for the development of new, or the expansion of existing port facilities outside PPDAs, for the next ten years.” Figure 2 shows the current main ports in the World Heritage Area and detailed maps of each port area are provided in Appendix C.

In the World Heritage Area dredging and the disposal of dredge material in the marine environment is only permitted after comprehensive environmental assessment and approval under Queensland and Commonwealth legislation (which, as of March 2015, are undergoing significant changes, as noted above). Under the Commonwealth, this includes the *Environment Protection and Biodiversity Conservation Act 1999* and the *Environment Protection (Sea Dumping) Act 1981*, and, within the Great Barrier Reef Marine Park, the *Great Barrier Reef Marine Park Act 1975*. Dredging and disposal are also subject to a number of policies and guidelines to prevent or minimise environmental harm that may be caused by these activities (for more details see[6,8]). In particular, dredging proposals require application of the internationally recognised National Assessment Guidelines for Dredging (NADG)[9].

There are also engineering approaches that can be used to reduce release of fine sediments during dredging and disposal and to reduce the need for or provide alternatives to dredging[10].

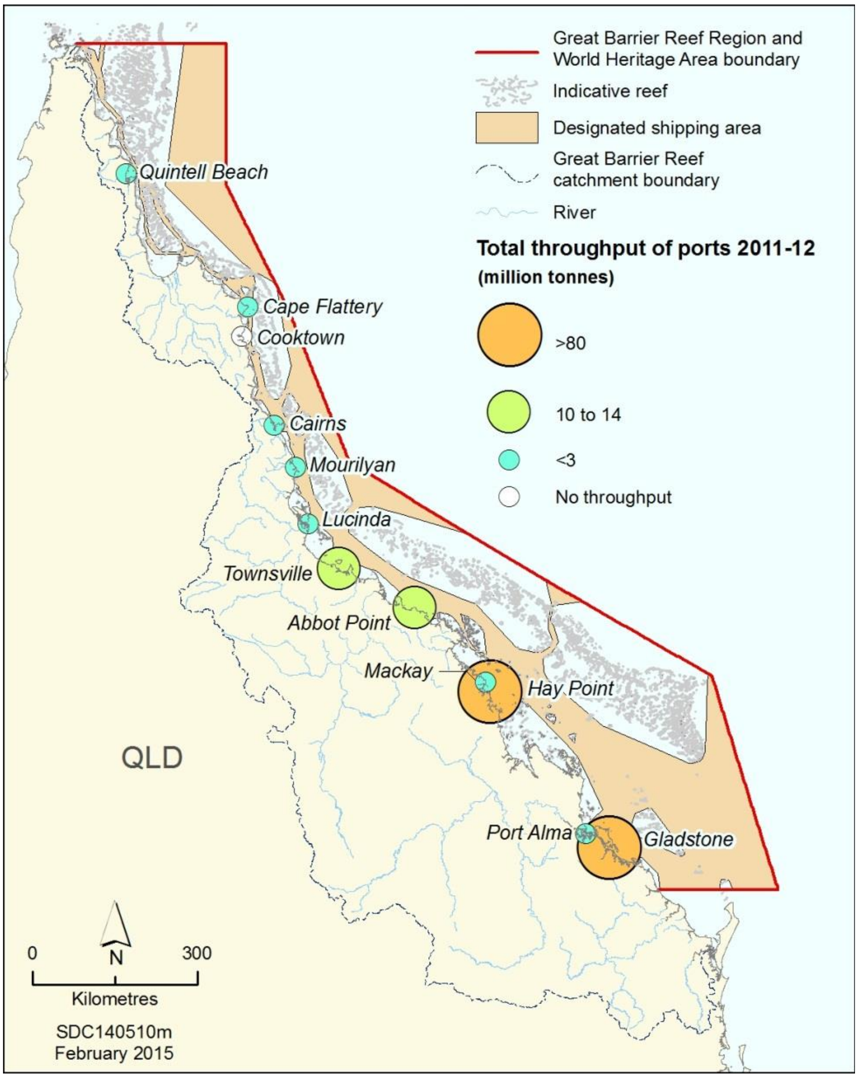

Figure 2: Existing ports in and adjacent to the Great Barrier Reef World Heritage Area

Expert Panel process and report

The dredge synthesis project is a joint initiative between the Great Barrier Reef Marine Park Authority (GBRMPA) and the Australian Institute of Marine Science (AIMS). The process involved convening an Expert Panel to develop and publish this synthesis statement. Key experts were invited to participate, with the aim of bringing together a broad range and diversity of skills, experience and perspectives (further detail on the process is provided in Appendix A; see Acknowledgements for contributing organisations).

This report synthesises information and knowledge of the actual and potential pressures posed by dredging and sediment disposal on the physical, chemical and biological environment of the Great Barrier Reef. It focuses on coral reefs, seagrass meadows, inter-reefal, soft-bottom and pelagic habitats, fish, marine megafauna and other threatened species. Where the information was sparse, the report also draws on information from outside the Great Barrier Reefs.

The purpose of this project and report is to provide an independent, objective and evidence-based overview of the biophysical effects of dredging pressures, thereby providing a stronger foundation for further development of policy, guidelines and assessment procedures for development proposals that involve dredging. The report seeks to provide improved understanding of the risks associated with dredging; that is, what is known and not known about past and potential future biophysical impacts of dredging in the marine environment of the Great Barrier Reef Region. This understanding includes identification of points of agreement and disagreement among technical experts.

The scope of this synthesis is limited to biophysical effects, and does not address social, economic, cultural or heritage aspects at this stage (but see final Next Steps section). Aside from the (March 2015) updated analyses of projected dredge amounts noted above (Fig. 1), the Report reflects available information as of August 2014.

The approach and terminology[b] used in this synthesis report are consistent with those of the Great Barrier Reef Outlook Report 2014[2] and the Great Barrier Reef Region Strategic Assessment [11], drawing on the frameworks of the *Vulnerability Assessment*[12] approach (Figure 3) and the DPSIR framework[13] of *Drivers* (dredging and disposal activities), *Pressures* (Section 1 of this report), *State* and *Impact* (Section 2 of this report) and management *Response* (out of scope for this project). Although a comprehensive vulnerability assessment is beyond the scope of this report, it does aim to provide the foundations for such assessment. Specifically,

[b] A range of different terms are used to refer to disposal (e.g. dumping, disposal, placement) of dredged material (sometimes referred to as spoil) in scientific, legislative and public domains. For this report, Panel members had a range of views, but overall felt that the most appropriate terms in this context are "*disposal*" and dredge "*material*".

Section 1 of the report outlines general aspects of *exposure* to dredging related pressures, and Section 2 considers the exposure for specific habitats and biodiversity values, along with their sensitivity and adaptive capacity.

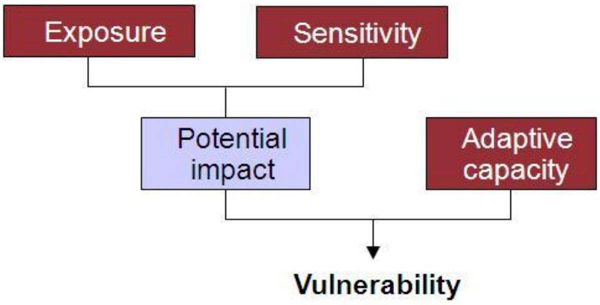

Figure 3: Components of vulnerability assessments[12].
The *exposure* to a pressure (or cumulative pressures), combined with the *sensitivity* of a species or habitat to that pressure, indicates the *potential impact*, which may be modified by *adaptive capacity* to give the vulnerability of the species or habitat to the pressure/s.

Handling uncertainty and incomplete information

The workshop and resulting report aimed to synthesise the state of knowledge, but not necessarily to achieve complete consensus amongst panellists across all topics. Rather, the intent was to explicitly identify areas of:

1. Broad, scientific agreement (and the evidence-base for this);
2. Scientific uncertainty, debate or disagreement (and related evidence, and the nature of further evidence required to resolve the issue);
3. Knowledge gaps (and the research that would adequately address those gaps).

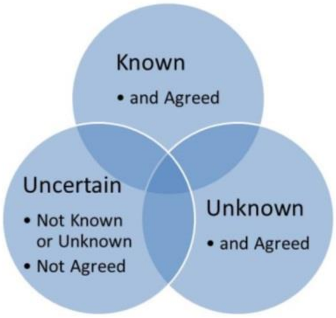

Figure 4: Handling uncertainty within the Expert Panel process

This approach (Figure 4) allowed the Expert Panel to focus on identifying what is known and agreed, and provide focus for resolving or progressing areas of disagreement or debate, rather than stalling on those areas.

It is significant that, although the panel worked hard to focus on identifying useful, current knowledge and resist the scientist's tendency to dwell on the unknowns, most members could not avoid recognising the very considerable extent of information gaps.

1. Changes to the physical and chemical environment from dredging and dredge material disposal: Pressures

Overview

Dredging can directly affect the marine environment, within the physical footprint of the excavation work, by removing sediment, hard substratum and associated plants and animals (Table 1; conceptual model in Figure 5). In addition, there are multiple indirect effects, especially effects associated with the release of fine sediments into the water column during the excavation. This generally increases water turbidity (reducing availability of light underwater) and sediment deposition, and potentially releases nutrients, carbon and contaminants (if present), over areas larger than the direct excavation footprint. Finer sediments are of particular concern because they are most readily resuspended and transported and may carry more chemicals, due to their high surface area to volume ratio.

Table 1: Dredging activities and related pressures

Phase	*Activity/process*	*Pressures*

Dredging	• Excavation of channels, berth pockets, etc.	• Removal of benthos and substrate (direct)
		• Suspended sediments:
		  ○ Turbidity and reduced light
		  ○ Sediment deposition
		• Bathymetric and consequent hydrodynamic changes
		• Underwater noise
		• Chemical effects:
		  ○ Nutrients, organic matter
		  ○ Contaminants, if present

Disposal (immediate effects)	• Disposal of sediment in designated area	• Burial of habitats (direct)
		• Suspended sediments:
		  ○ Turbidity and reduced light
		  ○ Sediment deposition
		• Bathymetric and consequent hydrodynamic changes
		• Underwater noise
		• Chemical effects:
		  ○ Nutrients, organic matter
		  ○ Contaminants, if present

Sediment dynamics (intermediate and long-term)	• Resuspension
	• Transport
	• Consolidation, armouring
		• Suspended sediments:
		  ○ Turbidity and reduced light
		  ○ Sediment deposition
		• Chemical effects:
		  ○ Nutrients, organic matter
		  ○ Contaminants, if present

The disposal of dredged sediment has the direct effect of burial (covering) of habitats and organisms at permitted dredge material disposal areas, and indirect effects including immediate release of fine sediments, and over longer time frames the potential dispersion of deposited fine sediment. Release and dispersion of fine sediments may involve release of nutrients, carbon and contaminants (if present). In this report, we distinguish between complete burial (by very large amounts of sediment during dredge disposal), and sedimentation and smothering effects (due to general deposition and settlement of suspended sediments).

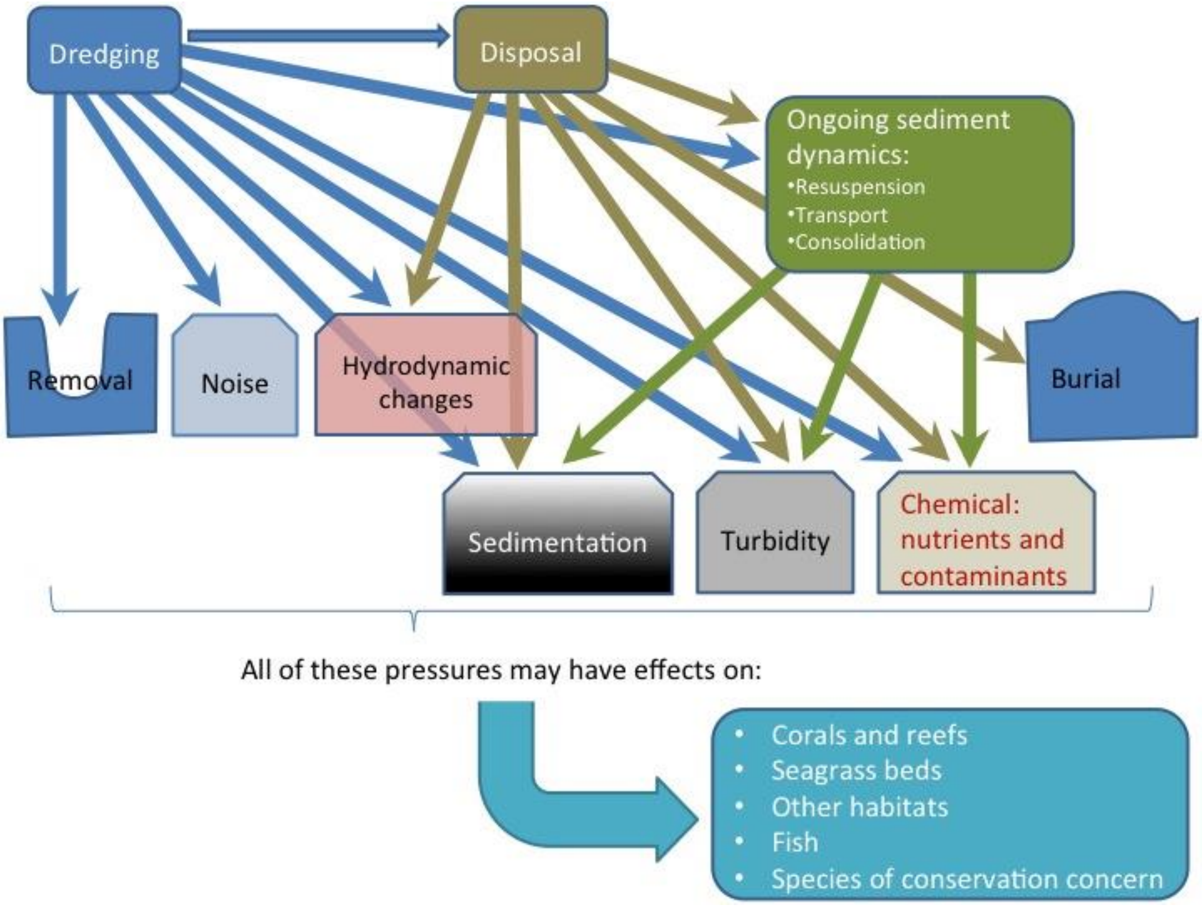

Figure 5: Relationships between the activities of dredging and dredge material disposal, the major (potential) pressures and their effects on key habitats and other biodiversity values of the Great Barrier Reef World Heritage Area.

The immediate and ongoing contributions to sediment dynamics are issues of fundamental importance and significant uncertainty.

Other dredging related pressures may include changes to bathymetry and hydrodynamics, and effects on the underwater noise and above-water light environments during dredging operations.

Dredging activities have the potential to affect the marine environment at spatial and time scales well beyond those of the activities of dredging and disposal. The actual effects of dredging and sediment disposal and their temporal and spatial extent depend on many factors, including: the scale of the dredging operation; the characteristics of the dredged sediment, such as particle size, nutrient and contaminant content; the type of dredging equipment used; the prevailing physical (e.g. currents, tides, waves) and water quality conditions in the area and the proximity and type of biological communities.

Many of these pressures are addressed by existing management procedures[6,8,9,10].

Table 2: Qualitative risk assessment of the exposure of Great Barrier Reef ecosystems and values to major pressures from dredging.
Explanation of approach and terms below tables; explanation of assessments in following subsections. Assessments refer to dredging in the Great Barrier Reef overall, but would depend greatly on the size of the dredging operation, and would vary amongst locations and with other conditions such as weather and currents."?" indicates high degree of uncertainty in score.

Capital dredging and disposal					
Pressures	***Likelihood***	***Consequence***	***Spatial Scale***	***Temporal Scale***	***Predictability***
Immediate: during dredging and disposal activities					
Removal	Certain	Severe	Small (Immediate area)	Permanent	High
Burial	Certain	Severe	Small (Immediate area)	Permanent	High
Sedimentation	Certain	Moderate	Local	Days-Months	Moderate
Turbidity	Certain	Moderate	Local	Days-Months	Moderate
Nutrients	Certain- (Likely #)	Moderate (-Minor #)	Local	Days-Months	Moderate
Contaminants	Rare*	Major (variable)	Local	Days-Months	High
Hydrodynamics	Certain	Minor – Moderate # (variable)	Local	Permanent	? Moderate
Noise	Likely	? Minor - Moderate	? Small - Local	Days -weeks	High-moderate **
Medium -long-term: due to resuspension and transport					
Sedimentation	? Likely	? Minor - Moderate (variable)	? Large	Years-Decades	Limited
Turbidity	? Likely	? Minor - Moderate (variable)	? Large	Years-Decades	Limited
Nutrients	Possible	? Minor	? Large	Years-Decades	Limited
Contaminants	Rare	Major (variable)	? Large	Years-Decades	Moderate #

Maintenance dredging and disposal					
Pressures	***Likelihood***	***Consequence***	***Spatial Scale***	***Temporal Scale***	***Predictability***
Immediate: during dredging and disposal activities					
Removal	Certain	Minor	Small (Immediate area)	? Months-Years	High
Burial	Certain	Moderate #	Small (Immediate area)	? Months-Decades	High - moderate
Sedimentation	Certain	Moderate- Minor #	Local	Days-Months	Moderate
Turbidity	Certain	Moderate- Minor #	Local	Days-Months	Moderate
Nutrients	Certain	Moderate- Minor #	Local	Days-Months	Moderate
Contaminants	Rare*	Major (variable)	Local	Days-Months	High
Hydrodynamics	Certain	Minor- Insignificant	Local	Permanent	High
Noise	Likely	? Minor	? Small	Days -weeks	High - moderate**
Medium -long-term: due to resuspension and transport					
Sedimentation	? Likely	? Minor - Moderate (variable)	? Large	Years-Decades	Limited
Turbidity	? Likely	? Minor - Moderate (variable)	? Large	Years-Decades	Limited
Nutrients	Possible	? Minor	? Large	Years-Decades	Limited – moderate #
Contaminants	Rare	Major (variable)	? Large	Years-Decades	High

Explanation for Table 2: In order to manage pressures on the values of the Great Barrier Reef, management agencies need to understand key attributes of those pressures—the what, where, when and how much. These attributes include the elements of risk assessments (likelihood and consequences), which in turn require explicit consideration of the spatial and temporal scales of the pressures: a small but long-term risk requires a different response to a large but short-term risk. Also important for management is our ability to predict those properties; that is, how accurately we can predict the what, where, when and how much, and hence implement management that matches the risks. Likelihood and Consequences categories are adapted from the Great Barrier Reef Outlook Report[2], except that in Table 2 assessments refer to impacts within affected areas, with temporal and spatial scales identified separately:

Likelihood:	Refers to how probable a pressure is to occur: Certain; Likely; Possible; Unlikely; Rare.
Consequences:	Refers to the impact of the pressure, where and when it does occur: Severe; Major; Moderate; Minor; Insignificant.
Spatial Scale:	Refers to the approximate spatial extent over which a pressure occurs: Small: Immediate, defined area of activity (e.g. dredging excavation or disposal ground) < ~20 km^2; Local: Bay-wide: ~20–200 km^2; Large: 200–2000 km^2; Regional: >2000 km^2.
Temporal Scale:	Refers to the approximate duration in time over which a pressure occurs: Hours to days; days to weeks; weeks to months; months to years; years to decades; permanent.
Predictibility:	Refers to the precision and accuracy with which managers can predict the likelihood, consequences and scale of each pressure, whether using computer models or other techniques; assumes availability of relevant sampling and data: High; Moderate; Limited.

Assuming effective implementation of current management guidelines[9].
** Adequate data not currently available, but should be readily acquired using available technology and methods.
# Assessments differed among the Expert Panel.

1.1 Physical and chemical changes to the environment due to dredging operations

The process of excavating the seabed during dredging operations can lead to direct and indirect, immediate and long-term changes to the physico-chemical environment.

The most immediate, direct effect is that of removal of habitat through the excavation: within the limited footprint of the area dredged, there will be complete and effectively permanent removal of the substratum, including any benthic biota living there. The extent of this effect can be predicted with considerable precision and as early as the design phase of any dredging project.

Changes in the bathymetry, and hence hydrodynamics, due to the dredging of a new or expanded channel can affect local flows, tidal currents, hydrology and sediment transport patterns, especially in shallow coastal and estuarine locations. The nature and importance of these changes will be specific to the location and depend on depth, length and other aspects of the excavated area or channel. These changes will be certain and permanent, potentially significant at a local scale, and are predictable with appropriate hydrodynamic modelling[14]. Unacceptable impacts could be managed through the approval process, with appropriate arrangements. Changes to the coastal hydrodynamics due to coastal infrastructure are not considered in this synthesis.

One of the main immediate, and difficult to manage, effects of dredging is the creation of high concentrations of suspended sediments, due to the partial loss of (mostly fine) sediments into the water column at the dredge site. This suspended sediment changes light quality and quantity causing turbidity, increases sedimentation, and potentially releases contaminants and nutrients occurring from natural or anthropogenic sources at the site. The severity, spatial extent and duration will be highly dependent on the characteristics of the dredged sediment, the site and time-specific physical conditions such as winds, waves, currents and tides (hereafter referred to as 'metocean conditions'[c]) and the type, scale and duration of dredging operation. The fine sediments transported away from the dredging site eventually settle and are potentially available for secondary resuspension by wind, currents and tides. Sedimentation and turbidity increases can be predicted using modelling (but see discussion of limitations below, Section 1.3), given sufficient calibration and validation sampling before the dredging. The extent and significance of sediment dynamics are discussed in detail in Section 1.3.

Sediment disturbance through dredging will release particulate and dissolved nutrients from sediment pore waters, and readily soluble nutrients desorbing from suspended sediment. While these nutrients are already present in the system, they are mobilised by the sediment disturbance which can potentially increase the nutrient availability at a local scale. Although the National Assessment Guidelines for Dredging (NAGD)[9] do not require analysis of nutrients in sediments before dredging, analyses are frequently undertaken[15]. Available information on nutrient release is assessed in detail in Section 1.5.

Chemical contaminants are sometimes present in dredged sediments as a result of existing port, industrial, urban and agricultural activities, but are generally considered a relatively low risk in the Great Barrier Reef[16]. Any such contamination is generally confined to inner harbour areas and berthing pockets, and in most areas of the World Heritage Area, including shipping channels outside the ports, chemical contamination is considered relatively low[16]. The NAGD[9] prescribe a stringent process of testing and management of chemical contaminants in sediments as part of assessments for the marine disposal of dredge material. Further discussion of chemical contaminants in dredged or disposed sediment is below in Section 1.5.

Increased underwater noise during dredging operations, due to the machinery involved, is certain and predictable in severity and duration, and generally comparable with noise from other shipping activities (see e.g.[17]). How underwater noise affects marine animals, especially marine megafauna, is discussed below in Section 2.7. Dredging activity at night will contribute to the overall increased (above-water) light levels, with potential consequences for marine wildlife (Section 2.7).

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[c] 'metocean conditions' is a combination of the terms meteorological and oceanographic, used to describe the physical conditions at a marine location, especially the wind, wave current and tidal conditions.

1.2 Physical and chemical changes to the environment due to disposal of dredge material in the marine environment

Depositing dredge material in the coastal or marine environment will lead to direct, indirect, immediate and long-term physical and chemical changes to the environment.

The burial and smothering of habitats and sessile organisms at the disposal site is certain, effectively permanent and will be complete, as most organisms will be buried too deep to survive. Recolonisation and recovery of habitats and organisms may occur over time following cessation of disposal activities, although the recolonised assemblage may differ from the natural assemblage due to differences such as depth or sediment composition. These localised impacts are an unavoidable consequence of dredge material disposal but are typically limited to the actual, designated disposal site. As at January 2012, the combined area of dredge spoil disposal grounds in the Great Barrier Reef World Heritage Area where localised effects are concentrated was 66 square kilometres[1] (which amounts to less than 0.02 per cent of the World Heritage Area).

Planning and site selection (see Appendix C for detailed maps of currently used dredge material disposal sites) allows for minimisation of the direct impacts, such as by avoiding high-value habitats. The extent to which burial results in environmental impacts is generally site-specific and depends on the characteristics and volume of the dredged sediment, the frequency of disposal, the water depth and hydrodynamic conditions, and the type of benthic community present. Available literature indicates that impacts vary from few or no detectable effects to large, long-term impacts[18,19,20,21]. Given suitable planning, appropriate characterisation of the material to be dredged and appropriate hydrodynamic modelling and measurements, the spatial extent of burial should be highly predictable.

The immediate release of fine sediment during placement of dredged material at the disposal site will have broadly similar, short-term effects to the re-mobilisation of sediment during the dredging process, depending on the depth and size of the disposal area and metocean conditions. These effects will include sedimentation and turbidity (Section 1.3) and potential increases in concentrations of nutrients and contaminants at and often beyond the disposal site (Section 1.5; release of contaminants during sediment disposal should be minor, as highly contaminated sediments are not permitted for marine disposal under the National Assessment Guidelines for Dredging (NAGD)[9]).

However, the disposed sediment also has the potential for ongoing, long-term resuspension, contributing to suspended sediments and turbidity over many years (Section 1.3). Some Great Barrier Reef disposal areas are generally retentive of sediments, while others are dispersive[22], depending on the extent of resuspension and transport from the site. Released fine sediments are transported away from the disposal site, eventually settle and are available for repeated resuspension by currents and waves (detailed explanation in Section 1.3).

The placement of dredged material at a disposal site will cause changes in hydrodynamics by locally raising the seabed, although this is likely to be minor at the depths (10–20 m) of existing marine disposal areas in the World Heritage Area. The effect of disposal of large volumes in a small area would be predictable with appropriate hydrodynamic and sediment transport modelling and unacceptable impacts could be managed through the approval process. Disposal of dredged sediment into coastal bunded areas for reclamation will alter hydrodynamics by altering the coastline; although again this should be readily predictable (see also Section 3).

Increased underwater noise from shipping movement during disposal of dredged sediment is considered to be minor (see e.g.[17,23]).

1.3 Effects of dredging and dredge material disposal on immediate and long-term sediment dynamics, including transport and resuspension

Background

The immediate and longer term fate of sediments, especially fine sediments, mobilised during dredging and disposal is a critical issue that must be evaluated in the context of local and Great Barrier Reef-scale knowledge of hydrodynamics and sediment dynamics. Fine sediments can seriously affect key World Heritage Area ecosystems such as coral reefs and seagrass beds (Section 2; recent reviews[20,24,25,26]).

Sediment dynamics in the inshore Great Barrier Reef are largely dominated by the wave and current-driven resuspension and transport of accumulated seabed sediment deposits[27,28,29,30]. Important additional inputs of fine suspended sediments are delivered in catchment run-off, especially during flood events[24,31,32,33,34,35]. The delivery of fine sediments from the catchment to the Great Barrier Reef has increased many-fold, correlated with agricultural development after European settlement around 1850[32], as indicated by analyses of coral core records of suspended sediment delivery [24,36,37,38,39]. In the short-term, most of the suspended sediment transported in flood plumes is deposited on the seabed within 10 km of the coast[40]. However, a portion of the fine sediment fraction can form organic flocs and be transported far from its source (up to 100 km[41]). Most of these remain in the Great Barrier Reef lagoon for several months after a flood event, and sustain elevated turbidity through repeated resuspension[42,43,44,45].

In the long term, it is not clear what proportion of the ambient fine sediments resuspended by waves and currents is derived from recent, anthropogenic inputs such as increased catchment run-off (or dredging—see below) and how much is naturally a part of the system. Although resuspension of ambient seafloor sediments dominates suspended sediment regimes[27,30], in the very long term, without resupply, fine sediments would be transported and flushed from the system (through multiple cycles of resuspension, transport and settling; G. Brunskill, pers. comm.), reducing ambient fine sediments available for resuspension.

However, the many-fold increases in inputs of fine sediments over the last century or more would counter that flushing, and may have contributed significant proportions of the current ambient fine sediments available for resuspension. The demonstration that riverine inputs can have persistent effects on turbidity over months to years[44,45] supports this interpretation, suggesting resupply of fine sediments does contribute to overall turbidity. Not all members of the Expert Panel supported this interpretation. The following sections summarise current understanding of these processes and the significant knowledge gaps therein.

The effects of increased inputs of fine sediment on marine ecosystems depend on the balance between, or relative rates of, sediment settlement/deposition, and resuspension, transport and flushing[29] (see Figure 6).

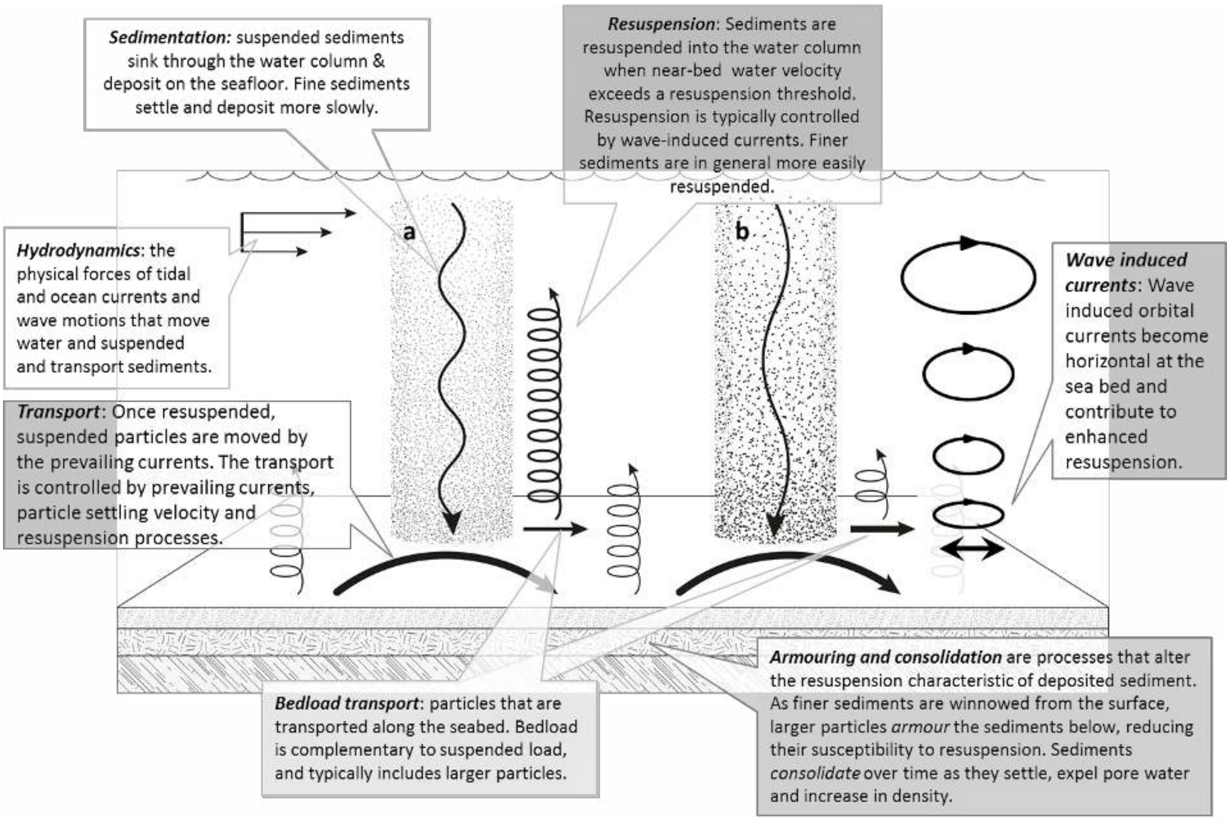

Figure 6: Conceptual illustration of important sediment dynamics processes in the Great Barrier Reef. Sediment column (a) shows fine "cohesive" sediment (particle size <63 µm), which can aggregate, (b) shows "non-cohesive" sediment of generally larger particle size.

Rates of sediment deposition and transport depend on numerous factors, including the supply of suspended sediments, their particle sizes, particle-to-particle interactions, the properties of the ambient seabed, and the local metocean conditions. Biological processes, such as bioturbation by burrowing animals, vertically mix sediment layers and may increase resuspension if fine sediments are brought to the seafloor surface. The significance of bioturbation to sediment mixing in the Great Barrier Reef is poorly documented[46], but may be important in some circumstances.

Different sizes of sediment particles are subject to different physical processes. For example, 'cohesive' particles are primarily clays (<2–4 µm diameter, depending on classification system[47]) and silt (<63–75 µm), often mixed with organic matter, while 'non-cohesive' particles are primarily sand and larger-sized materials (>63 µm) [48]. Transport and deposition of cohesive particles is primarily controlled by advection, dispersion, aggregation, settling, consolidation, and erosion, while transport of non-cohesive particles is controlled by advection, dispersion, settling, armouring, and transport in suspension and along the seabed as 'bedload' [49]. These generic sediment transport processes require site-specific information on; for example, grainsize distribution of the dredged material, settling rates, resuspension thresholds and potential consolidation rates. In addition, reliable field measurements of hydrodynamic parameters and a detailed bathymetry are needed before any meaningful predictions can be modelled, as part of the development of an effective dredging and spoil disposal management plan.

Sediment transport is mostly northward along the coast, driven by residual currents and the prevailing south-east trade winds, with much of the fine sediments eventually trapped in north-facing bays[50]. Tropical cyclones have the potential to carry coastal sediments further offshore[43] and also influence the formation of distinct cross-shelf zones with fine sediments mostly restricted to the inner and inner-middle shelf of 0 to 20 m depth, at least in the central Great Barrier Reef[51,52]. Overall, longer term fine sediment transport processes in the Great Barrier Reef are not well quantified.

Surveys of large areas of the seabed of the Great Barrier Reef lagoon[53] show a wide range of sediment types in the coastal and interreefal areas (see Figure 7). Within this broader picture, there is considerable spatial variation at local scales in the dispersive or retentive characteristics of the seabed in relation to fine sediment, depending on coastline features (bays compared to promontories), bathymetry and hydrodynamics. At present there is insufficient understanding of the temporal and spatial variability of sediment retention and dispersion processes within the various ecosystems of the World Heritage Area, and the influence of extreme conditions such as major storms or tropical cyclones on these processes. Addressing that knowledge gap will be facilitated by the eReefs project, which is currently developing and applying Great Barrier Reef-scale models of hydrodynamics, sediment transport and biogeochemistry[d].

[d] For more information see: www.emg.cmar.csiro.au/www/en/emg/projects/eReefs/Overview.html

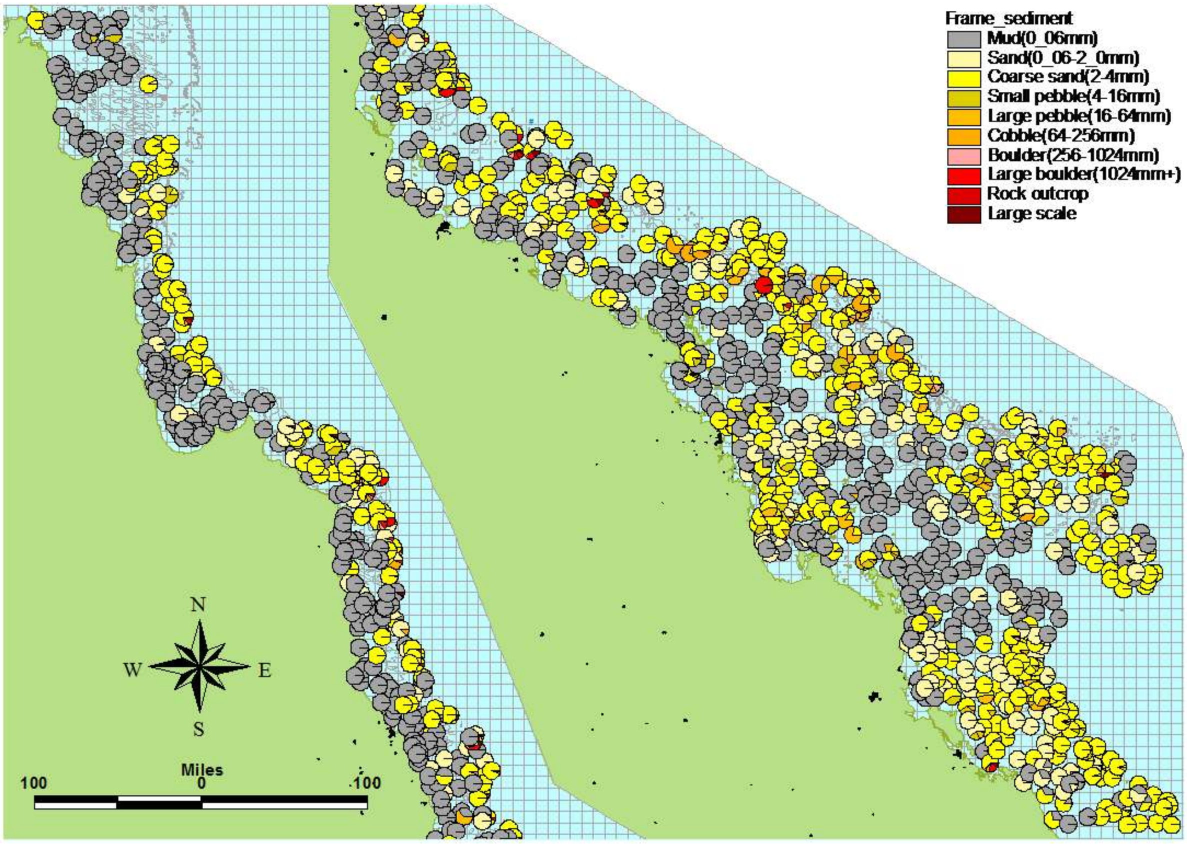

Figure 7: Distribution of sediment sizes in Great Barrier Reef seafloor
Map is split into northern (left) and southern (right) areas. Courtesy of CSIRO/AIMS/QDPI/QM Seabed Biodiversity Project[53].

A key knowledge gap, hindering understanding of sediment dynamics generally and dredging impacts specifically, is a means to accurately measure net sediment deposition rates within sensitive ecosystems over appropriate time frames. While research to develop methods and sensors is currently underway[e], there is currently no technique that can be deployed over the large spatial scales required for dredge monitoring programs. The available techniques in shallow marine environments have been recently reviewed[54,55] and by far the most common technique has been the use of sediment (settling) traps, which have become standard tools for describing sedimentation rates on reefs and in laboratory experiments[56]. There are, however, problems associated with using sediment traps to quantify the vertical flux (deposition) of material. These problems have been discussed and reviewed many times in different fields of marine research (see e.g.[57,58,59,60,61] and most recently in relation to coral reef studies[54,56,62,63]). Essentially, sediment accumulating in traps has a lower chance of resuspension than sediment settling on the adjacent seabed and traps therefore provide an estimate of gross rather than net sedimentation rate[64]. This effect is

[e] E.g. research currently underway in the dredging research hub of the Western Australian Marine Science Institution, www.wamsi.org.au/dredging-science-research-node-projects

more pronounced at flow speeds >10–20 cms^{-1}, which is typical of coral reef environments[27,65,66] and suggests that sediment trap data should be interpreted with care[56].

Fate of dredged material

To evaluate potential impacts of dredging on the World Heritage Area, it is critical to understand the long-term fate and transport of fine material (i) disturbed from the dredge site, including dredge overflow; (ii) released during disposal; and (iii) resuspended from the dredge material disposal area. Technically, maintenance dredging does not generally add new sediments to the system; rather, it releases/remobilises sediments that are subsequently available for further resuspension and transport. During capital dredging campaigns, deeper excavation releases sediment previously not available to resuspension, and rock or other hard substrate may be broken up into smaller material to enable excavation and extraction.

Some members of the Expert Panel considered that dredging has contributed to the long-term siltation[70] of the inshore Great Barrier Reef, at least locally and potentially at larger scales through ongoing resuspension and transport. However, others disagreed, considering that contribution highly unlikely. Irrespective, the extent of the contribution of sediment mobilised by dredging to the overall fine sediment budget of the Great Barrier Reef has not been assessed; Section 1.4 attempts a simple quantitative comparison using existing information (and a range of assumptions).

The degree to which such resuspension and dispersal of dredged sediments contributes to or increases ambient or background resuspension of fine sediment from the seabed will depend on a complex interplay of many factors: (i) the composition of the dredge material, particularly the proportion of fine sediments. Dispersal of clay particles may be reduced by aggregation into clumps which settle quickly. Conversely, organic-rich fine sediments can aggregate/flocculate, stay in suspension longer and be dispersed farther; (ii) metocean conditions at the dredging and disposal sites, including 'typical' and extreme conditions such as calm, strong south-easterlies, and cyclone conditions, which may resuspend and disperse the disposed sediment (but also the surrounding seafloor sediments over large areas); (iii) consolidation or compaction of the sediment; (iv) 'armouring' by coarser particles, due to the winnowing out of fine materials from the surface layers and (v) biological colonisation and stabilisation (microbial mats, seagrasses and other benthos) and bioturbation (vertical mixing of sediment layers by burrowing animals, potentially bringing fine sediments from deeper layers to the surface).

Longer term fine sediment transport processes are not well quantified in the World Heritage Area (see above). Timescales, over which freshly deposited material from dredging and disposal will continue to be resuspended and transported until consolidation (see e.g.[43]), are likely to vary considerably between disposal sites depending on the site-specific conditions (above). Settling behaviour of fine sediment from dredging plumes has been investigated in the US and Europe[67,68,69]. Although there is information from tropical Australia, much of this is unpublished, and sediment dynamics, including the longer term transport and fate of disposed sediments, are poorly understood and an area of active research[f].

Because all of these factors will vary greatly in time and space with different locations, it is not possible to provide a general conclusion. Rather, careful location and circumstance specific assessment (supported by modelling) is required to predict the long-term contribution of dredging to turbidity and sedimentation in the context of natural and river-based background levels. In all large-scale dredging programs in Australia, the site selection of disposal grounds is given careful attention, as per regulatory requirements[9].

Monitoring effects of dredging on sediments

Two issues make it particularly difficult to quantify the effects of dredging on sedimentation rates and turbidity:

- The difficulty of predicting and measuring biologically relevant rates of net sedimentation, described above.
- The difficulty of distinguishing suspended sediments, turbidity or sedimentation due to ongoing resuspension from dredging activities from those due to river inputs and those due to background, historically accumulated sediments.

As a consequence, comparisons of sedimentation and turbidity levels with control sites need to be undertaken very cautiously to avoid confounded comparisons. In most recent dredging projects in Gladstone and Western Australia, there have been comparisons with pre-dredging data at the same site as well as comparisons with multiple control sites, selected to have the most similar water quality characteristics (determined beforehand through statistical analysis of baseline data of at least one year[8,70]). However, data from these projects are largely not yet in the public domain; the Expert Panel suggested that such data should be publically accessible, collected at large spatial scales, and that baseline monitoring of one to two years will provide better foundation for management.

Major capital dredging campaigns in the Great Barrier Reef (and many maintenance dredging campaigns) have been required, as part of approval conditions, to monitor turbidity or suspended sediments (as total suspended solids or TSS), often as part of reactive monitoring programs[3]. These included requirements for baseline data collection and the use of trigger values to assess compliance as part of an adaptive management plan[71,72,73]. If these trigger values were exceeded, dredging operations would have to be modified in order to prevent sublethal or lethal effects on sensitive biological receptors (mostly coral[73]).

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[f] E.g. research currently underway in the dredging research hub of the Western Australian Marine Science Institution, www.wamsi.org.au/dredging-science-research-node-projects

Ecologically relevant light trigger values for seagrass[74] (see also Section 2.2) have recently been applied in the adaptive management of the dredging associated with the Western Basin Port development in Gladstone Harbour[g]. Monitoring of turbidity and/or suspended sediment during dredging operations has improved in recent years (e.g. during the recent Gladstone Harbour expansion and in Western Australia). However, historical monitoring data for the World Heritage Area were limited in time (generally not extending long beyond the dredging campaign), and space (e.g. transects in the general vicinity of the dredging and, for capital dredging, selected potential impact and reference (control) sites away from the dredging site and disposal area).

For this synthesis, comparison and assessment of available water quality monitoring data was hampered because most data collected during dredging operations in the World Heritage Area constitute proprietary data that are not publicly available. Data were only readily available in summary form, often dispersed over multiple (e.g. monthly[h]) compliance monitoring reports. The ability to interpret these data in the context of background turbidity/suspended sediments was also limited as there are very few long-term and large-scale data available. The latter issue will improve in the future, with detailed analyses of regional water clarity currently underway[45], and longer term site-specific time series now available[75,76]. Synoptic Great Barrier Reef-scale data for suspended sediments from remote sensing (as non-algal particulates, NAP) are produced in near-real time as part of the new eReefs Marine Water Quality Dashboard[i].

The Expert Panel strongly suggests that future water quality monitoring campaigns should be peer-reviewed at design and reporting stages as a matter of course, and that data associated with dredging campaigns in the World Heritage Area should be collected and reported in a standardised way and the data lodged in a central, publicly accessible repository that would allow researchers, as well as practitioners and regulators, to undertake targeted, comparative analyses.

Monitoring of light and turbidity (as a surrogate for suspended sediments) during capital and maintenance dredging campaigns in the World Heritage Area confirms the effects of dredging, but indicate that potential effects are very specific to different projects (and struggle to distinguish dredge-related and other causes of suspended sediment). An early study[77] during maintenance dredging of the access channel to the Port of Townsville showed that in calm conditions, the resuspended fine sediment settled quickly, while in turbulent conditions a 1– 2 m thick turbid layer formed near the seafloor. This layer, which comprised

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[g] www.environmetrics.net.au/docs/Light%20Based%20Management%20Approach%20for%20Dredging%20-%20QA.pdf

[h] e.g. www.westernbasinportdevelopment.com.au/environmental_reports/section/environmental

[i] www.bom.gov.au/marinewaterquality/

both dredged and naturally resuspended sediments, was transported away from the disposal site by currents[78] (the previous disposal site was relocated to the current designated area as a consequence). During monitoring of two capital dredging campaigns for the Port of Townsville in 1993 and 2012/13, dredge effects could not be conclusively distinguished from high background turbidity during high turbidity events at Cleveland Bay and at Magnetic Island monitoring sites. Background turbidity at these sites varies considerably with metocean conditions, and is intermittently high[79,80].

During and after the 2006 Hay Point capital dredging campaign (including disposal of dredged sediment), suspended sediment concentrations were significantly increased at two islands north and south of the dredging area and disposal site, causing frequent exceedance of the compliance trigger level of 100 mgL^{-1} [72] (for comparison, the Great Barrier Reef water guideline for open coastal and mid-shelf waters of the Great Barrier Reef lagoon is 2 mgL^{-1} suspended sediment, based on an annual average[81]). Analysis of long-term turbidity data in the Gladstone region showed that sites close to the recent dredging campaign in the Western Basin had significantly higher turbidity during dredging periods, whereas turbidity at sites further away was not statistically different between dredging and non-dredging periods[82]. Analysis of turbidity data associated with the same dredging program found that dredging led to localised increases in turbidity[83]. Plumes with elevated turbidity (>10 NTU[j])[84] during maintenance dredging at the Port of Cairns were generally confined to within tens to several hundreds of metres from the dredge location and were visible on the surface for up to approximately two hours after formation[85,86] (note that surface and subsurface plumes may differ significantly). However, it is difficult to critique these analyses of data-rich time series from water quality instruments, as the statistical approaches are often not fully described.

Appropriate sediment transport models (see below) are valuable tools to track the fate of sediment inputs, as they use descriptions of physical processes rather than empirical data, and they have the potential to track sediments from different sources. This could be augmented with field data, for example, by measurements of the stability of the dredged material in the disposal area and its topography.

Modelling short and long-term sediment dynamics

Computer modelling of physical oceanographic processes assists with prediction and interpretation of sediment dynamics, but these models depend on adequate understanding of those physical processes under the full range of metocean conditions, spanning

[j] the Queensland Water Quality Guideline value for turbidity in enclosed coastal and estuarine water bodies is 10 NTU in the Wet Tropics region and 6 and 8 NTU, respectively, in the central coast region.

appropriate timescales for long-term transport processes. In many cases, there is a trade-off between complexity and availability of the process parameters incorporated into the models.

In some cases, previous modelling of predicted sediment plumes may have underestimated the dispersal of sediments, due to spatial and temporal limitations of modelling studies, and thus underestimated the full extent and potential magnitude of potential impacts. Comparison of predicted versus measured suspended solids at sensitive receptors to the north and south of dredging at Hay Point demonstrates that suspended sediment was underestimated, in particular at the southern site[72]. This was partially attributed to the metocean conditions during the dredging differing to those applied in the modelling; the modelling assumed dominant winds from a south-easterly direction when for a period of the dredging winds from a northerly direction dominated. This case highlights the importance for modelling to include a range of possible metocean conditions. Conversely, model predictions of dredging projects in Western Australia[87] and Northern Australia[3] over the past decade often over-estimated the extent of dredging plumes due to their precautionary approach and conservative assumptions.

Modelling techniques are available to forecast short-term, local scale changes to sediment transport and turbidity due to future dredging and disposal operations, including dispersion from disposal areas. Model calibration and validation can improve the quality of model outputs, but this is hampered by the lack of empirical data (e.g. settling velocity of disturbed dredged material, resuspension and consolidation rates), which either do not exist or are proprietary data not readily available for scientific studies. The Expert Panel is strongly of the view that future environmental monitoring data associated with dredging campaigns should be collected and reported in a standardised way, include large scales, and the data lodged in a central repository that would allow for hydrodynamic and sediment transport models to be continuously improved.

The Great Barrier Reef Marine Park Authority has produced guidelines[k] for hydrodynamic and dredge plume modelling that are required to be followed by proponents undertaking impact assessment for dredging and disposal in the Great Barrier Reef. These specify the expected procedures, methods and frameworks and include requirements for duration and nature of baseline data collection, model calibration and validation, model resolution, outputs and peer review. Importantly, given the depth-stratified plumes often observed (e.g. Townsville, previous section[77,78]), the guidelines recommend three-dimensional modelling as best practice.

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[k] www.gbrmpa.gov.au/__data/assets/pdf_file/0018/26532/Guidelines-on-Hydrodynamics-Modelling-15-Aug-2012.pdf

The combined applications of large-scale models such as eReefs and more specific local models will allow determination of not just the immediate, direct effects of mobilised sediment, i.e. including resuspension and transport, but also the fate of materials over multi-year timescales, large spatial scales and including extreme metocean conditions. These models would also offer opportunities to look at scenarios of long-term changes in environmental conditions, such as sediment transport and turbidity, and how these are affected by various pressures in space and time, including dredging and dredge material disposal. However, such combined models are currently not available.

A recent study was commissioned by the Great Barrier Reef Marine Park Authority to investigate the long-term dispersal of disposed dredged material at a whole-Great Barrier Reef scale over 12 months, and to perform a sensitive receptor risk assessment of alternative and current dredge material disposal sites offshore from six ports adjacent to the World Heritage Area (Cairns, Townsville, Abbot Point, Hay Point, Rosslyn Bay, Gladstone[88,89,90]). The study was the first dredge material disposal investigation to encompass a large, contiguous section of the Great Barrier Reef and simulate the transport of disposed material over annual timescales. As a result, the study showed that disposed dredged material has the potential to travel for longer distances, and remain mobile over longer timescales than previously recognised. However, due to the technical challenges posed by the large spatial coverage and the tight project time frame, a number of simplifying assumptions were made in the models, including: no sediment resuspension due to wave shoaling and breaking in shallow areas, no sediment consolidation in deeper areas, and a simplistic and unverified method for incorporating the influence of regional Great Barrier Reef lagoon-scale circulation on the long-term (in this case 12 month) sediment transport. These assumptions were designed to be precautionary and conservative, but their combined impact on the simulated potential for sediment dispersal is not fully understood, and it is probable that the modelling results over-estimated both the total sedimentation in shallow areas and the spatial distribution and extent of disposed dredged material. In terms of creating a tool for assessing the broad implications of dredging over the entire Great Barrier Reef this study represented an improvement on previous short-term, locally focused studies that are typically undertaken to support dredging activities. The Great Barrier Reef-wide project was undertaken as a hypothetical, desktop comparative study between existing and alternate disposal sites with no opportunity for field validation, and hence was not intended to be compared to or replace the need for local focused studies to support dredging activities.

The Expert Panel identified critical gaps in the capability to predict long-term and large-scale sediment dynamics, including dispersal of disposed dredged material, and a need to better quantify and model sediment transport processes in the World Heritage Area.

1.4 Comparison of sediment inputs to the Great Barrier Reef from dredging and terrestrial run-off

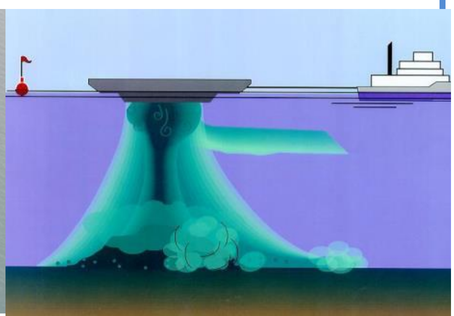
(Incorporates updated analysis as of March 2015).

Inputs of suspended sediment from rivers to the Great Barrier Reef are estimated to have increased by about 5.5 times to an average of ~17 million tonnes each year (total load of 35 river basins)[32] since European settlement. The increased suspended sediment affects water clarity[44,45] over much of the coastal and inshore areas. Of most concern are the fine fractions of the sediment, the clay and silt-sized particles. These particles settle slowly, are easily and repeatedly resuspended back into the water column by physical forces such as waves and currents, and can adversely affect benthic ecosystems such as seagrass beds and coral reefs (see review[25] and Section 2 of this synthesis).

Dredging and dredge material disposal has the potential to locally increase the mobilisation of fine sediment, in the vicinity of the dredging activity and at spoil disposal areas. We know with some certainty that the mobilised fine sediment will increase turbidity and sedimentation local to the activities, at least in the short term (previous section). The processes controlling the release and transport of dredged-derived fine sediment depend on a number of factors, most importantly the particle size distribution of the dredged sediment, and the local physical environment and conditions. The long-term consequences of increased fine sediment availability due to dredging are less certain (see Sections 1.1.–1.3 for more detail), and understanding these consequences requires understanding of the magnitude of contributions of fine sediments from other relevant processes, particularly inputs from the catchment and the 'background' or ambient resuspension.

Johnstone River discharging water with a high load of suspended solids, forming a visible turbid plume.

Dredged sediment being released at a disposal site, forming a turbid plume on the surface.



Sediment released from a hopper barge, forming plumes close to the surface and above the seafloor (Source: Applied Science Associates[91]).

The simple comparison detailed below has three main objectives:

- To provide a broader context for the amount of fine sediments potentially released by dredging and disposal;
- To illustrate that the amount of fine sediment from both sources changes greatly between years;
- To illustrate that human activity has altered the fine sediment availability.

However, the reader must understand that the comparison given here is an approximation that: (i) requires numerous assumptions (see Appendix B for details and data), and (ii) does not address important ecological aspects, such as the spatial distributions of sediment disturbances (i.e. whether they occur far away from or near a sensitive ecosystem), or the proportion of dredge sediments that are actually mobilised. Further, the analysis of projected dredging amounts is clearly only as current and valid as the source data; this analysis includes both data current in August 2014 and updated data provided in March 2015. For applications such as conclusively determining offset measures, more comprehensive assessments need to be undertaken. A small number of panel members questioned the validity of the overall comparison, while some others questioned the selection of data or specific assumptions for the comparison. However, overall, some panellists felt the comparison shown exaggerates the relative contribution of dredging, while others felt it was a significant under-estimate. Clearly, there is a need for more clarification of these issues, and the present comparison should therefore only be taken as a general indication of the context of sediment contributions from dredging and disposal, and not as a precise estimate.

For this comparison (Figure 8), we used the volumes of dredge material from 2000–2013 that were disposed in the marine environment of the World Heritage Area, or that are planned to be disposed in the future (see Figure 1; figures used were provided to GBRMPA at the time of compilation; some of these volumes may change with revisions to proposals and on-land disposal- Update March 2015: more current projected volumes were supplied by GBRMPA, as outlined for Figure 1). These volumes were converted to tonnes per year (but see notes below and in Appendix B Table B-6/7) and amounts of fine sediment calculated from available information about particle sizes in the dredged material. For this comparison, fine sediment is considered to include the silt and clay fractions[l].

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[l] *Note: The comparison above focuses on fine sediments, which we defined here as the silt and clay sediment fractions. There are a number of particle size classification systems which use different upper size limits for the silt fraction (between 45 and 75 µm). The available data on dredge material used limits between 60 and 75 µm or gave just a definition (e.g. 'silt') without stating a size range. River particle size data used <62 µm for the silt and clay fractions. Freshwater hydrologists considered this particle size class as 'suspended sediment', while hydrodynamic and sediment transport modellers refer to it as 'cohesive sediments' as these fine particles settle more slowly, are more easily resuspended and can form organic aggregates that allow for transport over 100 kilometres away from their initial source (see also Section 1.3).*

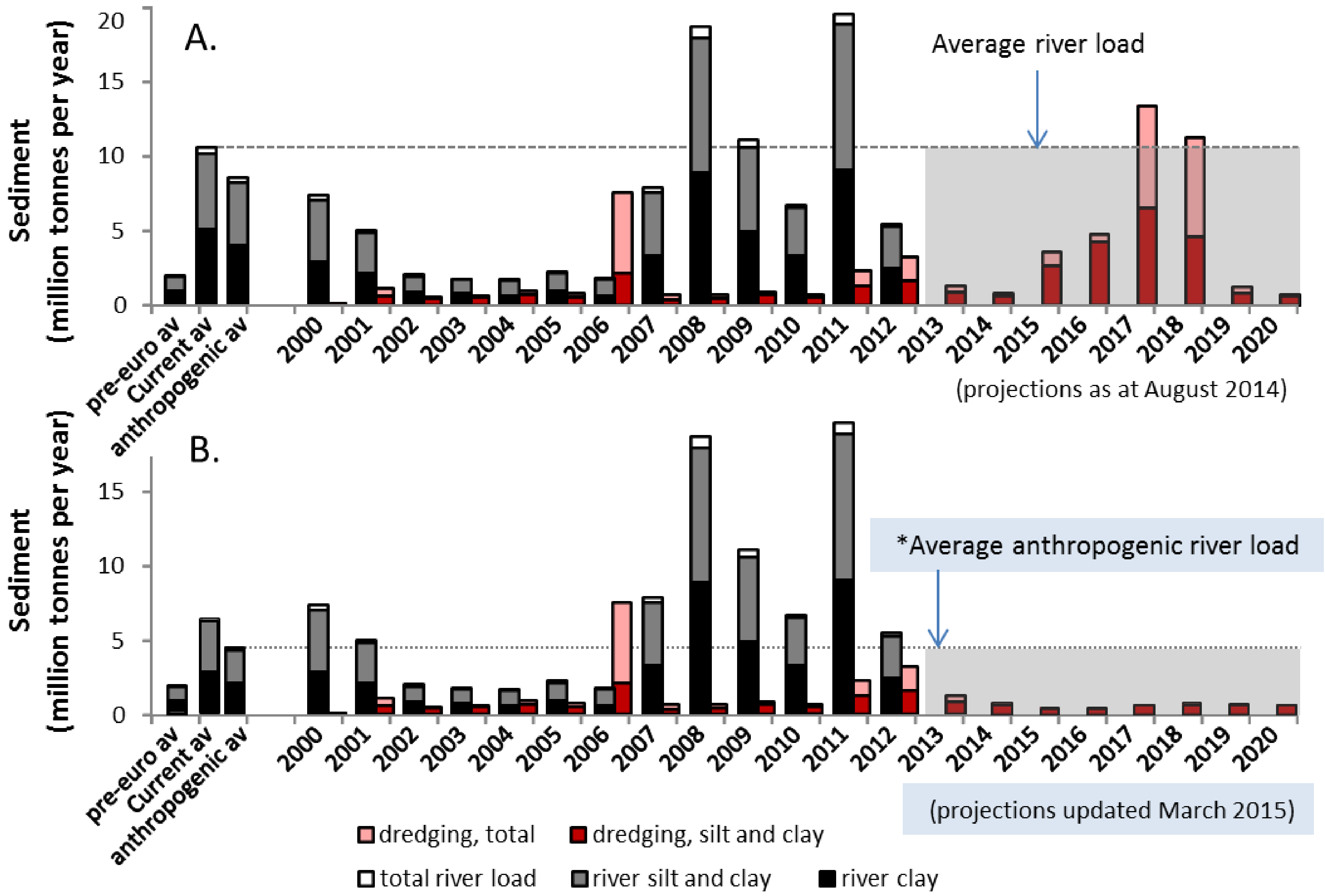

Figure 8: Comparison of estimated total and fine sediments from rivers (black/grey/white) and dredging (red).
Update March 2015: Graph A uses data including projected dredge amounts current at August 2014, based on proposals before the government at that time; Graph B uses updated projections for dredge disposal provided by GBRMPA in March 2015 which include no marine disposal of capital dredged material; see explanation at Figure 1 for further detail.

(i) Bars on left-hand side show estimated pre-European river loads, average load and estimated average anthropogenic load for comparison. As river amounts into the future are unknown, average amounts are indicated by grey area in Graph A – see Appendix B for data sources. In addition to updated dredge forecasts, new estimates of river loads are available since August 2014 [m]; these are included in Graph B. In Graph B, grey area indicates average anthropogenic river load, rather than overall average, to clarify comparison of human contributions with dredging. *Although not shown here, catchment modelling[m] has indicated that the long-term average anthropogenic river loads (for the period 1986-2009) are decreasing due to the adoption of improved land management practices. (ii) Estimated sediment loads (million tonnes per year) from 10 major rivers draining into the Great Barrier Reef between Cairns and Bundaberg (2000–2012): black bars: clay-sized fraction; grey bars: silt-sized fraction; white bars: other fractions of total suspended sediments – see Appendix B for data sources. (iii) Amount of dredge material disposed in the World Heritage Area (million tonnes per year) from 2000–2013, and future forecast (2014–2020): dark red bars: silt and clay-sized fraction; light-red bars: other fractions of total disposed sediments – see Appendix B for data sources. Notes: a) an unknown but significant proportion of dredged sediments will not be available to the ecosystem; b) conversion factors for dredge volume to weight used in other studies would make the dredge amounts as much as two-fold higher (discussion in Appendix B).

It must be emphasised that this comparison is intended to provide broad context for dredging and disposal only and that sediment released to the broader ecosystem will only be a proportion of these amounts; the comparisons should not be interpreted beyond that context.

Disclaimer: *Actual disposal volumes (2000-2013, capital and maintenance) were collated based on annual reporting requirements to the Great Barrier Reef Marine Park Authority and the Department of the Environment (as part of annual reporting requirements to the International Maritime Organisation under the Sea Dumping Act) and on historical disposal information provided by port operators. Maintenance dredge disposal volumes forecasted for future years were based on historical averages of actual disposal volumes supplied to the Great Barrier Reef Marine Park Authority and the Department of the Environment. Where increase in future maintenance dredging is anticipated as a result of capital expansion, forecasts are based on publicly available information contained in proposals referred under the EPBC Act as of 25 August 2014. Capital dredge volumes forecasted for future years were based on publicly available information contained in proposals referred under the EPBC Act as of 25 August 2014. They reflect the proposed volume to be disposed. Update March 2015: Current forecast is that no capital dredge material is disposed in the marine environment, resulting in the significantly reduced forecast amounts shown in Graph B. Particle size distribution information is based on Sample and Analysis Reports provided to GBRMPA in accordance with the National Assessment Guidelines for Dredging.*

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[m] Waters, DK, Carroll, C, Ellis, R, Hateley, L, McCloskey, GL, Packett, R, Dougall, C, Fentie, 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR*, Technical Report, Volume 1, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland (ISBN: 978-1- 7423-0999) p 120.

In a similar way, suspended sediment loads and particle size information for ten major Great Barrier Reef rivers (Cairns to Bundaberg, 2000–2012) were used to estimate fine sediment loads from these rivers in tonnes per year. These ten rivers deliver about 62 per cent of the total current suspended sediment load from all 35 river basins to the World Heritage Area; the average total load is 17 million tonnes per year (based on data[32]; alternative data being published[92]).

Fine sediment delivered from 10 major Great Barrier Reef rivers from Cairns to Bundaberg varies substantially between years, reflecting variability in rainfall, catchment run-off and groundcover (Figure 8, black, grey and white bars). In the 12-year period assessed, loads ranged from 1.8 to 19 million tonnes per year. The estimated current average fine sediment load from these 10 major rivers is about 10 million tonnes per year[32]. In comparison, the natural (i.e. pre-European settlement) fine sediment load from the same 10 Great Barrier Reef rivers (i.e. from undisturbed catchments) is estimated to have been substantially lower, i.e. about 2 million tonnes on average per year, while the average anthropogenic load (i.e. due to human activity in the catchment) is about 8 million tonnes[32]. Update March 2015: A more recent estimate of current average fine sediment load from these rivers is about 6 million tonnes per year, natural fine sediment load about 1.8 million tonnes, and the anthropogenic load about 4.2 million tonnes[m].

Total amounts of disposed fine sediment from dredging ranged from 89,000 to 2.2 million tonnes per year from 2000–2013 (Figure 8A red bars), with more substantial disposal volumes in the Great Barrier Reef projected for the future. The total amount of fine dredge material disposed in the Great Barrier Reef in 2006 was about 2 million tonnes, in the same order of magnitude as the estimated average pre-European fine sediment load from Great Barrier Reef rivers from Cairns to Bundaberg. While the suspended sediment load in river plumes is typically dominated by already suspended fine sediments with >90 per cent silt and clay fractions, dredged material (especially from capital dredging) usually consists of a mixture of different particle size fractions, including a considerable proportion (often >50 per cent) of coarser sands (Figure 8).

Update March 2015: the updated projections for future disposal of dredged fine sediments (Figure 8B) are clearly considerably less than in the earlier analysis, ranging from 350,000 to 620,000 tonnes per year. For context, these are approximately 5 to 10 per cent of the estimated average river load, or about 18 to 33 percent of the natural (pre-European) river loads (based on updated river load estimates), and similar in magnitude to the estimated reductions in river loads through Reef Plan as at 2013[n].

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[n] Great Barrier Reef Reef Water Quality Protection Plan Report Card 2012 and 2013: Catchment pollutant loads results. www.reefplan.qld.gov.au/measuring-success/report-cards/assets/gbr-report-card-12-13-catchment-pollutant-loads.pdf (viewed 12 March 2015)

It must be emphasised that this comparison is only intended as broad context for dredging and that dredge amounts released to the broader ecosystem will only be a proportion of these amounts; the comparisons should not be interpreted beyond that context.

A key assumption of the comparison involves the conversion of dredge material estimates from volumes in in situ cubic metres, to weight in tonnes. The comparison in Figure 8 uses conversion factors of 0.7 to 0.8 tonnes per cubic metre in situ (Appendix B, Table B-6), based on dredge records from a range of Great Barrier Reef ports[89]. However these factors are very low, and other comparisons have used values more than twice as high (see discussion in Appendix B, Table B-6/7). Using those values would more than double the relative contribution of dredging in Figure 8.

It is also important to emphasise that these figures are estimates of the amount of fine sediment placed in the marine environment, but for dredging it is not known how much of that fine sediment is actually available for resuspension, especially over long time periods. During disposal, a major portion of the dredged material ('dynamic plume') directly settles on the seafloor underneath the vessel or barge, and only a relatively small amount of the finer material becomes available in the water column ('passive plume')[93]. Some proportion of the settled fine sediment will be buried or otherwise unavailable, even in the very long term (including reworking by storms, etc.), so these figures represent an *estimated** upper limit on dredge material available for resuspension (*notwithstanding other uncertainties involved in the estimate). In reality, this will depend on metocean conditions and the nature of the dredged material, amongst other factors.

Longer term fine sediment transport processes are not well quantified in the Great Barrier Reef (see Sections 1.1–1.3 above). Timescales over which freshly deposited material from dredging and disposal will continue to be resuspended, until it is rendered unavailable for further resuspension and transport (see e.g.[43]) are likely to vary considerably between disposal sites depending on the site-specific metocean conditions, hydrodynamics and water depth.

In terms of potential contributions of mass of fine sediment, the comparison above of river loads and disposed dredge material shows that, in years with large capital dredging activities, dredging-derived amounts are similar to river loads during low flow years. Orpin and Ridd[30] argue that resuspension of bottom sediment, and not flood plumes, is the dominant process controlling inshore fine sediment dynamics, and calculations based on Larcombe et al.[27] suggest that, within Cleveland Bay (approx. area 200 km^2), resuspension due to wind waves is likely to episodically resuspend at least 2,000,000 tonnes annually[o].

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[o] Calculation of mass based on a resuspension event with total suspended solids of 50 mg/l, over an area of 200 km^2, to a depth of 8 m, occurring 25 times per year.

Scaling this local resuspension estimate up to a regional estimate is difficult, but simplistic extrapolation based on areas would suggest the total shelf-scale resuspension is likely to be orders of magnitude larger. This greatly exceeds the estimated potential mass of fine sediment from dredge material disposal activities. However, the material that is resuspended during a wind event is already a dynamic component of the shelf sediment budget, whereas the majority of sediments delivered from (capital) dredging would otherwise be unavailable for resuspension due to their depth of burial (except under very extreme conditions). Therefore, the majority of fine sediment produced from dredging can be considered as 'new' material and, as with new sediment from rivers, has the potential to significantly affect turbidity[44]. Fabricius et al.[44] suggest that the timescale of winnowing or consolidation of newly imported materials, and therefore the potential longevity of their impact on turbidity, light availability and sedimentation, is of the order of months to years.

1.5 Nutrients, organic matter and potential contaminants in sediment that is being dredged and disposed

Organic matter mobilisation

Sediment disposal after dredging represents an additional input of organic matter into the inshore Great Barrier Reef lagoon budget (assuming the budget area does not include the estuaries). After disposal, some of the organic matter in this material will decompose consuming oxygen and releasing dissolved inorganic carbon (DIC, which includes CO_2, a greenhouse gas), nitrogen and phosphorus, while some of the organic matter will be permanently buried. The released DIC will contribute to the decreasing pH (increasing partial pressure of carbon dioxide, pCO_2) in the Great Barrier Reef lagoon due to ocean acidification, although the contribution will only be small. The released nutrients will be recycled as detailed below. The cycling of organic matter will be ongoing and will continue away from the initial dredge disposal site as particulate material is resuspended, transported and deposited (see Figure 6). Dredging could contribute as much as 5,000 to 100,000 ty^{-1} of organic carbon into the inshore Great Barrier Reef lagoon carbon budget (Table 3). It should be noted that the inputs due to capital dredging will not be regular annual inputs, but will only occur during the period of operation.

Nutrient mobilisation

Inshore Great Barrier Reef sediments and pore waters generally have higher nutrient stocks than the overlying water column[94]. These are derived from organic matter from marine biota, as well as from terrestrial sources in inshore areas[31,95]. These nutrients can be recycled to the water column by diffusion across the sediment-water interface, by bioirrigation (advection) and by pore water and particulate resuspension. Resuspension of these sediments may release significant amounts of nutrients into the water column[94], especially after extreme weather events such as cyclones[96,97].

Disposal of dredged sediment represents an additional input of nutrients into the inshore Great Barrier Reef lagoon nutrient budget (assuming the budget area does not include the estuaries). As the Great Barrier Reef is generally oligotrophic, relatively small additional nutrient inputs are a significant concern. While sediment nutrients are already present in the system, sediment disturbance by dredging and sediment disposal will mobilise particulate nutrients and release dissolved nutrients that are otherwise contained within the sediments and pore waters and potentially increase the nutrient availability at a local scale.

After deposition, there will be ongoing release of nutrients to the water column from the disposal site, although a proportion of the nutrients contained in the disposal mound will also be permanently buried and some nitrogen will also be permanently lost to the atmosphere as nitrogen gas via denitrification and anaerobic ammonium oxidation (anammox)[98]. It is unknown what proportion of nutrients will be released to the water column and what proportion will be lost to the atmosphere or buried. The permanent loss/release ratio will vary due to similar factors that control the fate of dredge spoil (see Section 1.3) and biogeochemical processes in the dredge spoil. This biogeochemical cycling of nutrients will be ongoing and will continue away from the initial dredge disposal site as particulate material is resuspended, transported and deposited (see Figure 6).

Although initially the Expert Panel considered the potential effects of nutrients released or mobilised during dredging and sediment disposal operations were likely to be minor, subsequent calculations by panel members (Table 3) suggest this may not be so. As for sediments, the amount of nutrients released will depend greatly on the proportion of disposed dredge material which is permanently buried or unavailable (Section 1.3); this proportion is not clear, so only the amounts present in the total material dredged and disposed can be estimated. Based on available evidence (e.g. [15], Table 3), projected capital and maintenance dredging combined could contain as much as 500 to 10,000 tonnes of total nitrogen per year and 250 to 5,000 tonnes of total phosphorus per year, with an unknown proportion available to the inshore Great Barrier Reef lagoon nutrient budget. The projected estimate of nitrogen in dredge sediments (2014 to 2020) ranged from around 1.5 to 30 per cent of the anthropogenic load of nitrogen from rivers, with the upper limit more than the pre-European river load. The projected estimated amount of phosphorus in dredge sediments (2014 to 2020) ranged from around 3 per cent to 60 per cent of estimated anthropogenic load from rivers. However, as discussed above, not all this nitrogen and phosphorus would be released. Some panel members questioned the validity of assumptions underlying the calculations.

March 20-15 update: the significant reductions in projected volumes of future dredge disposal in the marine environment clearly also significantly reduce the estimates of nutrients present in that material (Table 3 update column). Projected dredging disposal could contain as much as 300 to 600 tonnes of total nitrogen per year and 150 to 280 tonnes of total phosphorus per year, with an unknown proportion available to the inshore Great Barrier Reef lagoon nutrient budget. The projected estimate of nitrogen in dredge sediments ranged from around 1 to 2 per cent of the anthropogenic load of nitrogen from rivers, or about 4 to 8 per cent of the pre-European river load. The projected estimated amount of phosphorus in dredge sediments ranged from around 2 to 3 per cent of estimated anthropogenic load from rivers, or about 18 to 32 per cent of the pre-European river load (concerns of some panel members about the original calculations also applied to these updated calculations).

Table 3: Comparison of projected nutrient content in dredged sediment with inputs from rivers.
Data for rivers[32], totalled over the same 10 main rivers as used in sediment comparison (Appendix B). Nutrient content of dredged sediments were estimated from the range of projected sediment amounts (Appendix B, Table B-7; 2014 to 2020) scaled by estimated nutrient concentrations as follows: 750 mg/kg for nitrogen based on range of data[99,100,101]; 350 mg/kg for phosphorus, based on range of data[99,100,101]; and for carbon at 7,368 mg/kg[100].
Figures are indicative estimates only, with an unknown proportion of dredging amounts available to the inshore Great Barrier Reef lagoon nutrient budget.

It must be emphasised that this comparison is intended to provide broad context for dredging only; the comparisons should not be interpreted beyond that context.

		Tonnes per year (August 2015)	Update March 2015: Tonnes per year
Total nitrogen	Rivers: Pre-European	7,191	
	Rivers: Current	41,030	
	Rivers: Anthropogenic	34,190	
	Dredging, maintenance only	<850	300-600
	Dredging total	500–10,000	
Total phosphorus	Rivers: Pre-European	867	
	Rivers: Current	9,306	
	Rivers: Anthropogenic	8,548	
	Dredging, maintenance only	<400	150-280
	Dredging total	250–5,000	
Total carbon	Rivers: Pre-European	*Not available*	
	Rivers: Current	*Not available*	
	Rivers: Anthropogenic	*Not available*	
	Dredging, maintenance only	<8,000	3,000-6,000
	Dredging total	5,000–100,000	

A study of sediment nutrients during dredging in the Port of Singapore showed that ammonium and nitrite in sediments decreased during dredging, while nitrate and organic carbon sediment concentrations increased. These changes were correlated with grainsize changes due to dredging and indicated that inorganic nutrients were released with mobilisation of the fine sediment fraction[102]. About one month after cessation of the dredging, sediment nutrient concentrations and grainsize distribution returned to pre-dredging levels. Increased concentrations of phosphate and ammonium released during disposal of dredged material from the Peel–Harvey estuary were confined to within 100 m of the disposal site, but ammonium concentrations remained elevated for about four days[103]. Another estuarine study during a small-scale dredging operation, albeit with coarse-grained sediments in a salt marsh, also demonstrated localised increases in water column nutrients for periods of hours to days[104]. This study recommended combining measurements of nutrient concentrations and currents to estimate nutrient flux rates as a more ecologically relevant measure, especially if the background fluxes are well understood, to provide a system-level perspective (for example, oligotrophic versus enriched, or highly variable versus more stable water quality, which may result in different effects of the same load of released nutrients).

Dissolved nutrients from any source are rapidly taken up by planktonic organisms and converted to organic matter[105], which combines with fine suspended sediment to form organic aggregates that change the properties and likely influence the fate of fine suspended sediments[41]. One consequence of this rapid processing is that inputs of nutrients may generate increased turnover without resulting in measurable increases in dissolved nutrient stocks.

The National Assessment Guidelines for Dredging[9] and current practices in the Great Barrier Reef do not require analysis of nutrients in sediments pre-dredging, although some recent dredging operations have included sediment nutrient analysis[15]. Some members of the Expert Panel suggested that sediment nutrient analysis (and perhaps elutriate testing) for the quantification of the contribution of released/mobilised nutrients should be part of assessments of large dredging projects or where there is a potential for high sediment nutrient concentrations, for example close to river mouths or nutrient point sources. Further, detailed biogeochemical measurements at dredge material disposal sites are suggested to determine the proportion of nutrients that are (i) released to the water column, (ii) buried, and (iii) lost to the atmosphere.

Contaminant mobilisation

Although considered relatively low in most Great Barrier Reef sediments, chemical contaminants are sometimes present in dredged sediments as a result of existing port, industrial, urban and agricultural activities on the adjacent land (see also discussion in Section 2.6). Where present, contaminated sediments are precluded from marine disposal under the National Assessment Guidelines for Dredging[9], which prescribes a stringent process of testing and management.

There are no recent broad-scale assessments of the distribution and concentrations of contaminants such as trace metals, organochlorine compounds and polyaromatic hydrocarbons (PAHs) in water, sediments and biota on the Great Barrier Reef. Such baseline data would be very useful. Data are available for pesticide concentrations in biota, sediments and water throughout the Great Barrier Reef[106,107,108]. Haynes and Johnson (2000)[16] concluded that concentrations of these contaminants were generally low in the Great Barrier Reef lagoon, apart from areas within ports and adjacent to intense urban, industrial or agricultural activity in the catchment. This view is supported by recent research on contaminant concentrations in Port Curtis (Gladstone) and surrounding coastal waters[109,110,111]. Elevated nickel and arsenic concentrations in sediments are found in some regions but are a consequence of local geological formations rather than anthropogenic inputs[109].

Sediment-bound contaminants (both organic and inorganic) could potentially desorb during the dredging process or when sediment is entrained in plumes associated with the dredging and disposal operations. However, this is unlikely to be a major issue with dredging, as studies have shown that metals that desorb from disturbed sediment (e.g. by dredging) tend to bind to clays and particulate iron fairly rapidly[112]. This is supported by findings from Gladstone Harbour[83], which found very few statistically significant relationships between concentrations of dissolved metal and turbidity.

A recent study[113,114] found evidence of polynuclear aromatic hydrocarbons (PAHs) from coal residues in sediments across the continental shelf in the vicinity of Hay Point. However, it appears that the levels are an order of magnitude below those indicated in the relevant guidelines.

Impact assessments for dredging operations require analysis of sediment samples for contaminants, as prescribed by National Assessment Guidelines for Dredging[9] (unless sufficient information is available from previous assessments). Capital dredging projects in Great Barrier Reef ports rarely involve sediment with significantly elevated concentrations of contaminants; however, surface layers in some inner harbour areas may contain contaminants from port and industrial activities or catchment influences, such as urban stormwater. Most contaminant issues in subtropical or tropical ports are associated with maintenance dredging, for example of inner harbour areas with contaminated sediment as a result of port activities such as run-off or spillage from wharves, and of existing shipping channels that may contain residues of oil and grease, tributyltin or other compounds used in antifouling paint.

Sediments that exceed contaminant thresholds prescribed in the NAGD[9] are required to undergo further testing, including bioavailability and toxicity testing. If the sediments are found to be toxic, at-sea disposal is not permitted and the sediments must be disposed on land under strict conditions. If the sediments are found to be non-toxic, or contaminant levels do not exceed the High levels in NAGD, sea disposal is allowable.

Sediments containing potential acid-sulphate soils (PASS) are common in estuarine and coastal areas of the World Heritage Area[115]. If PASS are dredged and disposed on land, specific management techniques need to be adopted to avoid water quality impacts caused by the oxidation of iron pyrite present in these soils (e.g. production of sulphuric acid and the release of toxic quantities of iron, aluminium and trace metals) should such material be placed on land and exposed to air. The best way of preventing acid formation is to prevent drying and aerial oxidation by keeping the sediments immersed in water. The independent review of the Port of Gladstone[116] concluded that disposal of PASS-containing sediments in the marine environment is unlikely to result in significant oxidation of this sediment, hence reducing the potential to produce acid or release significant quantities of trace metals (where present) into the water column. More research is needed to fully understand the risks associated with PASS.

The Expert Panel considered the current guidelines[117] to be robust and fit for purpose for sediment contaminants. The Great Barrier Reef water quality guidelines[81] should be applied for chemicals not covered by the sediment quality guidelines. The ANZECC guidelines for toxicants in waters and sediment are currently under revision, based on the latest research. The revisions will include guideline values for dissolved aluminium and manganese in marine waters[118].

2. Effects on biodiversity of pressures from dredging and disposal

This section considers the effects of the dredging related pressures outlined above on specific habitats and biodiversity values. The Expert Panel explicitly considered the components of vulnerability (Figure 3): i.e. the *exposure* of each habitat or value to each pressure and the *sensitivity* to those pressures, along with any indications of the potential for *adapting* to, or recovering from, the potential impacts. As far as information is available, for each habitat or value, we first provide (i) context on the background *condition* and *trend* of the habitat, then (ii) review the exposure of specific habitats to those pressures, (iii) summarise what is known or can be deduced about the sensitivity (including adaptive or recovery capacity) of specific habitats to each pressure. We then (iv) review any specific evidence from monitoring and assessment of effects of dredging or sediments impacts on the Great Barrier Reef and finally (v) discuss any general observations and knowledge gaps. Exposure to the different pressures varies considerably amongst ports and habitats, precluding a summary table, but Table 4 provides a summary of proximity to coral reefs and seagrass habitats for major ports. Table 5 provides a summary of assessed sensitivity and adaptive capacity for all pressures and habitats; note this summary must be considered in the context of exposure (high sensitivity may not matter if exposure to that pressure is limited).

A number of common themes emerge from the following subsections, including:

- A key aspect, and a focus of diverging views within the panel, is the potential importance of dredge-related contributions to ongoing, chronic and long-term sedimentation and turbidity due to resuspension, as discussed in Section 1.3. *To the extent that dredging and disposal do make ecologically relevant contributions to the cumulative, ongoing suspended sediment and sedimentation levels, then this is a significant concern for many habitat types and species groups, but if that contribution is in fact minimal, then so would be the effects on those habitats and species groups; the extent of future impacts will also depend greatly on the amounts disposed within the marine environment (Figs. 8A and B)*. The range of views within the Expert Panel on Sections 1.3 and 1.4 is thus reflected in the range of views on the effects on biodiversity.

- All habitats intrinsically have very high (to high) sensitivity to direct removal and burial, but the exposure is very limited or even non-existent: due either to the relatively small footprint of these activities (the dredged channel, and the disposal area), or because dredging and disposal rarely take place in that habitat type (e.g. coral reefs). Further, in some habitat types, there may be recolonisation by biota, either similar to the original habitat, or novel for that location, after dredging/disposal is complete.

- The following subsections focus on broad-scale information, but it is important to identify and record project-specific, local-scale physical impacts, as foundational information for other contexts such as social impacts.

- For most habitat types, the timing and duration of exposure to dredging pressures are potentially as important as the intensity or extent. For example, increased intensity of turbidity during wet seasons may have less impact on annual growth by photosynthetic organisms than prolonging turbidity periods during the dry, clear water season. In some jurisdictions, it is already recognised practice to avoid key ecological periods, such as coral spawning. The Expert Panel identified this as a knowledge gap with considerable scope for reducing dredging impacts.

- The amount of information available for different habitats varied considerably, but does not reflect their exposure to dredging on the Great Barrier Reef. Thus, for example, much more information relevant to coral reefs is available than for seafloor habitats.

There are also common knowledge gaps across most habitats and species groups, including:

- Better knowledge of which parameters of sedimentation (net, gross, over what timescales, season, etc.) are critical to biota, whether seagrasses, corals or sponges. Better understanding of dose-response relationships needs to consider both duration and amplitude of the dose (i.e. sedimentation), as well as interactions with other pressures, such as temperature. These are open questions for most species except one species of seagrass in Gladstone Harbour[119,120]. However, addressing this issue involves also facing the practical challenge of biologically meaningful measurement of sedimentation rates (see Section 1.3).

- Knowledge of the 'key ecological periods' for important species, for example periods of reproduction.

- Mechanistic knowledge of the causal links/vulnerabilities, and interactions between those effects, for a wider range of taxa to (i) sediment deposition, (ii) suspended sediment concentrations, (iii) light (including spectral changes/photosynthetically active radiation (PAR)).

- Longer term monitoring data after dredging and disposal, and analyses of existing data after maintenance dredging. This in turn requires better knowledge and quantitative description of baseline condition and trend for affected habitats, as the basis for interpretation of changes (see comments in Appendices D to G).

Table 4: Proximity of coral reefs and seagrass meadows to dredging and disposal activities associated with major ports. Amounts are shown relative to other ports: - nil; ★ little; ★★ moderate; ★★★ large amounts. Adapted from Morton et al.[22].

Location	Dredging history	Maintenance dredging	Amount of coral within:				Amount of seagrass within:			
			0–2 km	2–10 km	10–30 km	30–50 km	0–2 km	2–10 km	10–30 km	30–50 km
Cairns	~100 years	★★★	-	★	★★	★★★	★★	★★★	★★★	★★★
Townsville	131 years	★★★	★★★	★★★	★★	★★	★★	★★★	★★★	★★★
Abbot Pt	30 years	★	-	★	★★	★★★	★★	★★	★★★	★★★
Mackay	~75 years	★	★	-	★★	★★	★	★★	★★★	★★★
Hay Pt	~43 years	★★	-	★	★★	★★★	★★	★★	★★	★★★
Gladstone	~100 years	★★	★	★★	★★	★★★	★★	★★★	★★★	★★

Table 5: Summary table: Sensitivity (incorporating adaptive capacity or recoverability) of key habitats and biodiversity values to dredge-related pressures; *Note that this table must be interpreted together with assessments of exposure: high sensitivity may not matter if exposure to that pressure is limited*. For example, exposure to contaminants was generally considered negligible due to restrictions under the NAGD (Section 1.5). Sensitivity assessments based on grading statements developed by GBRMPA for Vulnerability Assessments to support Biodiversity Conservation Strategy[121]. ? indicates limited direct evidence, but indicative assessment made based on habitat and organism properties; there would be considerable variability among species and locations within each assessment.

Key value or attribute	Overall sensitivity	Removal	Burial	Light limitation / turbidity	Deposition	Nutrient effects	Contaminants
Coral reefs	High (variable)	Very high	Very high	High for corals and macroalgae. Impacts vary greatly among species.	High for corals and other filter feeders. Impacts vary among species.	High	High
Seagrass meadows	Moderate	Very high	Very high	High–moderate; depth dependent	Moderate	Moderate	High
Seafloor habitats	Moderate; Negligible direct evidence	? High, variable amongst habitat types/species	? High, variable amongst habitat types/ species	? Low except for plants/ photosynthetic symbionts	? High to low	? Moderate, vary amongst habitat types/species	? High, variable amongst habitat types/species
Pelagic habitats	Moderate to high, limited direct evidence	Not applicable	Not applicable	? Moderate (to high)	Not applicable	High	Moderate
Estuaries/ mangroves	Moderate	Very high	Very high to high	Moderate (to low)	Low	Low to moderate	High
Fish populations	Moderate	Not applicable	Not applicable	? High (vision critical)	Not applicable	Moderate	Moderate
Megafauna/ species of conservation concern	Potentially high; also high sensitivity to noise	High	Not applicable	? High, indirectly through habitat effects	? High, indirectly through habitat effects	? High, indirectly through habitat effects	High: bioaccumulation is of concern

2.1 Effects on coral reefs

Current condition and trend: Coral reefs are an iconic component of the Great Barrier Reef, although they occupy less than six per cent of the entire Great Barrier Reef World Heritage Area. The condition of Great Barrier Reef coral reefs, measured predominantly by coral cover, has declined over recent decades [122,123,124,125,126,127]. The drivers of this decline vary between reefs and regions, and between coastal and offshore reefs, and largely depend on the exposure to disturbances such as tropical cyclones, outbreaks of the crown-of-thorns starfish, high temperature, and catchment run-off [126,127,128,129] [p]. Most reefs are affected by multiple disturbances and their resilience depends on the sensitivity of their biological communities to the various pressures and their ability to recover from disturbances [126,130]. Reefs in the inshore, populated regions of the Great Barrier Reef, where dredging occurs, are known to experience naturally higher turbidity, but have been severely affected by discharge of fine sediments, nutrients and pesticides from the adjacent catchments[131]. These inputs both increase the susceptibility of corals to disturbances and suppress their recovery from those disturbances[25,132].

Exposure: The exposure of coral reefs on the Great Barrier Reef to dredging pressures is generally low to medium, as the majority of current (recent and proposed) dredging and disposal on Great Barrier Reef takes place at some distance (kilometres) from coral reefs, predominantly inshore reefs (depending on disposal site—see Table 4; views within the panel ranged from low to medium). Direct removal of corals by dredging has been rare on the Great Barrier Reef, with most major capital dredging and all maintenance dredging occurring in soft bottom areas with minimal hard substratum suitable for corals (but see Appendix D—e.g. Nelly Bay marina and some resort islands). Similarly, dredge material disposal sites in current use are located in soft bottom areas of the Great Barrier Reef lagoon, precluding direct burial of corals and reefs.

This also reduces the exposure of reefs to the immediate (indirect) effects of suspended sediments, turbidity/light reduction, sedimentation, and resuspended nutrients and organic matter. Inshore coral communities generally experience higher and more variable turbidity, and have higher tolerance to elevated turbidity, suspended sediments, and sedimentation rate, than communities in clear offshore waters[26,133,134,135], and reefs with high coral cover and diversity can persist in highly turbid environments on the Great Barrier Reef on geological timescales[136]. However, inshore reefs on the Great Barrier Reef have lost much of their

[p] It is important to note that these investigations of causes of coral mortality on the Great Barrier Reef apply principally to offshore reefs, with minimal direct exposure to dredging, and did not address potential impacts of dredging on the more vulnerable, degraded inshore reefs on the developed coast.

natural coral cover and undergone shifts in coral composition in recent decades due to declines in water quality[131,137].

However, the exposure of inshore reefs over longer time frames and the contribution of dredging-related (fine) sediment to the turbidity and sedimentation processes at individual sites is not known (see discussion in Sections 1.3 and 1.4). Further, there is a lack of measured or modelled data to accurately assess the long-term (>one year) patterns of ambient sediment exposure at coral reefs in the vicinity of dredging and disposal operations as context for any exposure to dredging-related changes in these conditions. If dredging and disposal activities are contributing significantly to the chronic exposure to turbid conditions (Section 1.3), or prolonging that exposure, then processes such as enhanced likelihood of coral disease, or reduced population resilience through settlement effects may be more important than previously recognised.

Exposure of coral reefs to chemical contaminants from dredging is apparently minimal, based on available evidence (due to screening and management practices: see Section 1.5).

Sensitivity and adaptive capacity: Coral reefs, and corals in particular, are highly sensitive to sediment related pressures, although this varies substantially among reefs and species[26]. *Within the limited footprint (see Exposure, above),* the direct effects of excavation and burial will generally kill corals and other reef organisms[26] and usually make the habitats unsuitable for future recovery[138].

Indirect effects on corals from suspended sediments involve a wide variety of mechanisms, which may act independently or in concert[139]. The responses of coral reefs to poor water quality are relatively well understood from studies of the effects of catchment run-off (recently reviewed[25]). Although available information is heavily focused on corals, this information is fundamental to understanding effects on the whole reef ecosystem. In particular, the effects of sediments on corals have been documented[138,139,140,141,142,143] and this knowledge is highly relevant to understanding the effects of dredging on coral, recently summarised[26]. The sensitivity of a coral reef to dredging and disposal impacts and its ability to recover depend on the antecedent ecological conditions of the reef, its resilience and the ambient conditions normally experienced[26]. There is limited information available for reef organisms and processes other than corals, with some limited work on coralline[144,145], turfing[146] and fleshy algae[147,148].

High levels of suspended sediments can reduce available light for photosynthesis[149]. Photosynthesis is fundamentally important to corals, which partially rely on endosymbiotic unicellular, photosynthetic, dinoflagellate microalgae (*Symbiodinium* spp. zooxanthellae) for their energy and growth[150] and for enhanced calcification[151]. As light attenuates with water depth, the deeper the habitats, the less sediment is needed to reduce light to suboptimal levels. High suspended sediment levels may also affect zooplanktivory and feeding activities of corals[152], although this has not been directly quantified, and such effects may be more significant for filter-feeding organisms such as sponges[153,154].

Corals are sensitive to sedimentation[143,155]. At low rates of sedimentation, corals can remove sediments by a host of active and passive processes including ciliary action, hydrostatic inflation, pulsed contractions, polyp distension, mucus secretion and tentacular sweeping[142,156]. However, once self-cleaning rates are exceeded and a thin layer of sediment has built up on the surface, sediments will progressively accumulate, gradually smothering parts of the colony. Tissues underneath the sediments will become hypoxic and then anoxic, reducing pH levels and leading to localised tissue mortality and lesions[157] (unless water movement removes the sediment). These changes probably account for mortality and documented changes in photophysiology of the coral's algal symbionts in response to sediment smothering[155,157,158].

Importantly, coral sensitivity may involve indirect mechanisms. Laboratory studies have described microbially mediated mechanisms of lethal and sublethal impacts of exposure to organic-rich sediments[158], while a recent field study demonstrated a small increase in prevalence of coral disease on reefs exposed to prolonged (months) high turbidity after dredging[159].

Early life history stages of corals are particularly sensitive to the impacts of poor water quality associated with dredging and dredging-related activities[141], in addition to effects on mature, adult corals. These life cycle stages include gametogenesis, spawning, fertilisation, embryonic and larval development, settlement and early growth, and are dependent on conditions both on the reef, and in the water column and surface. The majority of corals (~63 per cent) are hermaphroditic spawners, with external fertilisation and subsequent embryo and larval development occurring in the planktonic phase[160,161]. Larvae then undergo a demersal stage on the reef seeking suitable habitats before undergoing a final, benthic stage, involving settlement, metamorphosis and permanent attachment[162].

Several studies have shown high suspended sediment levels inhibit fertilisation[163,164,165], although the outcomes of the studies have been variable, due to either differences among species, or experimental methods. The settlement of larvae is one of the most sensitive life history stages to turbidity, with many studies in the early 1990s suggesting that even low levels of deposited sediment can affect settlement[166,167,168,169]. Recently settled larvae appear to have some ability to clear sediment, however it is reasonable to assume that, because of their very small (<1 mm) size and slow growth rates, they are highly susceptible to the effects of sediment deposition as smothering[141]. Coral settlement depends strongly on the presence of coralline algae, which are known to be sensitive to sedimentation[144,145]. Other key stages of the life cycle remain untested, including the effects of light reduction and high sedimentation rates on gametogenesis, synchronisation of coral spawning and early embryogenesis.

The sensitivity of early life stages of corals to dredging and disposal-related sediment is particularly important, as it may decrease the capacity of the reef's ecosystem to recover from other sources of damage or coral mortality. Although there is no published evidence to test this directly, loss of recruitment may be more important than adult mortality in explaining long-term population declines[123]. The significance of this is that damage to reefs from turbidity-generating events may not occur in the short term associated with physiological effects on adult corals, but over longer (ecological), intergenerational time frames associated with decreased recruitment success. Any contributions from dredging to chronic turbidity and sedimentation may be a key cause-effect pathway affecting coral reefs in the long term. These timescales are much longer than those typically addressed in environmental impact assessments. The potential inhibition of recovery is especially important given the degraded condition of many inshore reefs in the regions where dredging takes place.

The sensitivity and capacity to adapt to turbidity and sedimentation varies considerably among coral species[142,170], with inshore species on the Great Barrier Reef able to adapt to higher sediment levels[134], although this may reflect a shift in species composition caused by anthropogenic sediments[131]. Physiological adaptation to high sedimentation rates and sediment deposition has not been observed. For some species, the ability to feed on suspended particulate matter[134,152,171] and to switch to heterotrophic feeding may offset stress from high particulate loads and reduced light levels[134,152,172]. The response of underlying coral communities will vary between lethal (partial and whole-colony) and sublethal effects including reduced energy, growth and fecundity. Ultimately these will depend on conditions such as the physiological condition of the corals, the community composition and past disturbance history of the reef including both anthropogenic and natural disturbances such as cyclones[8,26].

Despite this variability, detailed species-specific and quantitative dose-response information is scarce, with direct evidence available for less than 10 per cent of all species of hard corals[26] and few other reef organisms. This is the focus of a major current research program in Western Australia using laboratory-based studies and in situ studies during dredging programs[q]. There is a particular need to identify dose-response relationships for a wider range of coral species (see e.g.[143]) and to establish quantitative relationships between sediment deposition rates and coral health.

However, providing that information involves many of the challenges outlined above (Section 2 initial paragraphs), including in particular the need to understand the importance

[q] www.wamsi.org.au/research-category/research-programs-dredging-science viewed 30 Aug 2014

of, and interactions between, suspended sediments, changes in quantity and quality of light, and sediment deposition for any particular conditions. The difficulties in measuring ecologically relevant sedimentation rates (above) led Storlazzi et al.[56] to conclude that prior research results on coral responses to sedimentation should be interpreted with care in the context of reef processes in the field. Many laboratory (and field) studies of impacts of sediment on corals have used inappropriate sediment types (especially grainsize) or high levels of sediment deposition that may not represent the exposure during Great Barrier Reef dredging programs, potentially exaggerating the perceived sensitivity of corals to dredging, disposal and other sediment disturbances[26]. The complexities and interactions amongst effects, such as enhanced energy status and effects on early life history stages, mean that sediment effects may operate at the population and community level, rather than physiological levels in adult corals[134,135].

The sensitivity of corals and reef ecosystems to increased nutrient inputs has been documented extensively (recently reviewed in Schaffelke et al.[25]). Any deposition of organic matter on a coral reef from dredging or dredge material disposal would increase the reef pCO_2 and lower the reef pH when the organic matter decomposes. Increased pCO_2 and lower pH would enhance the ongoing impact of ocean acidification on coral reefs[173] such as reduced calcification and increased dissolution[174].

Corals are quite sensitive to a range of chemical contaminants, such as antifoulants from ships' hulls[175,176,177], industrial chemicals or minerals (e.g. coal[113,114]), metals, herbicides, and pesticides[178,179,180]. Legacy contaminants released from pore water or sediments have the potential for acute and chronic toxicological, cellular and physiological effects, including genotoxic (mutagenic, teratogenic and carcinogenic) effects, as well as bioaccumulative effects through uptake and ingestion of contaminants. However, at the levels of such contaminants likely to occur in Great Barrier Reef dredged sediments, sensitivity will be low.

Great Barrier Reef monitoring evidence: Currently available monitoring information on responses of Great Barrier Reef coral reefs to dredging is limited as there have been only six studies, summarised in Appendix D. (Monitoring programs were approved by regulators, designed on the basis of site-specific risk assessments, and most involved sampling at multiple sites that included impact and reference sites; reactive monitoring during dredging and placement works was common).

These studies provide evidence for only minor effects of past dredging operations in the Great Barrier Reef, and indicate that proximity to dredging is a key risk factor. However, with hindsight, all studies had some shortcomings in design (often unavoidable), which limit the validity or generality of these conclusions[90] (Appendix D). Examples include selection of impact and control/reference sites that, *in retrospect*, did not adequately distinguish dredging impacts from background changes; short duration of sampling, preventing detection of long-term sublethal effects; lack of baseline information on both coral reef condition and sensitivity to provide context for the short-term results. Given these considerations, panel members had differing views on whether these studies overall provide evidence for a lack of impact, or rather a lack of evidence.

Previous monitoring may also have overlooked indirect mechanisms for impacts[72,181], such as microbially mediated impacts of organic rich sediments[158], or coral disease promoted by dredging related sedimentation[159].

The challenge of designing effective impact monitoring programs is exacerbated by the historical disturbance and the degraded condition of inshore reefs along the developed Great Barrier Reef coast. If dredging pressures were to inhibit recovery of degraded reefs (through effects on early life history stages), such impacts would not be detected by monitoring mortality of established corals, as currently required. Monitoring for such effects (and other sublethal impacts) would be complex as this would require differentiation of dredging related impacts from other anthropogenic influences and potentially significant natural variation.

The Expert Panel considered that increased effort is needed to assess chronic effects, and to differentiate between effects of dredging pressures and variability due to natural or other anthropogenic processes (which may be large).

General: A key focus of current dredging research, planning and management is the identification of environmental time windows for dredging to minimise cumulative impacts and avoid sensitive life history phases (especially periods of mass coral spawning) or to minimise exposure (e.g. by avoiding certain tidal phases, see[8]). For example, scheduling operations during periods of high ambient turbidity and sedimentation (e.g. during the wet season) *may* have less additional impact than operating during periods of otherwise low turbidity (dry season): that is increasing the *duration* of high suspended sediments may be more serious than smaller proportional increases in the *magnitude* of high suspended sediments. However, implementation of such strategies, and demonstration of their effectiveness, is much more difficult in practice than in principle.

The panel suggests that dredging activity should particularly avoid periods critical to coral settlement and recruitment, as well as spawning.

2.2 Effects on seagrass meadows

Current condition and trend: Seagrasses in the World Heritage Area have been under significant pressure in recent years with major declines in shallow coastal and deeper water communities between 2009 and 2011 associated with flooding, cyclones and strong La Nina climate patterns[182,183,184,185]. These declines have included seagrass communities within ports adjacent to the World Heritage Area. Since 2011 seagrasses in many ports have begun to recover, but the extent of recovery has varied substantially between locations, depending on the species present and the severity of the declines (see Figure 9 below). Although these recent declines in the abundance of Great Barrier Reef seagrasses have been attributed to climate/extreme weather effects[183,184], this is likely to have reduced resilience to other pressures, including dredging[1].

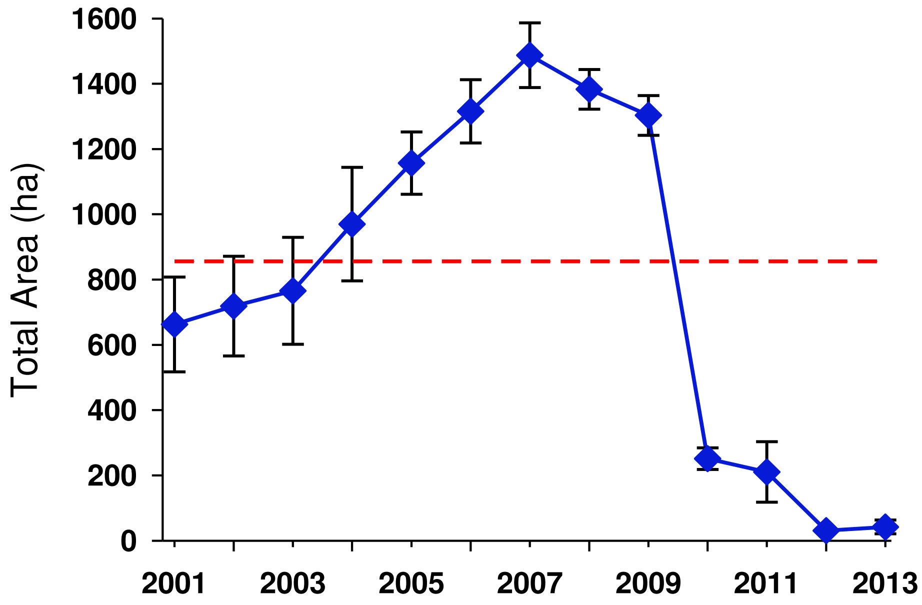
Seagrass meadows are recognised as important structural components of coastal ecosystems[186]. Seagrass/algae beds have been rated the third most valuable ecosystem globally (on a per hectare basis) for ecosystem services, preceded only by estuaries and swamps/flood plains[187].

Exposure: Exposure to dredging pressures is often high for seagrasses in the Great Barrier Reef, as dredging operations are generally in close proximity to seagrass habitats, exposing them to removal, burial, light limitation, and increases in nutrients and organic matter. In most World Heritage Area ports, seagrasses are the key sensitive receptor identified in proximity to dredging operations (maintenance and capital)[90], with seagrasses commonly occurring within or immediately adjacent to dredge channels, disposal grounds and port infrastructure. Where seagrasses are in a lower state of resilience, maintenance dredging is reviewed to avoid additional stresses, through a Dredging Technical Advisory and Consultative Committee process established for all ports where annual maintenance dredging is conducted in the World Heritage Area.

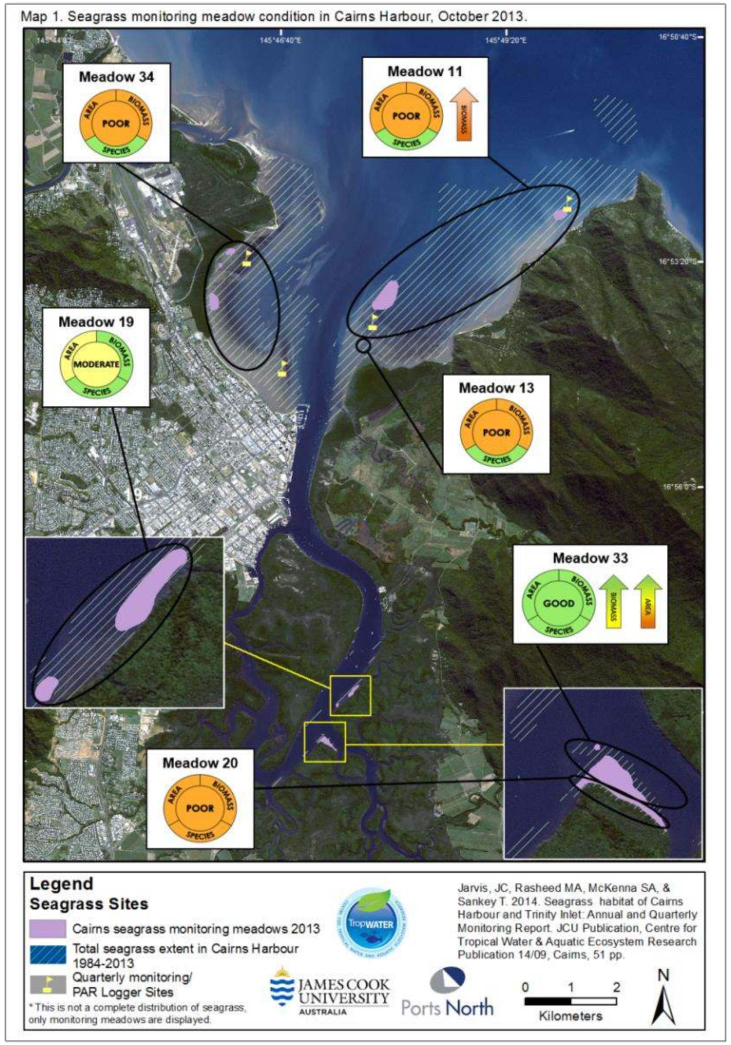
Sensitivity and adaptive capacity: The sensitivity of Great Barrier Reef seagrasses to dredging pressures is considered to be high, as light-dependent (photosynthetic) plants, but their (adaptive) capacity to recover can also be high, due to fast growth rates and capacity to colonise new substrate[20]. Seagrass species vary considerably in their sensitivity and tolerance to reduction in light, sedimentation and burial[188] and some species can survive light intensities below that required for net photosynthetic gain for many weeks, using physiological and morphological adjustments to reduced light conditions[120,189]. Recovery capacities are highly dependent on species and location and the severity of impacts. Recent studies in the Great Barrier Reef have shown that the capacity for recovery of different species at the same location varied markedly[183]. Widespread losses can lead to a state change, creating conditions that may make it difficult for seagrasses to recover and lead to long-term or permanent losses.

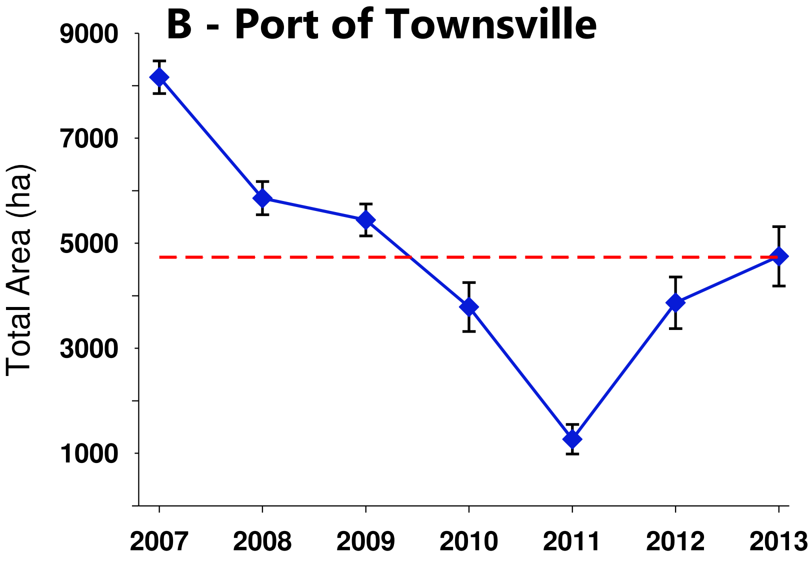
Some seagrass populations have seed banks that increase recovery and resilience, providing a mechanism for recovery within three to five years. However, this will differ between habitats, species and the scale and severity of impacts, and several studies have shown that seed banks are not always present in some local populations, making them slow to recover from losses of adult seagrasses[183,190]. Deepwater (>10 m) *Halophila* meadows at Hay Point were impacted by capital dredging in 2006 but their normal annual cycle of recruitment and senescence was re-established within 12 months of the cessation of dredging[191,192]. In contrast, intertidal *Zostera muelleri* meadows in the Port of Mourilyan have had no recovery

A - Port of Cairns



Total area of seagrass in Cairns monitoring meadows from 2001 to 2013 (error bars = "R" reliability estimate). Red dashed line indicates 13-year mean of total meadow area.





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

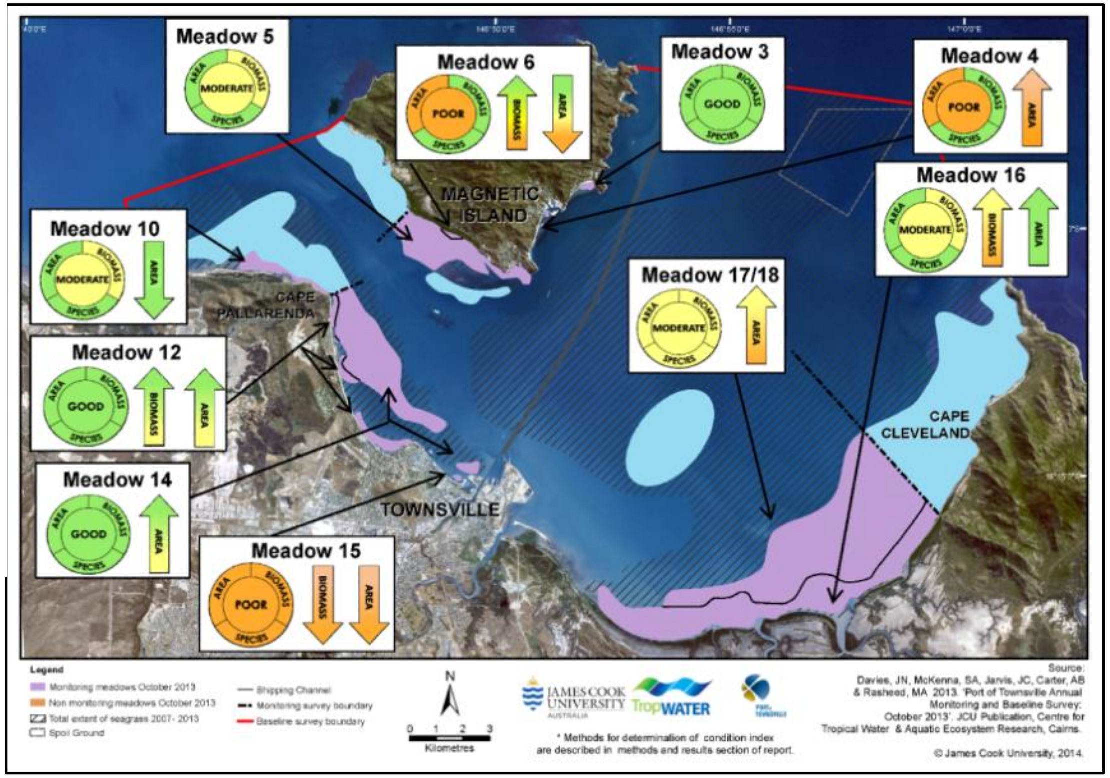


Figure 9: Contrasting condition and recovery of seagrasses in the Ports of Cairns and Townsville.
Seagrass meadow condition index for 2013 and annual change in seagrass area[198,199].

four years after their loss[193]. Although this loss was unrelated to port activity it demonstrates the variety of potential trajectories for seagrass recovery in the region.

Great Barrier Reef monitoring evidence: There is a strong, long-term empirical base of monitoring information for understanding direct effects of dredging operations on Great Barrier Reef seagrass habitats[r,182], including over 15 years of monitoring (Appendix E). This monitoring provides no evidence for long-term impacts of maintenance dredging on seagrass[194,195], although it cannot preclude short-term impacts, such as impacts on productivity or reproduction, or impacts that recover within 12 months (the typical cycle for seagrass monitoring).

Capital dredging campaigns have caused 'permitted loss' of seagrass, such as burial of seagrass by reclamation (permanent loss of habitat), sediment disposal (scope for recolonisation) or removal of seagrass in new channels (limited scope for recolonisation) and 'high impact zones' where turbid plumes may reduce light available to seagrasses to below their growth thresholds. Direct and indirect impacts of past capital dredging have been documented (Appendix E) but these impacts were generally inside predicted areas, for indirect impacts, and were of medium duration (less than five years). Although these losses were a relatively small proportion of regional seagrass populations, such losses are more significant at a local harbour/bay level, especially if there are locally dependent populations of reliant animals such as dugongs and green turtles and the distance to alternate sources of viable seagrasses are large. In the context of the overall degraded condition of Great Barrier Reef seagrass populations, noted above, even small-scale losses take on a heightened importance.

Previous monitoring has not been designed or required to assess the extent of the ongoing, indirect effects of dredging as part of the overall sedimentation and turbidity from resuspension (Section 1.3), beyond the duration of dredging campaigns: that is, the contribution to chronic, long-term effects. Previously assessed as a low risk, any such effect cannot be detected by the monitoring, as it is confounded by natural variability and other contributions to long-term increases in turbidity and sedimentation.

A historical review by Pringle[5] noted seagrass burial and mangrove mortality in the 1970s and 1980s that coincided with both very large volumes of dredging and with cyclones and floods, making it difficult to unambiguously attribute causality.

Management of the impacts of dredging operations on seagrass habitats has recently been improved by the development of local, species-specific light (PAR) requirement

[r] www.jcu.edu.au/TropWATER/research-programs/seagrass-ecology (viewed 29 August 2014)

thresholds[119,120] that enable active management of dredging operations to ensure ecological light requirements of seagrasses can be met. Similar light thresholds are being developed for other regions and species, an important knowledge requirement, but these require ongoing funding support.

The existence of extensive, long-term data allow for definition of baselines of seagrass health and dynamics, and for investigation of environmental, climatic and anthropogenic drivers[183,184,194,195]. The Queensland Ports Seagrass monitoring program[s], has recently established a condition index for seagrass in Queensland Ports based on seagrass area, biomass and species composition changes compared with a long-term baseline condition.

General: Important knowledge gaps currently being addressed include the development of tools and indicators to adequately assess sublethal levels of stress in seagrasses[196,197]. There is also a need for better understanding of the responses to dredging pressures of microbial communities and related biogeochemical processes in seagrass sediments (Section 1.5).

2.3 Effects on other seafloor habitats

Current condition and trend: Although the nature and distribution of seafloor habitats and assemblages (other than coral reefs and seagrass meadows) are now well described for the broader Great Barrier Reef[53], including specific local surveys around disposal grounds and within port limits[72,200,201,202,203,204,205], there is little information available on their current condition relative to their natural condition, or on temporal dynamics. The recent Outlook Report[2] estimated condition to be good, but with low confidence inferred from very limited evidence, and noting concern about historical effects of trawling in some habitats. Importantly, these other seafloor habitats include a wide range of very different habitats, from hard bottom areas such as sponge gardens with long-lived and fragile assemblages to soft-bottom areas of sand or mud, with sediment-dwelling infauna (Figure 10)[53]. These different habitats will naturally respond very differently to dredging pressures. Most inshore seafloor habitats have naturally high levels of accumulated loose sediments, notwithstanding potentially increased inputs over the last century.

Exposure: In some areas, inshore seafloor habitats have high exposure to dredging pressures, particularly for marine disposal areas, although the proportion by area of most habitat types exposed to direct dredging excavation or burial would be small.

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[s] https://research.jcu.edu.au/research/tropwater/resources/queensland-ports-seagrass-monitoring (viewed 31 August 2014).

Sensitivity and adaptive capacity: Seafloor habitats will have high sensitivity to excavation (removal) and to burial within the specific footprints of those activities and designated areas, but there is some evidence for recolonisation of some infaunal (sediment-dwelling) populations in disposal areas within 12 months[3]. The extent and rate of this recolonisation

Figure 10: Contrasting examples of seafloor habitats:
Left picture shows habitat dominated by long-lived seafans. Right picture shows habitat in the area proposed for disposal of sediments at Abbot Point, dominated by loose, carbonate (biogenic) sandy mud with sediment-dwelling, burrowing infauna. These two habitat types will be very different in their sensitivity and recovery from dredging pressures. Photographs courtesy of CSIRO/AIMS/QDPI/QM Seabed Biodiversity Project[53].

will depend considerably on the habitat type, as well as a range of other factors, including the properties of disposed sediments, the frequency of disposal (maintenance or capital) and the composition of the previous and surrounding community: communities around accumulative mobile sediments may be more adaptable than long-lived organisms on stable substrates. Recolonisation may be more rapid in high energy areas because communities in such areas are adapted to high rates of environmental stress associated with frequent sediment erosion and deposition[206]. Any historical and current chronic trawling pressure complicates sensitivity and adaptive capacity because (i) dredge spoil will often come as an additional impact further stressing already degraded habitats, and (ii) the interactive effects of dredge spoil and chronic trawling will combine to complicate recovery and compromise adaptive capacity. Where disposal involves reclamation, this inevitably involves permanent loss of coastal seabed habitat.

Dispersal of sediments may have effects on adjacent seafloor habitats, depending on proximity. Although there is very little direct evidence for the sensitivity or adaptive capacity of seafloor organisms and habitats to sedimentation and turbidity, inference from first principles suggests that sensitivity and adaptive capacity vary greatly among habitats and species. Many seafloor organisms are filter feeders which may benefit at low levels of supplemental suspended organic matter but may be overwhelmed at higher levels. Photosynthetic organisms (macroalgae and benthic microalgae) may be close to light limitation, making them sensitive to further reductions in light. Benthic microalgae are probably a major source of primary production for the inshore Great Barrier Reef lagoon[207]. There is potential to use the detailed knowledge[53] of relationships between habitats and biophysical properties (sediment composition and size fractions), to develop modelling tools for predicting the sensitivity of habitats to changes in those sediment properties.

Great Barrier Reef monitoring evidence: There is some limited evidence from monitoring of inshore dredge material disposal areas (Cairns and Townsville[201,203,205]) consistent with findings from overseas assessments (see [206] for review). These indicate that, notwithstanding designation as a high impact area, impacts from dredged material placement may be short term, with recolonisation (by similar invertebrate communities as found within the surrounding habitats) occurring within 12 months[3].

Other monitoring evidence (summarised by SKM RPS Apasa 2013[90], rearranged in Appendix F), show a range of outcomes, from minimal impacts on adjacent habitats to significant albeit small long-term impacts; some instances reported some recovery after one year. Once again, a range of limitations were noted in the survey design for several of these studies.

General: There is considerable scope for improving knowledge of the sensitivity and recovery capacity for seafloor habitat types exposed to dredging pressures, including better understanding of microbial communities and related biogeochemical processes.

2.4 Pelagic habitats

Current condition and trend: The Outlook Report 2014[2] reported inshore waters to be degraded in the region of the World Heritage Area were dredging has occurred, principally due to declines in water quality.

Exposure: Pelagic habitats may be the most exposed to water quality impacts (turbidity, nutrients, etc.) resulting from dredging and disposal, although they are by nature not exposed to excavation and burial. The relative significance of this exposure in the context of other impacts (riverine inputs, weather events) is not well understood (Sections 1.3 and 1.4). Some panellists felt it would have minor impact in that context, whereas others considered the additional stress on an already degraded system was potentially important to cumulative impacts.

Sensitivity and adaptive capacity: There is limited information on the sensitivity or adaptive capacity of pelagic habitats, although it is known that increased turbidity, suspended matter and nutrients in the water column can lead to changes in phytoplankton, with presumed consequences for pelagic food web structure.

Great Barrier Reef monitoring evidence: The panel did not identify any direct monitoring of pelagic habitat changes in response to dredging activities (as distinct from water quality changes, see Section 1, which provides indicative information).

General: There is a need for better understanding of pelagic food webs and processes, including the effects of increased suspended sediments, and dredged sediments specifically.

2.5 Estuarine and mangrove habitats

Current condition and trend: Mangrove habitats were assessed in the Outlook Report 2014 as being in good (but not very good) condition and stable[2]. Mangrove and estuarine habitats and food webs, including intertidal mudflats and wetlands, are important components of the broader, interconnected Great Barrier Reef ecosystem, with ecological connections to fish stocks (e.g. as nurseries[208]), to offshore habitats[209] and to species of conservation concern such as inshore megafauna and migratory birds (Section 2.7).

Exposure: The exposure of estuarine and mangrove habitats to dredging-related pressures will vary greatly between locations, and with the nature of material disposal in particular: offshore disposal will have limited direct exposure, whereas reclamation will often have high exposure.

Sensitivity and adaptive capacity: Estuarine food webs, and planktivores in particular, are inferred as being sensitive to habitat removal and burial, and having moderate to low sensitivity to turbidity and sedimentation changes, based on their biological and ecological properties. Mangroves can adapt and increase in response to low to moderate levels of sedimentation, but excess accumulation may lead to mortality[210]; there is a need to consider the sensitivity of mangrove biota, and mangrove seedlings, as well as the trees themselves. Compaction, soil subsidence and sea level rise complicate the prediction, measurement and interpretation of effects of enhanced sediment deposition in mangrove environments. Mangroves may be particularly sensitive to changes to hydrology (e.g. channel deepening, reclamation). They may also be affected by clogging of tidal creeks due to dredging, which can alter the tidal hydrology of mangrove stands, causing ponding and localised mortality (Erftemeijer et al. *in prep.*), with potential flow-on effects for coastal stability.

Dredging in mangrove and other nearshore areas may result in the exposure of (potential) acid sulphate soils (PASS), especially during on-land disposal, which requires special care and lime-treatment to prevent fish kills and other impacts from acidity in run-off water (see Section 3.2).

Great Barrier Reef monitoring evidence: The panel did not identify any direct monitoring of estuarine and mangrove habitats in the Great Barrier Reef in response to dredging, reflecting assessments of risks as low.

General: Potential effects on habitats such as intertidal mudflats, microbial communities and related biogeochemical processes, and flow-on effects (for example, on migratory birds) were identified as particular knowledge gaps.

2.6 Effects on fish

Current condition and trend: Fish populations in the Great Barrier Reef overall were recently assessed as in good condition but declining[2]. Populations in the area of relevance to most dredging activity, the southern inshore regions, were in worse condition than the rest of the ecosystem, as they have the highest fishing pressure, and the most extensive impacts on habitat condition[1].

Exposure: Fish populations in the inshore Great Barrier Reef will certainly be exposed to elevated turbidity from dredging activities, but evidence from other areas suggests that levels high enough to directly affect fish physiology will be limited to the immediate vicinity of the dredging and disposal operations[211,212,213]. Although fish demonstrate avoidance or escape responses to extreme turbidity, at the local scale such responses constitute a population reduction. Studies elsewhere by the US Army Corps of Engineers[214] found that suspended sediments resulting from dredging were an order of magnitude (or more) less than lethal concentrations and persisted for only hours after operations ceased.

In the longer term, although some panel members felt that dredging-related contributions to chronic increases in sedimentation and turbidity (Sections 1.3 and 1.4) would not be sufficient to significantly affect inshore Great Barrier Reef fish populations, others felt there was a reasonable likelihood of such effects, especially in the context of cumulative impacts with other pressures. There was particular concern about species that use coastal waters for key life history functions (such as spawning) in the late dry season when the water is generally at its clearest (e.g. school, spotted, broad-barred and Spanish mackerel[215,216,217,218]).

As outlined above, exposure to chemical contaminants on the Great Barrier Reef is considered low, given current management practices.

Sensitivity and adaptive capacity: Appendix G provides an overview of evidence for fish sensitivity to dredging pressures. The main sensitivity of fish is considered to be linked to physiological and behavioural responses to increased suspended sediments and to potential habitat degradation or loss (see previous sections). Key potential effects include degradation of pelagic habitats, changes to visual environments and indirect effects on food webs, connectivity, and changes in ecosystem processes, such as the loss of herbivorous fishes on turbid reefs. High levels of turbidity/suspended sediments may affect the functioning of fish gills, although evidence from other areas suggests these impacts are limited (at exposure levels found in most dredging operations[211,212,213]). Some effects of turbidity on fish behaviour are known; effects on visibility will particularly affect the many species which are visual feeders[219]. Dredge material may affect fish fertilisation, or survival of eggs or larvae[220]; however, knowledge of the timing of recruitment is very limited[221,222].

Great Barrier Reef monitoring evidence: There are few direct monitoring studies available, especially for pelagic species, except in Gladstone Harbour. Surveys of benthic fish on islands around Hay Point found no statistically significant effects, although statistical power was not reported[72,90,181]. Outside the Great Barrier Reef, monitoring in Darwin Harbour during a large dredging program did not find evidence of effects on fish health[t].

Potential effects of dredging on fish populations in Gladstone Harbour have been the focus of considerable attention[116,223]. In 2011, fish in Gladstone Harbour were reported with a range of abnormalities, such as skin redness, lesions and eye damage, along with an increase in the incidence of shell erosion on mud crabs and symptoms in other crustacea and sharks[224]. A special Gladstone Harbour Fish Health Investigation monitored fish health and environmental parameters from August 2011 to September 2012. This work concluded that the main cause of the fish health issues was overcrowding, following a significant introduction of fish from Lake Awoonga into Gladstone Harbour after the extreme flood events in early 2011. Although the study did not preclude contributions from extra stress on the ecosystem from dredging and associated turbidity, these were not considered to be the primary cause[225]. This study did not address effects on other biota reported by Landos[224].

These findings were disputed by Landos[224], based on a weight of evidence approach to suggest that the resuspension of contaminated sediments was the main factor for the compromised health of fish and other biota. A review of this report by Batley[226] states that concentrations of metals and metalloids in the waters and sediments of Gladstone Harbour were unlikely to result in chronic toxicity effects on fish[227]. Trace metals, metalloids and other contaminants are present[111,228,229,230], but review of sediment data for Gladstone dredging projects over the past two decades[116] found they were not significantly elevated in sediments throughout the Port of Gladstone, on which basis, exposure to or disturbance of these sediments would not cause toxicological effects[116]. Although some panel members agreed with these interpretations, one panel member disagreed about the appropriate guideline levels[u] that should be applied to the reported levels of toxic metals and contaminants in

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[t] www.ichthysproject.com/environment/reporting-monitoring-results

[u] Differences of interpretation concern the level of toxicity under the guidelines that is appropriate to apply to Gladstone Harbour (i.e. 95% or 99% species protection levels), as the ANZECC117 guidelines indicate 99% species protection levels for ecosystems of "*high conservation/ecological value*" and the 95% level for "*slightly to moderately disturbed ecosystems*". One panel member considered that, given the World Heritage Area status, the appropriate level is the more stringent 99% level, whereas other panel members considered that, as a working

Gladstone Harbour[111,228,229,230]. That panel member also suggested that limitations in the oversight and coordination of monitoring[223] prevent clear conclusions on the causes for ill health of fish or other taxa. Other panel members considered that the major contaminant concerns in Gladstone Harbour involve water column pollutants[228], which would not be significantly affected by dredging.

The Expert Panel held a range of views on the relative importance of different factors in Gladstone Harbour, but the need for further research into those issues was largely agreed. The impacts may be the result of the complex, combined and cumulative effects of multiple stressors, including chronic pressure to the system from industrial and shipping operations, a recent increase in disturbance by further development of the harbour and Curtis Island and the extreme flood events of the summer of 2010/11. Such complex circumstances make specific causes and effects difficult to untangle and attribute[116,223].

2.7 Effects on marine megafauna and other species of conservation concern

Current condition and trend: Populations of many species of inshore marine megafauna, including dugongs, marine turtles, inshore dolphins, seabirds and shorebirds, sharks and rays are matters of National Environmental Significance, either as threatened species[v] or migratory species[w]. Populations of most inshore marine megafauna, including dugongs, some species of marine turtles, inshore dolphins, sharks and rays are considered to be in poor condition, and many are declining[2]. Although there is little information available on migratory shorebirds, both shorebird and seabird populations are considered to be in poor condition[2].

Exposure, sensitivity and adaptive capacity: There is a serious lack of direct evidence on the vulnerability of most species of marine megafauna species to the effects of dredging. However, many of these species have life history characteristics (slow growth and reproduction) that make their populations very vulnerable to very low levels of human-related mortality; they have high sensitivity and low adaptive capacity to any such mortality. Several species of migratory shorebird are in rapid population decline, with two species (great knot *Calidris tenuirostris* and eastern curlew *Numenius madagascariensis*) considered globally threatened by the International Union for Conservation of Nature (IUCN), and two currently being considered for admission to the Environment Protection and Biodiversity

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harbour with more than 50 years major industrial and shipping activity (pre-dating World Heritage status), the appropriate guideline is the less stringent 95% species protection level.

[v] www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=fauna

[w] www.environment.gov.au/cgi-bin/sprat/public/publicshowmigratory.pl.

Conservation (EPBC Act) list of threatened species in Australia (eastern curlew and curlew sandpiper *Calidris ferruginea*). Many migratory shorebird populations are in rapid decline in Moreton Bay in south-east Queensland[231], but no formal analysis exists for elsewhere in Queensland.

Dugongs[232], turtles, especially green, loggerhead and flatback turtles[233,234,235,236,237,238], and coastal dolphins (snubfin and Australian humpback) as well as shorebirds[239] and sharks and rays occur around ports in the Great Barrier Reef. Thus the potential for interactions with dredging is high. Both humpback and snubfin dolphins are considered strictly inshore coastal and estuarine species. Snubfin dolphins seem to prefer shallow waters (1–2 m), preferably over seagrass beds[240,241], and are often observed in some ports (e.g. Townsville, Marsh pers. comm.). Although humpback dolphins are more often sighted in water ranging from 2 to 5 m and showed a preference for dredged channels in the Gladstone area[240], they are also often sighted in ports such as Gladstone[240] and Townsville (e.g. Marsh pers. comm.). Satellite tracking indicates that marine turtles tend to sit in deep water pools, including dredge channels (C.J. Limpus pers. comm.). Sharks and rays of various age classes use a wide array of shallow and deep inshore habitats including those in ports like Townsville[242,243,244]. Some port areas such as Gladstone[239] are important migratory shorebird habitat and habitat loss due to coastal development is a major threat to shorebirds at a global scale[245].

The extent to which this potential exposure translates into direct effects of dredging on mortality for megafauna remains unknown, although there is evidence of green, loggerhead and olive ridley turtles being caught in dredges in Queensland[233,234,236]. Current practices incorporate use of exclusion devices to manage this risk. Intensive monitoring over two years of a large dredging project in Darwin Harbour found no impacts from the dredging on dugongs, turtles or dolphins[x], although the probability of failing to detect a response even when one is present is high[246,247].

Many species are potentially vulnerable to indirect effects of loss or reduced quality of habitat and food, especially seagrasses for dugongs and green turtles. Dugongs are seagrass community specialists[248], green turtles eat seagrass (and algae)[249] and snubfin dolphins are often sighted near seagrass beds[240,241]. Sharks and rays are also often dependent on seagrass habitats as a source of prey and in some cases as refuge from predation[244], and shorebirds often forage in or near seagrass in the Region[250].

Migratory shorebirds feed on the extensive tidal flats in the Gladstone region, with up to 15,000 shorebirds regularly being present[239,251]. They are dependent on access to benthic invertebrates at low tide, and sediment deposition is known to negatively affect the birds, for

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[x] www.ichthysproject.com/environment/reporting-monitoring-results

example, driving rapid redistributions after major flood events cause sediment to settle onto tidal flats[252].

Large, long-lived species have ample opportunity to bioaccumulate contaminants, but increased exposure due to dredging should be minimal on the Great Barrier Reef (Section 1.5); the attribution of accumulated contaminants to specific causes (dredge related or other) is very difficult. However, maternal offloading of contaminants does occur, so contaminants could persist in the population beyond the lifetime of exposed individuals[253,254]. Migratory shorebirds could potentially act as agents of transfer of pollutants within and among estuaries[255].

Reclamation has the potential to cause severe loss of habitats for dolphins, shorebirds and turtle nesting, although the panel was not aware of this occurring in recent operations in the Great Barrier Reef.

Any elevated continuous background noise has the potential to mask megafauna communication systems and listening capabilities for predator avoidance, as well as disturb normal behaviour due to displacement from critical habitats[256]. Thus the noise from dredges is a potential risk, especially to turtles because their hearing range falls within the main energy band[256]. Research from elsewhere suggests that, compared to other sources of underwater noise, dredging is within the lower range of emitted sound levels[17,257]. Shorebirds seem unlikely to be affected by underwater noise, and the migratory species in particular are not heavily reliant on acoustic communication while they are in Australia during the non-breeding season[258,259].

Lighting is a considerable threat to marine turtles, particularly due to direct effects on their nesting behaviour, to the extent it is considered a form of 'habitat loss'. As Limpus and Kamarowshi[260] point out, artificial light close to nesting beaches disrupts the orientation of hatchling turtles after they emerge from the nest, either causing movement in the wrong direction[261], or preventing the hatchling from discerning which direction to travel in[262]. Both responses have severe consequences for hatchling survival since extended time on land increases the risks of death from predation, dehydration, or over-heating. Artificial lighting can also affect the location of nesting sites by adults and their ability to return to the sea after nesting[260]. Disorientation of nesting flatback turtles has been documented at a low-density nesting beach at Hummock Hill Island (Gladstone region), caused by light pollution some 18 km away from the nesting beach. Artificial lighting disrupts shorebird foraging routines; for example, leading to visual nocturnal feeding at a time when birds normally switch to tactile foraging[263,264]. The extent to which such changes in behavioural routines represent a negative impact or an opportunity remains unclear[265]. Exposure to lighting from dredging per se may contribute relatively little overall, but consideration of this risk can limit the impacts from dredging.

General: The Expert Panel considered there was limited information on the risks, realised or potential, caused by dredging to megafauna and other species of conservation concern. It was agreed that it would be very difficult to distinguish such impacts from those caused by other anthropogenic and climatic disturbances. On that basis, and given the overall vulnerability of these species, proactive preventative measures, such as deflectors, and careful consideration of timing windows and lighting, are vital to avoid any impacts.

3. Disposal of dredge material in reclamation and on land

General

Placement of dredged sediments in coastal reclamation or on land is considered as an alternative[y] to disposing of dredged sediments into the coastal or marine environment. However, the Expert Panel considered that these approaches can also involve significant direct and indirect, immediate and long-term impacts on coastal environments, including the loss of or damage to existing habitats, which need to be assessed as carefully as marine disposal impacts. The nature and severity of those impacts, as with the impacts of disposal at sea, will be site-specific and depend on the nature and scale of the project.

Many members of the Expert Panel were concerned that a 'one-size fits all' approach would preclude case-by-case consideration and minimisation of any long-term, environmental harm associated with disposal at sea, in reclamation or on land. There is a need to weigh the balance between potential impacts of all alternatives, including potential, permanent losses of productive coastal habitat that may have more ramifications for world heritage values.

This section provides an overview of the key issues involved with reclamation and land-based disposal and their relevance to management of dredging in the World Heritage Area. As with the rest of the report, it is limited to biophysical impacts and does not consider aspects such as technical feasibility or project costs. However, the panel acknowledges that those aspects are also important to the context and that some options for reclamation or disposal/re-use on land may not be financially feasible, may be developmental or may simply not effective at large scales.

The National Assessment Guidelines for Dredging (NAGD)[9] require an assessment of alternatives to accompany any application for a permit to dispose of dredged material at sea. This requires consideration of the environmental, social and economic impacts of each disposal option. Under the *Environment Protection (Sea Dumping) Act 1981* "loading for the purpose of dumping" may also be covered by NAGD if the spoil is being pumped directly from a dredger to an aquatic disposal location such as a reclamation area.

Reviews of land-based options have therefore previously been undertaken by Queensland ports in association with dredging permit applications. Most recently, GBRMPA commissioned a review[266] of disposal options for all Queensland ports within the World Heritage Area as part of the Great Barrier Reef strategic assessment[1]. These studies concluded that, for those ports, options for management of dredged material onshore or for beneficial use are limited,

[y] E.g. The assessment framework for the National Assessment Guidelines for Dredging requires proponents to "demonstrate that all alternatives to ocean disposal have been evaluated".

largely due to physical properties of the sediments involved and the lack of available land for drying out the dredged material.

Disposal on land and reclamation are generally only considered for capital dredging projects if the dredged sediment has a sufficient proportion of coarse sediment (sand). Sediment from maintenance dredging is generally too fine for land use such as construction. Capital dredging for World Heritage Area ports typically involves large equipment to handle large volumes of sediment (generally more than one million m^3) and is usually undertaken as a single exercise (due to the costs of dredge establishment, project management and monitoring) requiring large volumes of material to be managed over a relatively short time frame (weeks/months rather than years).

Disposal on land and reclamation requires pumping dredged sediments to the disposal area as a water/sediment slurry through pipelines from the dredge equipment (using trailing suction hopper dredge or cutter suction dredge; use of backhoe dredges and barge transfers unloading into trucks or similar are viable only for small volumes). As a consequence, the pumped dredge material includes very large volumes of salt water which must be removed before sediments can be used on land or as fill.

Where the distance between the dredge location and the land/reclamation area is too great for effective or economical direct pumping, a 're-handling' process may be used (e.g. options currently under consideration for Gladstone Harbour channel duplication). Effectively this involves dredging the material and dumping in an unconfined area of the sea closer to the reclamation/land disposal site where it is then re-dredged and pumped to the reclamation. Naturally, this double-handling process creates additional suspended sediment and turbidity.

'Dewatering', run-off of fine sediments and water quality management

The large amount of saltwater present in the dredge material presents a number of significant engineering and environmental problems. Material needs to be dewatered or dried before the disposal area can be used for another purpose (e.g. development) or the material relocated. The slurry is pumped into settlement ponds, which capture much of the dredged sediment, but significant amounts of 'tailwaters' require decanting and discharge back into the marine environment, and this water can contain considerable amounts of the finest sediments (which are slowest to settle out), causing significant turbidity, sedimentation and potential release of nutrients and carbon (and any pollutants) in the discharge area. This is generally in coastal areas with high ambient turbidity regimes and high fisheries values (e.g. critical nursery grounds).

Land-based disposal and reclamation are thus unlikely to completely remove the risks associated with fine sediments in the marine environment. For the reclamation works undertaken as part of the recent Western Basin strategic dredging and disposal by the Port of Gladstone, the supplementary environmental impact statement indicated an ongoing discharge of fine sediments as high as 100 mgL^{-1} from those reclamation works, into shallow waters adjacent to the reclamation[267]. Those works drew criticism for their reclamation operation[116], due to failure of the bund wall to retain sediments, requiring remediation works during which large volumes of sediment were discharged.

Current approaches to dewatering dredge sediment require very large areas (hundreds of hectares) and long time periods for processing, in order to place the dredge material in a layer thin enough to dry within a reasonable time period[268]. The period required to dry the material using natural solar processes alone depends upon the thickness of the placed material and the climatic regime (especially rainfall). Experience at several Queensland ports has shown that dredged material placed in layers 1.0–1.5 m thick could take up to a year to reach a rehandling consistency and greater than five years (potentially decades) if material was placed in layers several metres thick[269]. This has direct implications for the area of land required and its potential future use. Management of settlement ponds can be complex, especially during extreme weather events such as cyclones, heavy rainfall and floods.

Options are available to enhance drying rates (e.g. chemical thickeners, surcharging, sand and wick drainage) and ensure treated material is of suitable engineering strength. In Australia (and globally[270]), such techniques are typically only used where the land is to be developed for commercial purposes because they are expensive and development provides an element of cost recovery. None are likely to dry pumped material sufficiently to be rehandled within six months. Emerging technology may reduce these requirements, but have not been tested at the scales and fine grainsizes required by proposed dredging in the Great Barrier Reef.

From both engineering and environmental perspectives, there is a clear need to reduce the amount of fine sediment (silts and clays) released into the marine environment and this needs to be managed and monitored carefully. Successful management requires settlement basins engineered to contain all tailwaters from dredging or strict environmental conditions on tailwaters returned to the receiving environment; retained tailwaters should not be drained until suitable water quality has been obtained within the basin (as per approval requirements).

In addition, the presence of large amounts of fine sediments in both reclamation and land disposal areas may generate ongoing problems with turbid run-off and sedimentation in adjacent waters, and requires careful management.

Further exploration of the engineering (and other) challenges in handling, retaining and re-use of fine sediments is given in a recent report to GBRMPA[266]. The high proportion of fine sediments in dredge material from some Great Barrier Reef operations limits its suitability for land-based uses such as construction or agriculture. The report[266] also evaluated the potential for re-use of dredged material, such as for reclamation, landfill, agricultural uses, environmental enhancement, construction industry, bricks or other building materials or beach nourishment[270,271,272]. Most of these have limited applicability to dredge material in the Great Barrier Reef, due to limited demand; many also have very high energy requirements (e.g. brick manufacture). Re-use of sands and gravels from some capital dredging projects may have greater potential, but regional demand for sand and general fill is limited, and particle size separation and transport costs from the drying and processing area to potential markets would be unlikely to be competitive.

There are risks associated with design and construction of bunds and settlement ponds (as with any engineered structure). Even in carefully managed and regulated circumstances, the potential for unforeseen failures remains. Recent experience at Gladstone Western Basin Project with bund wall leakage indicated the possibility of such issues[116]. In the longer term, these risks are exacerbated by the likelihood of extreme weather, such as cyclones or floods. Disposing of material in areas distant from coastal erosion or storm surge influences may be difficult considering the limited distance that sediment slurry can be pumped, although such issues might be addressed through engineering design. In sensitive coastal areas, this long-term management requirement (and risk) represents a significant issue.

3.1 Disposal of dredge material in reclamation

Reclamation, by its very nature, involves the permanent loss of coastal habitats, as intertidal or shallow marine areas are buried by the dredged material. This burial of habitats and sessile organisms is certain, effectively permanent and will be complete, as most organisms will be permanently buried and the reclamation area will cease to be part of the marine environment. Again, these impacts are an unavoidable consequence of reclamation works in natural water bodies but are typically limited to the actual reclamation site. Planning and site selection allows for minimisation of direct impacts, for example, by avoiding high value habitats. The extent of these impacts is generally site-specific and depends on the characteristics and volume of the reclamation site, the water depth and hydrodynamic conditions, and the type of benthic community at the disposal site. Given suitable planning, appropriate characterisation and bulking of the material to be dredged (in particular, silts and clay volumes) and appropriate hydrodynamic modelling and measurements, the spatial extent of the reclamation area influence should be highly predictable. However, in the majority of World Heritage Area ports, coastal reclamations mean loss of seagrass, mangrove or other coastal wetland habitat, all of which provide key values to the World Heritage Area[1]. This is of particular concern because substantial proportions of these habitats have already been lost across Great Barrier Reef coasts over the last 100 years, increasing the significance of any further loss[273].

It is worth noting that reclamation, by changing the location of the coastline, intrinsically involves a (very small) reduction in the area of the World Heritage Area. This is because the landward boundary of the World Heritage Area is defined as the low-water tide mark[1]. (In the Great Barrier Reef context, reclamation is a misnomer, as it is actually creating new land from intertidal or shallow seafloor, rather than reclaiming land from the sea). Although this reduction in area is small, the impact is confined to one particular component of the World Heritage Area (coastal intertidal habitats), thus representing a higher proportional impact on these habitats within the World Heritage Area.

Changes to the coastline will cause permanent changes in local hydrodynamics, as discussed in Section 1.2, with potential consequences for adjacent habitats and fauna (Section 2).

The reclamation process begins with the construction of bund/revetment walls to isolate the reclamation area from the marine environment during its operation and to prevent subsidence of the new lands back into the marine environment once the reclamation operations are complete. Construction of bund walls can cause resuspension through disturbances from rock placement, propeller wash or along shorelines from boat wash. The placement of bund walls also adds weight to coastal seabeds, which may produce a seabed deformation, known as a mud wave, adjacent to the bund wall. These mud waves may erode and contribute to the turbidity of the waters as they flow along the bund wall[116,267]. Further, pipeline networks are constructed between the dredging operations and the reclamation area, which may also generate turbidity from propeller wash, boat wash along shorelines, dredging to bury the pipelines[274] or scouring of the seabed or seagrass meadows by the pipelines[116].

The release of fine sediments at the reclamation site, from pipeline scour, mud wave deformation erosion and via the tailwater stream will have similar effects to the re-mobilisation of sediment during the dredging process, except it may be more concentrated due to the shallow water nature of reclamation sites. Shallow waters also involve additional metocean effects such as littoral drift and nearshore wave break zones, which transport sediments. These effects must be factored into understanding and modelling of nearshore sediment plumes, sedimentation and resuspension beyond the reclamation area. However, the understanding of the longer term transport and fate of sediment dynamics is poor (see discussion in Section 1.3).

3.2 Disposal of dredged material on land

Land-based disposal options involve placement of material in a dedicated storage area or use as fill material for future land development projects. This requires large areas of land both for the processing areas and the final placement. Large areas of coastal land (preferably flat) within pumping distance of dredging projects in the World Heritage Area are limited, with much of the land near ports fringing the World Heritage Area already in residential or commercial use. A potential disposal site requires access to drainage or creek lines to enable tailwater discharge (recognising tailwater will be saline and have suspended fine sediment loads). There are also issues around right-of-way access for the pipeline alignment, sometimes through, or adjacent to, highly urbanised areas, road crossings and risks associated with spills or pipeline failure. Storage of large quantities of fine sediments with poor engineering qualities and negligible re-use potential would require long-term site management to address bund integrity, water quality and site safety issues, and the sites would effectively be alienated from other coastal lands with associated odour, dust and visual amenity issues.

Disposal of dredged sediments in undeveloped coastal lands will likely involve permanent loss of significant areas of terrestrial coastal habitats, some of which may have high conservation values (e.g. National Parks, Fish Habitat Areas, State Parks, Environmental Reserves, World Heritage listing) or significance for species of conservation significance (e.g. migratory birds). Large areas of suitable coastal land (preferably flat) near Great Barrier Reef dredging projects are limited and many have environmental constraints, are sensitive ecosystems such as wetlands, and have already suffered significant declines in extent and condition, with loss of the associated ecosystem services[1].

As with reclamation, there are potential impacts associated with runoff of fine sediments, to freshwater or marine waters.

Habitat damage will be exacerbated by the salinity of the sediment, which effectively sterilises disposal or storage areas for long periods. Any saline run-off to waterways could also have serious impacts on those habitats, and drainage into groundwater may affect a range of dependent habitats (and human uses). Lining of drying and settlement ponds to prevent saline intrusion is possible but expensive and may not be reliable in the long term.

Of particular concern is the risk of potential acid sulphate soils (PASS) associated with capital dredging of marine sediments. Exposure to air can result in oxidation of iron pyrite present in these sediments, leading to production of sulphuric acid and the release of toxic quantities of metals such as iron and aluminium. Disposal of PASS at sea is unlikely to result in such effects as there is insufficient oxygen in the water to cause significant oxidation[116]. Specific management techniques need to be adopted to avoid water quality impacts should such material be placed on land. Land placement of PASS material is liable to require costly long-term management and monitoring to avoid issues associated with acidic water discharges unless all such material is placed below the water table. Lime treatment (or similar neutralising approaches) of large quantities of PASS dredge material has not been undertaken in Australia, the logistical issues, techniques and costs are untested and there are significant associated risks.

The Expert Panel suggested that strong measures be undertaken to avoid any exposure of PASS during disposal of dredged sediments from the Great Barrier Reef, and that further research be undertaken to improve management strategies for dealing with PASS when placed on land. This work should particularly focus on strategies to effectively manage large volumes in a short time (such as result from large dredges during capital dredging) and on ensuring long-term effectiveness of treatment.

4. Cumulative pressures and declining condition on the Great Barrier Reef and the contribution and context of dredging and disposal

In considering the effects of dredging and disposal on the Great Barrier Reef, these effects cannot be considered in isolation, but need to be considered in the context of the documented declining condition of, and the increasing cumulative pressures on, the Great Barrier Reef World Heritage Area ecosystem. Together, the declining condition and cumulative pressures are considered to have significantly reduced system-wide resilience, despite a range of programs intended to avoid such declines[1,2].

This is especially critical because the region in which dredging takes place, the populated, central and southern inshore region, is the region suffering the greatest declines in ecosystem condition[1,2,126], including the most pronounced increases in terrestrial run-off of sediments, nutrients and chemical contaminants[25,275]. Thus, for example, the previously documented moderate indirect effects of past capital dredging (e.g. Appendices D and E) may be much more significant in future, given these declines in ecosystem condition in this region.

Cumulative pressures need to be considered in terms of accumulation through/across[276]:

- operations (e.g. development of multiple facilities at Abbot Point[z]);
- time (at decadal scales; for example, historical, current and pending pressures);
- space (at local to regional and entire Great Barrier Reef scales; for example, decline of water quality in multiple regions);
- pressures (from local to global: for example, combined effects of terrestrial run-off and dredging on suspended sediments; combined effects of turbidity, ocean warming and acidification, extreme weather and crown-of-thorns starfish outbreaks on coral populations);
- different habitats and other values (for example, declines in seagrasses *and* coral populations).

Understanding the effects of these cumulative pressures is extremely challenging as the multiple pressures may interact in complex ways, generating effects which are greater, and much more difficult to predict, than a simple summation of individual impacts. Some simple interactions of multiple pressures (for example, water quality and temperature, pesticides, or overfishing) are relatively well understood on a small, experimental scale[145,277,278,279] but not at the much more complex level of ecosystems. What these simple experiments do show is that

[z] www.nqbp.com.au/abbot-point/

interactions between pressures are rarely simple, but often exacerbate the effects of individual pressures[280].

Cumulative effects need to be considered not simply in terms of cumulative intensity (for example, cumulative contributions of run-off and dredging to suspended sediment levels) but also duration (for example, prolonging periods of high turbidity, reducing the annual window for seagrass growth).

Considerations of dredging in the context of cumulative pressures on nearshore Great Barrier Reef ecosystems identified by the Expert Panel included:

- Loss of habitats through removal and disposal (including reclamation) needs to be considered in the context of the very considerable previous losses in recent decade/s[126,127,137,182,185] and the wide range of other, ongoing pressures in the highly populated areas of most ports. In this context, the relatively small footprint of these effects in isolation becomes more significant in the context of cumulative impacts and documented declines[1,2].

- Similarly, changes in hydrodynamics may potentially have greater (or lesser) significance in the context of other changes in coastlines, loss of mangroves and tidal habitats.

- Effects of noise generated by dredging operations will also need to be considered in context of other sources of marine noise, particularly considering the timing of activities and consequences for wildlife (Section 2.7).

- Understanding effects of dredging and disposal on sedimentation and turbidity is challenging but needs to be placed in the context of the clearly documented declining baselines of those parameters due to terrestrial run-off (including recent improvements in run-off). The extent of dredge-related contributions to long-term suspended sediment levels is insufficiently understood (Sections 1.3 and 1.4), but it is important to emphasise that these contributions are *cumulative* with other anthropogenic sources, even if dredge-related contributions are relatively minor, as argued by some panel members. The cumulative effects must be considered in terms of both:
    - cumulative inputs to the ecosystem, including ongoing contributions from dredge material disposal grounds and dispersed materials due to resuspension;
    - cumulative effects on the timing and duration of high turbidity periods, due to both timing of dredging operations, and the potential ongoing supply of resuspended sediments.

- Comparisons of run-off and dredging (Section 1.4) are valuable in prioritisation of management, but must be seen as cumulative inputs, not as alternatives: even relatively small increases in supply of suspended sediments are of much greater significance in the current context of river run-off than if they took place in the context of pristine water quality and intact, resilient ecosystems.

In this context, it is important to understand the quality of existing baseline information for condition of biodiversity values.

- Coral reefs: good long-term datasets for the Great Barrier Reef currently exist for reference locations, but limited information for dredging-relevant sites. Some very limited data on historical baselines indicate 'shifted baselines' due to historical changes in water quality[137].
- Seagrasses: good long-term datasets for the Great Barrier Reef currently exist, for both dredging-relevant and reference locations, although these datasets do not extend far back enough to preclude 'shifted baselines' due to historical changes in water quality (but see[185]).
- Water quality: remote sensing data for large-scale patterns in turbidity (last 15 years) are available, along with limited data for reference locations. Although considerable data from monitoring of ports and dredging operations exists and is provided to regulators as part of approval conditions, many panel members considered the availability or accessibility to researchers to be uncertain or limited.

Understanding the regional scale significance of dredging effects in the context of other natural and human pressures, shifted baselines and cumulative impacts will remain challenging for some time, but would be facilitated by long-term, large-scale scenario analyses using combinations of large-scale models, such as eReefs, with local models (and appropriate field data). These combined tools could be used to look at long-term scenarios of changes in environmental envelopes/background conditions and how they are affected by various pressures, including dredging and disposal.

Understanding different cause–effect contributions to cumulative pressures would also be enhanced by analyses of long-term trends in environmental conditions in concert with environmental covariates such as water turbidity.

5. Next steps

Many, but not all, of the Expert Panel agreed strongly that this report is just one of a number of steps required to facilitate more effective, and less contentious, management of dredging issues in the Great Barrier Reef. Other key steps include:

Social, economic, cultural and heritage aspects

There is a strong need for a similar synthesis of available knowledge on the social, economic, cultural and heritage aspects, including Indigenous cultural heritage in particular. Many panellists agreed it is very important to also address human dimensions as part of the broader process of synthesis, as do many of the stakeholders and Traditional Owners. These aspects are also explicitly identified as fundamental to the Outstanding Universal Value of the Great Barrier Reef as a World Heritage Area[281]; many Traditional Owners do not recognise a distinction between biodiversity and cultural/heritage values[1].

Many of the potential effects of dredging on human systems stem from effects on the ecosystem (e.g. through effects on tourism or fisheries). Such synthesis should be therefore facilitated by the clearer definition of agreed knowledge, areas of contention, and knowledge gaps provided by the present synthesis report. It is likely that these human aspects would require broader involvement of Traditional Owners and stakeholders to provide input, especially around Indigenous knowledge and cultural heritage. Economic and social or community benefits may be contentious, given contrasting views of perceived economic and social benefits associated with industrial development and concerns for reef health. There will therefore be a strong need to anchor discussions in evidence rather than perceptions or assertions by any interest group.

Management and policy application[aa]

Although the scope of this report explicitly excluded consideration of application to management of dredging, the Expert Panel identified the need for ongoing and further review and update of existing policies, assessment procedures and governance arrangements, to take account of developing knowledge, particularly around the condition of the Great Barrier Reef ecosystem (see[276] for detailed discussion). Ongoing, interactive update of knowledge and policy is fundamental to adaptive management[282]. Such review should involve collaboration with the Ports sector, to ensure efficiency, but also include

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[aa] March 2015 update: The Expert Panel notes the considerable focus of the Australian and Queensland Governments and the ports sector over the last twelve months to update management of dredging in the Great Barrier Reef. Detailed coverage of these developments and how they relate to the synthesis in this Report is out of scope of this Report, although clearly the exclusion of disposal of capital dredged sediments in the marine environment will reduce the impacts within those marine environments (but see Section 3).

engagement with the full range of Great Barrier Reef stakeholders and Traditional Owners. Undertaken carefully, such review should provide greater clarity and certainty for Ports, other stakeholders and, most of all, better protection for the Great Barrier Reef. It should also reduce the controversy and community division surrounding the issue, and ensure better acquisition, integration and availability of knowledge and information. The Expert Panel particularly felt that governance differences between the Great Barrier Reef Marine Park, Great Barrier Reef World Heritage Area, and Port Exclusion zones do not reflect the biophysical continuity between these areas: sediment plumes are not affected by the boundaries between these areas.

Examples of areas suggested for review include:
(note: not all suggestions were agreed by all panel members)

- Update of current policies, particularly:
  - Great Barrier Reef Marine Park Authority Dredging and Spoil Disposal Policy 2010[283], to take account of developing knowledge and declining condition of the Great Barrier Reef ecosystem, especially the inshore areas, and to provide scope for greater innovation and adaptability in approach;
  - National Assessment Guidelines for Dredging and Disposal to incorporate assessment of nutrient and organic matter released/mobilised during large dredging projects or where there is a potential of high sediment nutrient levels (e.g. disposal in offshore, oligotrophic waters of sediments dredged close to river mouths or other nutrient point sources).
- Provision of greater clarity in guidelines and requirements for dredging proponents, for environmental impact assessment:
  - Scaled requirements according to the size of the proposed dredging (small boat ramp, or major international coal terminal);
  - Scope of assessments, including spatial and temporal coverage, and issues to be addressed;
  - Updated hydrodynamic modelling requirements;
  - Monitoring requirements, including design, integration, quality control and scientific/public accessibility, to enhance knowledge for the ports sector and uptake by the broader scientific community; incorporation of both pressures and biological responses into monitoring requirements (e.g. findings in Section 4.6 in the recent Independent Review of the Bund Wall at the Port of Gladstone[223], particularly points d and e);
  - Strategic approach to guide selection of disposal strategies and sites (marine, reclamation or land-based);

- Policy on land reclamation in the World Heritage Area (considering the reduction in area of the WHA).

- Offsets policy (see recent discussion in Bos et al.[284]).

Information gaps/needs and prioritisation:

The Expert Panel identified a number of knowledge gaps during the synthesis process that are considered important in terms of future management of dredging and disposal in the Great Barrier Reef. These are summarised and prioritised below.

High-priority, short-term knowledge needs—within the next 12 months

The panel considered that a key requirement was to develop an improved capability to quantify and predict long-term (>12 months) sediment dynamics and sediment transport processes. This is vital to predicting and managing potential impacts associated with dredging and disposal, and to placing those impacts in the context of other ambient and anthropogenic processes and inputs. This will require assessments that include:

- Review of detailed hydrographic, before and after data from disposal sites and surrounding areas, to quantify dispersion processes (including the influence of extreme conditions such as major storms or tropical cyclones).
- Better quantitative understanding of sediment deposition, resuspension, consolidation and armouring processes to validate numerical models and improve prediction of long-term (>12 months) sediment dispersion.
- Accurate description of sediment deposition dynamics, to develop a better understanding of the natural variability of turbidity and sedimentation in the inshore Great Barrier Reef, especially on coral reefs and seagrass meadows. This would include both gross and net sedimentation over a range of relevant timescales.
- Field assessments to define material resuspension during dredging and disposal activities (recognising these will vary between dredges and sediment types).

The panel also noted the need for:

- Comprehensive analyses/compilation of the very extensive, existing data/information from dredging monitoring and impact assessments, much of which has not been utilised as fully as possible.
- Greater accessibility of such information, much of which is contained in reports and permit documentation which are difficult to access.
- Developing a standard approach for representing Great Barrier Reef lagoon-scale circulation processes in dredge plume models.

- More detailed synthesis of potential impacts and risks associated with disposal of dredge material on land and in reclamation than was able to be provided in this report.

High-priority, medium-term knowledge needs—within the next three years

- Understanding the regional-scale significance of dredging effects in the context of shifted baselines and cumulative impacts, e.g. using long-term, large-scale scenario analyses, combining models with data from field observations and experiments.
- Implementation of sustained, long-term environmental monitoring in the World Heritage Area integrated with short-term, local to regional monitoring for impact assessments and compliance, including the creation of a central, accessible data repository.
- Review of approaches to assess chronic effects associated with dredging and disposal and to distinguish those from effects of natural and other anthropogenic processes (monitoring to date has focused on acute impacts).
- Improved identification of environmental time windows for dredging to minimise cumulative impacts and avoid sensitive life history phases (e.g. periods of coral spawning and recruitment, seagrass growth seasons) or to minimise exposure (e.g. by avoiding certain tidal phases). One panel member suggested the need to ensure effectiveness of such measures.
- Develop critical tolerance thresholds of light and turbidity for a range of key species to inform more biologically relevant management thresholds during dredging (expansion of recent work with seagrass in Gladstone to other species and habitats). Work should integrate laboratory and field-based approaches and include co-occurring stressors, respite periods and age-specific variation (e.g. vulnerable juveniles).
- Detailed biogeochemical measurements at spoil disposal sites to clarify effects (and scales) of dredging activity on nutrient and organic matter dynamics and budgets.
- Research into potential effects of dredging pressures on fish health.
- Improved knowledge of the biogeochemistry and potential impacts of acid sulphate soils, the long-term effectiveness of management measures, and the capacity to effectively manage large PASS volumes in short times.

Long-term knowledge needs—within the next 5–10 years

- Development of tools (e.g. bio-indicators) to adequately assess sublethal levels of stress in marine organisms, associated with dredging and sediment disposal activities.

- Further development/enhancements of preventative measures to minimise impacts of dredging to megafauna and other species of conservation concern (e.g. deflectors, timing windows).
- Identification of the effects of increased suspended sediments, and dredged sediments specifically, on pelagic food webs and processes, microbial communities and related biogeochemical processes, and on habitats such as mangroves and intertidal mudflats.
- Improved knowledge and technology for dewatering dredged material for reclamation or land-based disposal, including understanding of tailwater treatment and impacts.

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Appendix A: Synthesis panel and workshop process

Purpose and overview

The dredge synthesis project is a joint initiative between the Great Barrier Reef Marine Park Authority (GBRMPA) and the Australian Institute of Marine Science (AIMS).

Given the public attention on issues of dredging and disposal in the Great Barrier Reef World Heritage Area, there was a need for an objective, independent synthesis of knowledge on the effects of dredging and spoil disposal on Great Barrier Reef values. In particular, there was a need for that synthesis to have broad credibility with the wider public and stakeholders, along with robust scientific credibility.

To achieve this, the approach taken by GBRMPA and AIMS was to convene a panel of authoritative technical and scientific experts with a broad range of skills, experience and perspectives — from oceanographic modelling to water quality and coral ecology. To ensure strong public confidence in a transparent and accountable process, the project engaged with a broad range of stakeholders to invite input on the focus of the synthesis, the expertise required, and appropriate mechanisms for communicating the outcomes of the process (further detail below). Based on that input, and on predetermined, explicit criteria for the expertise required (see below), a panel of 19 experts was invited. All 19 agreed to participate and agreed to abide by explicit guidelines to ensure an effective process (see below).

This Expert Panel met for a three-day, facilitated workshop in May 2014 to review existing information on the physical and biological effects of dredging and disposal. The agenda for the workshop is included below.

This report incorporated the advice and input from the Expert Panel during the workshop, along with subsequent input and two rounds of detailed review by the panel. The work is not linked to any specific port development or permit application; it is part of an ongoing process to improve scientific understanding as the foundation for management and policy development.

Where the Expert Panel was not in agreement on the interpretation of available evidence, the project did not aim to resolve all aspects, but to document the different interpretations and the scientific basis for those interpretations. Thus the report aimed to *synthesise* scientific knowledge of the topic, but not necessarily provide *consensus* across all aspects.

Engagement

The project has included active engagement with key Traditional Owner and stakeholder groups, to ensure strong uptake of the outcomes. Key groups included:

- Traditional Owners (10 Traditional Owner representatives and the North Queensland Land Council)

- ports and the resources sector
- consultants to ports
- conservation and community groups
- commercial fishing industry
- recreational fishers
- tourism industry
- science and research agencies and professional societies.

Engagement activities included:

- an initial letter to nearly 50 representatives of the above sectors, inviting input on the focus of the synthesis, the expertise required, and appropriate mechanisms for communicating the outcomes of the process
- informal advice to GBRMPA Reef Advisory Committees and to Local Marine Advisory Committees, including presentations
- email updates (four issues) to the representatives of the sectors outlined above
- engagement with the ports sector to facilitate a collaborative approach and access to information.

Follow-up engagement is planned after publication of the report. Based on stakeholder input, this is likely to include face-to-face presentations, as well as email and web-based summaries of the outcomes. Requests for information or engagement opportunities should be sent to info@gbrmpa.gov.au.

Project scope

To ensure effective outcomes, it was important to limit the scope of the workshop. The scope of the project was developed from a compilation of suggested questions from stakeholders, and included:

- biophysical effects of dredging, including spoil disposal in the marine environment
- particular focus on physical and ecological aspects, around transport, settlement and dispersal of sediments, and incorporating explicit consideration of time (rates) and spatial extents; and ecological impacts
- spatial extent of the Great Barrier Reef World Heritage Area
- explicit identification of areas of:
    - broad, scientific agreement
    - scientific uncertainty, debate or disagreement
    - knowledge gaps

By taking this approach, the Expert Panel was able to focus on identifying what is known and agreed, and provide focus for resolving areas of disagreement or debate, rather than stalling on those areas.

- current context of the inshore, southern Great Barrier Reef in poor health and in decline, with compromised water quality
- consideration of dredge effects against the context of background conditions and terrestrial run-off
- incorporating information from:
  - existing, peer-reviewed scientific publications
  - scientific, expert opinion
  - consultancy reports, where feasible.

Although aspects such as the social, economic, cultural and heritage effects and the management consequences are vitally important, these were beyond the scope of this phase of the project (see the Next Steps section in the report). Indeed, understanding many of these aspects depends on first clarifying the biophysical effects that underpin them; to do so would also have required panel members with different skills and capacities. The following were not included in the scope of work for this phase of the project:

- alternatives to dredging and spoil disposal, including new engineering solutions
- application to specific development proposals
- existing environmental impact assessment processes and governance, legislation, policies and guidelines, or application of the synthesis to those processes and guidelines
- offsets/net environmental benefit
- effects on other industries, such as tourism and fishing
- other social and economic effects and considerations
- effects on cultural, heritage and outstanding universal values, including Indigenous dimensions and perspectives
- human health effects.

Panel selection and composition:

1.6 Criteria for selecting Expert Panel members for dredge synthesis

(These criteria were agreed and recorded prior to finalisation of panel composition.)

Panel membership was based on scientific or technical expertise of strong relevance to the scope of the project. Membership was not based on representation of different sectors or interests.

Panellists were required to have current, demonstrated relevant scientific and/or technical experience, including but not limited to:

1. Experience with the biophysical impacts of:
   - dredging
   - dredge spoil disposal in the marine environment

- sediment dynamics, hydrodynamics and/or biogeochemistry of sediments in the Great Barrier Reef

2. Recent research experience with stressors related to:
   - turbidity
   - light limitation
   - sedimentation
   - pollutants and contaminants associated with dredged sediments
   - effects on corals and reefs, seagrass meadows, and other relevant Great Barrier Reef habitats, especially inshore habitats.

Panel membership was limited to a maximum of 20. Final membership aimed to reflect a range and diversity of technical and scientific perspectives and expertise.

Finalisation of the panel membership was made by the panel convenors, Dr Laurence McCook and Dr Britta Schaffelke, with input from senior management at the Great Barrier Reef Marine Park Authority and the Australian Institute of Marine Science. While suggestions and input were sought from a wide range of stakeholders and Traditional Owners, the Great Barrier Reef Marine Park Authority and the Australian Institute of Marine Science reserved the right to nominate final panel membership.

1.7 Science Expert Panel for dredge synthesis project

Detailed biographies for the panel follow.

Expertise	Name	Affiliation
Coral ecology/impacts	Dr Ross Jones	Australian Institute of Marine Science
Seagrass ecology/impacts	Dr Michael Rasheed	James Cook University
Dredging, corals and seagrasses	Dr Paul Erftemeijer	Consultant – Sinclair Knight Merz
Fish habitat	Prof. Marcus Sheaves	James Cook University
Seafloor habitats	Dr Roland Pitcher	CSIRO
Megafauna/species of conservation interest	Prof. Helene Marsh	James Cook University
Hydrodynamic modelling	Dr Richard Brinkman	Australian Institute of Marine Science
	Dr Brian King	Consultant – APASA
	Dr Andy Symonds	Consultant – Royal Haskoning/DHV
Water quality	Mr Jon Brodie	James Cook University
Sediment biogeochemistry-distribution-movement	Prof. Brad Eyre	Southern Cross University
Pollutant biogeochemistry	Dr Simon Apte	CSIRO
	Dr Michael Warne	Queensland Government
Engineering/dredging/port operations	Mr Frans Hoogerwerf	Consultant – Hoogerwerf Maritime
	Dr Rick Morton	Consultant – Rick Morton Consulting
Policy/environmental impact management	Dr Ray Masini	Western Australian Government
	Dr Ian Irvine	Consultant – Pollution Research Pty Ltd
Panel coordinators/Science – policy transfer	Dr Britta Schaffelke	Australian Institute of Marine Science
	Dr Laurence McCook	Great Barrier Reef Marine Park Authority

The workshop was facilitated by Tim Moltmann, Director of Australia's Integrated Marine Observing System, based at the University of Tasmania in Hobart.

Workshop guidelines:

Prior to participating in the workshop, each member of the Expert Panel formally agreed to a set of guidelines for the workshop and report production. Those guidelines included outlines of the purpose, scope and process for the project (as outlined above), as well as the following agreements:

As far as possible, this process sought to be collaborative, independent, objective, evidence-based and transparent, with the aim that it be perceived as such by the broader community. It was important for the panel to work together not only to produce the outcomes, but also to contribute to the shared intent of the process. This did not require the experts to agree on all matters considered, however it did require a collaborative, courteous and respectful process, based on a team approach.

Where the panel members were not in agreement on a matter, the precise nature of the different interpretations was recorded, along with related evidence or rationale.

The synthesis was supported by clearly identified, relevant evidence readily accessible within the public domain, incorporating information from:

1. existing, peer-reviewed scientific publications
2. consultancy or other technical reports
3. scientific, expert opinion, where the basis of that opinion can be made explicit.

1.8 Workshop organisers agreed to:

- accurately represent the views of the panellists in all reporting, public commentary and media
- ensure all panel members were given sufficient opportunity to express their understanding and interpretations of available evidence
- strive to address the full scope of the agreed workshop agenda within the time available, recognising that this would place limitations on the depth of coverage possible within the workshop. The written outputs would provide opportunity for greater depth of information and treatment.
- produce the synthesis outputs in a timely fashion, with due recognition of the contributions of the full panel membership.

1.9 Panellists agreed to:

- commit to and engage fully with the goal of an effective, cohesive synthesis, and maintain a high standard of professionalism concerning panel deliberations
- contribute based on their professional expertise, and not as representatives of any interest or group
- adhere to the agreed scope of the panel and workshop (see below)
- identify and have documented areas of disagreement as part of the workshop process and avoid subsequent public commentary or engagement which may reduce

the effectiveness of the final outcomes, in terms of addressing public perceptions of debate

- focus on the clarification of areas of agreement and disagreement, rather than on complete resolution of such issues.
- treat the proceedings, deliberations and outcomes of the workshop as shared, privileged information until outcomes of the workshop are finalised.

Workshop—Agenda

Start	Finish	Topic	Sub-topic	Lead	Present
			Monday 12 May 2014, Rydges Southbank, Room Portside		
Start	**Finish**	**Topic**	**Sub-topic**	**Lead**	**Present**
08:15	08:30	Arrival	Tea & Coffee		
08:30	09:00	Setting the scene	Welcome Brief introduction of workshop House keeping	GBRMPA LMcC / BS	Panel members, GBRMPA & AIMS executive
09:00	10:00	Workshop goals	Discussion and agreement of goals and process	TM	Panel members, GBRMPA & AIMS executive
10:00	10:30	Morning tea			Panel members, GBRMPA & AIMS executive
10:30	11:30	Session 1	How does dredging affect the biophysical environment/water quality?		Panel members
11:30	12:30	Session 2	How does dredge spoil disposal affect the biophysical environment/water quality?		Panel members
12:30	13:00	Lunch			Panel members
13:00	15:00	Session 3	Short and long-term sediment dynamics: Transport, resuspension / consolidation		Panel members
15:00	15:30	Afternoon Tea			Panel members
15:30	16:30	Session 4	Modelling short and long-term sediment dynamics		Panel members
16:30	17:00	Wrap-up	• Recap of days findings • Outlook for tomorrow		Panel members

Tuesday 13 May 2014, Rydges Southbank, Room Portside					
Start	**Finish**	**Topic**	**Sub-topic**	**Lead**	**Present**
08:15	08:30	Arrival	Tea & Coffee		
08:30	08:45	Setting the scene for Day 2	Brief review of agenda Discussion of goals and process (if required)	TM, LMcC / BS	Panel members
08:45	9:45	Session 5	Contaminants in sediment that is being dredged and disposed	TM	Panel members
09:45	10:15	Session 6	Effects on Coral Reefs		
10:15	10:45	Morning tea			Panel members
10:45	11:45	Session 6 continued			Panel members
11:45	12:30	Session 7	Effects on seagrass meadows		
12:30	13:30	Lunch			Panel members
13:30	14:15	Session 7 continued			Panel members
14:15	15:00	Session 8	Effects on interreefal, soft-bottom, pelagic and other habitats and on fish		Panel members
15:00	15:30	Afternoon Tea			Panel members
15:30	16:45	Session 8 continued			Panel members
16:45	17:00	Wrap-up	• Recap of days findings • Outlook for tomorrow		Panel members

Wednesday 14 May 2014, Rydges Southbank, Room Portside					
Start	**Finish**	**Topic**	**Sub-topic**	**Lead**	**Present**
08:15	08:30	Arrival	Tea & Coffee		
08:30	08:45	Setting the scene for Day 3	Brief review of agenda Discussion of goals and process (if required)	TM, LMcC / BS	Panel members
08:45	10:30	Session 9	Effects on marine megafauna and other threatened species	TM	Panel members
10:30	11:00	Morning tea			Panel members
11:00	12:00	Session 10	Cumulative impacts on the Great Barrier Reef and the contribution of dredging and disposal		Panel members
12:00	13:00	Session 11	Summary and outstanding issues		Panel members
13:00	13:30	Lunch			Panel members
13:30	14:00	Wrap-up 1	Moving forward: Write up process, etc.		Panel members
14:00	15:00	Wrap-up 2	• Recap of workshop- summary of main findings		Panel members, GBRMPA & AIMS executive
15:00	15:30	Afternoon Tea			Panel members, GBRMPA & AIMS executive
15:30	17:00	Wrap-up continued	• Recap of workshop- summary of main findings • Write-up / finalisation process • Stakeholder engagement • Next steps- application to management and policy, etc.	LMcC / BS	Panel members, GBRMPA & AIMS executive
17:00		Workshop closes			

Panellist biographies

1.10 Dr Laurence McCook

Dr Laurence McCook works on science-based management of marine ecosystems, especially coral reefs. He has more than 30 years' experience, including coral reefs in Australia, the Coral Triangle, the Pacific and the Caribbean as well as in temperate ecosystems. He has authored around 60 peer-reviewed scientific papers and contributed to more than 20 science-based policy documents.

Laurence's role at the Great Barrier Reef Marine Park Authority involves ensuring the management of the Great Barrier Reef is based on the best available scientific information, in the face of increasing cumulative impacts, ecosystem declines and climate change. Over the past decade, he has managed adaptive management and the strategic integration and application of science into management, including the Great Barrier Reef Outlook Report, Strategic Assessment, Climate Change Action Plans and monitoring programs for the groundbreaking Reef Water Quality Protection Plan and the rezoning of the Marine Park. He has worked in community engagement around science-based management of the Great Barrier Reef.

Laurence has led a number of trans-disciplinary collaborations and synthesis projects between managers and scientists. He previously spent twelve years at the Australian Institute of Marine Science, researching water quality and other impacts on reef resilience.

His interests include:

- The strategic application of science in environmental management:
  - the application of scientific rigour, uncertainty, and the burden of proof in management
  - shifting baselines, and management of cumulative impacts
  - the role of marine reserves in conservation of marine ecosystems
  - the interface between environmental and economic values.
- The ecological processes underlying coral reef resilience and degradation, with emphasis on the effects of water quality, climate change and overuse on reef resilience.

In 2005, Laurence was awarded an international Pew Fellowship in Marine Conservation. This focused on management and policy initiatives to protect the resilience of coral reefs under climate change, and included developing and delivering a series of workshops on coral reef management for reef managers and communities across Indonesia, and in Malaysia.

Acknowledgment of interests related to ports development and dredging operations:
I am employed by the Great Barrier Reef Marine Park Authority, which is the principal client and joint instigator of this panel and project. To the best of my knowledge, I do not have any other direct or indirect financial or other interests in dredging or its impacts in the marine environment.

1.11 Dr Britta Schaffelke

Dr Schaffelke leads the Research Program Sustainable Coastal Ecosystems and Industries in Tropical Australia at the Australian Institute of Marine Science.

Over the last two decades, Dr Schaffelke's interest and expertise has been the research and management of environmental impacts, especially those related to deteriorating marine water quality and coastal development. Dr Schaffelke has published more than 60 journal articles and technical reports and is a key author of the 2013 *Reef Plan Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition,* published by the Queensland Government.

Prior to joining AIMS in 2005, Dr Schaffelke held a variety of positions spanning marine ecological research, environmental management and knowledge exchange. After being a lecturer at the University of Kiel, Germany, she migrated to Australia in 1995 for postdoctoral research at AIMS. In 2000 she joined the CSIRO to work on introduced marine pests. After positions in the Water Quality and Coastal Development group of the Great Barrier Reef Marine Park Authority and at the CRC for Reef Research, Dr Schaffelke returned to AIMS to manage the AIMS component of the Reef Rescue Marine Monitoring Program. In 2006, she became Research Team Leader of the 'Measuring Water Quality and Ecosystem Health' Team and in 2012 Research Program Leader.

Acknowledgment of interests related to ports development and dredging operations:
Currently Dr Schaffelke is serving on the Gladstone Healthy Harbour Partnership Independent Science Panel and the Darwin Harbour Integrated Monitoring and Research Program Committee. At AIMS, Dr Schaffelke leads a research team of more than 30 staff, focusing on understanding the human and environmental drivers of tropical coastal and shelf systems and on forecasting the responses of key ecosystem components to a changing environment. This research supports coastal and marine planning, development and conservation and has in part been funded by private companies and port authorities.

1.12 Dr Simon Apte

Dr Simon Apte leads the Contaminant Chemistry and Ecotoxicology research program in CSIRO's Land and Water division. Dr Apte's research focuses on the analysis of trace metals and the links between trace metal speciation and bioavailability. This involves the application of specialist analytical techniques to measure ultratrace concentrations of trace metal species in environmental samples. Much of this work is directed to understanding the impacts of mining on aquatic environments and the impacts of metals in marine systems. Recent research has covered the issues around nanomaterial fate, transport and toxicity in aquatic systems. Dr Apte is author of over 70 peer-reviewed publications in international journals and over 70 technical reports. He has over 2400 ISI listed citations (H Index = 28). He was the recipient of the Royal Australian Chemical Institute 2010 Environment Medal.

Acknowledgment of interests related to ports development and dredging operations:

I have been involved for over a decade in studies focusing on understanding contaminant inputs and their distribution in Gladstone Harbour. This included leading the first contaminants risk assessment in Port Curtis which was conducted as part of the Coastal Zone CRCs activities. Recent work has included a study which investigated trace metal distributions during the recent dredging operations in Gladstone Harbour. This project was funded by Gladstone Ports Authority.

1.13 Dr Richard Brinkman

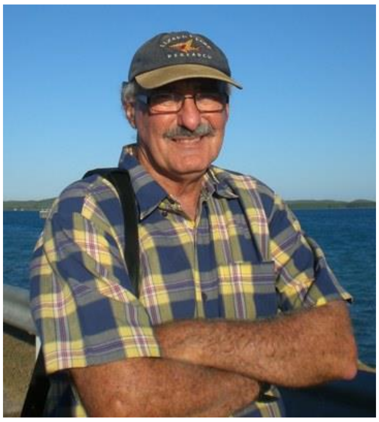
Dr Brinkman leads the Shelf Dynamics and Modelling Team within the Sustainable Coastal Ecosystems and Industries in Tropical Australia Research Program at the Australian Institute of Marine Science.

Richard is a physical oceanographer/numerical modeller with research interests that fall within the broad topics of coastal oceanography and physical–biological interactions on continental shelves. He has significant expertise in conducting observational and modelling based research on shelf dynamics, coupling of shelf and ocean circulation, and physical–biological interactions at regional and local scales on Australia's tropical coasts and marginal seas. Richard has published over 40 scientific, technical and client reports, including studies on hydrodynamics and sediment transport dynamics within the Great Barrier Reef.

Acknowledgment of interests related to ports development and dredging operations: Dr Brinkman is a current member of the Gladstone Healthy Harbour Partnership Independent Science Panel. As the Lead Physical Oceanographer at the Australian Institute of Marine Science, a number of staff that he has supervisory responsibility for have current and historical research projects for industrial clients within the Great Barrier Reef and adjacent ports.

Richard has also served on the Darwin Harbour East Arm—Marine Supply Base dredging program Technical Advisory Group, and has provided scientific and technical advice to the Dredging Technical Advice Panel (DTAP) for the Chevron Wheatstone Project. Richard also provides scientific and technical advice to the Great Barrier Reef Marine Park Authority in the areas of hydrodynamics, sediment transport and numerical modelling.

1.14 Jon Brodie



Positions held

Chief Research Scientist, Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), 2014 and Team Leader, Catchment to Reef Research Group – TropWATER (2001–2014)

- Principal Research Scientist, Australian Centre for Tropical Freshwater Research, James Cook University, 2001–2013
- Deputy Director and Director, Research and Monitoring Section, Director, Water Quality and Coastal Development Section, Great Barrier Reef Marine Park Authority, 1990–2001
- Research Scientist, Australian Centre for Tropical Freshwater Research, James Cook University, 1988–1990
- Director, Institute of Natural Resources, University of the South Pacific, Suva, Fiji, 1986–1987
- Research Fellow, Institute of Natural Resources, University of the South Pacific, Suva, Fiji, 1981–1986

My research interests are in the sources of pollutants in catchments, transport of pollutants to the marine environment, the dispersal of land-based pollutants in coastal and marine environments, and the effects of terrestrial pollutants on marine ecosystems. I am particularly interested in the following research areas: water quality in tropical coastal marine environments; the effects of sediments, nutrients, pesticides and other contaminants on coral reef and seagrass bed ecosystems; catchment sources of sediment, nutrient and pesticide discharge to coastal environments; land use practices which lead to enhanced rates of sediment, nutrient and pesticide discharge to coastal environments; river plume dynamics and biological, physical and chemical processes occurring in river plumes; temporal and spatial dynamics of water quality on the Great Barrier Reef; water quality management systems in coral reef environments. I have published over 100 peer-reviewed articles in this field as well as more than 100 technical reports.

I am also heavily involved in policy advice to Australian governments regarding management of water quality issues for the Great Barrier Reef. I was the lead author of the Scientific Consensus Statement (2008) documenting the status of knowledge and management for water quality issues affecting the Great Barrier Reef for the Queensland Government and I have recently completed the 2013 Scientific Consensus Statement leading a group of more than 50 scientists and policy experts.

Recent research projects

- Torres Strait water quality monitoring program—*TSRA. 2014*.
- Burnett Mary Water Quality Improvement Plan—*BMRG NRM. 2014*.
- Wet Tropics Water Quality Improvement Plan—*Terrain NRM. 2014*.
- Reef Plan Herbert Water Quality Monitoring Program—*Queensland Government and SRDC. 2011–2014*.
- GBRMPA coastal catchments program water quality chapters—*GBRMPA, Australian Government. 2012–2013*.
- Pesticide dynamics in the Great Barrier Reef catchment and lagoon: management practices (grazing, bananas and grain crops) and risk assessments—*Reef Rescue Initiative, Caring for Country, Australian Government. 2010–2013*.
- Pesticide dynamics in the Great Barrier Reef catchment and lagoon: management practices in the sugarcane industry—*Reef Rescue Initiative, Caring for Country, Australian Government. 2010–2013*.
- Tracking coastal turbidity over time and demonstrating the effects of river discharge events on regional turbidity in the GBR—*NERP, Australian Government. 2012–2014.*
- Hazard Assessment for water quality threats to Torres Strait marine waters, ecosystems and public health—*NERP, Australian Government. 2011–2013*.
- Conservation planning for a changing coastal zone—*NERP, Australian Government. 2011–2014*.
- Socio-economic systems and reef resilience—*NERP, Australian Government. 2011–2014.*
- Catchment to coast conservation planning—*NERP, Australian Government. 2011–2014*.
- Assessment of vegetated systems as options for treating pollutants in run-off from cane farms—*Queensland Government. 2012–2014.*
- Reef Rescue MMP—Assessment of terrestrial run-off entering the Great Barrier Reef—*Great Barrier Reef Marine Park Authority.*
- Risk assessment for water quality and the GBR—*Queensland Government. 2012–2013.*

- 2013 Scientific Consensus Statement—*Queensland and Australian Governments. 2012–2013.*

See also: http://research.jcu.edu.au/research/tropwater/resources/jon-brodie

Acknowledgment of interests related to ports development and dredging operations:
I am employed by James Cook University. I am currently a potential expert witness in the Gladstone fishermen's compensation court case and in that role I have prepared a summary document for the use of the court. I am also likely to be an expert witness (not yet agreed) in the appeal in the Federal Court of the decision granted by the Federal Environment Minister to allow dredging at Abbot Point.

1.15 Dr Paul Erftemeijer

Current position
Principal Marine Scientist, Jacobs Group (Australia) Pty Ltd

Qualifications
MSc in Biology (1988), Nijmegen University
PhD in Marine Biology (1993), Nijmegen University
Diploma in NGO Management (2000), University of London

Professional memberships and affiliations

- Research Professor (adjunct) at the UWA Oceans Institute, University of Western Australia
- C-Chairman of PIANC Envicom 157 Working Group on Dredging and Port Construction near Coastal Plant Habitats
- Committee Member of the World Seagrass Association
- Member of the IUCN SSC Seagrass Specialist Group

Dr Paul Erftemeijer works as a principal marine scientist with Jacobs (previously SKM) from Perth. He also holds an adjunct position as Research Professor at the Oceans Institute of the University of Western Australia.

Paul has over 25 years of international experience as an applied scientist and specialist consultant focusing on human impacts, management, recovery and restoration of critical marine and coastal ecosystems around the world. He has extensive working experience as technical advisor to address environmental concerns related to dredging operations, in particular with regards to the potential impacts of dredging on sensitive marine habitats (seagrass meadows, coral reefs and mangroves). He is the author of over 60 scientific publications, including two milestone scientific review papers on the environmental impacts of dredging on seagrasses (2006) and corals (2012), as well as a range of book chapters and technical reports.

Paul served as invited member on a technical working group for PIANC on ‘Dredging and Port Construction around Coral Reefs’ and currently serves as co-chair on a new PIANC working group on ‘Environmental Aspects of Dredging and Port and Waterway Construction near Coastal Plant Habitats’.

Prior to joining SKM (now Jacobs) in Australia in 2011, Paul worked for nine years as senior marine ecologist at Delft Hydraulics (Netherlands), six years as program director for Wetlands International (in Thailand and Indonesia), four years as technical advisor for DGIS on development aid projects in Kenya and Tanzania, and four years as PhD researcher at the Netherlands Institute of Ecology.

Acknowledgement of interests related to ports development and dredging operations: Paul’s work on environmental aspects of dredging includes the development of water quality thresholds and management triggers for reactive monitoring programs of several large-scale dredging operations for the Wheatstone (Pilbara) and Ichthys (Darwin Harbour) dredging projects. He also worked on a host of environmental impact assessments and related studies (including sediment plume model interrogation) of proposed dredging, land reclamation and industrial development projects on marine ecosystems in the Arabian Gulf, Red Sea, Mediterranean, Wadden Sea, North Sea and Singapore.

1.16 Prof. Bradley Eyre

Professor Bradley Eyre is the foundation Director of the Centre for Coastal Biogeochemistry at Southern Cross University. The Centre undertakes research that contributes to the understanding of coastal biogeochemical cycles and associated improved management of coastal waterways impacted by global change (e.g. changes in the carbon and nitrogen cycles, climate changes, ocean acidification, land use changes). In the government’s assessment of research excellence (ERA) at Australian universities the Centre for Coastal Biogeochemistry was a major contributor to Southern Cross University’s top ERA rank of 5 (well above world average) in 0402 Geochemistry in both rounds.

Brad is a biogeochemist with diverse research interests, but mostly focused on the flow of carbon and nitrogen through coastal ecosystems. He uses a variety of research approaches in his work, on scales from a few metres to global estimates, including in situ process measurements, natural abundance, tracer and compound specific stable isotopes measurements, experimental manipulations, ecosystem comparisons, ecosystem stimulation modelling and material mass-balances. Much of his work has been in (sub) tropical coastal systems, but he has also worked in warm and cold temperate and arctic systems.

Brad is active in research with 123 articles in ISI listed journals (H-index = 32, Total citations >2700, Google Scholar; H-index = 26, Total citations>1800, Scopus) and has attracted over $8.5 million in research funding including six ARC Discovery Grants (all as lead CI), seven ARC Linkage Grants (five as lead CI) and eight ARC LIEF Grants (five as lead CI) and $3.3 million in contract research. He has mentored 15 early- and mid-career researchers (nine current), including two Australian Postdoctoral researchers, an Australian Postdoctoral (Industry) researcher, two Discovery Early Career Researcher Awards and a Future Fellow and supervised 26 PhD students (12 current).

His publications include topics such as whole ecosystem carbon, nitrogen and phosphorus budgets, net ecosystem metabolism estimates, benthic and pelagic production and respiration, dissolved organic carbon fluxes, carbon stable isotopes (fluxes and assimilation), carbon burial and air–sea CO_2 flux estimates, benthic denitrification, benthic habitats and seascapes, historical and ecosystem comparisons, ocean acidification, hypoxia, eutrophication, submarine groundwater discharge and permeable sands.

Acknowledgment of interests related to ports development and dredging operations:
To the best of my knowledge, I do not have any direct or indirect financial or other interests in dredging or its impacts in the marine environment.

1.17 Captain Frans Willem Hoogerwerf

Independent advisor on dredging reclamation and disposal at sea technical and commercial issues

Experience in technical support roles to environmental panels

Frans established Hoogerwerf-Maritime P/L in 2003, specialising in providing independent advice to port authorities, large corporations, State and Federal governments. Prior to these advisory roles, he has been involved in many dredging works around Australia, as Project Manager, Executive Director and Managing Director of WestHam Dredging Company Pty Ltd. In these positions, he has had direct involvement and gained experience in many projects with similar technical challenges relating to environmental and operational aspects and issues, as may be needed to inform the Abbot Point panels.

Environmental management:

During the period of time (1968–2003) when Frans was involved in general and top management of Australia largest locally based dredging company, the regulations and laws in relation to environmental management evolved.

As executive manager and director, he has been at the forefront to apply better, but efficient, work practices and procedures for dredging in order to limit responsibly and as much as possible, any remaining negative environmental effects, whilst also meeting the statutory environmental conditions.

The results of these endeavours, and further adaptations of this experience as regulations were tightened or changed, have been a very important source of background information to predict and to assist with monitoring and to confirm effects of the dredging and disposing of dredge spoil for assessments by the scientific members of environmental panels.

Operational management

Whilst holding top management positions in a large dredging company for more than 30 years, Frans, who is a qualified master mariner, has gained extensive experience in leading and working within teams to achieve deadlines involving the control and report processes for the successful completion of a large range of small and large dredging projects.

He has extensive dredging experience with the full range of the most modern equipment from very large THSDs, CSDs and mechanical dredges to the smallest units.

Acknowledgment of interests related to ports development and dredging operations:
As above, my company, Hoogerwerf-Maritime P/L, is a consultancy providing independent advice to port authorities, corporations, and governments. I am confident that I can provide advice that is fully independent for the purposes of the dredge synthesis workshop and reports.

1.18 Dr Ian Irvine

Dr Irvine is the Principal of Pollution Research Pty Ltd, a specialist consulting firm he established in 1986. The firm carries out environmental assessment of contaminated sediments, marine ecological risk assessment, and water pollution studies.

Ian Irvine has a PhD in marine science (University of Sydney, 1981—assessment of contaminated sediments throughout Sydney Harbour) and 32 years postdoctoral experience in the assessment and management of environmental pollution, with particular expertise with contaminated sediments, their chemistry, toxicity and water quality effects in situ, as well as during dredging and disposal.

Dr Irvine has been the principal consultant to the Commonwealth Department of Environment for the development and implementation of the three editions of the national dredging and spoil disposal guidelines (1998, 2002 and 2009), the latest being the *National Assessment Guidelines for Dredging 2009*. He has been a member of the Department's technical panel for the assessment of dredging and sea disposal applications since its founding in the late 1990s.

Dr Irvine has also provided advice to various state governments and many companies on marine environmental and dredging issues, and acted as an expert witness in legal proceedings. He has conducted independent peer reviews of the contaminated sediment work for a number of major projects including the Port of Melbourne Corporation's Port Phillip Bay *Channel Deepening Project* (2006–2007), the recent *Independent Review of the Port of Gladstone* (2013) and Ports Australia's report, *Dredging and Australian Ports, Subtropical and Tropical Ports* (2014).

Dr Irvine has also carried out many consultancies in the Asia-Pacific region for the World Bank and other international agencies.

Ian's detailed CV: http://pollution-research.com/about/

Acknowledgment of interests related to ports development and dredging operations:
Dr Irvine is currently on the Commonwealth Department of Environment's technical panel for the assessment of dredging and sea disposal applications. He has also acted as a consultant to State governments, private companies and Ports Australia.

1.19 Dr Ross Jones

Dr Jones leads the *Impacts of Dredging* research team (10 + people) at the Australian Institute of Marine Science (AIMS). He is also the Node Leader (Science) of the *WAMSI Dredging Science Node*, a multimillion dollar scientific initiative amongst government and research institutions in WA to improve capacity for government and industry to predict and manage impacts of dredging.

His major research interest is the biology of the coral–algal symbiosis and understanding and quantifying how the relationship changes during conditions of altered environmental conditions (natural and anthropogenic). He is involved in developing ways to examine and quantify the condition of corals in both laboratory-based setting (i.e. for determining water quality criteria for reefal ecosystems) and in the field (i.e. examining dredging or construction-related activity, or point/diffuse source pollution).

He completed a PhD at James Cook University (1992–1996), and then ARC postdoctoral fellowships at The University of Sydney (1996–2000) and at The University of Queensland (2000–2004). From 2004 to 2009 he was head of the marine environmental program at the Bermuda Institute of Ocean Sciences (BIOS) and was involved in designing and implementing various long-term monitoring programs (water quality, seawater temperature, ecological surveys), as well as ecotoxicological studies and surveys of contaminant concentrations. In 2009, he returned to Australia to take up his present position at AIMS-WA in Perth.

Acknowledgment of interests related to ports development and dredging operations:
Dr Jones is a member of the Expert Panel (Dredging Technical Advice Panel) for the Wheatstone dredging project at Onslow in WA, and a member of the Expert Panel (Technical Advisory Group) of the Anketell project near Cape Lambert.

1.20 Dr Brian King

Dr Brian King has been a dedicated researcher of water circulation and mixing in freshwater and marine environments for the last 28 years. Brian's specialty utilises data from rivers, the sea and earth observing satellites and simulation models, to enhance our understanding of water movement and material transport and fate in marine, estuarine and coral reef environments. These techniques have been used to minimise the environmental impacts of sediment transport, oil spills and petroleum platform discharges and understand natural outcomes from river plumes and larval movement. He also initiated the distribution and support of OILMAP, MUDMAP, SIMAP, DREDGEMAP and WQMAP systems for Australia and South East Asia which provide computer modelling technology and environmental decision support and management systems for industry and government agencies.

Brian has provided risk assessment modelling using stochastic techniques and undertaken research and provided expert advice regarding novel modelling techniques for new industries such as deepwater sediment mining. Brian also helped develop an advanced current forecast system for the Asia-Pacific region which incorporates tidal dynamics into large-scale ocean forecast systems such as HYCOM and BLUElink. This data is distributed to subscribers for use in search and rescue and oil and chemical spill response. Clients include international government agencies and Fortune 500 companies.

Selected project experience:

- Sediment transport and mixing advisor to Nautilus Minerals for their planned operations of deepwater mining at the Solwara Prospect in Papua New Guinea since 2008, including presentations of reports for their environmental impact statement, related radio interviews and public lectures in Australia and Papua New Guinea.

- Specialist workshop facilitator—oceanography, sediment transport and dredging in the Great Barrier Reef. Tailored for the staff of the Great Barrier Reef Marine Park Authority, Townsville, February 2013.
- Expert panel member to develop a synthesis statement on the effects of dredging and offshore spoil disposal on the Great Barrier Reef. A joint initiative between the Great Barrier Reef Marine Park Authority (GBRMPA) and the Australian Institute of Marine Science (AIMS), ongoing.
- Undertook field research and modelling studies of the fate of sediments from dredging and dumping operations (Port of Townsville and Cleveland Bay).
- Undertook field research and modelling studies of the fate of background sediment dynamics associated with natural resuspension and deposition processes in the Port of Gladstone, the Normandy River, Gold Coast Broadwater and Hinchinbrook Channel (Australia), the Fly River Estuary, Sepik River and Bismarck Sea (PNG) and Jiaojiang Estuary (China).
- Numerous industry reports to quantify the fate of sediment discharges associated with offshore petroleum drilling operations in Australia, Thailand, Vietnam and Indonesia.
- Expert witness for Courts in New South Wales and Queensland—provided and defended many expert witness reports during trial processes.

Acknowledgment of interests related to ports development and dredging operations:
I am employed by RPS as a Principal Oceanographer. RPS is a global consultancy company listed on the UK stock exchange. RPS has a significant client base and, as such, would have in place a number of relationships that are related to dredging, port development, government and special interest groups, almost all of which I would not be specifically involved with or, for that matter, even aware of. I have been involved in projects for the Great Barrier Reef Marine Park Authority and industry in regards to dredging and its impacts in the marine environment.

1.21 Professor Helene Marsh

Helene Marsh is a conservation biologist with some 30 years' experience in research into species conservation, management and policy with particular reference to coastal tropical marine megafauna of conservation concern. The policy outcomes of her research include significant contributions to the science base of dugong conservation in Australia and internationally. Helene is committed to informing interdisciplinary solutions to conservation problems and has collaborated widely with colleagues in other disciplines.

Helene is a Fellow of the Australian Academy of Technological Sciences and Engineering and has received international awards for her research and conservation from the Pew Charitable

Trust, the Society of Conservation Biology and the American Society of Mammalogists. She is President of the Society of Marine Mammalogy and Co-chair of the IUCN Sirenia Specialist Group. She is on the editorial boards of *Conservation Biology*, *Endangered Species Research* and *Oecologia*.

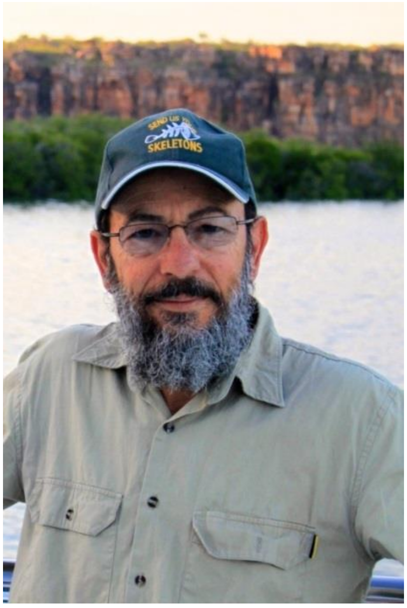
Helene is Dean of Graduate Research Studies and Distinguished Professor of Environmental Science at James Cook University. Her publications include two books, more than 130 papers in professional journals, some 30 chapters in refereed monographs/conference proceedings, more than 30 papers in conference/workshop proceedings, plus numerous technical reports and popular articles. Helene has supervised more than 70 research higher degree candidates to completion and numerous postdoctoral fellows.

https://research.jcu.edu.au/portfolio/helene.marsh

Acknowledgment of interests related to ports development and dredging operations:

Currently Helene Marsh serves on the Port Curtis and Port Alma Ecosystem Research and Monitoring Program Advisory Panel for the Western Basin Dredging and Disposal Project and chairs the national Threatened Species Scientific Committee. At JCU, Helene is affiliated with the TropWater Research Centre and is co-leader of a research group of postdoctoral fellows and PhD candidates focusing on the conservation of marine wildlife, dugongs, cetaceans and marine turtles. This research supports coastal and marine planning and is mostly funded by the Australian government but has received funds from developers, port authorities and Indigenous groups.

1.22 Dr Raymond John Masini



Manager, Marine Ecosystems Branch
Strategic Policy and Planning Division
Office of the Environmental Protection Authority

Dr Ray Masini is a marine ecologist with about 30 years' experience working in Western Australian marine ecosystems with particular focus on the temperate and tropical arid ecosystems of the central-west and north-west coasts.

He holds an adjunct professorship in the Centre for Ecosystem Management at Edith Cowan University and for the last 17 years has held the position of Manager, Marine Ecosystems Branch of the Office of the Environmental Protection Authority (EPA).

The group he manages develops marine environmental policy and provides technical advice to the EPA and government generally on the assessment and management of development proposals including aquaculture, desalination and industrial discharges, petroleum-based exploration and production, and port development and expansion.

Ray has sat on a number of expert groups and committees and is involved in environmental management strategy and policy formulation at the state and national levels. He has been centrally involved in the planning and management of a range of multidisciplinary marine-scientific studies around the state's 13,000 km coastline, including the site selection and assessment of an LNG precinct on the remote Kimberley coast.

More recently, he has been instrumental in the establishment of a multimillion dollar dredging science initiative within the Western Australian Marine Science Institution (WAMSI) that uses environmental offset funds to undertake science to better predict and manage the impact of dredging in tropical coral reef communities. Ray is the Node Leader (Policy) of the WAMSI Dredging Science Node and is primarily responsible for translating the science into products that can be readily used by government and industry alike.

Acknowledgment of interests related to ports development and dredging operations:
I am responsible for providing technical advice and contributing to the development of recommended conditions of approval for all significant port development and dredging proposals in Western Australia. Recently I provided independent scientific advice on the adequacy of water quality monitoring associated with the Port of Gladstone Western Basin Dredging Project, Queensland. The advice was to the independent panel established by the Commonwealth Minister for the Environment and the work was done under a service agreement with the Australian Government Department of the Environment.

1.23 Dr Rick Morton

Dr Rick Morton has over 30 years' experience in marine environmental planning and impact assessment. He has worked in research, consulting and senior management positions for both government and private companies. Rick's particular areas of expertise relate to dredging, dredge material management, environmental monitoring and approvals processes.

Rick presently operates RMC Pty Ltd, a private consulting company that provides independent environmental management advice on coastal and port development.

Rick has extensive technical experience in dredging impact assessment near areas of high conservation value. He has been a principal/contributing author of numerous publications associated with environmental impacts of dredging and dredged material management projects (most recently the Australian representative for the PIANC report: *A practical guide* *for a sustainable seaport*). He also regularly provides technical advice on dredging and port environmental issues to State/Commonwealth governments, Ports Australia and Queensland Port Association.

Rick has been involved in the development of port management guidelines and policies in Australia for more than 15 years. He has been a member of many national and international committees on port environmental management.

Rick has a detailed knowledge of dredging projects in Australia, particularly in the Great Barrier Reef Region. He has extensive international travel experience reviewing leading environmental practices adopted by ports for dredging in Asia, USA, United Kingdom and Europe. He has presented at many dredging and port related conferences, both nationally and internationally, and undertook a Green Port study tour of European ports in relation to sustainable port operations and dredge management.

Rick previously held the position of General Manager Planning and Environment at the Port of Brisbane Corporation, was an Associate (water quality and coastal development impact specialist) in a leading Australian environmental consulting company and was employed by the Queensland Fisheries Department as a researcher investigating the impacts of coastal development. Rick recently held the role of Independent Chair of the Dredge Technical Reference Panel for the Gladstone Western Basin Dredging Project, which utilised a new light-based approach to managing dredge related impacts.

Acknowledgment of interests related to ports development and dredging operations:
I operate an independent private consultancy and regularly undertake consulting for a broad range of clients including various ports and port associations and larger consulting companies involved in port management/dredge impact monitoring.

1.24 Dr Roland Pitcher

Dr Roland Pitcher is a marine ecologist with CSIRO Oceans and Atmosphere Flagship. He has diverse interests in seabed ecology including dynamics of habitat-forming biota, drivers of distribution and abundance, the effects of human uses and management. Roland has >30 years' experience in marine ecology and fisheries research, covering coral reef fishes, tropical rock lobster, effects of trawling, recovery and dynamics, biodiversity mapping and prediction, modelling and assessment, and management evaluation—providing a science foundation supporting management for sustainability of the seabed environment.

Dr Pitcher leads research in CSIRO to better understand regional seabed ecosystems and provide information that supports improved planning of ocean uses, more detailed quantitative assessments of the effects of human activities and evaluations of the efficacy of management measures. His research addresses issues such as:

- Characterisation and mapping of large marine regions, using available (and often sparse) survey data, and where required designing and implementing new marine biodiversity surveys.
- Planning for management of multiple uses of the marine environment, to ensure appropriate and sustainable use of different habitat types, and comprehensive, adequate and representative design of marine reserves.
- Understanding the effects of trawling and other bottom fishing methods, and the environmental benefits and trade-offs of fisheries management and spatial management in seabed ecosystems.
- Understanding the effects and impacts of climate variability and events on seabed ecosystems.
- Application of technologies such as underwater instrumentation, airborne and satellite remote sensing, oceanographic datasets and model outputs to provide new macroecological insights for better scientific understanding and management.

Dr Pitcher joined CSIRO in 1988, researching tropical rock lobster (TRL) in Torres Strait—the most important commercial fishery for local indigenous people and subject to an international treaty with Papua New Guinea. He developed and led a broad range of research including commercial and traditional fisheries, seabed habitat mapping, effects of trawling on the seabed, GIS and remote sensing, marine conservation planning, dynamics of seabed megabenthos, among others. His work has also included early development of a number of innovative technological solutions for obtaining quantitative data remotely without extractive sampling, such as towed-video, remotely operated vehicle (ROV), and acoustics—complete with precise positioning and underwater tracking, and advanced data recording. He has managed research projects and supervised staff ranging from single-project teams to very large multi-agency multi-disciplinary programs and international projects.

Dr Pitcher's current research provides a science foundation in support of management for environmental sustainability of seabed ecosystems. He has published 45 peer-reviewed papers, more than 30 other articles and around 60 major reports for clients.

Acknowledgment of interests related to ports development and dredging operations:
Dr Pitcher is employed by CSIRO; he led the Great Barrier Reef Seabed Biodiversity Project, and contributed to or led projects on the effects of trawling in the Great Barrier Reef. To the best of his knowledge, Dr Pitcher does not currently have any other direct or indirect financial or other interests in dredging or its impacts in the marine environment. Potentially, he could be interested in contributing to relevant future research on this topic.

1.25 Dr Michael Rasheed

Dr Michael Rasheed has been conducting research on tropical marine habitats focusing on coastal and seagrass ecology for over 20 years. His passion is finding science based solutions to apply in the management of marine habitats. Michael has built a team whose work focuses on coastal development and risk and has significantly impacted on the way seagrass and marine habitats are managed and protected through research and monitoring partnerships with industry and government with a focus on the tropics and the Great Barrier Reef World Heritage Area. Results of his work have not only led to advances in the field of seagrass ecology, but have changed practices within coastal development, ports and shipping industries and improved the ability of managers and regulators to protect marine habitats (www.jcu.edu.au/portseagrassqld).

Michael's team are world leaders in assessment and management of anthropogenic risks to tropical seagrasses. He actively promotes the benefits and impacts of these projects and work to industry, government, community and scientific peers. Michael's recent work has focused on developing thresholds and management tools to protect seagrasses during major dredging projects in the Great Barrier Reef World Heritage Area and he currently leads active seagrass assessment, research and monitoring programs in all of the major commercial ports in the World Heritage Area.

Michael has extensive experience in the oversight of dredging programs and provision of expert advice to ensure positive outcomes for seagrass habitats and currently sits on the dredge technical advisory committees in the Ports of Mackay, Hay Point, Abbot Point, Weipa, Karumba, Cairns, and Gladstone. He has reviewed dredging and monitoring programs for seagrass throughout tropical Australia and has been part of dredge management review groups for the majority of major capital dredging programs in Queensland over the past 15 years as well as major programs in Western Australia.

Acknowledgment of interests related to ports development and dredging operations:
I am employed by James Cook University and have multiple research assessment and monitoring programs focusing on ports and shipping and the marine environment in the Great Barrier Reef World Heritage Area, including funding for the Queensland Ports Seagrass monitoring program from the majority of Queensland port authorities as well as related research projects funded by the Australian Research Council, Maritime Safety Queensland, Australian Marine Safety Authority, Torres Strait Regional Authority and BHP Billiton Mitsubishi Alliance.

1.26 Prof. Marcus Sheaves

Professor Marcus Sheaves is an estuarine ecosystems and fisheries ecologist. He leads the School of Marine and Tropical Biology's Estuary and Tidal Wetland Ecosystems Research Group, is Deputy Director of James Cook University's Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), and leads TropWATER's Coastal and Estuarine Ecology theme. His research spans nursery ground function, and fish–habitat relationships, through patterns of productivity, and the interaction between coastal fisheries and food security both in Australia and in developing countries, to coastal ecosystem repair and adaptation to the effects of extreme events. Marcus has extensive experience in estuarine and wetland ecological research throughout Australia and the Asia-Pacific, having conducted major research projects in Papua New Guinea, Fiji, Solomon Islands, Vanuatu, Samoa, Tonga and Vietnam.

Marcus heads a research team that has a strong focus on innovation, cutting-edge approaches and strategic outcomes, and comprises four postdoctoral researchers, six research staff, eight PhD students, one MSc (Phil) and two honours students. He has extensive research collaborations with other Australian universities (Griffith, Murdoch, Adelaide, Queensland), and with CSIRO; GBRMPA; Queensland's Department of Environment and Heritage Protection; Queensland's Department of Agriculture, Fisheries and Forestry; Northern Territory Department of Fisheries. He has international links to the National Oceanic Atmospheric Administration, the Smithsonian, Hanoi University, PNG National Fisheries Authority and the University of the South Pacific. He leads major research projects funded by the Fisheries Development and Research Corporation (FRDC), FRDC/Department of Climate Change and Energy Efficiency ($550k), and the Australian Centre for International Agricultural Research, as well as many smaller projects. He has published over 90 peer-reviewed articles in international journals and books.

As well as extensive postgraduate teaching, Marcus coordinates two third-year marine biology subjects, is Associate Dean Research Education for the faculty of Science and Engineering at James Cook University, and acts as a statistical consultant for the School of Marine and Tropical Biology and the university at large.

Acknowledgment of interests related to ports development and dredging operations:
I am employed by James Cook University in an academic capacity. To the best of my knowledge, I do not have any other direct or indirect financial or other interests in dredging or its impacts in the marine environment.

1.27 Dr Andrew Symonds

Dr Andrew Symonds leads the coastal and marine numerical modelling team at Haskoning Australia (HKA). Throughout his career Andrew has developed numerical modelling expertise in hydrodynamics, waves, sediment transport, morphology, shoreline response, water quality and thermal and pollutant dispersion. He has extensive experience in the use of a range of numerical modelling software.

Over the last two years Andrew has been involved in a project with Griffith University which aims to improve emergency management decision making during extreme tropical cyclone storm tide events in Queensland. This project included the development, calibration and validation of a tidal and storm surge model of the entire Queensland coast including the Great Barrier Reef. As part of this project Andrew worked closely with Deltares to carry out the first validation of the new Delft Flexible Mesh model (D-Flow FM) for cyclonic storm surges.

Prior to joining HKA, Andrew worked for a number of consultancies both in Australia and the UK. He has been involved in a large number of dredging projects, especially during the time he worked for the Associated British Ports Marine Environmental Research (ABPmer) in the UK. Andrew has also completed a PhD at the National Oceanography Centre, Southampton. This was a field and laboratory based study focused on hydrodynamics, waves and sediment transport at an intertidal mudflat and salt marsh environment in a large tidal embayment in the UK.

Acknowledgment of interests related to ports development and dredging operations:
I am employed by Haskoning Australia (HKA), a specialist marine and coastal consultancy, who are involved in port development and dredging operations work for both industry and government. We are currently engaged by North Queensland Bulk Ports to undertake numerical modelling and data collection for the Abbot Point T0, T2 and T3 development. HKA are also involved in a number of other port development and dredging projects outside of Queensland.

1.28 Assoc. Prof. Michael Warne

Dr Warne is an internationally recognised leader in the areas of ecotoxicology and the derivation and implementation of environmental quality guidelines (for water, soils and soil additives). He developed the method for deriving the Australian and New Zealand water quality guidelines for toxicants and was a key author of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality published in 2000. He led the team that derived the soil quality guidelines for contaminants in the National Environmental Protection (Assessment of Site Contamination) Measure and another team that derived guidelines for contaminants in biosolids that are being adopted by various state regulatory organisations. He is currently part of the Technical Working Group revising the Australian and New Zealand Water Quality Guidelines for toxicants and sediments.

In addition he has expertise in:

- aquatic and terrestrial ecotoxicology for metals, inorganic and organic chemicals;
- ecological hazard and risk assessments; and
- water quality monitoring and loads estimation.

He currently is the Science Leader of the Water Quality and Investigations group in the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) and an Honorary Associate Professor at the National Research Centre for Environmental Toxicology at the University of Queensland. Prior to this, he was a Principal Research Scientist in Land and Water, CSIRO; a Senior Research Ecotoxicologist in the New South Wales Environment Protection Authority; a Guest Lecturer at the University of Queensland and a Lecturer at Griffith University.

Dr Warne is regularly invited to present at international conferences. He has written one book (two editions); six book chapters; over 90 articles in peer-reviewed scientific journals; eight Australian National Guidelines on the Environmental Management of Chemicals; over 160 published and client reports and conference proceedings. He has been awarded over $9.9 million in research grants and consultancies.

Acknowledgment of interests related to ports development and dredging operations:
I am employed by the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) and was involved in the DSITIA water and sediment quality monitoring program associated with the Gladstone fish health issue between 2011 and 2013. To the best of my knowledge, I do not have any other direct or indirect financial or other interests in dredging or its impacts in the marine environment.

Appendix B Details and data sources used for the comparison of sediment and nutrient inputs into the Great Barrier Reef World Heritage Area from dredge material disposal and terrestrial run-off

Calculations for estimating the river loads of fine suspended sediment:

River discharge data for the water years 1999–2000 to 2005–06 were obtained from the website of the Queensland Department of Natural Resources and Mines: http://watermonitoring.derm.qld.gov.au/host.htm (accessed 08 September 2014), data for the water years 2006 to 2012 were provided by the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) in August 2014.

Table B-1 Discharge of 10 major rivers in the Great Barrier Reef region (in megalitres per water year, October to September). © State of Queensland

		1999_00	2000_01	2001_02	2002_03	2003_04	2004_05	2005_06	2006_07	2007_08	2008_09	2009_10	2010_11	2011_12
Catchment	Gauging station	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)	Discharge (ML)
Barron	110001D	1,643,548	852,458	165,895	113,644	950,206	392,223	745,779	470,249	1,582,454	781,075	532,775	1,863,908	767,359
Johnstone	112004A	3,215,647	2,073,998	657,433	819,665	2,316,733	1,483,325	2,170,982	2,196,180	1,886,422	1,990,882	1,615,516	3,661,422	2,024,224
	112101B	1,399,501	825,426	345,066	311,763	431,547	542,835	1,014,726	953,313	811,696	1,043,123	652,887	1,588,294	922,589
Tully	113006A	5,286,940	3,556,981	1,208,801	1,442,043	3,283,940	2,200,706	3,624,129	4,191,491	3,232,663	3,770,791	2,572,793	6,169,781	3,601,029
Herbert	116001F	9,370,780	4,661,616	929,933	688,775	3,303,782	1,481,771	3,874,894	4,350,993	3,312,560	9,495,201	2,962,209	11,451,334	4,096,068
Haughton	119101A	488,914	133,595	113,242	70,394	106,968	87,736	97,197				245,486	600,261	325,917
Burdekin	120001A	13,849,188	8,765,755	4,485,312	2,092,834	1,516,194	4,328,246	2,199,734	9,168,801	27,970,635	29,490,715	7,906,763	34,759,867	14,992,382
Pioneer	125007A/ 125013A	1,502,946	731,454	218,342	111,602	44,900	196,115	72,711	884,963	1,364,326	927,461	1,326,065	3,372,934	1,216,712

		1999_00	2000_01	2001_02	2002_03	2003_04	2004_05	2005_06	2006_07	2007_08	2008_09	2009_10	2010_11	2011_12
Plane	126001A	272,326	187,244	91,452	47,759	10,110	71,555	6,327				364,569	627,058	351,376
Fitzroy	130005A	1,640,007	3,120,928	579,616	2,734,901	1,310,320	920,295	677,845	872,784	12,414,773	2,164,758	10,961,125	38,538,796	7,221,975
Burnett	136014A	102,915	199,370	106,888	523,464	221,477	136,959	69,506	35,183	88,074	33,107	966,998	8,884,946	629,170
Total		**38,772,712**	**25,108,825**	**8,901,980**	**8,956,844**	**13,496,176**	**11,841,766**	**14,553,830**	**23,123,958**	**52,663,602**	**49,697,112**	**30,107,184**	**111,518,601**	**36,148,801**

Data for the **total suspended solid load** for the water years 2006 to 2012 were based on monitoring data, provided by the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) in August 2014. Data for the water years 1999–2000 to 2005–06 were not available from monitoring data and were calculated by multiplying a simple load/discharge factor for each river (see Table B-3) with the discharge in the respective year (from Table B-1). Note that other estimates of river loads will be available in the near future[1], which might change the outcomes of this comparison.

Table B-2 Loads of total suspended solids of 10 major rivers in the Great Barrier Reef region (in tonnes per water year, October to September). © State of Queensland. *Data from 1999-00 to 2005-06 are estimated based on a load/discharge factor (see Table B-3)

				1999_00	2000_01	2001_02	2002_03	2003_04	2004_05	2005_06	2006_07	2007_08	2008_09	2009_10	2010_11	2011_12
Catchment	**Gauging station**	**TSS load (t) pre-Eur (Kroon 2012)**	**TSS load (t) current (Kroon 2012)**	**TSS–estimated* (t)**							**TSS (t)**	**TSS (t)**	**TSS (t)**	**TSS (t)**	**TSS (t)**	**TSS (t)**
Barron	110001D	25,000	100,000	416,022	215,778	41,992	28,766	240,521	99,281	188,775	69,280	383,139	305,969	174,425	365,844	164,146
N&S Johnstone	112004A	41,000	320,000	394,932	248,112	85,787	96,820	235,179	173,385	272,611	168,670	383,881	198,902	114,338	618,380	226,371
Tully	113006A	24,000	92,000	160,640	108,077	36,729	43,816	99,781	66,867	110,117	162,035	83,163	105,546	69,506	231,605	91,386
Herbert	116001F	110,000	380,000	704,485	350,455	69,911	51,781	248,375	111,398	291,310	683,986	5,650	19,948	336,382	1,571,603	160,832
Haughton	119101A	29,000	300,000	69,269	18,928	16,044	9,973	15,155	12,430	13,771				21,360	183,218	10,689
Burdekin	120001A	480,000	4,000,000	4,924,137	3,116,701	1,594,771	744,116	539,089	1,538,926	782,125	6,490,261	12,625,837	9,836,193	1,937,798	6,167,024	3,268,805
Pioneer	125013A	50,000	52,000	299,197	145,613	43,466	22,217	8,938	39,041	14,475	126,954	252,492	155,739	373,818	819,023	210,830
Plane	126001A	54,000	550,000	26,654	18,326	8,951	4,674	989	7,003	619				37,814	63,116	31,359
Fitzroy	130005A	1,100,000	3,400,000	430,100	818,479	152,007	717,242	343,638	241,352	177,768	235,443	4,920,301	474,947	3,563,583	6,969,482	1,315,051
Burnett	136014A	99,000	1,400,000	15,963	30,923	16,579	81,192	34,352	21,243	10,781				146,732	2,578,047	14,732
Total		**2,012,000**	**10,594,000**	**7,441,400**	**5,071,394**	**2,066,238**	**1,800,597**	**1,766,017**	**2,310,927**	**1,862,352**	**7,936,628**	**18,654,462**	**11,097,242**	**6,775,756**	**19,567,342**	**5,494,201**

Table B-3 Calculation load vs discharge factor used to estimate loads in the 10 major rivers for years 1999-00 to 2005-06. The factor is calculated by dividing the TSS loads by the discharge volumes for each river and year from data for 2006-07 to 2011-12 (see tables B-1 and B-2). The average of these ratios is the factor used to calculate TSS loads using available annual discharge data (in Table B-1); results of the calculations are in Table B-2 as "TSS-estimated".

		2006_07	2007_08	2008_09	2009_10	2010_11	2011_12		
Catchment	**Gauging station**	**TSS/discharge**	**TSS/discharge**	**TSS/discharge**	**TSS/discharge**	**TSS/discharge**	**TSS/discharge**	**Average load/discharge factor**	**Standard Deviation**
Barron	110001D	0.15	0.24	0.39	0.33	0.20	0.21	**0.25**	0.09
Johnstone	112004A	0.04	0.18	0.04	0.04	0.11	0.08	**0.08**	0.06
	112101B	0.08	0.05	0.11	0.07	0.13	0.07	**0.09**	0.03
Tully	113006A	0.04	0.03	0.03	0.03	0.04	0.03	**0.03**	0.01
Herbert	116001F	0.16	0.00	0.00	0.11	0.14	0.04	**0.08**	0.07
Haughton	119101A				0.09	0.31	0.03	**0.14**	0.14
Burdekin	120001A	0.71	0.45	0.33	0.25	0.18	0.22	**0.36**	0.20
Pioneer	125013A	0.14	0.19	0.17	0.28	0.24	0.17	**0.20**	0.05
Plane	126001A				0.10	0.10	0.09	**0.10**	0.01
Fitzroy	130005A	0.27	0.40	0.22	0.33	0.18	0.18	**0.26**	0.09
Burnett	136014A				0.15	0.29	0.02	**0.16**	0.13

Particle size distribution data for the 10 major rivers were provided by the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA)[2].

Table B-4 Particle size distribution in 10 major rivers in the Great Barrier Reef region[2]. © State of Queensland.

Station name	**Barron**	**Johnstone**	**Tully**	**Herbert**	**Haughton**	**Burdekin**	**Pioneer**	**Plane**	**Fitzroy**	**Burnett**
Station ID	110001D	112004A 112101B	113006A	116001F	119101A	120001A	125013A	126001A	130005A	136014A
Particle fraction										
Coarse sand (2000 µm to 250 µm)	3.84 (± 2.43)	0.18 (± 0.11)	0.42 (± 0.29)	0.56 (± 0.16)	1.02 (± 0.5)	0.61 (± 0.21)	0.78 (± 0.59)	1.07 (± 1.28)	0.76 (± 1)	0.47 (± 0.18)
Fine sand (250 µm to 62 µm)	5.52 (± 2.07)	9.11 (± 3.07)	3.84 (± 1.4)	7.23 (± 1.18)	10.54 (± 1.09)	3.57 (± 2.29)	5.16 (± 1.46)	2.12 (± 1.38)	0.79 (± 0.79)	1.87 (± 1.17)
Silt (62 µm to 4 µm)	66.2 (± 3.35)	75.47 (± 2.15)	66.41 (± 4.44)	70.2 (± 1.35)	61.52 (± 6.24)	50.18 (± 6.46)	69.53 (± 2.25)	41.13 (± 9.87)	38.21 (± 7.28)	52.72 (± 8.09)
Clay (4 µm to 0.24 µm)	23.99 (± 3.14)	15.25 (± 2.18)	29.31 (± 5.28)	22.02 (± 2.24)	26.92 (± 6.18)	45.58 (± 7.34)	24.54 (± 2.48)	56.49 (± 10.93)	60.41 (± 7.83)	44.91 (± 8.86)

The particle size distribution data (Table B-4) were used together with the total suspended sediment load data (Table B-2) to calculate the **fine sediment loads** for all 10 major rivers. Fine sediment was calculated as the silt and clay fraction as well as the clay fraction; results are in Table B-5.

Table B-5 Loads of fine suspended solids (in tonnes per year) of 10 major rivers in the Great Barrier Reef region (in tonnes per water year, October to September). Data are for the silt and clay fraction (<62 µm) and the clay fraction (<4 µm).

Catchment	pre-European		Current		1999_00		2000_01		2001_02		2002_03		2003_04		2004_05	
	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay
Barron	22,548	5,998	90,190	23,990	375,211	99,804	194,610	51,765	37,873	10,074	25,944	6,901	216,925	57,701	89,542	23,818
N&S Johnstone	37,195	6,253	290,304	48,800	358,282	60,227	225,088	37,837	77,826	13,082	87,835	14,765	213,354	35,865	157,295	26,441
Tully	22,973	7,034	88,062	26,965	153,765	47,084	103,451	31,677	35,157	10,765	41,940	12,842	95,510	29,246	64,005	19,599
Herbert	101,442	24,222	350,436	83,676	649,676	155,128	323,190	77,170	64,472	15,394	47,753	11,402	229,051	54,692	102,731	24,530
Haughton	25,648	7,807	265,320	80,760	61,261	18,647	16,740	5,095	14,189	4,319	8,820	2,685	13,403	4,080	10,993	3,346
Burdekin	459,648	218,784	3,830,400	1,823,200	4,715,353	2,244,422	2,984,553	1,420,592	1,527,153	726,897	712,565	339,168	516,232	245,717	1,473,676	701,442
Pioneer	47,035	12,270	48,916	12,761	281,455	73,423	136,979	35,734	40,889	10,667	20,900	5,452	8,408	2,193	36,726	9,581
Plane	52,715	30,505	536,910	310,695	26,019	15,057	17,890	10,353	8,738	5,056	4,563	2,641	966	559	6,837	3,956
Fitzroy	1,084,820	664,510	3,353,080	2,053,940	424,165	259,824	807,184	494,443	149,910	91,828	707,344	433,286	338,896	207,592	238,021	145,801
Burnett	96,654	44,461	1,366,820	628,740	15,584	7,169	30,190	13,888	16,186	7,446	79,267	36,463	33,538	15,428	20,740	9,540
Total	**1,950,677**	**1,021,843**	**10,220,439**	**5,093,527**	**7,060,773**	**2,980,783**	**4,839,875**	**2,178,555**	**1,972,392**	**895,528**	**1,736,932**	**865,605**	**1,666,284**	**653,072**	**2,200,566**	**968,054**

Table B-5 (continued) Loads of fine suspended solids (in tonnes per year) of 10 major rivers in the Great Barrier Reef region (in tonnes per water year, October to September). Data are for the silt and clay fraction (<62 µm) and the clay fraction (<4 µm).

Catchment	2005_06		2006_07		2007_08		2008_09		2009_10		2010_11		2011_12	
	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay	Silt&clay	Clay
Barron	170,256	45,287	62,483	16,620	345,553	91,915	275,953	73,402	157,314	41,845	329,955	87,766	148,043	39,379
N&S Johnstone	247,312	41,573	153,017	25,722	348,256	58,542	180,444	30,333	103,727	17,437	560,994	94,303	205,364	34,522
Tully	105,404	32,275	155,100	47,492	79,604	24,375	101,028	30,935	66,531	20,372	221,692	67,883	87,475	26,785
Herbert	268,646	64,147	630,772	150,614	5,210	1,244	18,396	4,392	310,211	74,071	1,449,332	346,067	148,319	35,415
Haughton	12,179	3,707							18,891	5,750	162,038	49,322	9,453	2,877
Burdekin	748,963	356,492	6,215,074	2,958,261	12,090,501	5,754,856	9,419,139	4,483,337	1,855,635	883,248	5,905,542	2,810,930	3,130,208	1,489,921
Pioneer	13,617	3,552	119,425	31,154	237,519	61,962	146,503	38,218	351,651	91,735	770,455	200,988	198,328	51,738
Plane	605	350							36,914	21,361	61,614	35,654	30,613	17,715
Fitzroy	175,315	107,390	232,194	142,231	4,852,401	2,972,354	468,392	286,915	3,514,406	2,152,760	6,873,303	4,210,264	1,296,903	794,422
Burnett	10,525	4,842							143,254	65,897	2,516,947	1,157,801	14,383	6,616
Total	**1,752,822**	**659,615**	**7,568,066**	**3,372,095**	**17,959,045**	**8,965,248**	**10,609,855**	**4,947,533**	**6,558,535**	**3,374,477**	**18,851,873**	**9,060,979**	**5,269,089**	**2,499,390**

Calculations for estimating fine suspended sediment content of dredged material disposed into the World Heritage Area

The content of fine suspended sediments was calculated using actual and predicted volumes of dredge material disposed in the World Heritage Area (Table B-6).

Table B-6 Volumes of actual sea disposal of dredge material in the World Heritage Area 2000-2013 (in *in situ* cubic metres, m^3). Data provided by the Great Barrier Reef Marine Park Authority and the Department of the Environment in August 2014. Figures in black font are for disposal from maintenance dredging, in red font from capital dredging campaigns.

Location	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Port Douglas	0	0	0	0	0	0	22,000	0	0	0	0	0	0	0
Cairns Port	172,092	357,121	358,175	408,672	522,629	381,506	372,878	221,828	193,458	285,056	299,522	431,068	236,377	410,546
Townsville Port—maintenance	0	342,800	325,700	228,500	489,240	300,900	297,000	120,691	361,722	592,851	331,480	558,000	424,950	369,684
Townsville Port—capital	0	0	0	0	0	0	0	0	0	0	0	0	242,025	167,400
Port of Abbot Point	0	0	0	0	0	0	0	0	201,315	0	0	0	0	0
Port of Hay Point—maintenance	0	678,572	0	0	98,900	295,708	0	0	150,000	0	216,000	0	0	11,623
Port of Hay Point—capital	0	0	0	0	0	0	8,611,889	310,000	57,500	0	81,316	96,410	0	0
Mackay Port	0	155,680	23,800	34,510	85,000	0	0	106,000	0	0	0	0	0	98,381
Rosslyn Bay Boat Harbour	0	0	29,153	0	0	0	31,000	0	0	24,000	0	0	22,870	94,930
Gladstone Port—capital	0	0	0	0	0	0	0	0	0	0	0	1,597,085	3,012,732	560,658
Gladstone Port—maintenance	0	0	0	241,532	174,150	148,462	225,242	160,972	17,955	282,000	3,000	342,000	150,000	0
TOTAL	**172,092**	**1,534,173**	**736,828**	**913,214**	**1,369,919**	**1,126,576**	**9,560,009**	**919,491**	**981,950**	**1,183,907**	**931,318**	**3,024,563**	**4,088,954**	**1,713,222**

Table B-6 (continued) Volumes of projected sea disposal of dredge material to the World Heritage Area 2014–2020 (in *in-situ* (= wet) cubic metres, m^3). Data provided by the Great Barrier Reef Marine Park Authority and the Department of the Environment in August 2014. Figures in black font are for disposal from maintenance dredging, in red font from capital dredging campaigns.

Update March 2015: Updated projections exclude all capital dredging disposed in the marine environment, as advised by the Great Barrier Reef Marine Park Authority (i.e all amounts in red font projected to be 0). Updated totals reflect this.

Location	2014	2015	2016	2017	2018	2019	2020
Port Douglas	0	0	0	0	0	0	0
Cairns Port	332,209	2,532,209*	2,532,209*	400,000	400,000	400,000	400,000
Townsville Port—maintenance	364,486	364,486	364,486	364,486	364,486	364,486	364,486
Townsville Port—capital	0	0	2,850,000	2,850,000	0	0	0
Port of Abbot Point	0	1,300,000	0	1,000,000	0	700000	0
Port of Hay Point (Dudgeon Pt)—maintenance	208,000	170,400	0	0	208,000	0	0
Port of Hay Point—capital	0	0	0	6,000,000	7,000,000	0	0
Mackay Port	0	0	70,000	0	0	0	0
Rosslyn Bay Boat Harbour	0	0	30,000	0	0	30,000	0
Gladstone Port—capital	0	0	0	6,000,000	6,000,000	0	0
Gladstone Port—maintenance	174,531	174531	174,531	174,531	174,531	174,531	174,531
TOTAL (as at August 2014)	**1,079,227**	**4,541,627**	**6,021,227**	**16,789,017**	**14,147,017**	**1,669,017**	**939,017**
Updated TOTAL (March 2015)	**1,079,227**	**709,417**	**639,017**	**939,017**	**1,147,017**	**969,017**	**939,017**

*Sum of capital and maintenance

As a first step, the *in situ* (= wet) volumes were converted into dry mass (tonnes) using conversion factors[3], being 0.8 tonnes/*in situ* m^3 for material from capital dredging and 0.7 tonnes/*in situ* m^3 from maintenance dredging; note that other estimates are more than twice this value[bb]. Results in tonnes per year of dredge material disposed/predicted are in Table B-7.

Table B-7 Estimated dry mass of actual sea disposal of dredge material in the World Heritage Area 2000–2013 (in tonnes) using conversion factors[3].

Location	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Port Douglas	0	0	0	0	0	0	15,400	0	0	0	0	0	0	0
Cairns Port	120,464	249,985	250,723	286,070	365,840	267,054	261,015	155,280	135,421	199,539	209,665	301,748	165,464	287,382
Townsville Port—maintenance	0	239,960	227,990	159,950	342,468	210,630	207,900	84,484	253,205	414,996	232,036	390,600	297,465	258,779
Townsville Port—capital	0	0	0	0	0	0	0	0	0	0	0	0	193,620	133,920
Port of Abbot Point	0	0	0	0	0	0	0	0	161,052	0	0	0	0	0
Port of Hay Point—maintenance	0	475,000	0	0	69,230	206,996	0	0	105,000	0	151,200	0	0	8,136
Port of Hay Point—capital	0	0	0	0	0	0	6,889,511	248,000	46,000	0	65,053	77,128	0	0
Mackay Port	0	108,976	16,660	24,157	59,500	0	0	74,200	0	0	0	0	0	68,867

[bb] These conversion factors are critical to the comparisons but are significantly inconsistent amongst sources. Values here were developed from geotechnical data and dredging records in consultation with the port authorities[3]. However, these are very low values (notwithstanding that the granular nature of sediments allows for a bulk density less than water). Other comparisons[4] have used the density of compacted clay, 1.746 tonnes per cubic metre, reflecting the consolidated nature of the material in capital dredging. An extensive survey[5] of more than 21,000 marine sediment densities measurements found densities ranged between 0.95 and 2.6 g/cm^3, with the vast majority between 1 and 2 g/cm^3 and an overall average of 1.7 g/cm^3 (1 g/cm^3 = 1 tonne/cubic metre).

Given their importance to the calculations, some panellists considered the factors warranted further consideration, including establishing specific values for different locations.

Location	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Rosslyn Bay Boat Harbour	0	0	20,407	0	0	0	21,700	0	0	16,800	0	0	16,009	66,451
Gladstone Port—capital	0	0	0	0	0	0	0	0	0	0	0	1,277,668	2,410,186	448,526
Gladstone Port—maintenance	0	0	0	169,072	121,905	103,923	157,669	112,680	12,569	197,400	2,100	239,400	105,000	0
TOTAL	**120,464**	**1,073,921**	**515,780**	**639,250**	**958,943**	**788,603**	**7,553,195**	**674,644**	**713,247**	**828,735**	**660,054**	**2,286,544**	**3,187,744**	**1,272,061**

Table B-7 (continued) Estimated dry mass of projected sea disposal of dredge material to the World Heritage Area 2014–2020 (in tonnes) using conversion factors[3].

Update March 2015: Updated projections exclude all capital dredging disposed in the marine environment, as advised by the Great Barrier Reef Marine Park Authority (i.e all amounts in red font projected to be 0). Updated totals reflect this.

Location	2014	2015	2016	2017	2018	2019	2020
Port Douglas	0	0	0	0	0	0	0
Cairns Port	232,546	2,025,767*	2,025,767*	280,000	280,000	280,000	280,000
Townsville Port—maintenance	255,140	255,140	255,140	255,140	255,140	255,140	255,140
Townsville Port—capital	0	0	2,280,000	2,280,000	0	0	0
Port of Abbot Point	0	1,040,000	0	800,000	0	560,000	0
Port of Hay Point—maintenance	145,600	119,280	0	0	145,600	0	0
Port of Hay Point (Dudgeon Pt)—capital	0	0	0	4,200,000	4,900,000	0	0
Mackay Port	0	0	49,000	0	0	0	0
Rosslyn Bay Boat Harbour	0	0	21,000	0	0	21,000	0
Gladstone Port—capital	0	0	0	4,800,000	4,800,000	0	0
Gladstone Port—maintenance	122,172	122,172	122,172	122,172	122,172	122,172	122,172
TOTAL (as at August 2014)	**755,459**	**3,562,360**	**4,753,080**	**13,337,312**	**11,202,912**	**1,238,312**	**657,312**
Updated TOTAL (March 2015)	**755,458**	**496,592**	**447,312**	**657,312**	**802,912**	**678,312**	**657,312**

*Sum of capital and maintenance

Table B-8 Proportion (in % of the total sediment) of fine sediment in dredge material. Fine sediment is defined as the clay and silt fraction, depending on the data source (and the particle size classification system used) this includes data <75, <63, or <60 µm. Data in black font = measured values, red font = values interpolated from measured values into other years.

Location	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Source/comment	Data used for forecast years 2014-2020
Port Douglas	50	50	50	50	50	50	50	50	50	50	50	50	50	50	no useful data available, assumed a 50% contribution	50
Cairns Port	74	74	74	74	**97**	97	97	**93**	93	**93**	74	74	74	74	Cairns Port Authority 2003. Sediment Analysis - Report, Cairns Port Authority, August 2003; Worley Parsons 2008. Cairns Port 2008 Annual Sampling and Analysis Plan - Report: Navy Base, Cairns Ports Limited; Worley Parsons 2011. Port of Cairns Maintenance Dredging 2011: Second Dredge Campaign Sediment Characterisation Report, Ports North; Worley Parsons 2013. Port of Cairns Maintenance Dredging: 2013 Sediment Characterisation Report and Introduced Marine Pest Survey Report, Ports North.	93
Townsville Port—maintenance	87	87	87	87	87	87	87	87	87	87	87	87	87	87	"87" from EIS 20013: data from study in 1997 used (p. 115), also detailed analysis results from 2008 in 2013 EIS but from different core depths- impossible to summarise, graph (p 3-16) show silt fraction ~30% in Platypus Ch, but no size classes defined & unsure if clay fraction not presented	87
Townsville Port—capital	87	87	87	87	87	87	87	87	87	87	87	87	87	87		87
Port of Abbot Point	15	15	15	15	**15**	15	15	15	15	**38**	15	15	15	15	Worley Parsons 2007, Port of Abbot Pt: Sediment Quality Assessment Report (p. 14), 2013 study for proposed dredging op.	38
Port of Hay Point—maintenance	35	35	35	35	35	35	35	35	35	35	35	35	35	35	SKM and APASA (2013)	35
Port of Hay Point—capital	24	24	**24**	24	24	24	**27**	**27**	27	27	24	24	**24**	24	Port of Hay Point-Capital Dredging Departure Path and Apron Areas Sediment Sampling and Analysis Report March 2005,BHP Billiton Mitsubishi Alliance Hay Point Coal Terminal Expansion Project Berth 3 Sediment Sampling and Analysis Report April 2009	27
Mackay Port	50	50	50	50	50	50	50	50	50	50	50	50	50	50	no data available, assumed a 50% contribution	50
Rosslyn Bay Boat Harbour	38	38	38	38	38	38	38	38	**76**	**76**	38	38	38	38	Rosslyn Bay Boat Harbour Dredging Sediment Sampling and Analysis Program September 2000 - FRC Coastal Resources & Environment; FRC Environmental, Sediment Sampling & Analysis 2011: Rosslyn Bay Boat Harbour October 2011	76
Gladstone Port—capital	38	38	38	38	38	38	38	**38**	38	38	38	38	38	38	GHD, 2009. Gladstone EIS Appendix L – Report for Western Basin Dredging and Disposal Project.	38
Gladstone Port—maintenance	72	72	72	72	72	72	72	72	72	72	72	72	72	72	Worley Parsons 2009, Australia Pacific LNG Dredge Area Option 1B, 2A-Sediment characterisation studies	72

In a final step the mass (in tonnes per year) of the silt and clay-sized sediment in dredge material was calculated using the dry mass of disposed sediments (in Table B-7) and the proportion of fine sediment particle size fraction (in Table B-8). The results of this calculation are in Table B-9.

Table B-9 Estimated dry mass of silt and clay-sized sediment in dredge material disposed in the World Heritage Area 2000–2013 (in tonnes). Red font = capital dredging, black font = maintenance dredging.

Location	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Port Douglas	0	0	0	0	0	0	7,700	0	0	0	0	0	0	0
Cairns Port	89,144	184,989	185,535	211,692	270,722	197,620	193,151	114,907	131,358	193,553	203,375	280,625	153,881	267,265
Townsville Port—maintenance	0	208,765	198,351	139,157	297,947	183,248	180,873	73,501	220,289	361,046	201,871	339,822	258,795	225,138
Townsville Port—capital	0	0	0	0	0	0	0	0	0	0	0	0	168,449	116,510
Port of Abbot Point	0	0	0	0	0	0	0	0	24,158	0	0	0	0	0
Port of Hay Point—maintenance	0	166,250	0	0	24,231	72,448	0	0	36,750	0	52,920	0	0	2,848
Port of Hay Point—capital	0	0	0	0	0	0	1,653,483	59,520	11,040	0	17,564	20,825	0	0
Mackay Port	0	54,488	8,330	12,079	29,750	0	0	37,100	0	0	0	0	0	34,433
Rosslyn Bay Boat Harbour	0	0	7,755	0	0	0	8,246	0	0	6,384	0	0	12,167	50,503
Gladstone Port—capital	0	0	0	0	0	0	0	0	0	0	0	485,514	915,871	170,440
Gladstone Port—maintenance	0	0	0	121,732	87,772	74,825	113,522	81,130	9,049	142,128	1,512	172,368	75,600	0
TOTAL	**89,144**	**614,492**	**399,971**	**484,659**	**710,421**	**528,142**	**2,156,974**	**366,158**	**432,644**	**703,111**	**477,243**	**1,299,154**	**1,584,763**	**867,137**

Table B-9 (continued) Estimated dry mass of silt and clay-sized sediment in dredge material projected to be disposed in the World Heritage Area 2014-2020 (in tonnes). Red font = capital dredging, black font = maintenance dredging.

Update March 2015: Updated projections exclude all capital dredging disposed in the marine environment, as advised by the Great Barrier Reef Marine Park Authority (i.e all amounts in red font projected to be 0). Updated totals reflect this.

Location	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Port Douglas	0	0	0	0	0	0	0
Cairns Port	216,268	1,883,964	1,883,964	260,400	260,400	260,400	260,400
Townsville Port—maintenance	221,972	221,972	221,972	221,972	221,972	221,972	221,972
Townsville Port—capital	0	0	1,983,600	1,983,600	0	0	0
Port of Abbot Point	0	395,200	0	304,000	0	212,800	0
Port of Hay Point— maintenance	50,960	41,748	0	0	50,960	0	0
Port of Hay Point (Dudgeon Pt)—capital	0	0	0	1,134,000	1,323,000	0	0
Mackay Port	0	0	24,500	0	0	0	0
Rosslyn Bay Boat Harbour	0	0	15,960	0	0	15,960	0
Gladstone Port—capital	0	0	0	1,824,000	1,824,000	0	0
Gladstone Port—maintenance	87,964	87,964	87,964	87,964	87,964	87,964	87,964
TOTAL (as at August 2014)	**577,164**	**2,630,847**	**4,217,959**	**6,505,936**	**4,573,296**	**799,096**	**570,336**
Updated TOTAL (March 2015)	**577,164**	**351,684**	**350,396**	**570,336**	**621,296**	**586,296**	**570,336**

References

1. Waters, D.K., Carroll, C., Ellis, R., Hateley, L., McCloskey, J., Packett, R., Dougall, C. and Fentie, B. 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments: Whole GBR, Volume 1,* Department of Natural Resources and Mines, Brisbane.

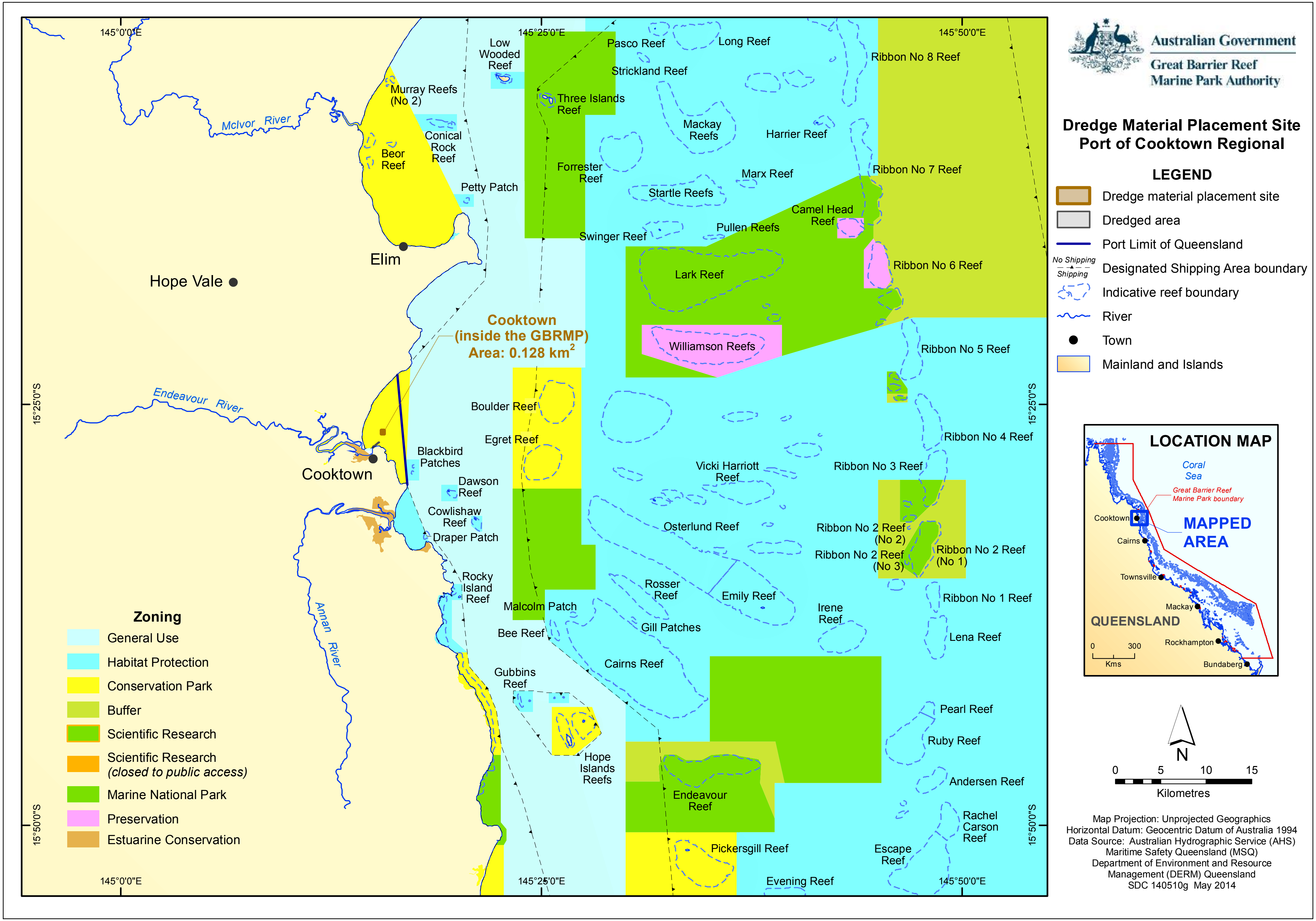
2. Turner, R., Huggins, R., Wallace, R., Smith, R., Vardy, S. and Warne, M.S.J. 2013, *Total suspended solids, nutrient and pesticide loads for rivers that discharge to the Great Barrier Reef: Great Barrier Reef loads monitoring 2010-2011,* Water Sciences Technical Report, Volume 2013, Number 1, Department of Science, Information Techniology, Innovation and the Arts, Brisbane, Queensland, .

3. Sinclair Knight Merz Pty Ltd and Asia-Pacific Applied Science Associates 2013, Appendix E: Modelling sediment migration from current and hypothetical alternative placement sites. Revision 2.5, 12 July 2013, in *Improved dredge material management for the Great Barrier Reef Region: Synthesis Report, Revision 1.3, 15 July 2013*, eds Sinclair Knight Merz Pty Ltd and Asia-Pacific Applied Science Associates, Great Barrier Reef Marine Park Authority, Townsville, pp. 192.

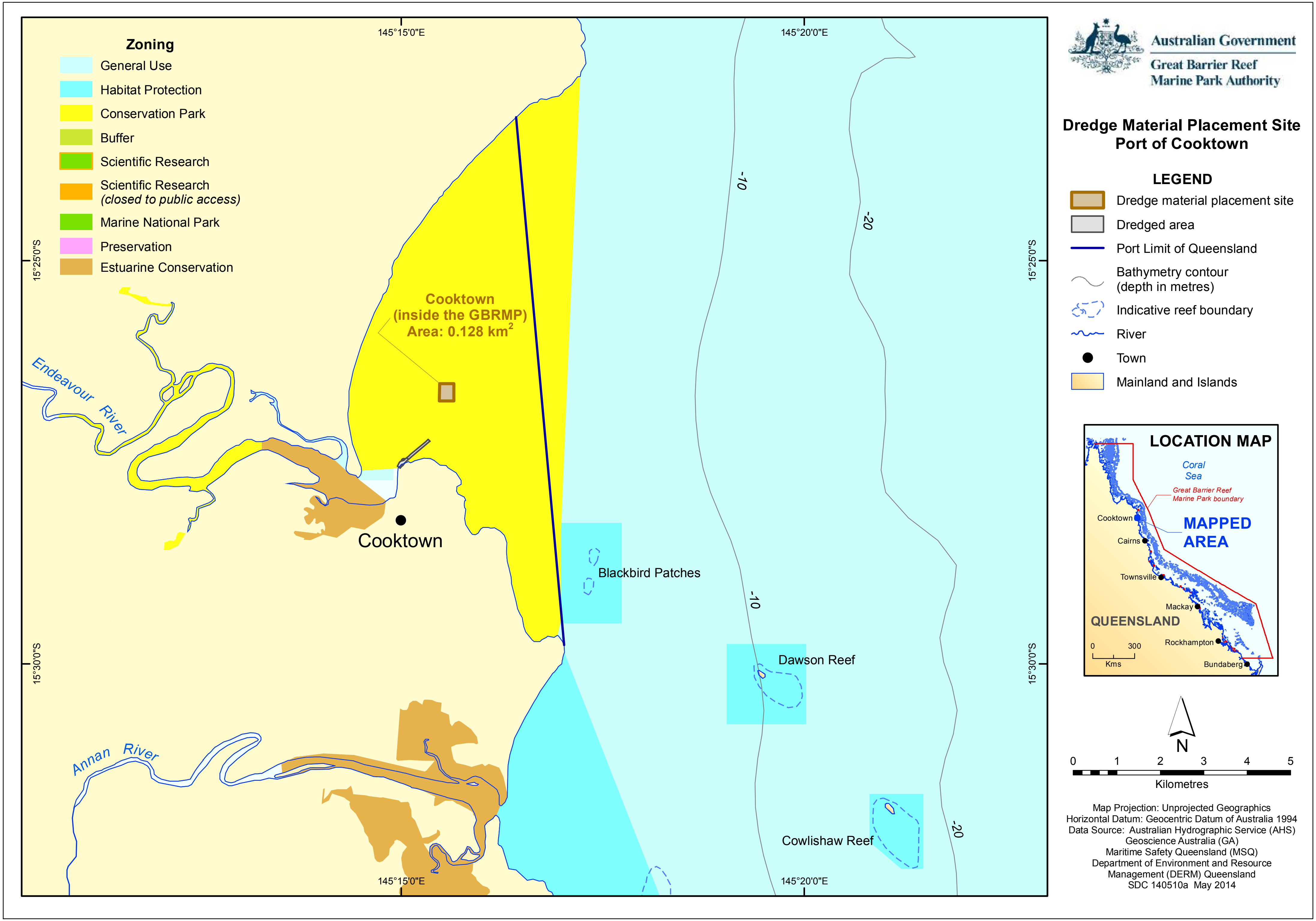
4. CDM Smith Australia Pty Ltd 2014, *Technical note: Comparison of material available for re-suspension from dredging and catchment based sources at Abbot Point,* North Queensland Bulk Ports Corporation, Brisbane.

5. Tenzer, R. and Gladkikh, V. 2014, Assessment of density variations of marine sediments with ocean and sediment depths, *The Scientific World Journal* 2014.

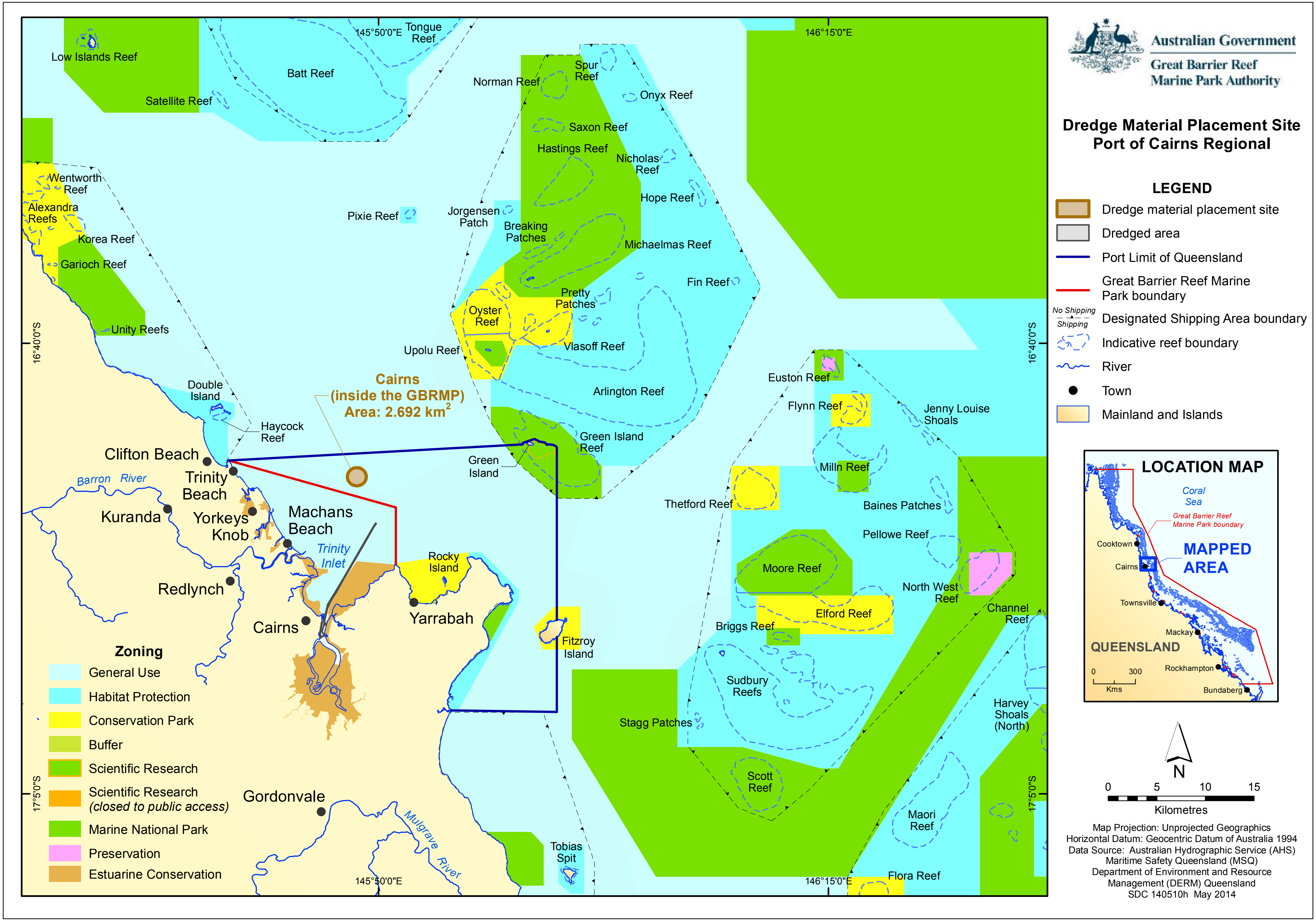
Appendix C: Maps of ports



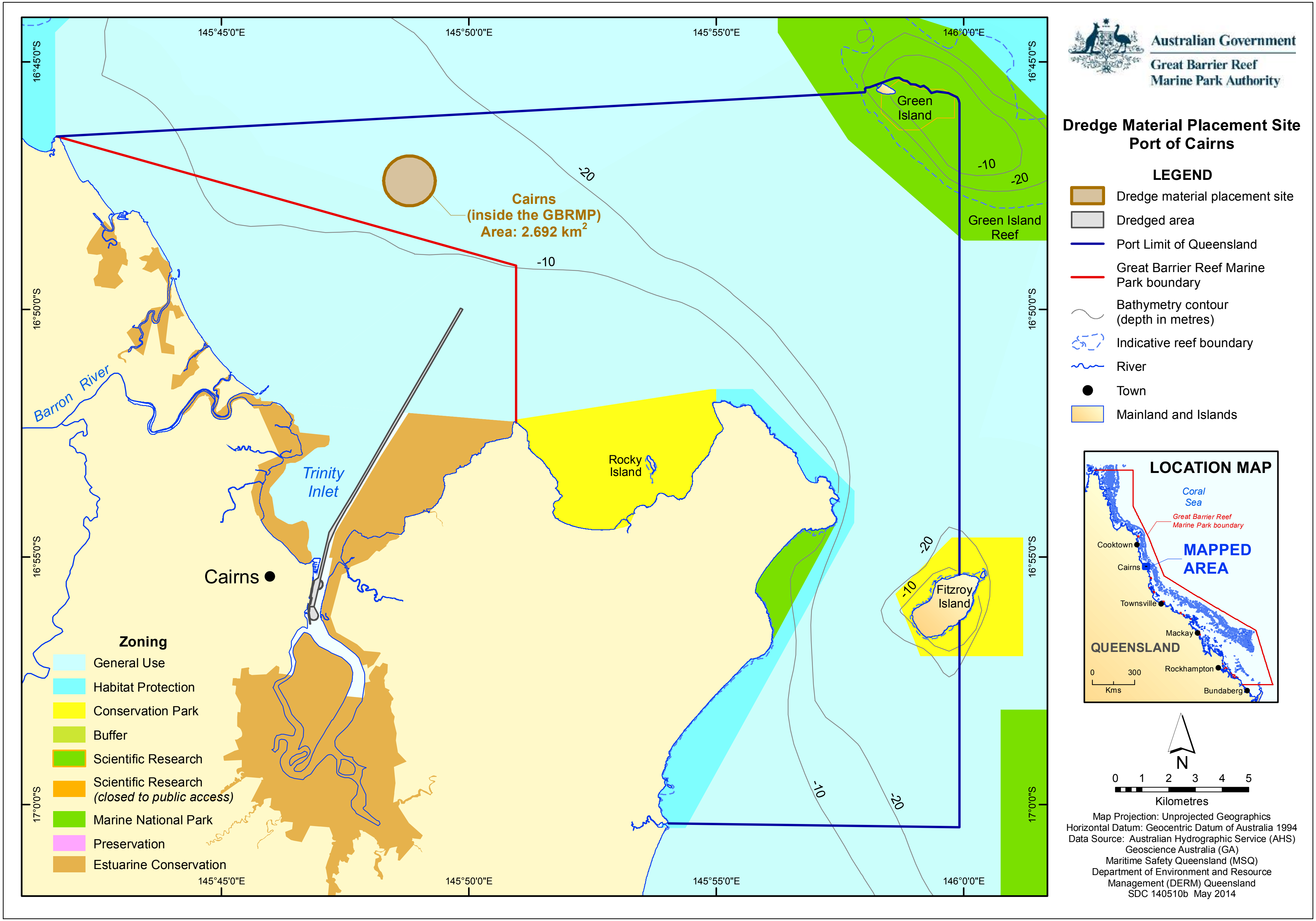
Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Cooktown Regional
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
No Shipping
Shipping
Designated Shipping Area boundary
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
Townsville
Mackay
Rockhampton
Bundaberg
QUEENSLAND
MAPPED AREA
0 300 Kms
N
0 5 10 15
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510g May 2014
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation
145°0'0"E
145°25'0"E
145°50'0"E
15°25'0"S
15°50'0"S
Cooktown (inside the GBRMP) Area: 0.128 km2
Hope Vale
Elim
Cooktown
McIvor River
Endeavour River
Annan River
Low Wooded Reef
Murray Reefs (No 2)
Conical Rock Reef
Beor Reef
Petty Patch
Pasco Reef
Strickland Reef
Long Reef
Three Islands Reef
Mackay Reefs
Harrier Reef
Ribbon No 8 Reef
Forrester Reef
Marx Reef
Startle Reefs
Ribbon No 7 Reef
Camel Head Reef
Pullen Reefs
Swinger Reef
Lark Reef
Ribbon No 6 Reef
Williamson Reefs
Ribbon No 5 Reef
Boulder Reef
Egret Reef
Blackbird Patches
Dawson Reef
Cowlishaw Reef
Draper Patch
Ribbon No 4 Reef
Vicki Harriott Reef
Ribbon No 3 Reef
Osterlund Reef
Ribbon No 2 Reef (No 2)
Ribbon No 2 Reef (No 3)
Ribbon No 2 Reef (No 1)
Rocky Island Reef
Rosser Reef
Emily Reef
Irene Reef
Ribbon No 1 Reef
Malcolm Patch
Gill Patches
Bee Reef
Lena Reef
Cairns Reef
Gubbins Reef
Pearl Reef
Ruby Reef
Hope Islands Reefs
Andersen Reef
Endeavour Reef
Rachel Carson Reef
Pickersgill Reef
Escape Reef
Evening Reef



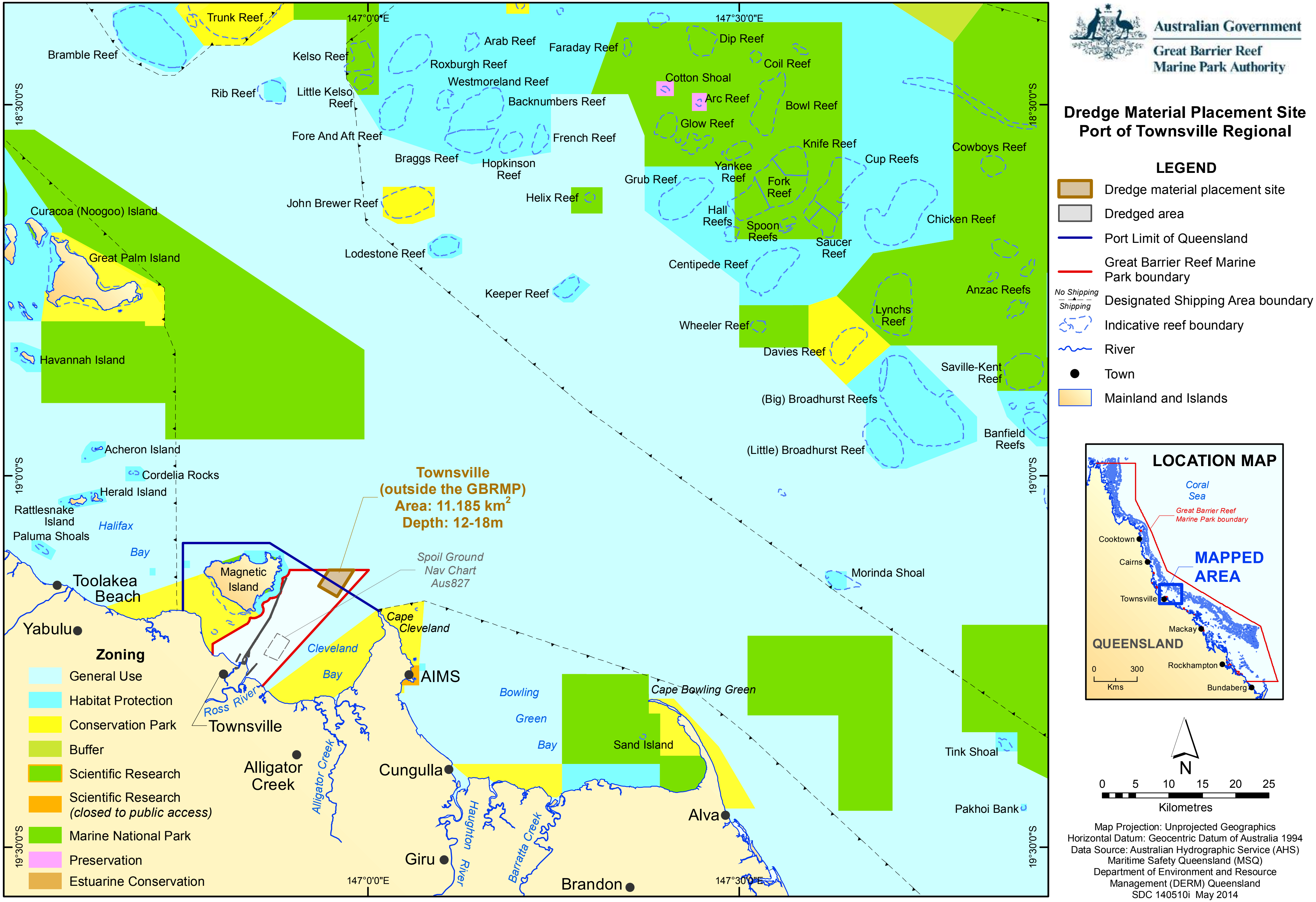
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation
145°15'0"E
145°20'0"E
15°25'0"S
15°30'0"S
Cooktown (inside the GBRMP) Area: 0.128 km2
Endeavour River
Annan River
Cooktown
Blackbird Patches
Dawson Reef
Cowlishaw Reef
-10
-20
Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Cooktown
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Bathymetry contour (depth in metres)
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
MAPPED AREA
Cooktown
Cairns
Townsville
Mackay
QUEENSLAND
Rockhampton
Bundaberg
0 300 Kms
N
0 1 2 3 4 5
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Geoscience Australia (GA)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510a May 2014

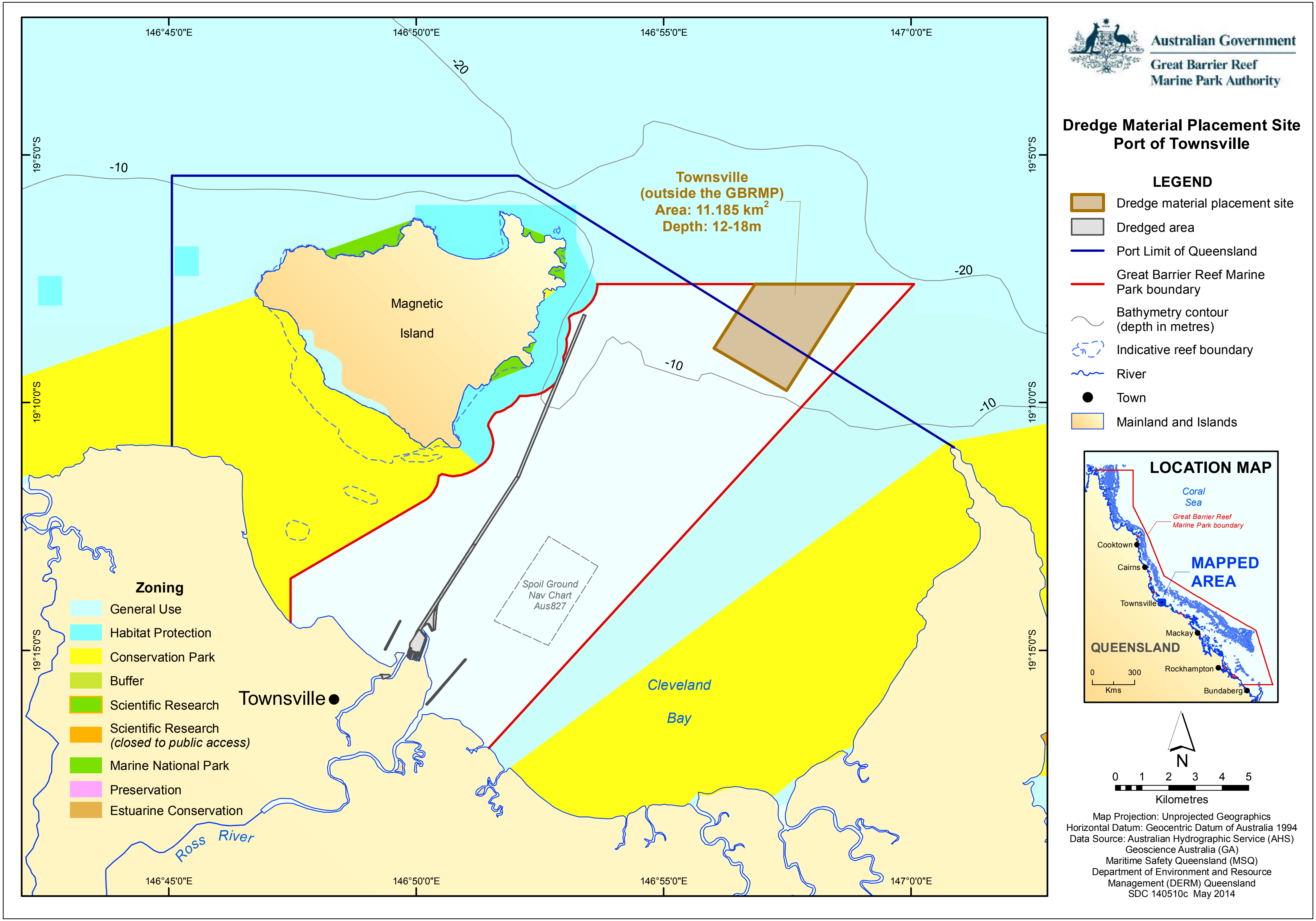


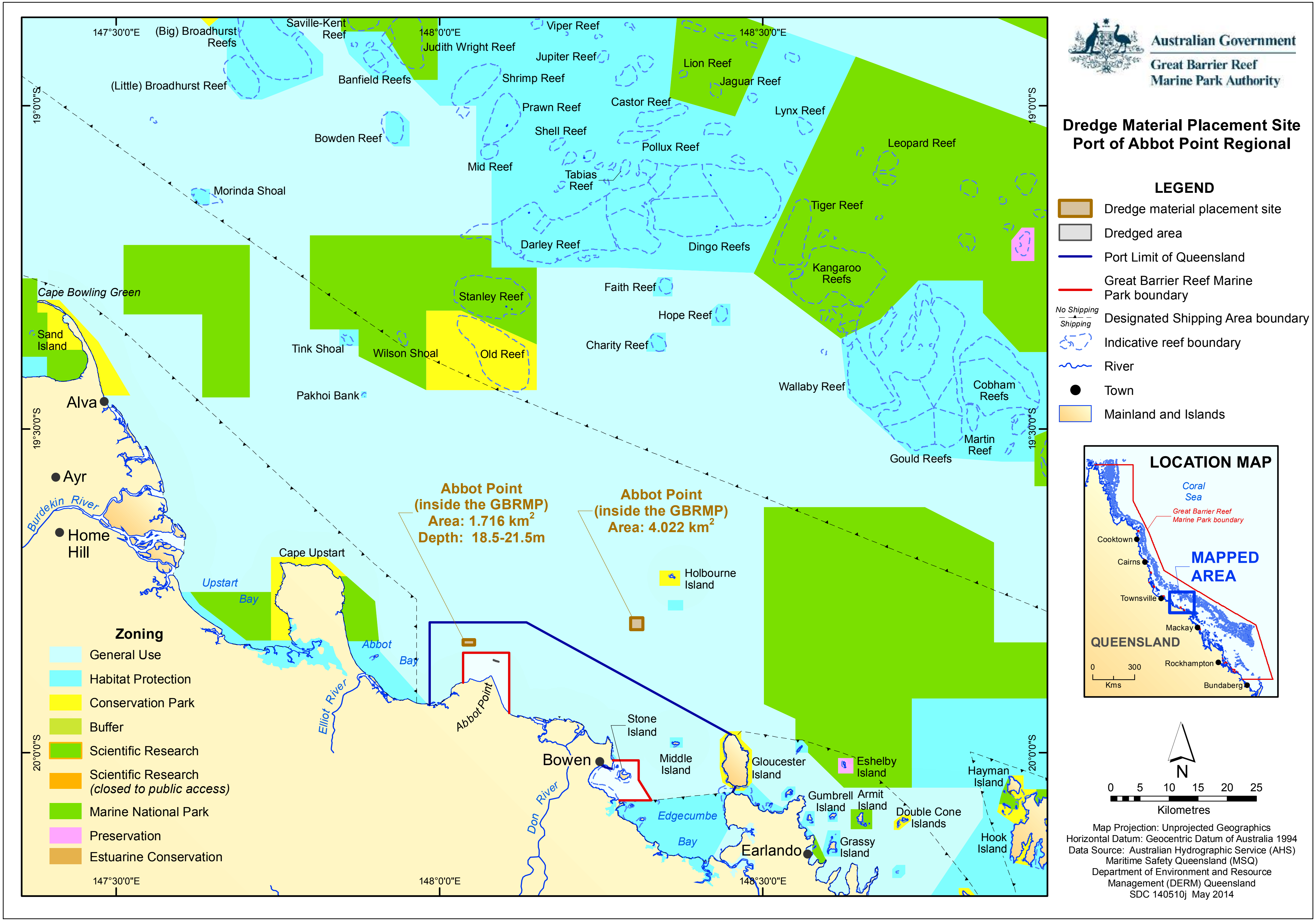
Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Cairns Regional
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
No Shipping
Shipping
Designated Shipping Area boundary
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
MAPPED AREA
Townsville
Mackay
QUEENSLAND
Rockhampton
Bundaberg
0 300
Kms
N
0 5 10 15
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510h May 2014
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation
Cairns
(inside the GBRMP)
Area: 2.692 km2
145°50'0"E
146°15'0"E
16°40'0"S
17°5'0"S
Low Islands Reef
Tongue Reef
Batt Reef
Satellite Reef
Norman Reef
Spur Reef
Onyx Reef
Saxon Reef
Hastings Reef
Nicholas Reef
Hope Reef
Wentworth Reef
Alexandra Reefs
Korea Reef
Garioch Reef
Unity Reefs
Pixie Reef
Jorgensen Patch
Breaking Patches
Michaelmas Reef
Fin Reef
Pretty Patches
Oyster Reef
Upolu Reef
Vlasoff Reef
Arlington Reef
Euston Reef
Flynn Reef
Jenny Louise Shoals
Double Island
Haycock Reef
Green Island Reef
Green Island
Milln Reef
Clifton Beach
Trinity Beach
Barron River
Kuranda
Yorkeys Knob
Machans Beach
Trinity Inlet
Thetford Reef
Baines Patches
Pellowe Reef
Moore Reef
Rocky Island
North West Reef
Redlynch
Yarrabah
Elford Reef
Channel Reef
Cairns
Briggs Reef
Fitzroy Island
Sudbury Reefs
Harvey Shoals (North)
Stagg Patches
Scott Reef
Gordonvale
Maori Reef
Mulgrave River
Tobias Spit
Flora Reef



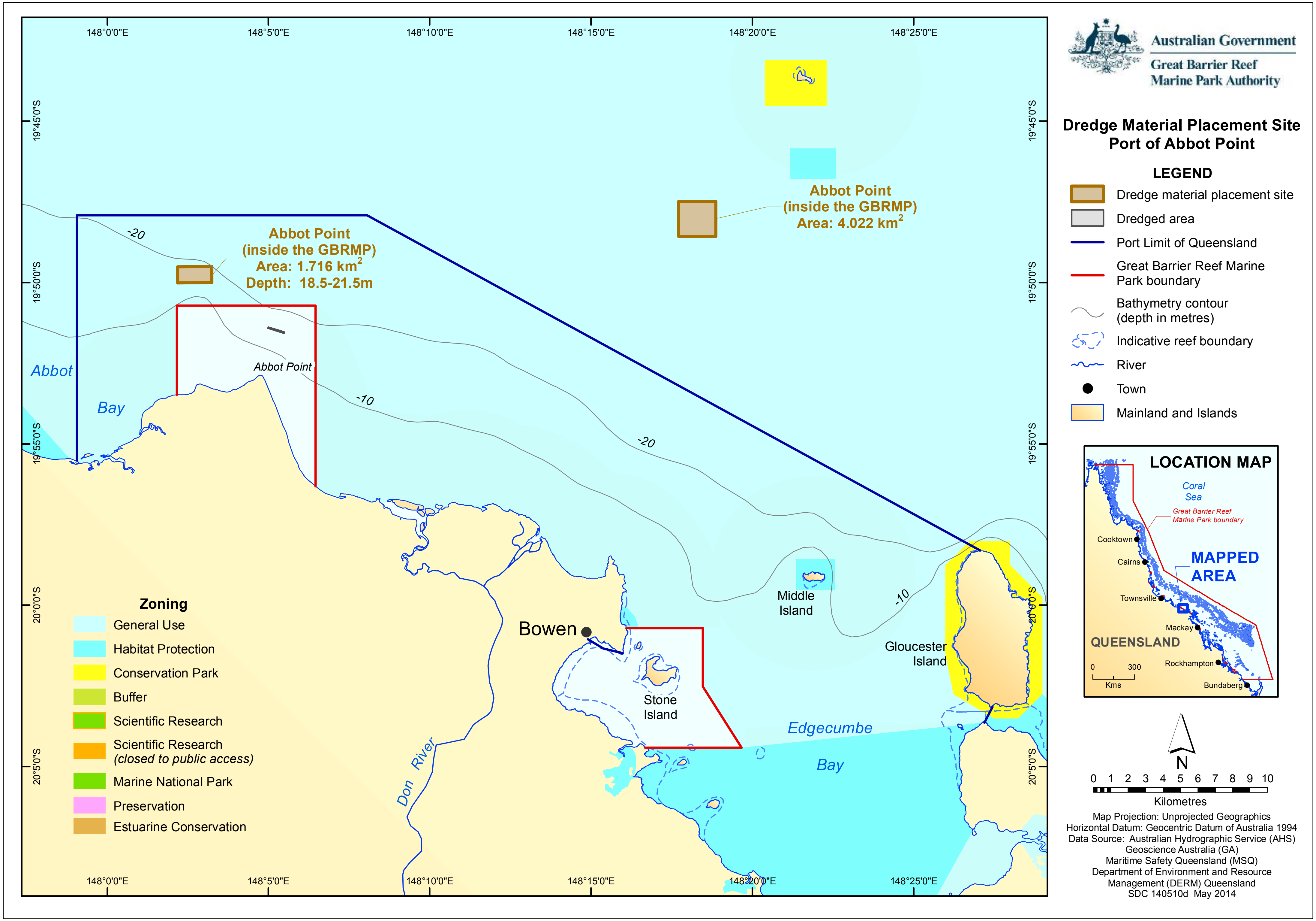
Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Cairns
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
Bathymetry contour (depth in metres)
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
MAPPED AREA
Cooktown
Cairns
Townsville
Mackay
QUEENSLAND
Rockhampton
Bundaberg
0 300 Kms
N
0 1 2 3 4 5
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Geoscience Australia (GA)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510b May 2014
145°45'0"E
145°50'0"E
145°55'0"E
146°0'0"E
16°45'0"S
16°50'0"S
16°55'0"S
17°0'0"S
Green Island
Green Island Reef
Cairns (inside the GBRMP)
Area: 2.692 km²
-10
-20
Barron River
Trinity Inlet
Cairns
Rocky Island
Fitzroy Island
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation

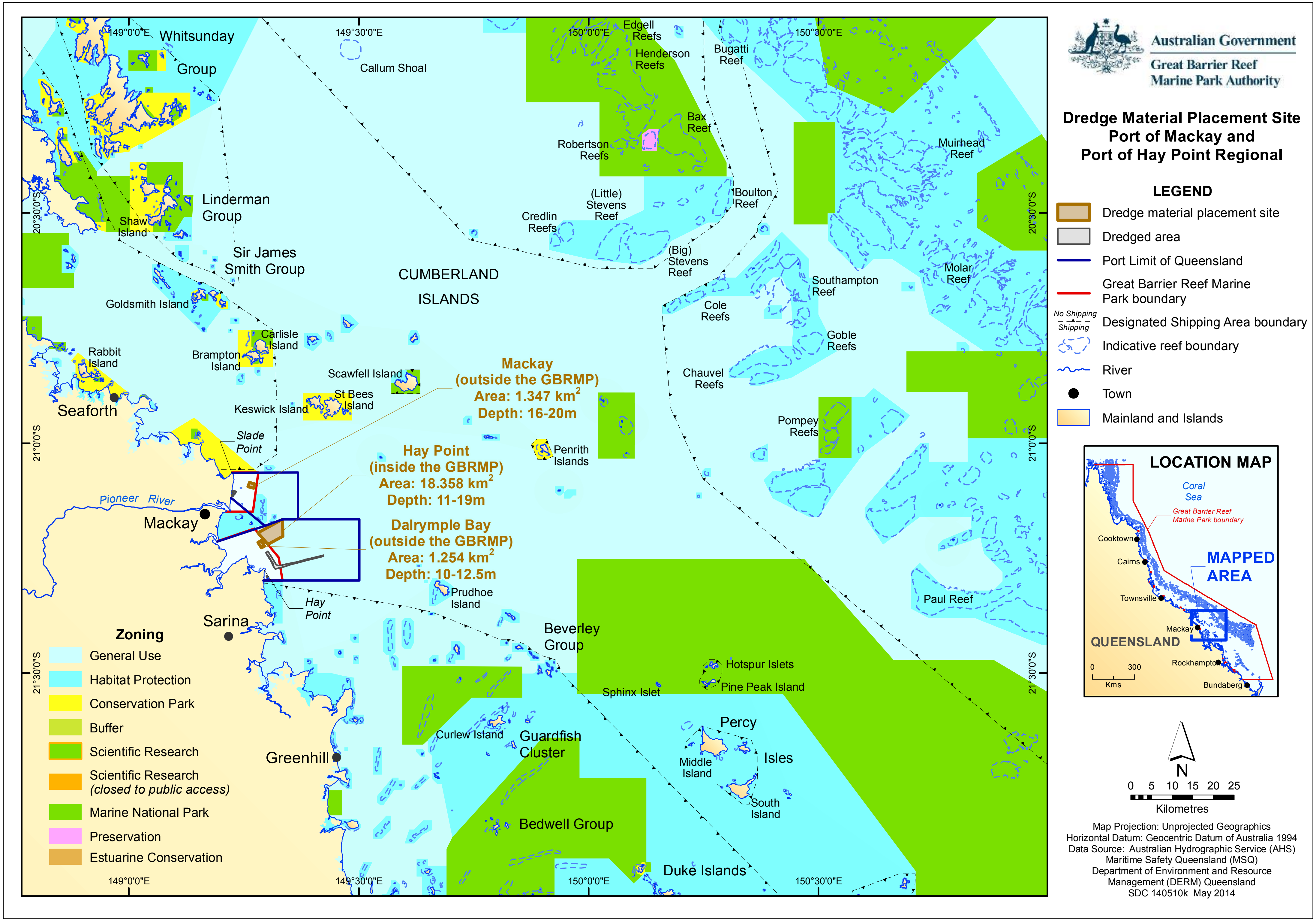

Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Townsville Regional
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
No Shipping
Shipping
Designated Shipping Area boundary
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
MAPPED AREA
Townsville
Mackay
QUEENSLAND
Rockhampton
Bundaberg
0 300 Kms
N
0 5 10 15 20 25
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510i May 2014
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation
Townsville (outside the GBRMP)
Area: 11.185 km²
Depth: 12-18m
Spoil Ground Nav Chart Aus827
147°0'0"E
147°30'0"E
18°30'0"S
19°0'0"S
19°30'0"S
Trunk Reef
Bramble Reef
Kelso Reef
Arab Reef
Faraday Reef
Dip Reef
Coil Reef
Roxburgh Reef
Westmoreland Reef
Cotton Shoal
Arc Reef
Bowl Reef
Rib Reef
Little Kelso Reef
Backnumbers Reef
Glow Reef
Fore And Aft Reef
French Reef
Knife Reef
Cowboys Reef
Braggs Reef
Hopkinson Reef
Yankee Reef
Fork Reef
Cup Reefs
Grub Reef
John Brewer Reef
Helix Reef
Hall Reefs
Spoon Reefs
Saucer Reef
Chicken Reef
Curacoa (Noogoo) Island
Great Palm Island
Lodestone Reef
Centipede Reef
Keeper Reef
Anzac Reefs
Lynchs Reef
Wheeler Reef
Davies Reef
Havannah Island
Saville-Kent Reef
(Big) Broadhurst Reefs
Banfield Reefs
(Little) Broadhurst Reef
Acheron Island
Cordelia Rocks
Herald Island
Rattlesnake Island
Halifax Bay
Paluma Shoals
Morinda Shoal
Magnetic Island
Toolakea Beach
Yabulu
Cape Cleveland
Cleveland Bay
AIMS
Ross River
Townsville
Bowling Green Bay
Cape Bowling Green
Sand Island
Tink Shoal
Alligator Creek
Alligator Creek
Cungulla
Haughton River
Barratta Creek
Alva
Pakhoi Bank
Giru
Brandon


Australian Government
Great Barrier Reef
Marine Park Authority
Dredge Material Placement Site
Port of Townsville
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
Bathymetry contour (depth in metres)
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
MAPPED AREA
Townsville
Mackay
QUEENSLAND
Rockhampton
Bundaberg
0 300
Kms
N
0 1 2 3 4 5
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Geoscience Australia (GA)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510c May 2014
146°45'0"E
146°50'0"E
146°55'0"E
147°0'0"E
19°5'0"S
19°10'0"S
19°15'0"S
-10
-20
Townsville
(outside the GBRMP)
Area: 11.185 km2
Depth: 12-18m
Magnetic
Island
Spoil Ground
Nav Chart
Aus827
Cleveland
Bay
Townsville
Ross River
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation



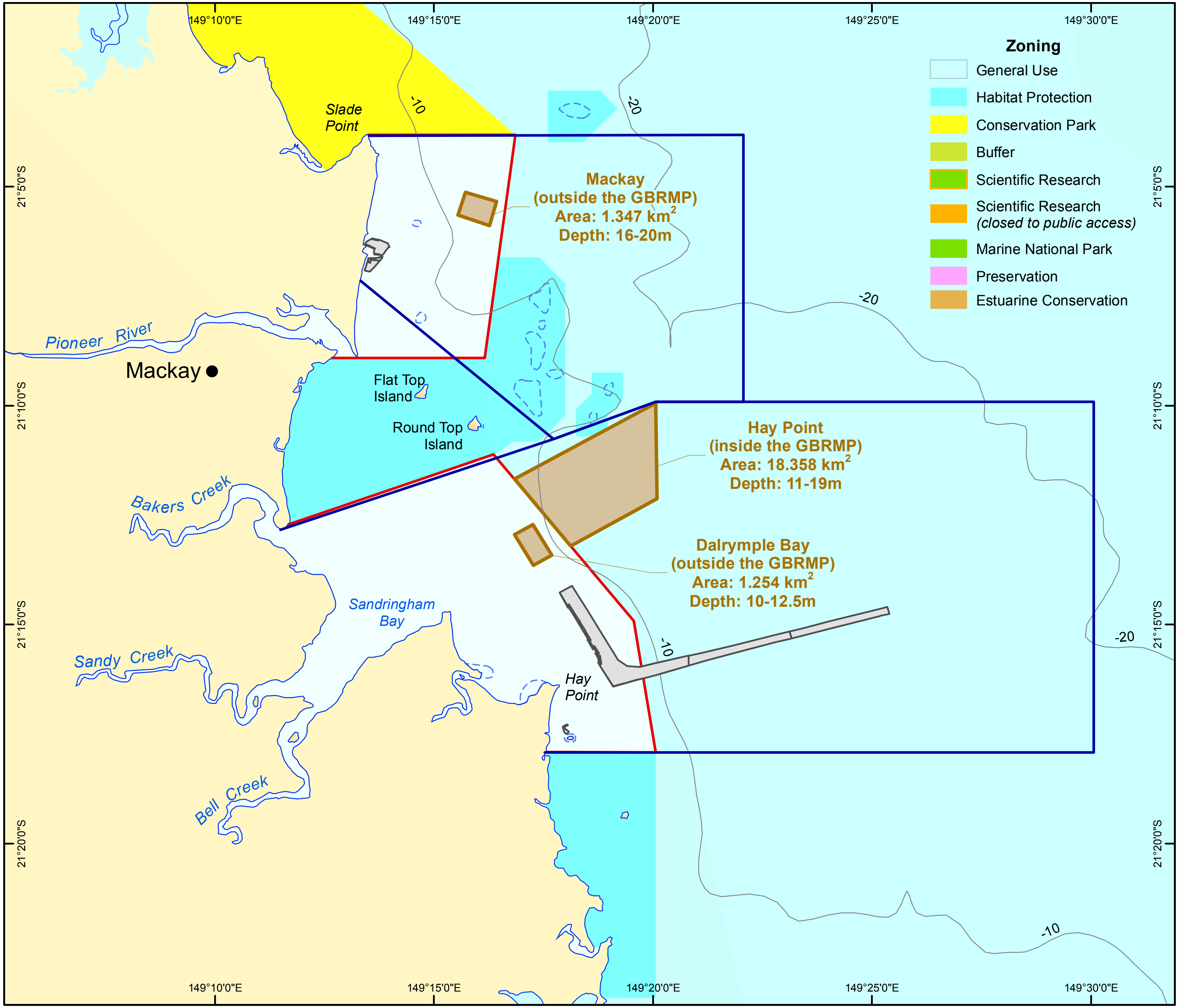
Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Abbot Point Regional
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
No Shipping
Shipping
Designated Shipping Area boundary
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
MAPPED AREA
Townsville
Mackay
QUEENSLAND
Rockhampton
Bundaberg
0 300
Kms
N
0 5 10 15 20 25
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource
Management (DERM) Queensland
SDC 140510j May 2014
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research
(closed to public access)
Marine National Park
Preservation
Estuarine Conservation
Abbot Point
(inside the GBRMP)
Area: 1.716 km2
Depth: 18.5-21.5m
Abbot Point
(inside the GBRMP)
Area: 4.022 km2
147°30'0"E
148°0'0"E
148°30'0"E
19°0'0"S
19°30'0"S
20°0'0"S
(Big) Broadhurst Reefs
Saville-Kent Reef
Judith Wright Reef
Viper Reef
Jupiter Reef
Lion Reef
Jaguar Reef
(Little) Broadhurst Reef
Banfield Reefs
Shrimp Reef
Prawn Reef
Castor Reef
Lynx Reef
Shell Reef
Bowden Reef
Pollux Reef
Leopard Reef
Mid Reef
Tabias Reef
Morinda Shoal
Tiger Reef
Darley Reef
Dingo Reefs
Kangaroo Reefs
Faith Reef
Cape Bowling Green
Stanley Reef
Hope Reef
Sand Island
Tink Shoal
Wilson Shoal
Old Reef
Charity Reef
Pakhoi Bank
Wallaby Reef
Cobham Reefs
Alva
Martin Reef
Gould Reefs
Ayr
Burdekin River
Home Hill
Cape Upstart
Holbourne Island
Upstart Bay
Abbot Bay
Elliot River
Abbot Point
Stone Island
Middle Island
Gloucester Island
Eshelby Island
Hayman Island
Bowen
Gumbrell Island
Armit Island
Double Cone Islands
Don River
Edgecumbe Bay
Grassy Island
Hook Island
Earlando


Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Abbot Point
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
Bathymetry contour (depth in metres)
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
Townsville
Mackay
Rockhampton
Bundaberg
MAPPED AREA
QUEENSLAND
0 300
Kms
N
0 1 2 3 4 5 6 7 8 9 10
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Geoscience Australia (GA)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510d May 2014
148°0'0"E
148°5'0"E
148°10'0"E
148°15'0"E
148°20'0"E
148°25'0"E
19°45'0"S
19°50'0"S
19°55'0"S
20°0'0"S
20°5'0"S
Abbot Point
(inside the GBRMP)
Area: 4.022 km²
Abbot Point
(inside the GBRMP)
Area: 1.716 km²
Depth: 18.5-21.5m
-20
-10
Abbot Point
Abbot
Bay
Bowen
Stone Island
Middle Island
Gloucester Island
Edgecumbe
Bay
Don River
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation


Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Mackay and
Port of Hay Point Regional
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
No Shipping
Shipping
Designated Shipping Area boundary
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
Townsville
Mackay
Rockhampton
Bundaberg
QUEENSLAND
MAPPED AREA
0 300
Kms
N
0 5 10 15 20 25
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510k May 2014
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation
Mackay (outside the GBRMP)
Area: 1.347 km2
Depth: 16-20m
Hay Point (inside the GBRMP)
Area: 18.358 km2
Depth: 11-19m
Dalrymple Bay (outside the GBRMP)
Area: 1.254 km2
Depth: 10-12.5m
149°0'0"E
149°30'0"E
150°0'0"E
150°30'0"E
20°30'0"S
21°0'0"S
21°30'0"S
Whitsunday Group
Linderman Group
Shaw Island
Sir James Smith Group
Goldsmith Island
Carlisle Island
Brampton Island
Rabbit Island
Seaforth
Scawfell Island
St Bees Island
Keswick Island
Slade Point
Pioneer River
Mackay
Hay Point
Sarina
Greenhill
Prudhoe Island
Penrith Islands
CUMBERLAND ISLANDS
Callum Shoal
Edgell Reefs
Henderson Reefs
Bugatti Reef
Bax Reef
Robertson Reefs
Credlin Reefs
(Little) Stevens Reef
(Big) Stevens Reef
Boulton Reef
Muirhead Reef
Molar Reef
Southampton Reef
Cole Reefs
Goble Reefs
Chauvel Reefs
Pompey Reefs
Paul Reef
Beverley Group
Hotspur Islets
Pine Peak Island
Sphinx Islet
Curlew Island
Guardfish Cluster
Percy Isles
Middle Island
South Island
Bedwell Group
Duke Islands

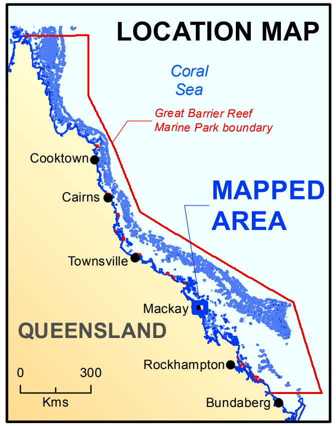
Australian Government
Great Barrier Reef
Marine Park Authority

Dredge Material Placement Site
Port of Mackay and Port of Hay Point



LEGEND

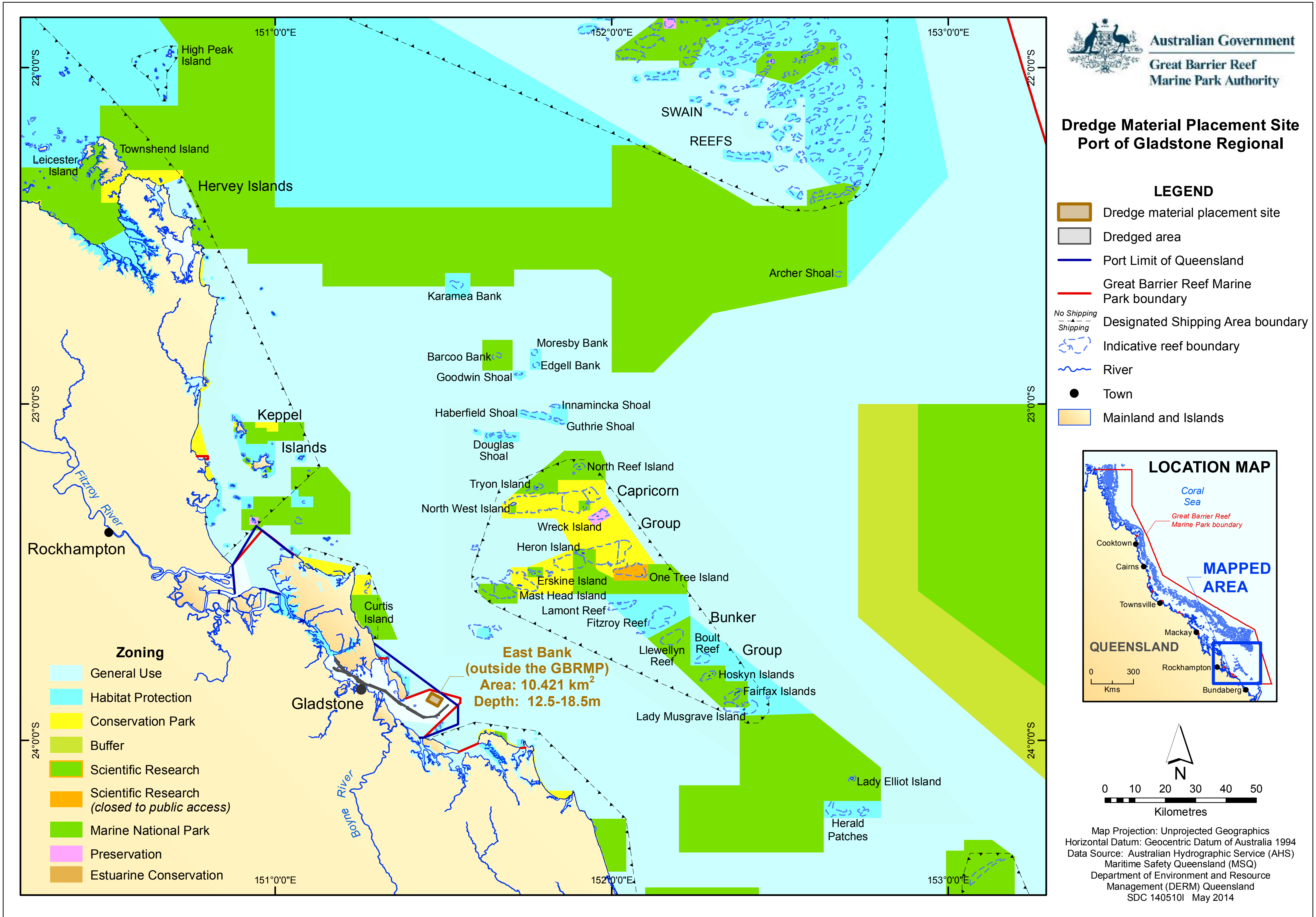
- Dredge material placement site
- Dredged area
- Port Limit of Queensland
- Great Barrier Reef Marine Park boundary
- Bathymetry contour (depth in metres)
- Indicative reef boundary
- River
- Town
- Mainland and Islands

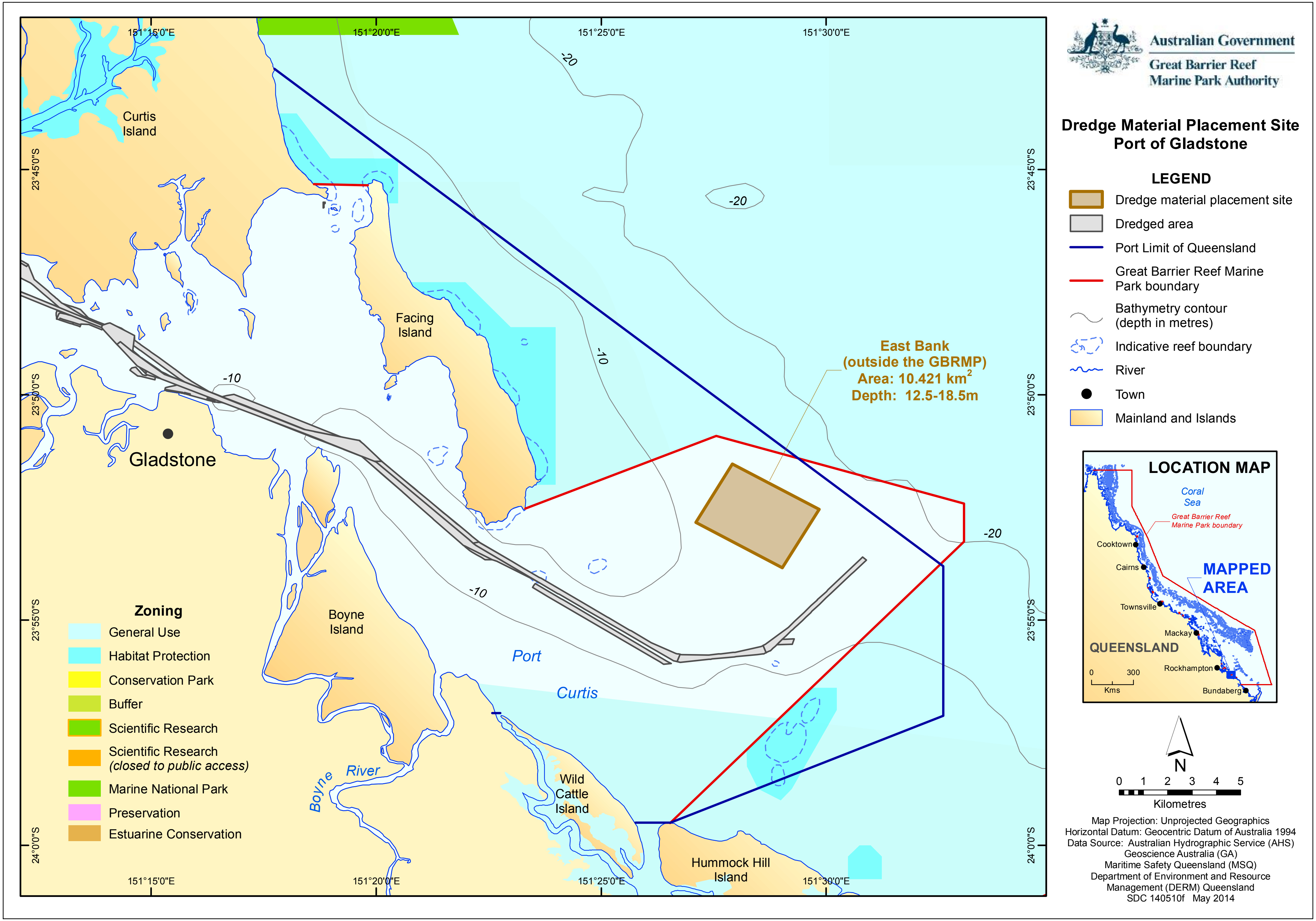


N

0 1 2 3 4 5 6 7 8
Kilometres

Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Geoscience Australia (GA)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510e May 2014


Australian Government
Great Barrier Reef Marine Park Authority
Dredge Material Placement Site
Port of Gladstone Regional
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
No Shipping
Shipping
Designated Shipping Area boundary
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
Townsville
Mackay
Rockhampton
Bundaberg
QUEENSLAND
MAPPED AREA
0 300
Kms
N
0 10 20 30 40 50
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510I May 2014
151°0'0"E
152°0'0"E
153°0'0"E
22°0'0"S
23°0'0"S
24°0'0"S
High Peak Island
Townshend Island
Leicester Island
Hervey Islands
SWAIN
REEFS
Archer Shoal
Karamea Bank
Barcoo Bank
Moresby Bank
Edgell Bank
Goodwin Shoal
Haberfield Shoal
Innamincka Shoal
Guthrie Shoal
Douglas Shoal
Keppel
Islands
North Reef Island
Tryon Island
Capricorn
North West Island
Group
Wreck Island
Heron Island
One Tree Island
Erskine Island
Mast Head Island
Lamont Reef
Fitzroy Reef
Bunker
Boult Reef
Llewellyn Reef
Group
Hoskyn Islands
Fairfax Islands
Lady Musgrave Island
Lady Elliot Island
Herald Patches
Fitzroy River
Rockhampton
Curtis Island
Gladstone
Boyne River
East Bank
(outside the GBRMP)
Area: 10.421 km2
Depth: 12.5-18.5m
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation


Australian Government
Great Barrier Reef
Marine Park Authority
Dredge Material Placement Site
Port of Gladstone
LEGEND
Dredge material placement site
Dredged area
Port Limit of Queensland
Great Barrier Reef Marine Park boundary
Bathymetry contour (depth in metres)
Indicative reef boundary
River
Town
Mainland and Islands
LOCATION MAP
Coral Sea
Great Barrier Reef Marine Park boundary
Cooktown
Cairns
MAPPED AREA
Townsville
Mackay
QUEENSLAND
Rockhampton
Bundaberg
0 300 Kms
N
0 1 2 3 4 5
Kilometres
Map Projection: Unprojected Geographics
Horizontal Datum: Geocentric Datum of Australia 1994
Data Source: Australian Hydrographic Service (AHS)
Geoscience Australia (GA)
Maritime Safety Queensland (MSQ)
Department of Environment and Resource Management (DERM) Queensland
SDC 140510f May 2014
East Bank
(outside the GBRMP)
Area: 10.421 km²
Depth: 12.5-18.5m
Curtis Island
Facing Island
Gladstone
Boyne Island
Port Curtis
Boyne River
Wild Cattle Island
Hummock Hill Island
-10
-20
151°15'0"E
151°20'0"E
151°25'0"E
151°30'0"E
23°45'0"S
23°50'0"S
23°55'0"S
24°0'0"S
Zoning
General Use
Habitat Protection
Conservation Park
Buffer
Scientific Research
Scientific Research (closed to public access)
Marine National Park
Preservation
Estuarine Conservation

Appendix D: Compilation of evidence for effects of dredging on Great Barrier Reef coral reefs

(Incorporating material summarised in SKM and APASA 2013)[1]

Daydream Island Monitoring Study, 1990[2]

Duration: Baseline surveys in July 1989 followed by post-construction surveys in August 1990
Dredging type: Small marina and external rock wall constructed on the western side of Daydream Island

Methods

- National Parks officers were present to supervise and to halt excavation works if and when excessive sediment plumes were visible (from land-based observations)
- Benthic community composition was examined on the reef flat and slope using belt transects and line intercept transects (LIT)

Monitoring sites and design

- Observations by National Park officers: no information provided
- Community composition:
    - 12 monitoring sites were established at: four potential impact sites (western side of Daydream Island), four possible impact sites (eastern side of Daydream Island) and 4 control/reference sites (on North, Mid and South Molle Islands). At each site, four 20 m permanent transects were established on the reef slope parallel to the reef crest.
    - Belt transects (0.5 m wide) were sampled at three potential impact sites and control/reference sites and belt transects were conducted on the reef flat for three of the four impact sites
    - Additional monitoring sites were installed in July 1990 (post-dredging) at each reef slope at the potential impact and control/reference locations

Frequency and duration

- Sampling was conducted in July 1989 before the construction and afterwards in August 1990

Summary of documented effects

- The study was compromised by failure to relocate one of the control/reference sites in the second survey, differences in interpretation of benthic categories between observers conducting the surveys and the lack of suitable reef flat control/reference sites. Further interpretation was compromised by the loss (from construction) of parts of several reef slope transect lines at the potential impact sites close to the marina and anchor damage from recreational boating at some of the possible impact sites. Overall conclusions from the study were that there were clear direct effects on the reef flat (caused by removal of the substrate and associated corals) and it was quite likely there was a reduction in abundance of reef flat hard corals from indirect effects (caused by sedimentation and turbidity). Overall it was suggested that there were no definite indirect effects on the reef slope communities near the construction.

Port of Townsville Eastern Port Development capital dredging, January–April 1993[3,4]

Volume

- 760,000 cubic metres dredged and marine disposal[5]

Parameters

- Short-term coral health (bleaching, partial mortality, sediment on corals)
- Per cent cover of benthos

Methods

- Coral health: Photographs and diver sketches of tagged corals
- Video transects: Fixed point counts from photo frames selected at 6 s intervals on 20 m transect

Monitoring sites and design

- Coral health:
    - Three primary impact locations, two subsidiary impact locations, two control locations
    - 20 tagged colonies of each of four coral species for short-term coral health monitoring at each location
- Video transects:
    - Four impact locations, one control location
    - Six sites within each location
    - Four permanent 20 m transects at each site

Frequency and duration

- Coral health: twice-weekly surveys at primary impact locations, weekly at control locations during dredging; subsidiary impact locations surveyed twice during dredging period; one survey June/July 1993 several weeks following bed levelling
- Video transects: three surveys of video transects of community composition prior to dredging, post-dredging, and several months following the completion of dredging

Summary of documented effects

- Coral health:
    - Some signs of stress (bleaching, tissue necrosis) in Geoffrey and Florence Bay (impact sites) in February, some partial mortality. No signs of coral stress at control locations, despite wet season conditions leading to adverse environmental conditions. Dredging operations appear to have contributed to

observed stress in impact locations, especially in *Acropora latistella*. No subsequent colony mortality was observed. Partial mortality at principal impact locations did not exceed 12 per cent, generally < 5 per cent; investigative trigger (Immediate Response Group) bleaching trigger exceeded on several occasions but no exceedances of higher level triggers for action. Complete mortality of one colony at one impact location occurred but was not considered dredging-related. At least one species was considered close to sedimentation/turbidity tolerance threshold.

- Video transects:
    - Declines in favid and soft corals consistent with dredging impacts; declines in other corals at control location not consistent with dredging impacts. Greater seasonal declines in macroalgae at impact locations, however, macroalgae cover at control location was low prior to dredging. All groups except *Montipora* varied significantly over time.

Comments/limitations

- Monitoring only extended several months after dredging.
- Detailed reporting of statistical power. Power to detect change at family level in corals ranged from 15 per cent probability of detecting 120 per cent change to > 99 per cent probability of detecting 11 per cent change. Power to detect change in *Sargassum* spp. was 14 per cent probability of detecting 281 per cent change.[4]
- Highest mortality at Rattlesnake (control location) toward end of dredging campaign; obvious signs of disease, but report did not link to dredging as design included control/impact comparison and disease not observed in other areas, and this location considered too far away from the dredging operation. However, still increased three months after dredging—transport of fines not considered.
- Authors urge caution as coral cover started from low base, less capacity to decline. Also lack of long-term data makes interpretation of change over short-term difficult.

Nelly Bay (Magnetic Island) Harbour, 2001–2002[6,7,8]

Volume

- 1,500 cubic metres approved dredging; no marine disposal

Parameters

- Coral health (bleaching, partial and whole colony mortality, mucus production, sediment on corals)
- Percent cover of benthos

Methods

- Coral health (Coral Condition Monitoring Program); photographs and diver sketches of tagged corals

- Video transects (Long-Term Coral Health Monitoring Program)—line intercept technique (LIT)

Monitoring sites and design

- Coral health (Coral Condition Monitoring Program);
  - Three primary impact locations, (two in Nelly Bay and one in Geoffrey Bay), two additional impact locations commissioned halfway through the project either side of the entrance channel, and four control/reference locations (two each in Florence Bay and Arthur Bay)
  - 25 tagged colonies (+10 redundancy corals) of each of four species (*Acropora latistella, A. subulata, Turbinaria mesenterina* and *Montipora aequituberculata*) were examined at each of the primary seven monitoring locations (= 700 colonies) and for *Turbinaria mesenterina* and *Montipora aequituberculata* at the secondary impact locations
- Video transects (Long-Term Coral Health Monitoring Program)
  - Two impact locations on the reef slope at Nelly Bay (14 sites) and Geoffrey Bay (six sites) and two control/reference locations at Arthur Bay (three sites) and Florence Bay (three sites). Four additional impact sites were commissioned halfway through the project either side of the entrance channel. Four x 20 m permanent transects at each site.
  - One impact location on the reef flat at Nelly Bay (four sites) and two control/reference locations at Arthur Bay (two sites) and Florence Bay (two sites). Four x 20 m permanent transects at each site.

Frequency and duration

- Coral health (Coral Condition Monitoring Program)
  - Mostly weekly and sometimes twice-weekly and sometimes fortnightly using semi-quantitative rapid visual surveys conducted at the impact sites only, continuously for 19 months. Quantitative surveys of all corals at control/reference and impact sites were conducted at the start of the project and at six-weekly intervals for 19 months with six additional surveys added during various phases of the operations.
- Video transects:
  - Surveys of community composition were conducted in March/April 2000, August 2000, March 2001, September 2001, June 2002, and a post-dredging follow-up survey in January 2003.

Summary of documented effects

- Coral health (Coral Condition Monitoring Program)
  - Many dredging/construction related and natural disturbances were recorded during the 19 months of continuous monitoring. Any incidence of damage by sediment was extremely localised i.e. within 10 m of the dredging operations in

the entrance channel. Construction related damage included inappropriate location of mooring weights anchors and anchor lines (at reference and impact sites), damage caused by delamination of silt curtains, poorly secured sediment curtains resulting in a concentrated spill of sediment and structural failure to silt curtains in high winds. Some damage to corals was noted towards the end of project but could have been related to propeller wash from a barge.
    - Many natural disturbances were also recorded including a natural solar bleaching of corals caused by extremely low daytime tides, a significant bleaching event occurred in January/February 2002 and a coral disease outbreak was also recorded in one of the species (*M. aequituberculata*) in December 2001 and January 2002. Detailed, forensic investigations of the bleaching and disease outbreak attributed the events to elevated water temperatures and not to any development activities[9,10].
- Video transects:
    - LIT recorded a 40 per cent decrease in hard coral cover at the impact and control/reference sites caused by cyclone Tessi on 2 April 2000 (with sustained wind speeds up to 60 knots). Following a gradual recovery of hard coral cover a significant effect of the 2002 coral bleaching event and disease outbreak was also recorded. By the post-dredging follow-up survey in January 2003, coral cover had begun to recover again and corals in all bays except Geoffrey Bay were healthy and appeared to be growing rapidly. Geoffrey Bay was hit worst by the bleaching, and coral disease was reported during the June 2002 survey. Some mortality in *Acropora* spp. near the Nelly Harbour entrance channel was suggested to be due to increased siltation.

Rosslyn Bay maintenance dredging, 2006[11,12]

Volume

- 31,000 in situ cubic metres marine disposal

Parameters

- Per cent cover of benthos categories (hard coral, soft coral, macroalgae, hydroids, sponges, dead coral, sand, rubble, etc.); some organisms identified to higher taxonomic levels including to species level

Methods

- Random point counts from photos taken at 5 m intervals on 50 m transects

Monitoring sites and design

- Bluff Rock and Monkey Point; three transects per location

Frequency and duration

- Baseline: one survey, one week before dredging

- Post-dredging: two surveys, two weeks and one year post-dredging—no post-dredging surveys at Bluff Rock

Summary of documented effects

- Impacts of dredging not determined—impact location not surveyed post-dredging
- No statistically significant change in coral cover, density or condition at reference site between surveys

Comments/limitations

- Reference site had significantly higher coral cover and different community structure than Bluff Rock in baseline survey; suitability as control doubtful
- Metrics used to distinguish coral cover and density, and to define coral condition, not reported
- Statistical power not reported

Hay Point apron areas and departure path capital dredging project, 2006[13,14]

Volume

- 8,611,889 in situ cubic metres marine disposal

Parameters

- Percent cover of benthos categories
- Coral condition: frequency/degree of coral bleaching, frequency intensity of mucus production by *Porites*, frequency/intensity of partial/total coral tissue disease and mortality
- Thickness of sediment deposits on corals

Methods

- Benthic Line Intercept Transects (LIT) for benthic cover assessments along four 20 metre, randomly positioned, line intercept transects within a narrow depth stratum along 50 metres of reef, at each location.

Monitoring sites and design

- Impact locations: Round Top Island (3 km NW of the Dredge Material Placement Area (DMPA) boundary), Victor Islet (21 km S),
- Reference locations: Slade Island (11 km NNW), Keswick Island (41 km NNE)
- Six sites each location, four 20 m transects each site

Frequency and duration

- LIT for per cent cover:
    - One baseline survey: 2–3 weeks before dredging
    - Two surveys during dredging (6–7 week intervals)
    - Two surveys post-dredging (five weeks and six months)
- Bleaching:

- One baseline survey: 2–3 weeks before dredging
  - Four surveys during dredging (first two fortnightly, then in conjunction with LIT)—impact sites only except during LIT surveys
  - Two surveys post-dredging (five weeks and six months)
- *Porites* mucus and sediment on corals:
  - One baseline survey: 2–3 weeks before dredging
  - Approx. fortnightly during dredging—impact sites only except during LIT surveys
  - Two surveys post-dredging (five weeks and six months)
- Damaged/diseased coral counts:
  - No baseline
  - Approx. fortnightly during dredging—impact sites only except during LIT surveys
  - Two surveys post-dredging (five weeks and six months)

Summary of documented effects

- Less than 1 per cent coral mortality at impact sites attributed to dredging activities, compared to approved mortality of 20 per cent
- Statistically significant decline in hard coral cover between baseline (April 2006) and first during-dredging LIT survey (July). Pattern of decline not significantly different between impact and reference locations with no statistically significant difference in pattern of decline between April and June.
- No significant change in coral cover from June 2006 to November 2006 (five weeks post-dredging)
- Overall, statistically significant decrease in coral cover between April 2006 and November 2006 due to observed decrease between April and July
- Coral condition monitoring undertaken showed sediment deposition associated with the migration of the dredge plume occurred at both Round Top Island (12 km N) and Victor Islet (6.5 km S). This deposition resulted in partial damage to some corals between three and six months after the start of dredging, with a maximum of about 4 per cent (Round Top Island) and 6.5 per cent (Victor Islet) of corals showing some patches of mortality.
- Net decline in coral cover April 2006 to November 2006 (six months post-dredging) at impact (Round Top Is.—3 per cent, Victor Is.—7 per cent) and control sites (Slade Is.—7 per cent, Keswick Is.—12 per cent)[14].
- Trimarchi & Keane (2007)[13] graphically report slight increases in coral cover at Round Top, Victor, and Slade Is. from November 2006 to April 2007, and a decrease at Keswick Is. Quantitative data not available to SKM.
- A maximum of 17 per cent of corals at any location during the dredging campaign were affected by sediment including observations of sediment on colony surface
- Disease levels stayed the same throughout the study but differed between sites. However, it is uncertain what mucus production (*Porites*) was measured at two surveys as indicator for sediment cleaning; but as it is uncertain how to interpret the results and it

was not measured in final survey. Declines in *Turbinaria* and *Siderastrid* cover at all locations due to disease and unexplained decline in *Goniopora* at Keswick Is.

- GHD (2006b)[14] reported fine sediment from dredging still being resuspended at impact sites five weeks post-dredging (November 2006).
- Trimarchi & Keane (2007)[13] report 80 per cent power to detect 20 per cent change in hard coral cover.
- Hydrodynamic model used predicted the suspended sediments at impact reefs relatively well. High values measured at Round Top in June and October (40–100 mgL), at Victor Is. whole period elevated (40–90 mgL) and very high values in February 2007. Compared to pre-dredging the concentration of total suspended sediment (TSS) during dredging was much increased (3–10x) and much more variable.

Comments/limitations

- Dredging of 8.6 million m^3.
- Coral mortality much lower than predicted or approved.
- Study area may have been influenced by previous dredging.
- Turbid plumes from dredging and dredge material placement extended over a greater distance than predicted, as far as 46 km to the north (Islam et al. 2007)[15], potentially compromising reference locations.
- Statistical analysis of changes in coral cover appears to compare all locations individually; no apparent test of control versus impact.

Hay Point Coal Terminal Expansion Project Phase 3 (HPX3; 2010–11)[16,17]

Volume

- 177,726 in situ cubic metres marine disposal

Parameters

- Per cent cover of benthos categories

Methods

- Random point counts from photo frames selected randomly along 20 m permanent video transects

Monitoring sites and design

- One impact site (Hay Reef, 1.5 km WSW of dredging site, 5.6 km S of nearest DMPA boundary)
- One reference site (Dudgeon Pt., 6 km NW of dredging site, 5 km SW of DMPA)
- 10 x 20 m transects per site

Frequency and duration

- One baseline survey April 2010
- One post-dredging survey October/November 2011

Summary of documented effects

- Moderate but statistically insignificant declines in hard coral cover at both impact and control sites. Control site had significantly higher coral cover both before and after dredging.
- Major, statistically significant, increases in macroalgal cover at both impact and control sites. Proportional increase at control site was significantly greater than at impact site.
- No difference in pattern of change between impact and controls, thus no detectible impact of dredging.
- Authors concluded changes probably driven primarily by cyclone and flood effects.

Comments/limitations

- Baseline survey conducted immediately after cyclone Ului passed through area. Hence, monitoring compromised by major changes due to cyclone damage and recovery 'masking' any dredge related effects: increases in abundance and diversity in some benthic communities during the dredge period probably reflect recovery from cyclone damage.
- Impact and reference location relevant to dredging but not material placement; baseline surveys conducted at potentially impacted reefs at Round Top Is., Slade Is. and Victor Is., but no post-dredging surveys conducted because water quality monitoring using continuous turbidity loggers, remote sensing and vessel-based measurements indicated no detectible turbidity plumes at those sites.
- Statistical power not reported.

Gladstone Western Basin dredging and disposal project 2011–13[18,19]

Volume

- 5,113,475 in situ cubic metres marine disposal (11 million cubic metres permitted, with 25 million total volume dredging permitted including disposal in reclamation).

Parameters

- Per cent cover by category (hard coral, soft coral, sponges, algae)
- Hard coral community composition at family level

Methods

- 50 m line intercept transects, four per site; benthic cover recorded in field, supplemented by photography
- Comparison of treatments (control–impact), sites and years for sites surveyed in both 2011 and 2012 using multivariate analysis

Monitoring sites and design

- Baseline: three baseline sites E side of Facing Is., approximately 6–9 km north-west from nearest boundary of DMPA. Three control sites at Rundle Island, approximately 45 km from DMPA.

- 12 months after start of dredging: as above, plus two additional impact sites E side of Facing Is., approximately 10 and 12 km from nearest boundary of DMPA and two additional control sites E side of Curtis Is. approximately 30 km from DMPA.

Frequency and duration

- Baseline: one survey, May 2011 prior to commencement of capital dredging
- During dredging: one survey, early June 2012, slightly over one year after commencement of dredging

Summary of documented effects

- Authors concluded there was no evidence of dredging impacts.
- Hard and soft coral cover increased slightly at impact control sites relative to controls between pre-dredging and during-dredging surveys; difference not statistically significant.
- Statistically significant increase in algal cover at both control and impact sites, more so at impact sites.
- Slight increase in sponges at impact but not control sites.
- Significant differences among sites within both control and impact groups, and lack of baseline data for added control and impact sites, complicates interpretation.

Comments/limitations

- Monitoring focused principally on seagrass, with coral monitoring minor component.
- Original control sites had statistically significantly higher hard coral cover in the June 2012 survey, graphically presented data indicate this was also true in May 2011 baseline survey.
- Statistical methods not reported in detail.
- Statistical power to detect change not reported.
- No available information on potential influence of prior dredge material placement on impact or control sites.

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Appendix E: Compilation of evidence for effects of dredging on Great Barrier Reef seagrass meadows

Capital dredging—Hay Point departure path project, 09 May–17 October 2006

(further bed levelling through to 13 February 2007)[3,5]

Volume

- 8,611,889 in situ cubic metres

Placement

- Sea disposal in the marine park

Distance to closest seagrass meadow

- Seagrass adjacent to channels and within spoil ground

Duration of monitoring

- Three baseline surveys: July 2004; December 2005; March 2006
- Seven monthly surveys during dredging and bed levelling May 2006 to January 2007
- Post-dredging surveys from March 2007 to October 2012 (every 2–4 months)

Summary of documented effects

- Allowed for temporary loss of approximately 4,500 ha of low cover seagrass/marine plant habitat.
- In 2004 very low cover deepwater *Halophila* communities covered 6,851.9 ha but prior to dredging in December 2005 this had reduced to 338.6 ha demonstrating a high level of interannual variability.
- Seagrass occurred annually, generally present between July and December each year. Extensive and persistent turbid plumes from dredging over an eight-month period resulted in a failure of the seagrasses to establish in 2006, but recruitment occurred the following year and the regular annual cycle was re-established.
- Results show that despite considerable interannual variability, deepwater seagrasses had a regular annual pattern of occurrence that was likely interrupted by light reductions associated with capital dredging, but a high capacity for recolonisation on the cessation of impacts.

Comments/limitations

- Limited length of pre-dredge baseline information available on the natural range of temporal change for deepwater seagrasses at the site made it difficult to put post-dredge seagrass changes into perspective.
- Originally designed as a BACI (Before-After, Control-Impact) monitoring program based on initial modelling of plume extent. Underestimates of the plume spread meant that all sites received some plume influence so no true control.

- Results are only relevant for *Halophila* species in deep water. Other shallower growing seagrass species are likely to have a substantially different level of resilience and capacity for recovery.

Capital dredging—Gladstone Western Basin development, September 2011 to September 2013[1,2,4]

Volume

- 5,113,475 in situ cubic metres marine disposal (11 million cubic metres permitted, with 25 million total volume dredging permitted including disposal in reclamation).

Placement

- Reclamation of intertidal bank and sea disposal

Distance to closest seagrass meadow

- Reclamation occurred directly on top of seagrass. Seagrass within tens to hundreds of metres from dredged channels.

Duration of monitoring

- Annual monitoring since 2002 baseline and ongoing
- Quarterly monitoring at selected impact and reference sites since November 2009 and ongoing until November 2016; associated monitoring of water quality and light levels
- Biannual mapping of entire area from November 2009 until June 2014

Summary of documented effects

- Direct and permanent (but approved) loss of 101.06 ha of *Zostera* and *Halophila* through bunded reclamation area for dredge material disposal.
- A zone of high impact that allowed for up to 210 ha of seagrass to be directly disturbed and 312 ha of seagrass to be indirectly and temporarily disturbed through light attenuation and sedimentation from dredge plume and sea disposal.
- While post-dredge seagrass monitoring is ongoing, outside the permitted loss areas it appears seagrasses were maintained successfully during the dredge program. There is evidence of (unpredicted) seagrass recolonising the zone of high impact.
- In the management zones light levels were generally maintained at levels required to support seagrass growth.

Comments/limitations

- Highly detailed and intense seagrass monitoring program. While dredging clearly impacted seagrasses within the permitted impact zones including permanent loss to reclamation, it appears that no unpredicted seagrass losses occurred and seagrass was maintained in those areas as required by approval conditions.
- Results particularly in the inner harbour were somewhat confounded by two major flooding events that resulted in massive declines of seagrass, one prior to the

commencement of the major dredging activity in 2010/11 and the second more recently in January 2013. This has made it difficult to assess any additional impacts of dredging within areas of expected plume impacts due to the very low base condition of seagrasses.
- Seagrass recovery from flood events occurred and in some areas seagrass recovered to preflood levels during dredging.

Maintenance dredging—Cairns, Mourilyan, Townsville, Gladstone, Abbot Point, Hay Point

(annual for Cairns, Townsville and Gladstone; periodic bed levelling only for Mourilyan; infrequent maintenance dredging for Abbot and Hay Point)[6,7,8,9]

Volume

- Various volumes for the different ports, all less than 500,000 cubic metres, with many less than 250,000 cubic metres

Placement

- Sea disposal

Distance to closest seagrass meadow

- Close to dredged channels and spoil grounds—tens to hundreds of metres

Duration of monitoring

- Annual seagrass monitoring at peak time for seagrass distribution and abundance (August–December) conducted as part of the JCU (and previously Fisheries Queensland) Queensland ports seagrass monitoring program since:
    - Cairns – 2001
    - Mourilyan – 1994
    - Gladstone – 2002
    - Abbot Point – 2005
    - Hay Point – 2004
    - Townsville – 2007

Summary of documented effects

- With some programs now extending for 20 years and most running for at least 10 years there is little evidence to support any long-term impacts to seagrasses of historical and current levels of maintenance dredging in the ports.
- Where seagrasses are in a lower state of resilience the information is used to help inform the way maintenance dredging is conducted to ensure additional stresses are not placed on vulnerable seagrasses. This is achieved through the Dredging Technical Advisory and Consultative Committee process that is established for all ports where annual maintenance dredging is conducted in the World Heritage Area.

Comments/limitations

- Seagrass surveys for maintenance dredging effects are conducted annually, so short-term impacts that recover prior to the annual surveys can not be ruled out. However, maintenance dredging is generally undertaken within the expected period of resilience for most seagrass species.
- Correlative analysis from the program has revealed the majority of annual seagrass changes can be linked to major climate events and storms, as well as flooding, and tidal exposure.
- Where large (non-port or dredging related) losses have occurred this could make seagrasses more vulnerable to impacts from maintenance dredging to which they have been previously resilient.

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Appendix F: Compilation of evidence for effects of dredging on Great Barrier Reef seafloor infaunal habitats

Rosslyn Bay State Boat Harbour, 2006 maintenance dredging[3,4]

Parameters

- Infauna: abundance, species richness, Shannon–Weiner Diversity Index (H), species evenness, community structure
- Sediment: particle size distribution (PSD), total organic carbon (TOC) content

Methods

- Sediment grab sampling with BACI (Before-After, Control-Impact) design

Monitoring sites and design

- Boat Harbour and Marina (dredging locations); Wreck Point and Bluff Rock (adjacent impact locations, approximately 3.5 NW and 2.5 km SSE of DMPA, respectively) and Monkey Point (reference location, approximately 15 km SE at Great Keppel Is.)
- Three sites within each location, except four sites within Marina location
- Triplicate grabs for infauna, PSD and TOC

Frequency and duration

- Baseline: one survey, one week before dredging
- Post-dredging: two surveys, two weeks and one year post-dredging

Summary of documented effects

- Decreases in abundance, species richness, and H, and increase in species evenness, at adjacent impact locations two weeks post-dredging, not at reference location. Graphical analysis indicates community structure changed at Wreck Point but not Bluff Rock or Monkey Point.
- One year post-dredging (based on graphically presented data): Wreck Point abundance, species richness, H, evenness increased but not to pre-dredging levels; Bluff Rock abundance decreased further below level at two weeks post-dredging, species richness, H, species evenness increased but not to pre-dredging levels; Monkey Point abundance and species richness increased above pre-dredging levels, H and evenness decreased from two weeks post-dredging but above pre-dredging levels.
- Authors report statistically significant change in community structure at Wreck Point one year post-dredging, but none at Bluff Rock or Monkey Point.
- Overall, authors interpreted results as evidence of impact of maintenance dredging on infauna communities at Wreck Point and Bluff Rock, with some recovery one year post-dredging but not to pre-dredging levels.

Comments/limitations

- Dredging volume was 31,000 m^3.

- Authors report size of grab sampler as 0.005 m^2—smaller than standard samplers (0.25 m^2 or larger).
- Significant survey design issues. Reference location at Monkey Point is in a different sedimentary regime than impact locations, compromising data analysis.
- Statistical significance of changes not entirely clear—text, graphical and table reporting of results not always consistent.
- Details of statistical design not clear. Appears to use separate pre versus post versus one year tests for each location rather than true BACI (i.e. simultaneous testing of before–after and control–impact in one analysis).
- Statistical power not reported.

Hay Point Coal Terminal Expansion Project Phase 3 (HPX3; 2010–2011)[5]

Parameters

- Infauna: abundance, family richness, taxonomic composition
- Sediment: PSD, TOC

Methods

- Grab sampling
- Infauna identified to family level

Monitoring sites and design

- One impact area (HPX3 placement site), one previous disturbance area (previously used for dredge material placement), two undisturbed areas
- Sampling locations in previous disturbance and undisturbed areas at distances of 250 m and 2 km on axis radiating N, SW, and SE from impact area
- Four sites within each of the seven locations
- Eight grabs for infauna, two for PSD/TOC at each site

Frequency and duration

- One baseline survey (late March–early April 2010)
- Two post-dredging surveys: one month (October 2011) and one year (September–October 2012) post-dredging

Summary of documented effects

- Order-of-magnitude increase in infauna abundance and tripling of family richness, and statistically significant changes in community structure, from baseline to first post-dredging survey; much smaller increases between the post-dredging surveys.
- Spatial patterns of abundance, species richness and community structure do not indicate any clear relationship to material disposal.
- No impacts detected from disposal of dredge material.
- Results probably reflect recovery from effects of cyclone Ului.

Comments/limitations

- Baseline survey conducted immediately after cyclone Ului passed through area.
- Severely compromised baseline makes valid before–after comparisons impossible.
- Statistical power not reported.

Port of Gladstone, February 2011 maintenance dredging and Western Basin dredging and disposal project

Monitoring of impacts within and adjacent to disposal area[2]

Parameters

- Infauna: abundance/diversity/community structure
- Sediment: PSD

Methods

- Sediment grab sampling with BACI design

Monitoring sites and design

- Two 500 x 500 m direct impact sites within dredge disposal area, two near-field sites adjacent to the Dredge Material Placement Area (DMPA) at distances of approximately 50–100 m, one north-west and one north-east of the DMPA, two far-field reference sites one approximately 4.5 km from the dredge disposal area boundary to the north-west and one approximately 5 km from the boundary to the south-east
- 12 replicate grabs within each site

Frequency and duration

- Three 'baseline' surveys seven months, five months, and one week before maintenance dredging in February 2011
- One survey four weeks post-maintenance dredging and four weeks pre-capital dredging; one survey at the onset of capital dredging (survey dates 23–26 May 2011, dredging commenced 24 May); two surveys 4.5 and 6.5 months after commencement of capital dredging

Summary of documented effects

- Statistically significant differences between the dredge disposal area and near-field sites, which were interpreted as legacy effects from previous maintenance dredging.
- Concluded infauna communities within and adjacent to the dredge disposal area were resilient to further change from 2011 maintenance campaign, but were impacted by capital material placement.

Comments/limitations

- 'Baseline' surveys reflected effects in DMPA and near field of previous placement of capital and maintenance dredging material.

- Authors state that power analysis of previous data from the area was using during sampling design but do not report statistical power.

Port of Townsville, annual maintenance dredging, 1998–2000[6,7]

Parameters
- Infauna: numerical abundance, species composition and richness, community structure
- Sediment: PSD

Methods
- Grab samples

Monitoring sites and design
- 28 sampling sites: four within DMPA in use, 22 on four transects radiating WNW, WSW, ESE and SSE to a distance of 15 km from DMPA, two reference sites
- Five grabs at each site

Frequency and duration
- Six surveys, before and after three maintenance dredging campaigns

Summary of documented effects
- Short-term impacts within DMPA from 1999 campaign; rapid recovery.
- No detectable long-term impacts from maintenance dredging on infauna.

Comments/limitations
- Pre-dredging survey was six months after 1997 maintenance dredging.
- Not all sites sampled in August 1999, June and September 2000.
- Analysis was entirely multivariate techniques to visualise similarity/dissimilarity of community structure—no tests of statistical significance (e.g. BACI).

Port of Cairns, long-term annual maintenance dredging[8]

Parameters
- Infauna: numerical abundance, family composition and richness, community structure
- Sediment: PSD

Methods
- Grab sampling

Monitoring sites and design
- Three locations: within current DMPA, NW (downstream) axis, SE (upstream) axis
- Five sites evenly distributed in DMPA, five sites on each axis at distances from 50 m–2 km from DMPA boundary
- Three infauna grabs, one PSD grab at each site

Frequency and duration

- One survey, May 2009

Summary of documented effects

- Small but statistically significant differences in infauna community structure within and possibly at 50 m from DMPA boundary.
- Concluded results are consistent with a long-term impact of material placement on infauna communities.
- Characterised difference in infauna communities at possible impacted sites from other sites as minor.

Comments/limitations

- Impact inferred from spatial pattern (change with distance from DMPA); no before–after or other temporal comparisons.
- Impacts on larger spatial scales possible.
- Statistical power not reported.

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Appendix G: Overview of potential effects of dredging pressures on fish and fish populations

Greyed cells indicate minimal information available.

	Sedimentation	Turbidity	Contaminants
Direct effects			
clogging of gills		at high levels	
health impacts			depends on species and contaminants[1,2]
habitat change	loss of stage-specific habitats	degradation of pelagic habitat excludes: clear water species, planktivores[3,4,5]	can render some habitats uninhabitable
	changes in habitat complexity alters habitat value[6]		
change to visual environment		prey advantaged (cephalopods[7]) or disadvantaged (fish) depending on their visual system	
		prey catching abilities of predators altered by turbidity (fish[8,9,10])	
		planktivore feeding inhibited by turbidity[9,11,12,13,14]	
other changes		changes in fish biomass, larval fish survival, development and recruitment cues[14,15,16]	
Indirect effects			
food web change	alteration in benthic prey[8]	inhibition of visual predators[9,17]	depletion of prey due to toxins
		inhibition phytoplankton → food limitation	
disruption to connectivity	loss of connecting habitats	barrier for clear water species to migrate	
disruption to		herbivorous fish richness and	

ecosystem processes		abundance reduced on turbid reefs → reduced reef resilience[18]	
bioaccumulation			potential: found in other vertebrates[19]

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