Australian Government

Great Barrier Reef
Marine Park Authority

Site Assessment Report

Douglas Shoal Remediation Project

Great Barrier Reef Marine Park Authority

8 November 2019

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Worley Group

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1 Executive summary

The bulk carrier *Shen Neng 1* ran aground on Douglas Shoal in April 2010 and remained on the shoal for ten days before being re-floated. The vessel suffered significant damage and loss of antifouling paint (AFP) through contact with the shoal over an area of approximately 42 hectares.

The Great Barrier Reef Marine Park Authority (the Authority) established the Douglas Shoal Remediation Project (the Project) in late 2016 with funds from a court settlement associated with the grounding. The primary desired outcome of the Project is that remediation supports natural recovery of the shoal. Key concerns for natural recovery were identified as AFP-related contamination and physical damage associated with grounding-related rubble and flattening of the shoal's topography. A preliminary site assessment commissioned by the Authority identified potential priority areas for remediation (Areas A, C, E and F) which covered approximately 42 hectares.

Advisian is providing planning and project management services to the Authority including remediation planning, stages of which include targeted fieldwork, site assessment and options analysis (Figure 1-1). Remediation planning is focused on the previously identified priority areas and key concerns for natural recovery of the shoal. An expectation for remediation planning is that it promotes best 'value for money' solutions that address the most significant impediments to natural recovery of the shoal.

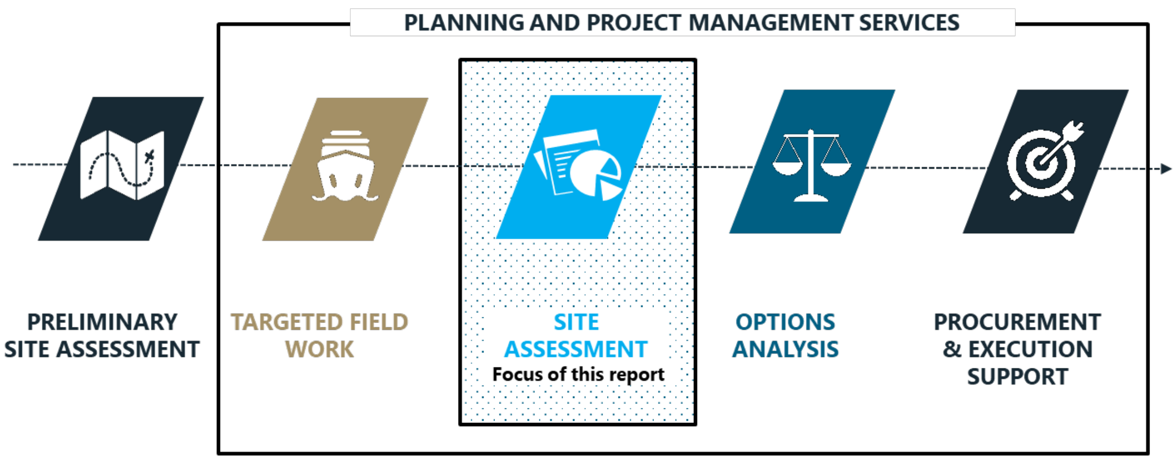


Figure 1-1 Planning and project management services

Targeted fieldwork was executed to provide information on physical damage and contamination:

- Diver-assisted sediment sampling at 237 georeferenced sampling locations conducted over a 17-day period in March 2019
- Visual survey including multibeam sonar and acoustic sub-bottom profiling, drop camera and towed underwater video survey conducted within a 15-day period in May and June 2019.

Fieldwork data was considered in the context of sediment and water quality guidelines, along with information relating to the background environment and previous investigations (Figure 1-2), albeit that significant gaps with respect this information are evident:

- There are no data relating to the pre-grounding incident condition of the shoal to provide information on habitat and how this may change seasonally and in response to natural events
- There is not a consistent or comparable set of information regarding contamination or physical damage to enable detailed quantitative analysis of change over time including natural recovery.

Given these information gaps the site assessment focuses on the current state of the shoal. Evidence regarding physical damage and contamination is used to delineate areas of 'high' and 'moderate' priority for consideration as part of the options analysis.

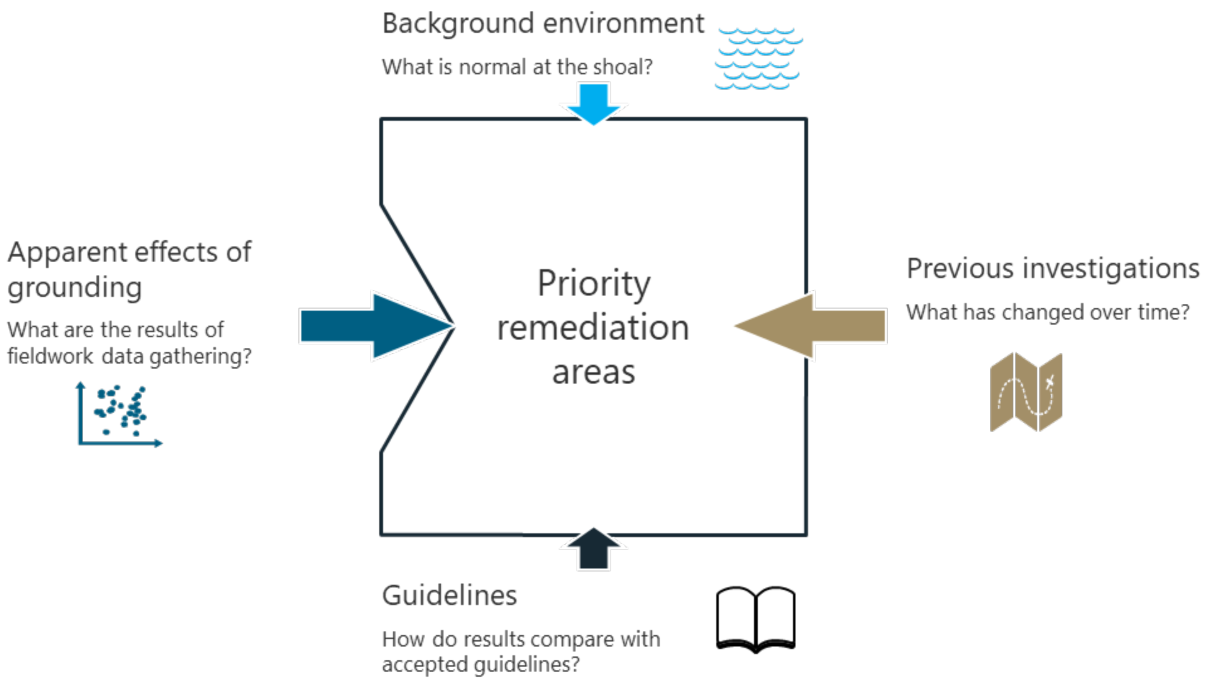


Figure 1-2 Priority remediation area delineation

While Douglas Shoal does not have a complex range of features, some habitat diversity is evident. Habitat areas of the Low Relief Terrace of the shoal include (Figure 1-3):

- Undulating expanses of densely covered (predominately macroalgae) hard reef substrate with occasional sandy patches
- Channels or gutters containing large pieces of dead coral or coarse sand with gently sloping sides
- Flat expanses of low relief corals with minimal sediment
- Holes containing sand or dead coral fragments with densely inhabited steep walls.

The High Relief Terrace to the north and north-west of the shoal contains more complex features:

- Spur and groove outcrops with moderate coral cover rising several metres from the sea floor
- Deep channels with large fragments of broken coral and coarse sand with sparse tufts of macroalgae growing within the sediment.

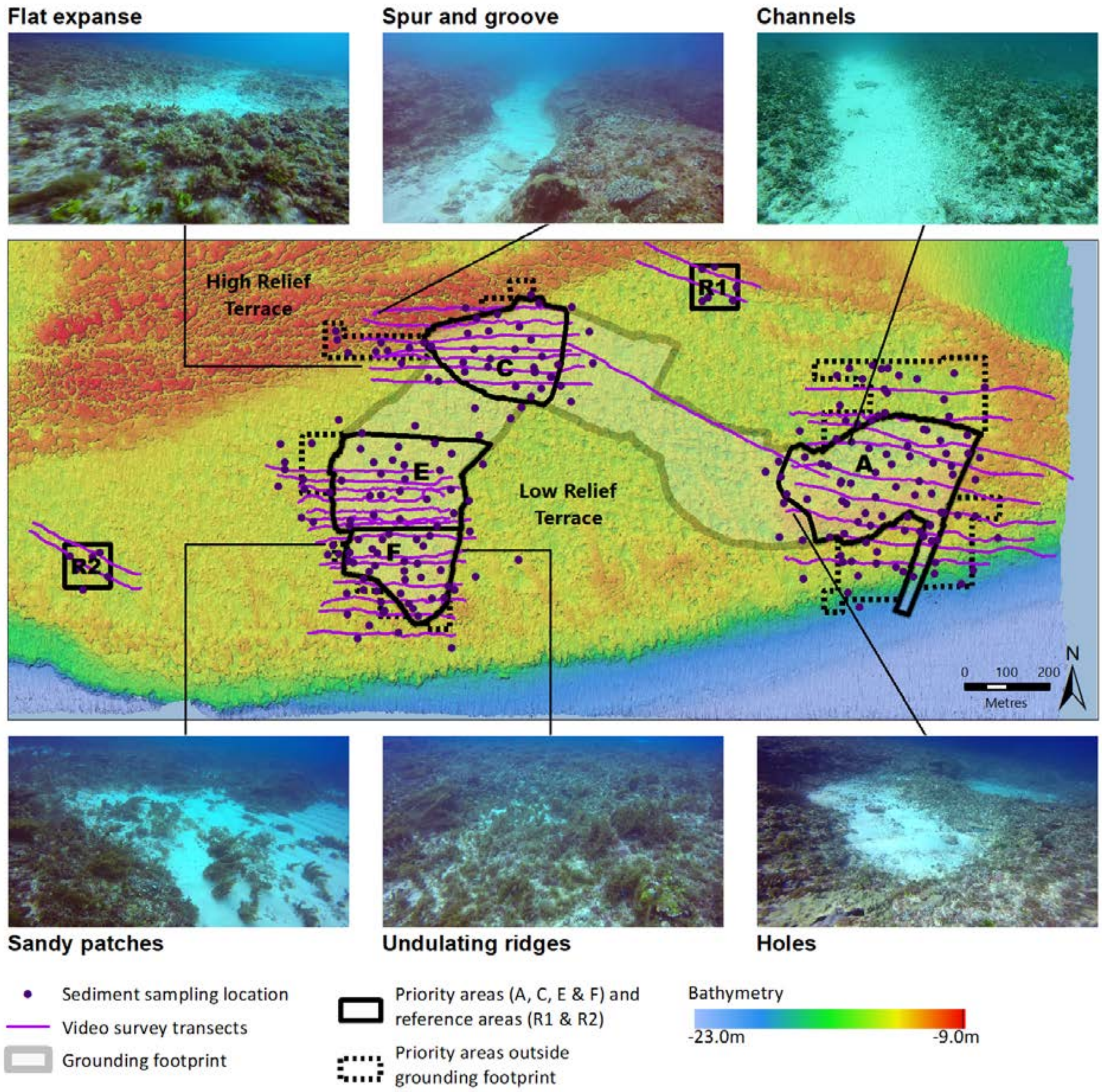


Figure 1-3 Field survey and habitat types at Douglas Shoal

The surveyed area of the Low Relief Terrace consists of large expanses of turf algae on rock (32.6%), macroalgae growing predominately on rock (38.5%) and hard (3.8%) and soft coral (2.0%) growing on rock, areas of grounding related rubble (10.2%), dead coral fragments (~1%) and sand (9.3%).

Sediment is not a dominant component of the substrate, nor is it uniformly distributed across the surveyed area of Douglas Shoal. It is typically located in depressions as patches in undulating areas and in channels, gutters and holes. The depth of sediment is limited across the surveyed area of the shoal, ranging from 5mm to 400mm, and averaging 73mm.

1.1 Contamination

Analysis of sediment samples taken during the site assessment focused on the constituents of AFP and particularly copper and tributyltin (TBT). A staged assessment process was applied like that set out in the National Assessment Guidelines for Dredging (NAGD, Commonwealth of Australia (2009)) with laboratory analysis results compared to both NAGD screening levels and the 95th and 99th % species protection default guideline values outlined in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018).

Analysis supported delineation of high and moderate priority areas for remediation with respect to contamination. Contamination of sediments exists primarily within part of the previously identified Priority Area A and is principally associated with TBT (Figure 1-4).

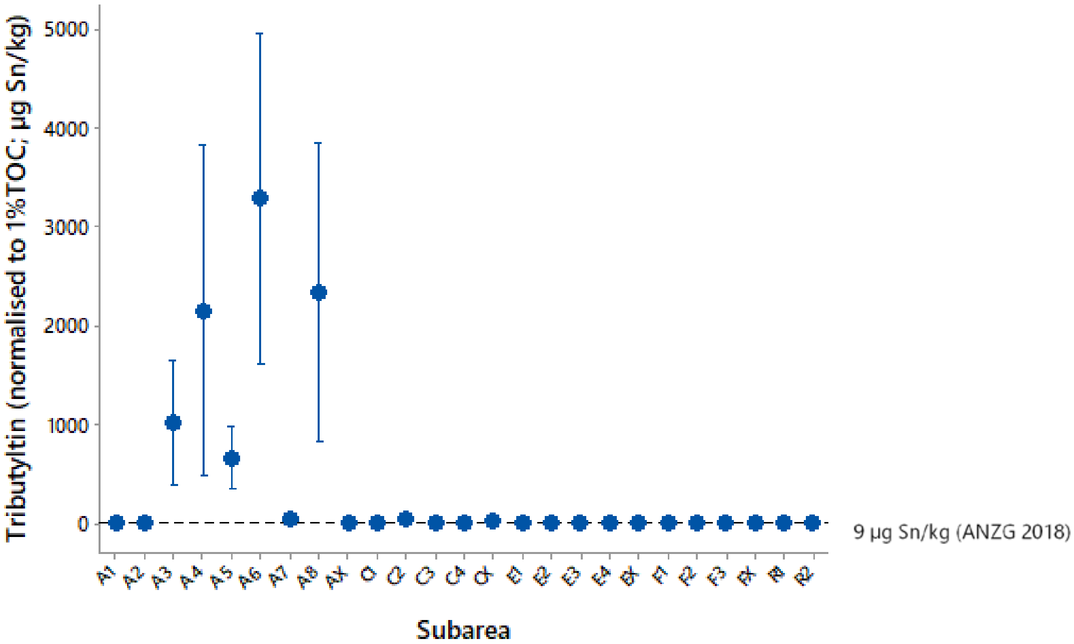


Figure 1-4 Mean concentrations of tributyltin (±standard error) by sub-area (ANZG (2018) default guideline value of 9µg Sn/kg is displayed as a dashed line)

No visible evidence of AFP smears, flakes or chips was identified during the survey. It is likely that the extent and level of contamination has reduced at the grounding site over time, with contributing factors to reduction including exposure to erosive forces (e.g. ocean currents and waves) through normal conditions and extreme events. Notwithstanding this, investigation of TBT persistence show it may be another decade before TBT ceases to be a contaminant of concern in Priority Area A. As such, it is considered that addressing AFP-related contamination should remain a priority for remediation.

Remediation planning and monitoring should recognise that sediments are not well mixed, with contamination typically associated with remnants of AFP flakes in fine sediment. Contamination of sediments may occur outside of the priority remediation areas; however, such areas are likely to be small, isolated and with lower levels of contamination.

1.2 Physical damage

Physical contact between the vessel and the shoal created rubble. The rubble is different from naturally occurring sediments (including dead coral fragments) as it is coarser, more angular, and typically without encrusting organisms (coralline algae or turf algae, encrusting sponges or coral). The rubble is commonly unconsolidated and its movement over time appears to impede natural recovery.

Fieldwork and analysis focussed on identification and delineation of areas of rubble. Data derived from sonar survey (including Angle-Range Analysis (ARA)) was correlated with sediment particle size distribution data and habitat characterisation data from underwater video survey to delineate areas of rubble (Figure 1-5). This analysis also shows that unconsolidated rubble has moved over time, generally in a westerly direction, and affected habitat on the shoal beyond the grounding footprint. Further analysis indicates in some locations the rubble has filled (partially or completely) natural depressions and therefore altered habitat complexity on the shoal.

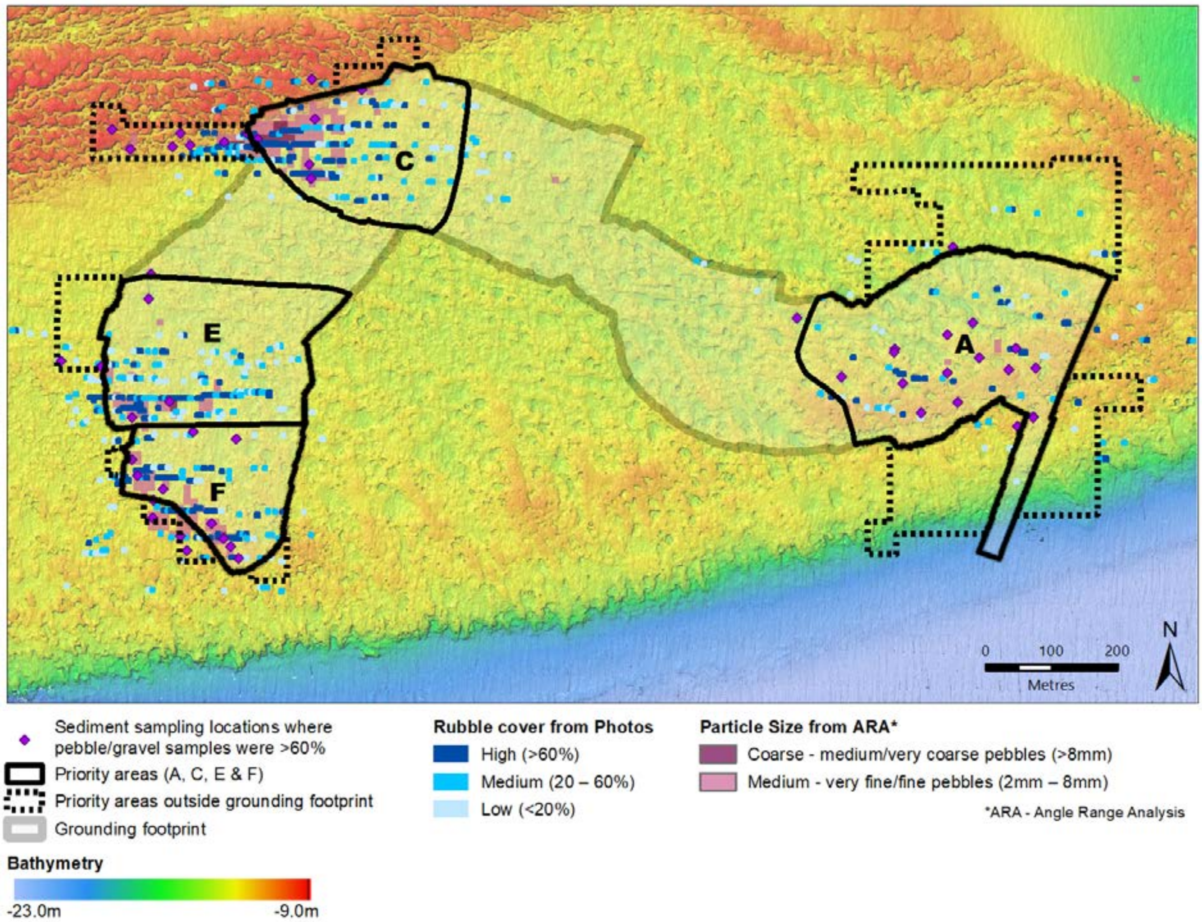


Figure 1-5 Rubble distribution across the priority areas

Physical damage associated with rubble is more obvious than areas affected by abrasive flattening and compaction as these areas are commonly obscured by the rubble. Analysis of changes over time (between 2010 and 2019 survey) in flattened extent suggests that grounding-related flattened areas are at least in part associated with rubble filling in depressions and 'flattening' the profile of the shoal.

1.3 Habitat changes

Data collected from underwater video survey was qualitatively compared with data from surveys immediately after the grounding in 2010. Both surveys found low cover of hard coral (<8%) and high abundance of macroalgae and 'bare' reef pavement outside the grounding footprint on the Low Relief Terrace of the shoal.

Comparison of 2019 survey benthic habitat and benthos data from inside and outside the area assumed to be impacted by the grounding is shown in Figure 1-6. Outside the impacted areas, hard and soft coral, macroalgae, turf algae on rock, sand and other benthos were more abundant. The impacted areas were characterised by having very high cover of rubble. Closer examination of the benthic groups shows the cover of rubble is highest inside the impacted area in Priority Area F (47.9%), followed by Priority Area C (23.5%), Area E (31.4%) then Area A (10.4%). It is considered likely that the grounding caused habitat changes on the shoal including the replacement of areas of 'turf algae on rock' and areas of 'sand' with 'rubble'.

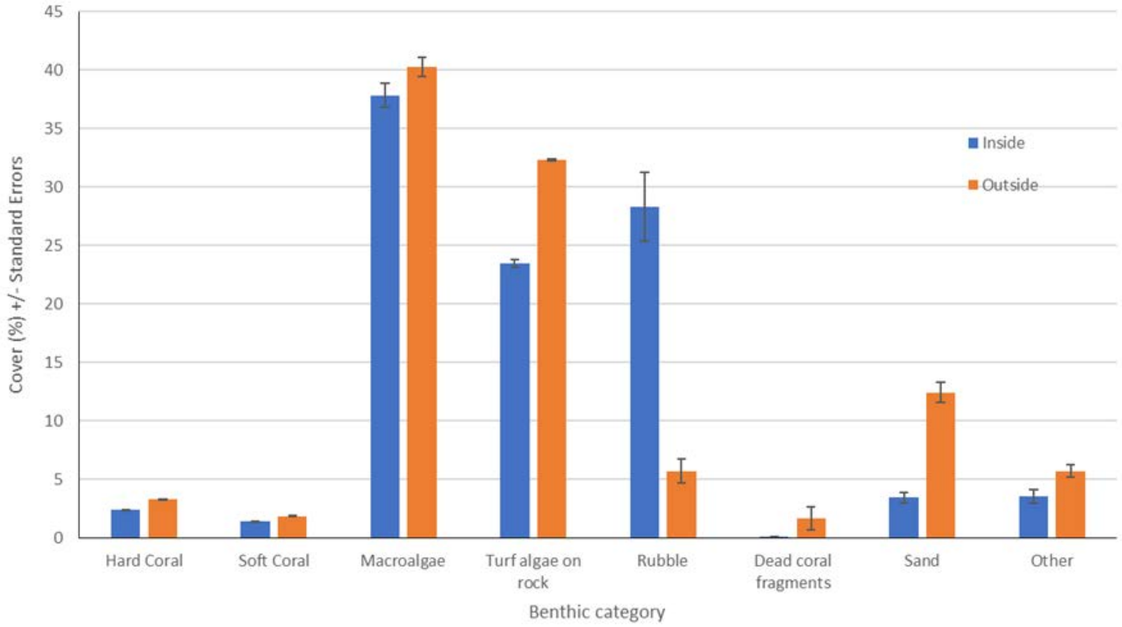


Figure 1-6 Percentage covers (+/- standard error) of benthic groups inside and outside the assumed impacted areas

The appearance of the rubble does not appear to have changed significantly since the grounding and remains obviously different to the natural sediments found in the reference or unaffected areas; however, some areas of rubble do support benthic organisms and have consolidated over time. It appears that some areas of substrate smothered by rubble following the grounding have been exposed with westward movement of rubble over time. Undulating substrate was found in these areas to be devoid of algal growth; however, now exposed these areas may support the settlement and growth of coral recruits and other benthos.

1.4 Priority remediation areas

The site assessment investigations show that almost ten years after the grounding incident contamination and physical damage remain as potential impediments to natural recovery, albeit their significance within the survey area may have diminished over time. The investigations support delineation of priority areas for remediation as follows (Figure 1-7):

- Remediation priority for contamination in part of Priority Area A:
  - Moderate priority assigned where analysis shows concentrations of TBT, copper or zinc in sediment are predominantly above default guideline values for ecosystem protection, with contaminant levels in sediment likely to remain above the guideline values for about ten years
  - High priority assigned where, in addition to the above, analysis shows that disturbance of the sediment is likely to release water with concentrations of TBT, copper or zinc above default guideline values for the protection of a high ecological or conservation value system.
- Remediation priority for persistence of rubble in part of priority areas C, E and F:
  - High priority assigned where analysis shows most substrate is rubble
  - Moderate priority assigned where analysis shows rubble is a significant part of the substrate.

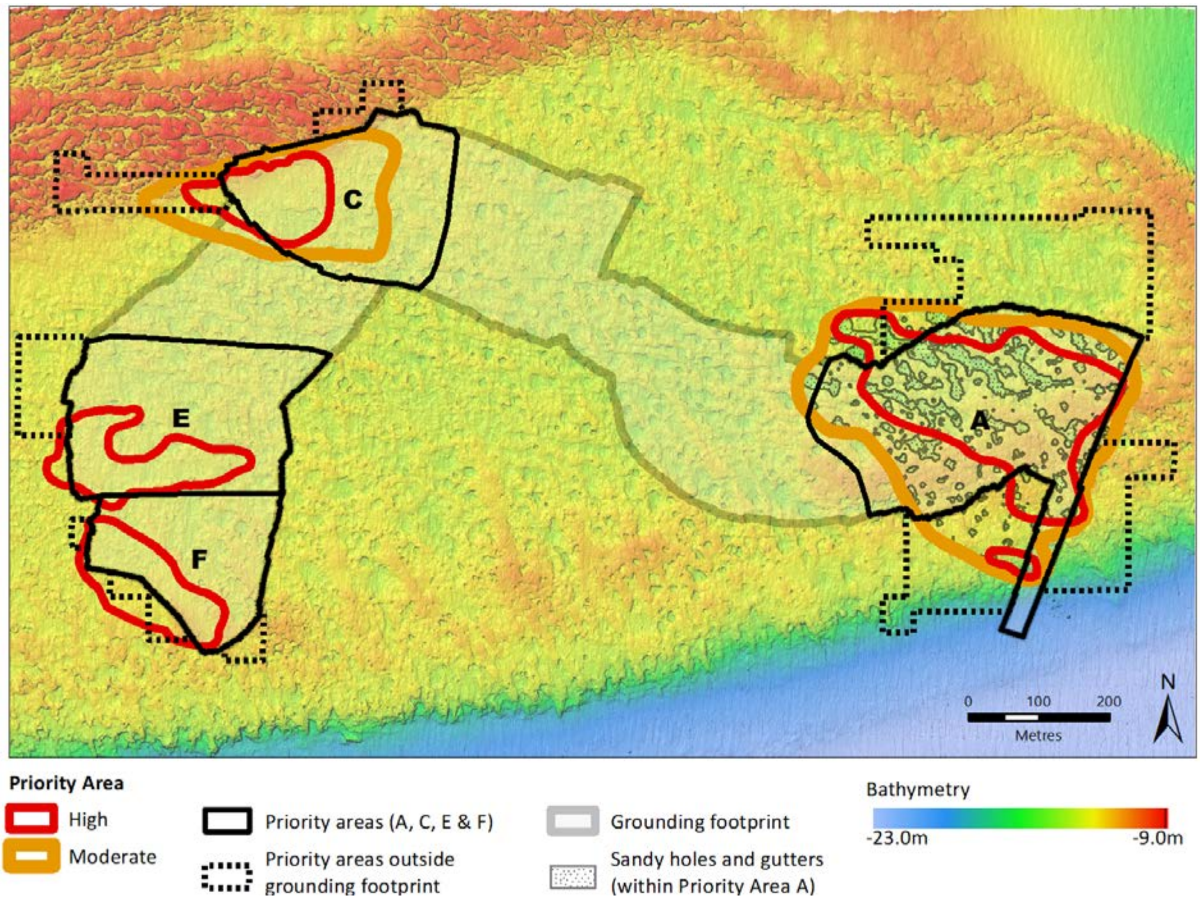


Figure 1-7 Delineation of high and moderate priority areas

The persistence of rubble obscures the extent of abrasive flattening and compaction damage on the shoal; however, these areas of abrasive flattening and compaction are considered to be of lower importance with respect to remediation, given that the areas are small, within identified areas of rubble and that 'natural' areas adjacent to the grounding footprint are likely to offer habitat of similar value to these abraded flattened areas. Areas of abrasive flattening and compaction damage are not mapped and are not considered to be a priority for remediation. It is considered that other areas within the grounding footprint, including the remainder of areas A, C, E and F (Figure 1-7) do not represent a priority for remediation as there is insufficient evidence to show that natural recovery of the shoal is impeded by any ongoing influence of the grounding in these areas.

The total area of high and moderate remediation priority (contamination and physical damage) is 9.8 hectares (Table 1-1). This includes 2.3 hectares considered to be of high and moderate remediation priority for contamination and 7.5 hectares considered to be of high and moderate remediation priority for physical damage. Using the average measured sediment depth for each area the volume of sediment within the high and moderate remediation priority areas (contamination and physical damage) is estimated to be 7,065m^3 (Table 1-1). This includes 1,386m^3 of sediment considered to be of high and moderate remediation priority for contamination within part of Priority Area A, and 5,679m^3 of rubble considered to be of high and moderate remediation priority for physical damage across part of priority areas C, E and F.

Table 1-1 Area and sediment volume estimates

Priority area	Impediment to natural recovery	Estimated area (ha)			Estimated volume of sediment (m^3)		
		High	Moderate	Total	High	Moderate	Total
A	Contamination	1.5	0.8	2.3	880	506	1,386
C	Physical damage	1.5	2.3	3.8	1,158	1,761	2,919
E	Physical damage	1.8	-	1.8	1,196	-	1,196
F	Physical damage	1.8	-	1.8	1,564	-	1,564
Totals	**Contamination and physical damage**	**6.6**	**3.2**	**9.8**	**4,798**	**2,267**	**7,065**

The site assessment has delineated the remediation priority areas based on detailed studies designed to reduce uncertainty with respect to the spatial distribution of physical damage and contamination. The total area identified through the site assessment as being of high and moderate remediation priority for physical damage and contamination (9.8 hectares) is significantly less than the area identified as a being of potential remediation priority for both contamination and physical damage in the preliminary site assessment (42 hectares).

2 Introduction

2.1 Background

2.1.1 Incident

The bulk carrier *Shen Neng 1* ran aground on Douglas Shoal in April 2010 and remained on the reef for 10-days before being re-floated. Following the initial grounding, and due to the vessel being inadequately secured, the vessel moved across and made contact with the shoal at various locations (Figure 2-1). The underside of the vessel suffered significant plate damage and paint loss (including antifouling paint (AFP)) during the grounding.

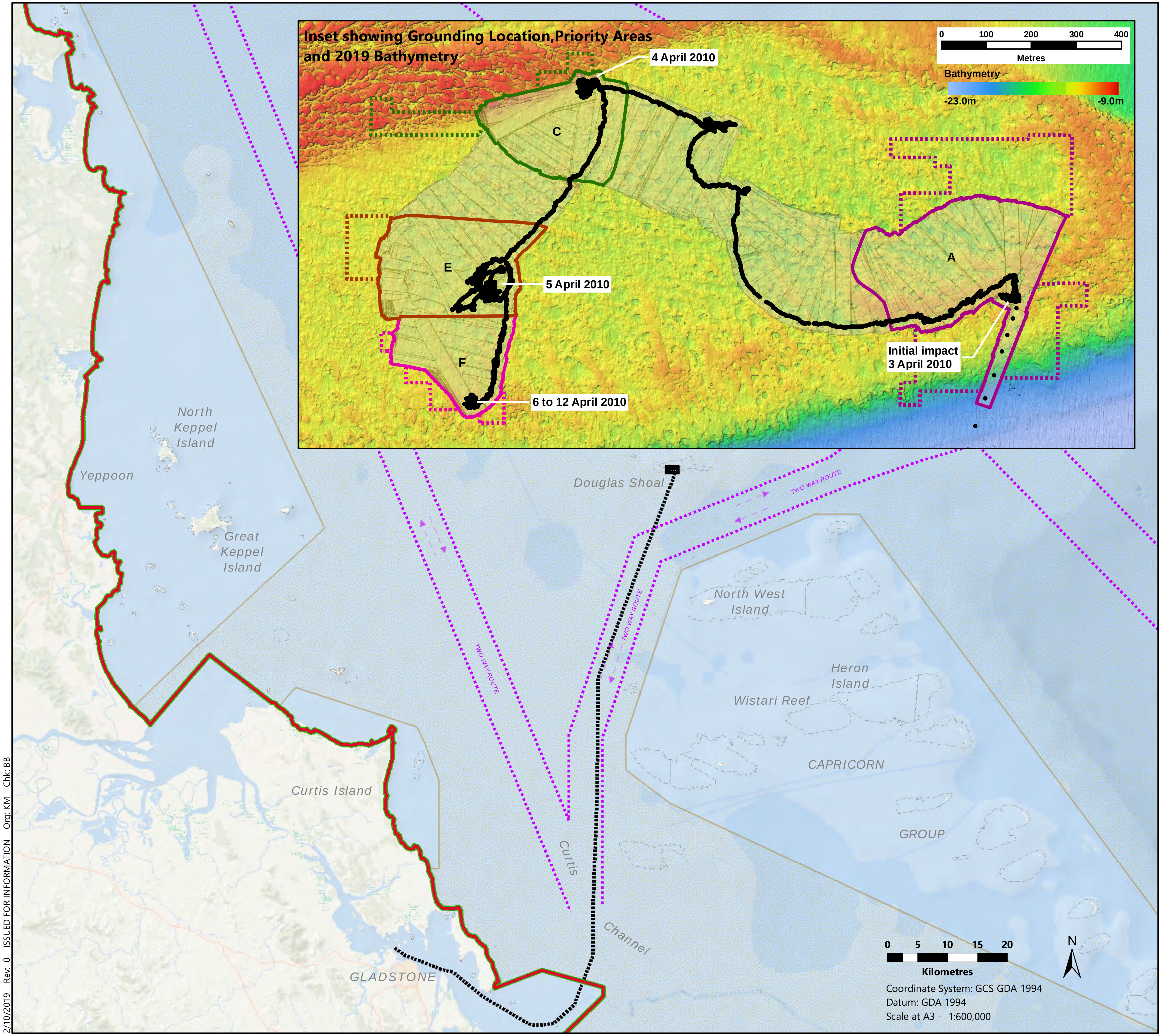
The total area directly impacted by the grounding was approximately 42ha which makes this incident the largest vessel grounding known in the Great Barrier Reef Marine Park, and possibly the largest reef-related direct shipping impact in the world.

2.1.2 Previous investigations

The Authority commissioned several site investigations following the incident which, amongst other things, sought to establish the extent of damage caused by the incident and the potential remediation liability. As part of remediation planning the Authority identified the need to synthesise findings from these previous studies and compile a preliminary site assessment.

Following engagement by the Authority, Costen et al (2017) drew from the site investigation reports to summarise the state of knowledge regarding the grounding site in the Douglas Shoal Preliminary Site Assessment Report. The preliminary site assessment report noted that while no data are available for 77% of the grounding footprint, the distribution of physical damage and contamination is focused at four distinct areas. This report identified four possible priority areas for remediation based on these earlier investigations; areas A, C, E and F (Figure 2-1).

A summary of the scope and findings of the grounding site investigations as relevant to this site assessment is provided in Table 2-1. Further detailed information regarding these investigations is provided in Costen et al (2017).



Douglas Shoal Remediation Planning

Figure 2-1
Vessel Grounding Incident Location

- Stern of the Shen Neng I
- Vessel track from Gladstone (indicative)
- Vessel heading and bearing
- Project area
- Reef
- Shipping lanes (indicative)
- Designated shipping areas of the Great Barrier Reef Marine Park
- Great Barrier Reef Marine Park boundary
- Management Areas of the Great Barrier Reef Marine Park

Priority Areas

- A
- A - outside grounding footprint
- C
- C - outside grounding footprint
- E
- E - outside grounding footprint
- F
- F - outside grounding footprint

Source Information:
Vessel Heading, Stern Location, Priority areas
Cardno 2017
Vessel track from Gladstone (indicative)
Digitised by Advisian from Stern Location (AllAMSA_AISwithHeading)
Bathymetry (50cm LAT)
Acoustic Imaging 2019
Shipping Lanes
Digitised from Australian Nautical Charts AUS00819P0 & AUS00820P0 (AusGeoTIFF)
Australian Hydrographic Office, Dept of Defence
Great Barrier Reef Marine Park Boundaries
Australian Government - Great Barrier Reef Marine Park Authority (GBRMPA) / Cardno 2017

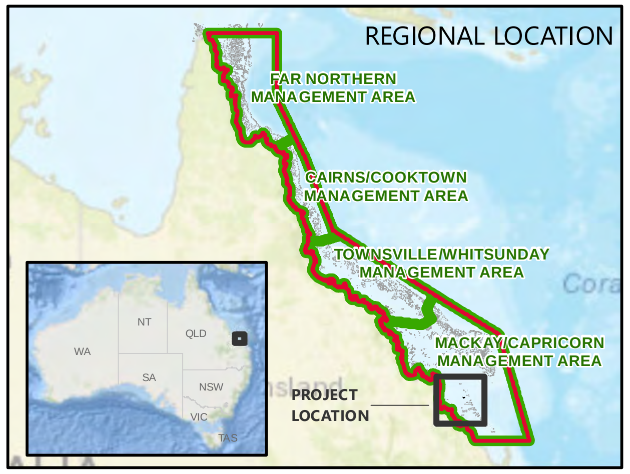


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Table 2-1 Grounding site field investigation reports

Report	Scope and relevant findings
Structural Damage to Douglas Shoal Caused by Grounding of *Shen Neng 1* - Derived from High-resolution Multibeam Sonar Bathymetry and Backscatter Strength (Stieglitz 2010). Supporting report to Negri et al. 2010.	Reported structural damage to Douglas Shoal caused by the grounding and derived from analysis of high-resolution multibeam sonar bathymetry and backscatter data captured by the Australian Institute of Marine Science (AIMS) in April 2010. Found evidence of damage (expressed as loss of small-scale bathymetric variability and flattening of the sea floor) in parts of the (later identified) priority areas A, C, E and F.
Grounding of the *Shen Neng 1* on Douglas Shoal: Multibeam Sonar Bathymetry and Towed Video Assessments (Negri et al. 2010). Appendix to GBRMPA 2011.	Reported results of habitat damage monitoring undertaken using multi-beam sonar (Stieglitz 2010) and towed video survey captured by the AIMS in April 2010. Described results of towed video surveys which indicated that native reef consisted of limestone (85%), rubble (10%) and sand (5%) and the biota was dominated by macroalgae, primarily Sargassum sp., (53%) and hard corals (8%). Noted areas impacted by the hull of the vessel were either sheared flat or pulverised into rubble (5 – 50mm diameter). Identified that rubble-beds were virtually lifeless, with less than 1% macroalgal cover identified. Described physical damage to the shoal as including almost complete elimination of sessile invertebrates and algae where the vessel contacted the reef. Estimated (using multi-beam sonar survey) a damaged area of approximately 80,000m^2 across parts of the (later identified) priority areas A, C, E and F. Opined that if AFP contamination is low, hard compacted areas should recover relatively quickly; however, noted that areas of rubble are unconsolidated making recruitment of macroalgae and invertebrates difficult over the short and medium term.

Report	Scope and relevant findings
Preliminary Impact Assessment: Grounding of the *Shen Neng 1* on Douglas Shoal (Marshall 2010). Appendix to GBRMPA 2011.	Preliminary assessment of ecological damage at the shoal using snorkel and diver-based survey techniques (image capture and sample collection) in April 2010. Identified that the shoal has characteristics of a highly dynamic environment, with moderate diversity, heterogeneous distribution of species and few large sessile organisms. Identified 19,087m^2 of the sea floor as recently damaged, with severe and minor damage in parts of the (later identified) priority areas A, C and F and moderate damage in other parts of the grounding footprint, noting that rubble occurred outside these areas in some locations. Observed AFP as flakes among rubble generally and as smears on exposed reef substrate at Priority Areas A. Indicated severely damaged areas were characterised by near-complete destruction of the ecological community, with the underlying reef substrate either scraped clear or covered in expanses of freshly created coral rubble. Opined that the presence of unconsolidated rubble and AFP in damaged areas suggests that recovery of the damaged areas is likely to take substantially longer than for natural disturbances.
Grounding of the *Shen Neng 1* on Douglas Shoal, April 2010: Impact Assessment Report (GBRMPA 2011).	Summary assessment of grounding impacts based on Stieglitz (2010), Negri et al. (2010) and Marshall (2010) along with additional survey (snorkel and diver-based survey with image capture and sample collection) undertaken in May 2010. Noted the grounding caused significant impacts to habitats including direct physical damage and AFP contamination. Estimated severe physical damage to an area of 115,000m^2 (parts of the later identified priority areas A, C, E and F). Estimated patchy or moderate damage to the sea floor within the remainder of the 400,000m^2 grounding footprint. TBT contamination of sediments was noted as severe (many samples above guideline values, some significantly) although highly patchy, with similar patterns of zinc and copper contamination. Patterns of damage and chemical contamination were described as being strongly related to the path of the grounding. Stated that shoal habitats and organisms, are likely to be significantly affected within the damaged areas for many years due to mortality of corals and other organisms directly due to the physical damage, toxic effects of AFP on remaining corals and other organisms, effects of AFP in inhibiting settlement and growth of new corals, and inhibition of settlement and growth of new corals on unconsolidated rubble on the shoal sea floor created by the grounding.

Report	Scope and relevant findings
Independent Review of Impact Assessment Report ''Grounding of the *Shen Neng 1* on Douglas Shoal, April 2010" (Kettle 2011).	Independent technical review of GBRMPA (2011) including supporting documents. Assessed report with respect to technical analysis relevant to extent, severity, consequence and remediation of grounding impacts. Review process included inspection of grounding site and desktop analysis. Concluded that GBRMPA (2011) addressed significant environmental injury associated with the grounding well. Stated that there is extensive grounding injury caused by the vessel comprised of physical and pollutant injury, with the latter including fixed phase (smears) and mobile phase (AFP flakes or finer material). States the degree of injury varies across site, with four focal areas (the later identified priority areas A, C, E and F) and a much broader footprint where physical and chemical injury is patchy but significant. Indicated a most plausible estimate of injury areas as 373,000m^2, and a maximum injury area of 583,000m^2.
October 2013 Reef Damage Reassessment of the *Shen Neng 1* Grounding Site, Douglas Shoal, Great Barrier Reef, Australia (Kettle 2014).	Reassessment of damage including diver-based survey (imagery capture and sample collection) three and a half years after the grounding and outlined a remediation method. Identified the grounding footprint as clearly visible (scraped areas, embedded AFP, rubble and AFP flakes), albeit AFP flakes and smears were beginning to erode. Noted maximum TBT concentrations observed were below those of 2010 survey; however, the proportion of 'extreme' levels had increased. Copper and zinc values noted as variable but typically less elevated. Stated no sign of rubble consolidation was evident. Indicated benthic communities in the grounding footprint are markedly different to areas outside of the footprint and that reef stabilisation and natural recovery processes are proceeding only slowly. Predicted the rubble fields will remain highly disturbed over decadal timescales, unless the material is removed or stabilised through remediation. Opined that portions of the site where the most extreme contaminant loadings exist were continually exposed to 'fresh' contaminants through sediment movement and abrasion. Suggested unless contaminants are removed or dispersed by a storm, areas of high TBT concentration are likely to persist for many decades. Found no plausible or compelling evidence that the estimates of GBRMPA (2011) or Kettle (2011) were incorrect.

Report	Scope and relevant findings
Remediation Trial for the *Shen Neng 1* Grounding Site, Douglas Shoal, Great Barrier Reef, Australia (Kettle 2015a, 2015b (supplementary report)).	Described results of a remediation trial undertaken to support AFP contamination remediation method development. Noted evidence of AFP particles found during the trial included smeared rubble, aggregates and flakes from 10cm to microscopic size. Identified a broad range of TBT levels in sediments up to high levels. Noted that AFP flakes are continuing to erode and liberate fine contaminants. Noted Tropical Cyclone Marcia produced waves to approximately 8m near the shoal, caused significant localised disturbance to the seabed and remobilised sediment without 'clearing' contaminants or rubble. Suggested east-west sediment dispersal driven by 'normal' tide, wind and wave processes. Opined that the remediation footprint was 90.7ha in August 2015, including 42.0ha of depression patches requiring remediation.

2.1.3 Douglas Shoal Remediation Project

The Authority established the Douglas Shoal Remediation Project (the Project) in late 2016 with funds from a court settlement for the grounding incident. The Project has as its primary desired outcome that remediation activities support natural recovery at Douglas Shoal.

The Project has three subsidiary desired outcomes:

- An effective Monitoring, Evaluation, Reporting and Improvement (MERI) framework delivers accountability and supports flexible, responsive decision-making
- Knowledge gained is recorded and shared to inform other (and future) remediation efforts worldwide, and
- Traditional Owner values and opportunities are enhanced through the Project.

An expectation for remediation planning is that it promotes best 'value for money' solutions that address the most significant impediments to natural recovery of the shoal.

Based on the investigations undertaken to 2016, the Authority identified key concerns for natural recovery of the shoal as:

- Contamination of the shoal associated with the vessel's loss of AFP during the grounding
- Physical damage caused by the vessel's grounding including:
  - Generation and persistence of rubble
  - Flattening of the shoal's topography.

The identification of potential priority areas for remediation by Costen et al (2017) focused on these key concerns for natural recovery.

2.1.4 Planning and Project Management services

In October 2018, Advisian were awarded a contract to provide Planning and Project Management services to the Authority for the Douglas Shoal Remediation Project.

The purpose of the remediation planning services is to fill critical knowledge gaps, finalise priority areas for remediation, identify remediation objectives for each priority area and identify the most feasible options for remediating each priority area.

The remediation planning services are designed to address the desired outcomes of the Project, and in doing so are focused on the key concerns for natural recovery of the shoal within and adjacent to the previously identified priority areas for remediation (A, C, E and F) as set out in the Douglas Shoal Preliminary Site Assessment Report. The remediation planning services build on the outcomes of the preliminary site assessment report and are staged as set out in Figure 2-2.

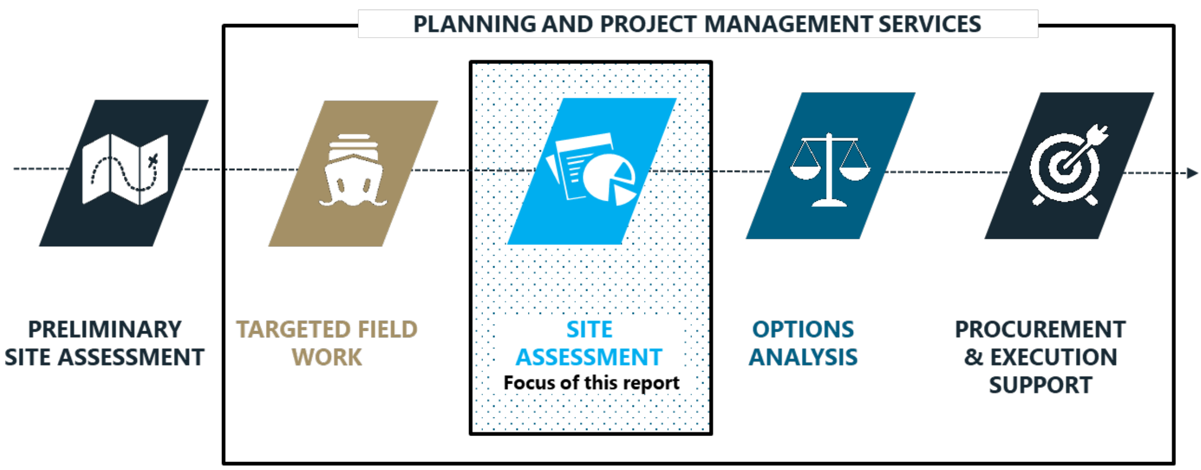


Figure 2-2 Planning and Project Management services

The planning services include the conduct of targeted fieldwork at Douglas Shoal within the grounding footprint and surrounds, followed by desktop investigations which include remediation area delineation as part of the site assessment, and options analysis. Table 2-2 sets out the stages and associated reporting for the remediation planning services.

Table 2-2 Remediation planning services staging

Stage	Reporting
Fieldwork planning	Sampling and Analysis Plan Health Safety and Environmental Management Plan
Fieldwork execution	Fieldwork reports
Laboratory analysis	Laboratory Analysis Report
Delineation of remediation areas	**Site Assessment Report (this report)**
Remediation options analysis	Options Analysis Report

2.2 Scope

Site assessment is part of the staged process of remediation planning as described above, and the assessment process is designed to address the desired project outcomes. The site assessment addresses the key concerns for natural recovery of the shoal, within and adjacent to the previously identified priority remediation areas A, C, E and F.

Information to support the site assessment is derived from the targeted fieldwork along with the previous investigations. The scope of the site assessment is to:

- Summarise the results of investigations regarding key concerns for natural recovery of the shoal
- Present detailed information including mapping of substrate type, contamination and physical damage
- Describe the nature and scale of physical damage and contamination and present areas that are considered to be of priority for remediation
- Identify gaps and uncertainties that may represent a risk to remediation planning and monitoring, and further work that requires consideration.

The site assessment is focused on the characterisation and delineation of the priority remediation areas in consideration of the desired project outcomes. The site assessment may guide the remediation options analysis and inform the scope of remediation works for subsequent stages of the Project.

2.3 Approach

The approach to the site assessment was developed in line with the scope described above to address the Project's desired outcomes and thus was focused on the key concerns for natural recovery of the shoal, within and adjacent to the previously identified priority remediation areas.

As noted in Costen et al (2017), the aggregation of information from the previous investigations to 2016 showed significant gaps in data coverage of the priority remediation areas A, C, E and F, with no physical damage or contamination data available for 82%, 60%, 73% and 54% of these areas respectively. In addition, the available physical damage and contamination data was mostly greater than five years old, with most data gathered in 2010 as part of the initial site assessment and some data gathered in 2013 as part of a reassessment, noting that later work was focused on a trial of a remediation method.

To address the significant gaps in data coverage and the age of the available data from previous investigations, the site assessment approach included fieldwork across the extent of the priority remediation areas to provide a comprehensive and current data set. The fieldwork was targeted to provide information on physical damage and contamination and included:

- A three-day scouting trip in January 2019 to facilitate fieldwork planning
- Sediment sampling conducted over a 17-day period between 6 and 22 March 2019
- Visual survey (including sonar, drop camera and towed underwater video survey) within a 15-day period between 19 May and 2 June 2019.

In addition, current and wave data has been collected periodically since deployment of continuous monitoring equipment in January 2019. The available data has been used to support an understanding of the physical setting.

Analysis of the data is primarily focused on the identification and assessment of areas of physical damage and contamination, using data gathered during the fieldwork within the grounding footprint and at reference sites i.e. the current state of the site. Given that no pre-grounding incident site-specific data is available for Douglas Shoal, habitat mapping data gathered through fieldwork and data from previous investigations have been used to support an understanding of change that may have occurred due to and after the grounding incident, along with an appreciation of the natural environmental state of the shoal.

The data analysis was used to support characterisation and delineation of the areas for remediation to facilitate targeting of different type and intensity of remediation activity in different areas. Priority remediation areas are identified separately for physical damage and contamination based on the assessment. Remediation options analysis may influence the ultimate delineation of priority remediation areas dependent on the availability and feasibility of remediation options.

2.4 Report structure

This report is set out to address the scope and objectives in alignment with the approach described above. The report is supported by several other documents. Table 2-3 sets out the report structure and identifies key supporting documentation.

A summary of key points for the sections describing setting, contamination, physical damage, volumes of sediment and discussion is provided at the end of each of the respective sections.

Table 2-3 Report structure and supporting documentation

Report section	Summary of content	Context and supporting documentation
Section 3 (Method)	Describes the method used in the site assessment.	Focused on the method applied to assess the site and delineate the remediation areas, with details of fieldwork and analysis provided in other documents. A detailed description of the field sampling and analysis method is provided in the Sampling and Analysis Plan (Advisian, 2019a). Deviations from the method are described in the Sediment Sampling Field Report (Advisian, 2019b) and Visual Survey Field Report (Advisian, 2019c). A detailed description of the statistical analysis undertaken on field data and Quality Assurance / Quality Control (QA/QC) processes and compliance is provided in the Sediment Characterisation Report (Advisian, 2019e) which is attached at Appendix A. A detailed description of the processing and analysis of acoustic data captured during fieldwork is provided in the report Douglas Shoal Survey May 2019 (Acoustic Imaging, 2019) attached at Appendix C.
Section 4 (Setting)	Provides an overview of the physical setting of Douglas Shoal.	Focused on the physical setting as relevant to delineation of remediation areas and drawn from data gathered during Advisian fieldwork. Sediment logs which include images of sediment collected from each sampling site are provided in Appendix B of the Sediment Characterisation Report (Advisian 2019e) attached at Appendix A. Detail regarding values and management arrangements relevant to Douglas Shoal is provided in the Douglas Shoal Preliminary Site Assessment Report (Costen et al, 2017). Discussion regarding the condition of the areas affected by the grounding and of adjacent areas is made in Sections 5 and 6 as relevant.

Report section	Summary of content	Context and supporting documentation
Section 5 (Contamination)	Describes the results of analysis and sets out priority remediation areas with respect to contamination.	Focused on the relevant fieldwork and other available information to support delineation and mapping of priority remediation areas with respect to contamination. A detailed description of the results of statistical analysis undertaken on field data and QA/QC processes and compliance is provided in the Sediment Characterisation Report (Advisian, 2019e) which is attached at Appendix A. A detailed description of the results of laboratory analysis (including laboratory reports) is provided in the Laboratory Analysis Report (Advisian, 2019d) attached at Appendix B.
Section 6 (Physical damage)	Describes the results of analysis and sets out priority remediation areas with reference to physical damage.	Focused on the relevant fieldwork and other available information to support delineation and mapping of priority remediation areas with respect to physical damage. A detailed description of the results of statistical analysis undertaken on field data and QA/QC processes and compliance is provided in the Sediment Characterisation Report (Advisian, 2019e) attached at Appendix A. A detailed description of the results of laboratory analysis (including laboratory reports) is provided in the Laboratory Analysis Report (Advisian, 2019d) attached at Appendix B. A detailed description of the analysis of acoustic data captured during fieldwork is provided in the report Douglas Shoal Survey May 2019 (Acoustic Imaging, 2019) attached at Appendix C.
Section 7 (Volumes of sediment)	Describes estimates of volume of sediment in priority remediation areas.	Uses information from the estimated area and measured sediment depths of each priority area to provide estimates of sediment volume. Uses Particle Size Distribution (PSD) results from each priority area to provide estimates of volume for each grain size.
Section 8 (Discussion)	Provides summary discussion on uncertainty and remediation priorities.	Highlights data gaps and uncertainty that may represent a risk to remediation planning. Sets out conclusions with respect to priority remediation areas.

3 Method

This section focuses on the method applied to assess the site and delineate the remediation areas following completion of fieldwork, with a detailed description of fieldwork, raw data processing and the statistical analysis method provided in other documents (refer to Table 2-3). Fieldwork data was used to support understanding of the setting and the areas potentially requiring remediation. The fieldwork data used as part of the assessment includes:

- Sediment sampling data including laboratory analysis data describing physical and chemical characteristics, along with physical data measured in-situ
- Drop camera and towed underwater video survey data including still and video imagery data
- Sonar survey data:
  - Multibeam sonar survey data including bathymetry and backscatter data
  - Sub-bottom profiling survey data
- Current and wave data.

Satellite imagery was acquired in late 2018 to support fieldwork planning, including for the identification of sediment sampling locations. The spatial extent of fieldwork survey data capture is summarised in Figure 3-1 for sediment sampling, video and still image data capture and Figure 3-2 for sonar survey, current and wave data capture, along with the satellite imagery capture extent.

A brief description of each field data source is provided below, followed by a description of how the data sources were used to facilitate remediation planning.

3.1 Field data

A detailed description of the method for data gathering, processing and analysis is provided in other documents (as set out in Section 2.4) with summary information provided below.

3.1.1 Sediment sampling

Sampling was undertaken to address information gaps regarding sediment including:

- Location, approximate area, depth and volume of sediment accumulation in the target areas
- Chemical and physical characteristics of sediment based on laboratory analysis and observation.

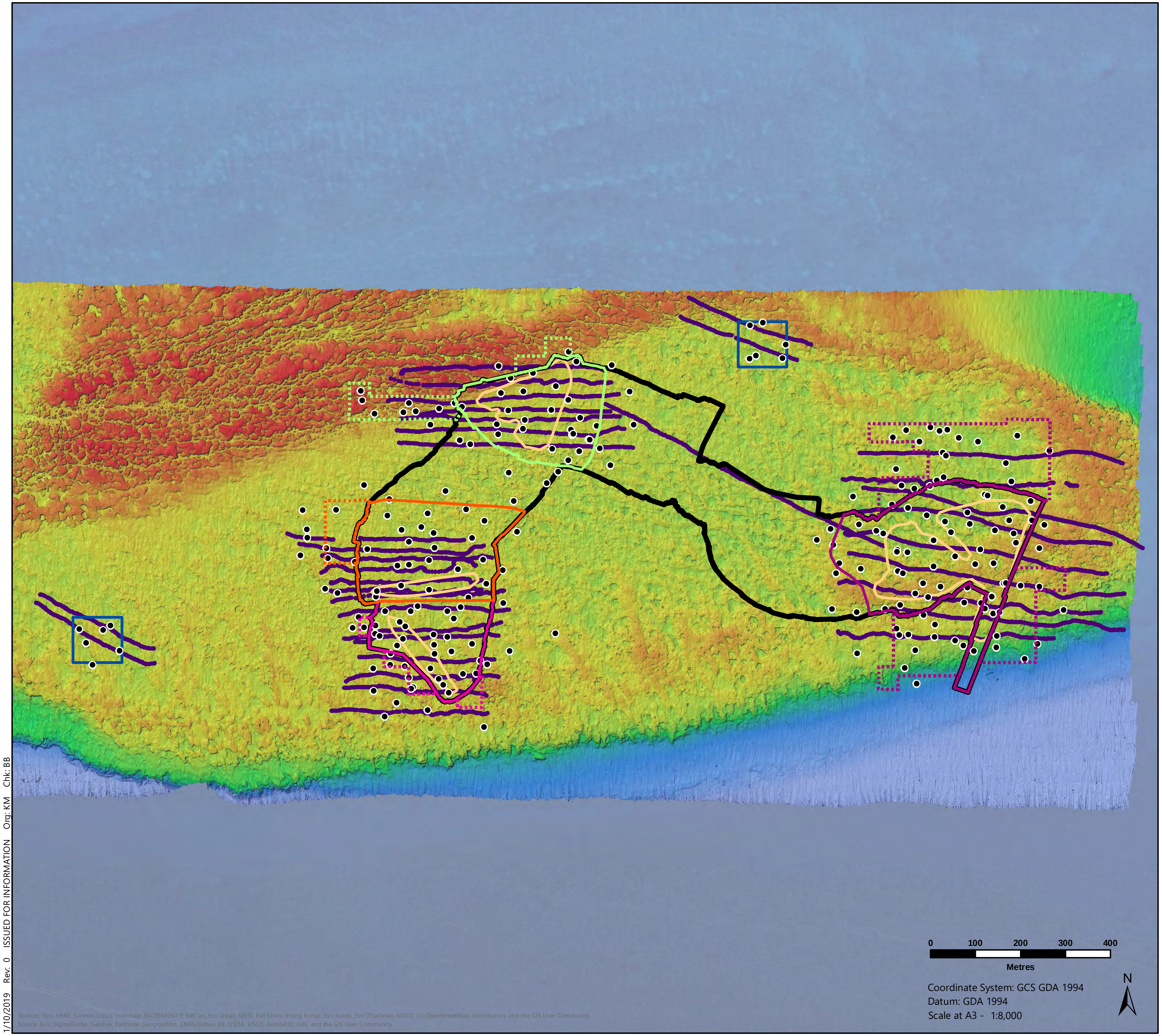
3.1.1.1 Data gathering

Review of existing information and the scouting trip fieldwork identified that sediment accumulates in depressions of the shoal’s bathymetric profile (such as holes and gutters) and is not uniformly spread. Satellite imagery and bathymetry information was used to select sites for sediment sampling.

Sampling sites were visually confirmed by divers based on the availability of sediment for sampling, and the sites were georeferenced. Given the generally limited amount of sediment in the sampling locations, samples were collected from the available material within approximately ten metres of the sampling site and five sediment depth measurements were taken from within this same area.

Douglas Shoal Remediation Planning
Site Assessment Report

Figure 3-1
Sediment sampling, video and still image data capture



Sediment sampling location
Transect locations
Grounding footprint
2010 Impact scars

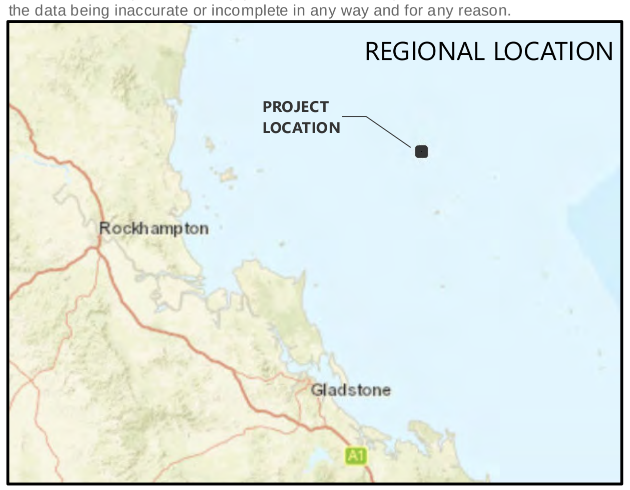
Priority Area

- A
- A - outside grounding footprint
- C
- C - outside grounding footprint
- E
- E - outside grounding footprint
- F
- F - outside grounding footprint
- Reference areas

Bathymetry (2019)

-23.0m -9.0m

Source Information:
Towed video transects
GeoOceans 2019
Sediment sampling locations
Advisian - March 2019
2010 Impact scars
AIMS 2010
Priority areas, Grounding footprint
Cardno 2017
2019 Bathymetry (50cm LAT)
Acoustic Imaging 2019



Advisian
Worley Group

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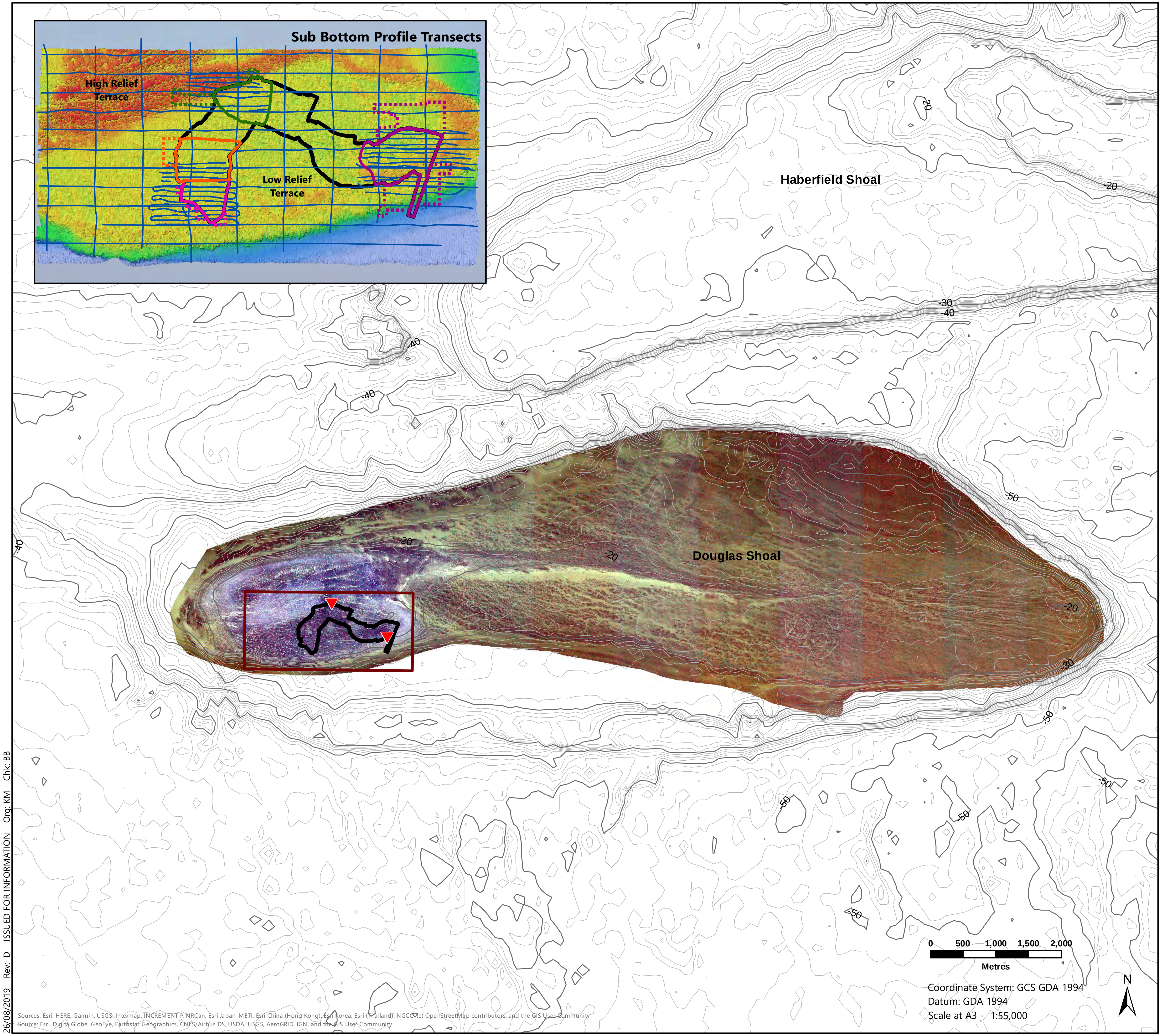
Douglas Shoal Remediation Planning
Site Assessment Report

Figure 3-2
Sonar survey, current and wave data capture



Current and wave monitoring locations (approximate)

Multibeam sonar survey data (2019)

Grounding footprint

Sub bottom profiling transects

Contour (eAtlas Bathymetry)

5m Contour

1m Contour

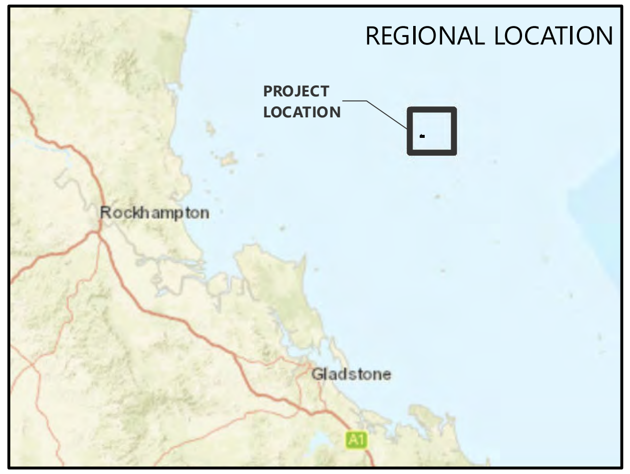
Priority Area

- A
- A - outside grounding footprint
- C
- C - outside grounding footprint
- E
- E - outside grounding footprint
- F
- F - outside grounding footprint

Bathymetry (2019)

-23.0m — -9.0m

Source Information:
Contour (eAtlas Bathymetry), Grounding footprint, Priority Areas
Cardno 2017
2018 Imagery
EOMAP GmbH & Co. KG (© DigitalGlobe Inc)
2019 Bathymetry (50cm LAT), Sub bottom profiling transects
Acoustic Imaging 2019



Advisian
Worley Group

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A video panorama was taken of each sampling site and general observations made of aspects such as sediment type and evidence of damage, metal or paint flakes. A total of 267 samples (including triplicate and duplicate samples) were taken from 237 sampling locations (Figure 3-1) and sent to laboratories for analysis of chemical and physical characteristics.

3.1.1.2 Analysis

The chemical and physical parameters chosen for analysis included relevant AFP constituents and physical parameters relevant to the investigation, along with other metals and metalloids that may be present in the environment. Analysis was undertaken of the following parameters:

- Metals and metalloids – Aluminium (Al), Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb), Selenium (Se), Silver (Ag), Tin (Sn), Vanadium (V), Zinc (Zn)
- Organotins – Tributyltin (TBT), Monobutyltin (MBT) and Dibutyltin (DBT)
- Zineb
- Total Organic Carbon (TOC)
- Moisture content
- Particle Size Distribution (PSD)
- Settleability.

A staged assessment process similar to that set out in the *National Assessment Guidelines for Dredging* (NAGD, Commonwealth of Australia (2009)) was applied to the results and to support consideration of further laboratory analysis and prioritisation. The approach is focused on determining whether sediment contaminant concentrations released into the water column via dredging (or similar relocation) pose a threat to local biota. This is done by comparing contamination concentration results to both NAGD screening levels and the 95^{th} and 99^{th}% species protection levels outlined in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018).

Where sediment concentrations of total or potentially bioavailable metals (derived from 1M HCL weak acid digestion analysis) and normalised TBT (normalised to 1% TOC) were near or above the NAGD or ANZG guidelines, these samples were flagged for Phase III elutriate testing and the results of this testing were then compared to the ANZG 99% species protection level.

Statistical analysis of the data was undertaken using the statistical analysis software PRIMER with PERMAOVA (v7) (Clarke et al. 2013). Analysis was targeted to identify:

- Significant differences in the contamination status between remediation priority areas and reference areas
- Differences in the particle size distribution between remediation priority areas, external sites and reference areas
- Contaminant hotspots within priority areas
- Sources of variability in the dataset, whether the observed patterns in the data were due to spatial factors (area or sites) or sediment characteristics (particle size distribution, total organic carbon, sediment particle density, sediment moisture content, sediment settling rate or sediment depth).

3.1.2 Imagery

Towed video survey with still image capture and drop camera survey was undertaken to address information gaps within the priority areas including:

- Location and physical attributes of substrate and sediment type in the target areas, including to enable 'ground-truthing' of other field data capture
- Sea floor habitat in the target areas.

3.1.2.1 Data gathering

Areas for image capture were targeted based on the results of previous investigations (Stieglitz, 2010, Negri et al., 2010) along with the sediment sampling and sonar survey fieldwork. Towed video and still image capture were undertaken along transects across target areas and drop camera survey was undertaken at a number of locations targeted for 'ground-truthing' other fieldwork outputs (Figure 3-1).

The towed video system consisted of a GO Visions Towed Camera System which was deployed and controlled from the survey vessel and included the following key components:

- Engineered frame to mount and protect the equipment components
- High resolution video cameras pointing forward
- High resolution digital still cameras pointing down
- Positioning and height measurement and control systems.

Prior to mobilisation from the Port of Gladstone to the shoal the towed video system equipment was tested to ensure all components were functioning correctly. For the survey the towed video system was lowered to within 1 to 2m of the sea floor and towed by the vessel along the predetermined transect capturing video and still images. Georeferenced mapping of habitat along each transect was undertaken in real-time during data capture.

The drop camera equipment consisted of a GoPro Hero 7 mounted on a solid monopod and attached to a rope capable of supporting 200kg of weight, which was then attached to the survey vessel. The drop camera was deployed by hand to within 3m of the sea floor at target locations to capture video imagery directly beneath and with reference to the survey vessel's positioning system.

3.1.2.2 Analysis

Imagery captured through use of the towed video system was processed with the assistance of the AIMS and using methods consistent with those of the AIMS Long Term Monitoring Program (LTMP) for benthic habitat characterisation (AIMS 2008). Image classification sought to identify substrate type (such as rubble, dead coral fragments, cobbles, rock, sand) along with benthic habitat (such as Hard Coral, Soft Coral and Macro algae) for each of the surveyed areas, with each image approximating a 5m x 5m georeferenced location. More common benthic organisms were categorized at a higher taxonomic level to look for differences in the percentage cover of these organisms within impacted areas compared to outside these areas. The categories used are listed in Table 3-1.

Consistent with the AIMS LTMP approach, five points were superimposed on each still image and the substrate and benthic category under each of the five points was manually identified. The analysis provided a measure of substrate and benthic habitat categories across the target areas.

Imagery captured from the drop camera equipment was used to support analysis of results from other survey methods, including sediment sampling and sonar survey work.

Table 3-1 List of categories used to characterise the benthic habitat (alive and dead) at Douglas Shoal

Benthic Category	Targeted Taxonomic/Broad categories
Hard Coral	*Acropora spp., Favid spp. Lobophyllia spp., Montipora spp., Other Coral, Pocillopora spp., Porites spp., Seriatopora spp., Stylophora spp., Turbinaria spp.*
Soft Coral	*Xenia, Sarcophyton, Sinularia*
Macro algae	*Sargassum, Dictyota, Halimeda, Asparagopsis,* macroalgae assemblage (combinations of those listed)
Turf algae on rock	Turf algae on hard bare reef substrate (rock)
Cyanobacteria	Cyanobacteria
Coralline algae	Coralline algae
Sponge	Sponge
Sand	Sand
Rubble	Angular rubble (indicative of grounding action)
Dead coral fragments	Coral fragments of various sizes

3.1.3 Sonar survey

Sonar survey was undertaken to address information gaps regarding the priority areas including:

- Bathymetric profile of the target areas
- Location and physical attributes of substrate and sediment type in the target areas.

3.1.3.1 Data gathering

Multibeam sonar uses multiple sound signals to map a swath of the sea floor under the survey vessel. Sound pulses are transmitted to the sea floor and the characteristics of the returning pulses enable generation of bathymetry and backscatter data. Backscatter data is commonly used to describe sea floor hardness and surficial sediment characteristics.

Acoustic Sub-Bottom Profiling (SBP) systems are typically used to determine physical properties of the sea floor and to image and characterise geological information a few metres below the sea floor. The SBP systems typically comprise a single channel source that sends sound pulses into the shallow sub-sea floor sediments. The qualities of the returning pulses may be related to characteristics of the sea floor and substrate e.g. hardness and depth of sea floor layers. These systems are typically used to map transects across areas of interest, rather than provide full sea floor mapping.

The sonar survey was undertaken on 22 and 23 May 2019 and included Multibeam sonar and SBP survey. Multibeam sonar survey was undertaken across an area of approximately 200ha, encompassing the priority remediation areas and reference sites, while SBP survey was undertaken across a subset of smaller target areas (Figure 3-2). Target areas for the SBP survey were focused on the priority remediation areas and took consideration of previous sonar survey work undertaken at the shoal (Stieglitz, 2010, Negri et al., 2010) and the results of the sediment sampling work described above.

The key components of the sonar survey system used for data gathering were:

- R2Sonic 2022 Multibeam Echo Sounder (MBES) operated in a multi-frequency manner (three frequencies used (170kHz, 300kHz, and 400kHz)) and providing bathymetry and backscatter data
- Innomar SES-2000 Sub-Bottom Profiler
- Applanix POS MV Wavemaster providing positioning, motion, and heading data
- SonTek Castaway CTD providing sound velocity through the water column.

The sonar survey system was installed on the survey vessel at the Port of Gladstone, and field testing and calibration was undertaken prior to mobilisation to the shoal. All sonar survey data was adjusted to the Lowest Astronomical Tide (LAT) metric as specified at Tyron Island tide station; 1.63m below Mean Sea Level (MSL). Horizontal projection used was UTM Zone 56S, WGS84.

3.1.3.2 Analysis

Bathymetry

Bathymetry data processing was undertaken with the QPS Qimera package using soundings from all three frequencies so that the sounding density was as high as possible. Positioning and sound velocity data was applied. Anomalous data was removed using filters and manual checks. Bathymetry data were gridded at a 0.5m bin size using a weighted moving average algorithm and exported for use.

Seabed slope magnitude was derived from the bathymetry data across the target area. This enabled further consideration of areas of ‘flattening’ of the seabed around areas where the grounding occurred, and relative to other areas.

Backscatter

The QPS FMGT software package was used for backscatter data processing. The MBES was operated in a multi-frequency manner to provide data from three different frequencies so these could be used subsequently in the assembly of a composite image to provide information on subtle changes to substrate and sediment types across the target area. The data sets from each of the three different frequencies were processed. Bathymetry data was applied to allow correction of the seabed intensity data for the slope differences across the target areas. Absorption values were set for each of the frequencies and pixel size and processing parameters set to generate the backscatter data products, particularly the backscatter mosaics and the layers for application of the Angle-Range Analysis (ARA) technique.

The ARA technique was derived from investigations by Fonseca, et al. (2009) and addresses seabed intensity response. Backscatter data was corrected for parameters that affect the intensity of the returns from the seabed (e.g. radiometric and geometric parameters) so the processed data reflects the "true" intensity of the seabed. Angle-Range curves were extracted across set areas of the seabed and compared to empirically derived responses of the seabed for different sediment types as defined in the model developed by Jackson et al (1986). Images were subsequently generated using the software to display the sediment grain size results as different colours mapped to a colour scale and therefore show sediment characteristics across the survey area.

Sub-Bottom profiling

The SBP survey data was processed using the Chesapeake SonarWiz software. The seabed was bottom tracked and a seabed reflector created in the dataset. Image enhancement algorithms were applied to the dataset and portions of the profile that were of interest due to their sediment characteristics (identified through sampling described above) were digitized and data exported.

As identified at the survey planning stage through the Sampling and Analysis Plan (SAP) the efficacy of the sub-bottom profiling survey technique in differentiation of substrate and sediment type at the shoal was unclear. Evaluation of the processed data for target areas indicated that an underlying reflector (representing hard substrate) was largely absent across most areas and acoustic penetration was only subtly different between areas with varying sediment characteristics (e.g. areas dominated by sandy material versus areas dominated by gravelly material). As such and given that the other survey techniques yielded suitable data, limited further consideration and interpretation of the SBP survey data was made.

Data comparisons

Sediment sampling and imagery capture data were compared with the sonar survey data to 'ground-truth' these broader scale datasets.

Comparison with the 2010 sonar survey data (Stieglitz, 2010, Negri et al., 2010) was pursued to facilitate understanding of change over time; however, the use of comparisons was constrained by the limitations of the 2010 sonar survey and the availability of information regarding data processing for that survey.

The datum used for the bathymetry data was aligned as closely as possible to the 2010 bathymetry data (i.e. to the LAT metric as specified at Tyron Island tide station, 1.63m below MSL); however it was noted that an apparently arbitrary shift of 50cm had been made to the 2010 data which is believed to have been made to better align with Royal Australian Navy (RAN) Laser Airborne Depth Sounder (LADS) data.

A surface difference analysis was conducted between the 2010 gridded bathymetry and the 2019 gridded bathymetry, with bin size specified as the same for both data sets (50cm). The intent of this analysis was to compare volume of sediment across the survey area from between the two surveys to identify areas of erosion and/or accretion; however, it appears this analysis is confounded by the arbitrary shift of data described above, noting that a median difference of +16cm exists between the two data sets (2010 data as the reference surface) and it is considered that this is not an accurate or appropriate reflection of sediment change on the shoal over time.

Notwithstanding this, qualitative (visual) comparison of the bathymetry data and related slope magnitude analysis data, along with the backscatter data from the 2010 sonar survey was made.

3.1.4 Current and wave

The primary objective of current and wave data capture from the shoal is to support and inform development of a hydrodynamic model of Douglas Shoal as part of the environmental monitoring. Model development and output are not described in this report; however, summary current and wave information was considered to support an understanding of the shoal's physical setting.

Two Acoustic Doppler Current Profilers (ADCPs) were deployed at the shoal at different locations (Figure 3-2) on 11 January 2019. The ADCPs provide current speed and direction data for the full water column at each site, along with wave height data; data is collected every 15 minutes. Data accessible for this report was downloaded from the ADCPs during maintenance events which were concluded on 16 March 2019, and 14 June 2019, with the deployment ongoing. Data was subjected to a three step QA/QC process as follows:

- The data set was screened for erroneous readings, with identified erroneous points removed from the data set, logged and saved as meta-data
- Data spikes caused by objects such as pollution, marine fauna and flora present in the water column are removed
- The data set is visually inspected and any erroneous data still present is identified and manually removed if necessary.

3.2 Remediation area planning

The site assessment is focused on characterisation and delineation of the priority remediation areas based on the current state of the target areas with respect to physical damage and contamination. While the main consideration for delineation of areas is the evidence from the field data of physical damage and contamination effects associated with the grounding, this information is considered in the context of information relating to the background environment, previous investigations and relevant guidelines (Figure 3-3).

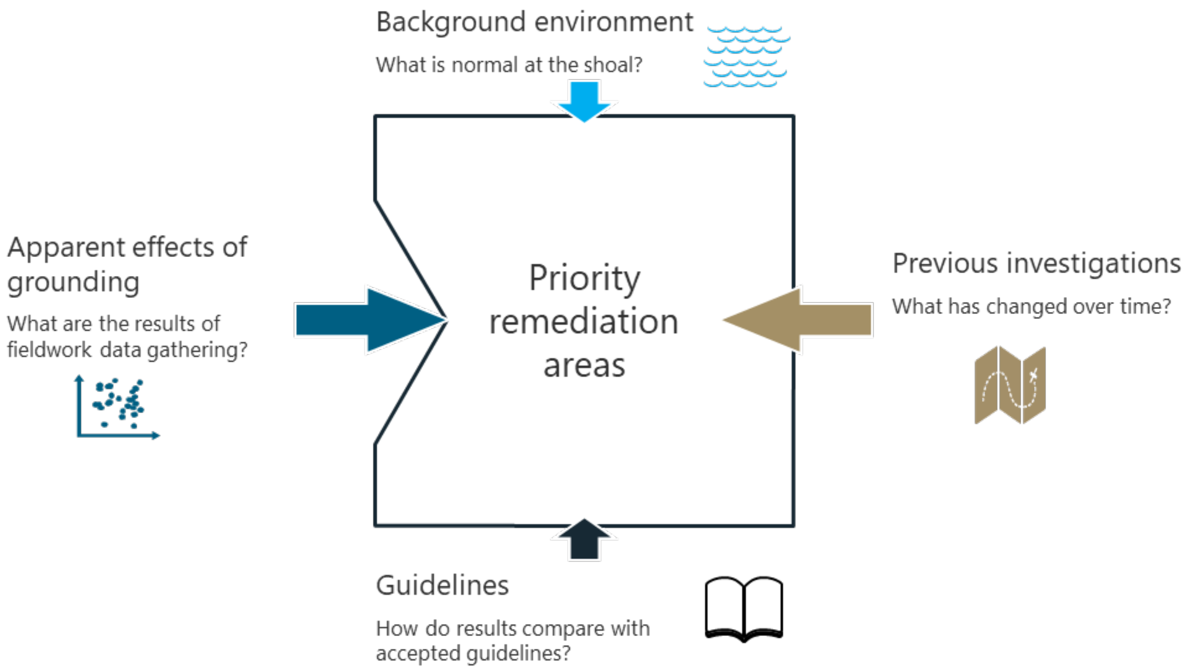

Figure 3-3 Considerations for priority remediation area delineation

The site assessment considers several lines of evidence regarding physical damage and contamination effects and uses these to delineate areas of 'high' and 'moderate' priority for further consideration as part of the subsequent stage of options analysis. The relative priority of physical damage versus contamination remediation areas may be considered as part of the options analysis.

The main consideration with respect to the relative priority of areas showing evidence of physical damage or contamination effects, is the extent to which these effects may impede the natural recovery of Douglas Shoal. Information gaps and uncertainties exist for the shoal, and these are identified as part of the discussion of results. Notably there is very limited information with respect to the shoal prior to the grounding incident and the previous investigations provide a limited perspective of physical damage and contamination effects due to the grounding. The assessment uses professional judgement and is necessarily subjective as it seeks to balance the various evidence of effects and take into consideration the data gaps and uncertainty. Table 3-2 provides a high-level summary of how various data were used in the description of the target areas and delineation of remediation area priorities.

Table 3-2 Data application to remediation area planning

Data	Aspect	Application
Sediment sampling	Contamination	Laboratory analysis data for chemical properties of sediment was compared against relevant guidelines including NAGD (2009) and ANZG (2018) Data from reference areas used to describe background conditions Statistical analysis used to provide context to the results, to examine relationships between laboratory analysis data sets and to describe contamination hot spots Comparisons made with contamination data from previous investigations and examination made of potential degradation of contaminants over time Comparison of elutriate analysis results with ANZG (2018) and laboratory analysis data with NAGD (2009) used to support delineation of 'high' priority areas for contamination Comparison of laboratory analysis data with NAGD (2009) used to support delineation of 'moderate' priority areas for contamination
	Physical damage	Statistical analysis was used to compare sediment characteristics inside and outside of the grounding footprint and in reference areas, and support differentiation of typical sediment profiles for these areas based on PSD
	Physical characteristics	Sediment depth measurements used to estimate volume of material across sampling areas Video panoramas used to support understanding of physical characteristics of sampling locations
Video and still imagery	Physical damage	Used in conjunction with sonar survey data to identify areas of physical damage associated with rubble or compaction related effects Qualitative comparison made with available imagery data from previous investigations to consider change over time

Data	Aspect	Application
	Physical characteristics and habitat	Used to support identification of substrate and sediment characteristics across target areas and consider differences between areas inside and outside of the grounding footprint and in reference areas
		Used to estimate proportions of habitat type across target areas and consider differences between areas inside and outside of grounding footprint and in reference areas
		Qualitative comparison made with available habitat type data from previous investigations to consider change over time
Sonar survey	Physical damage	Seabed slope magnitude derived from the bathymetry data used to consider areas of 'flattening' of the seabed within the grounding footprint and compare these with areas outside of the grounding footprint and in reference areas
		Seabed slope magnitude data qualitatively compared with available data from previous investigations to consider change in seabed slope magnitude over time
		Backscatter data used in conjunction with imagery data to identify areas of physical damage associated with rubble or compaction related effects
		Backscatter data qualitatively compared with available data from previous investigations to consider change with respect physical damage associated with rubble or compaction related effects
	Physical characteristics	Bathymetry, backscatter and sub-bottom profiling data used to describe and support understanding of physical characteristics of Douglas Shoal
		Bathymetry data used in conjunction with imagery data, sediment sampling data and other sonar survey data to estimate areas of sediment coverage across the target areas of Douglas Shoal and subsequently extent of priority areas with respect contamination and physical damage
Current and waves data	Physical characteristics	ADCP data used to support understanding of coastal processes at Douglas Shoal

4 Setting

Douglas Shoal is situated within the southern region of the Great Barrier Reef (GBR), within the Mackay Capricorn Management Area. Douglas Shoal is located approximately 90km east of Yeppoon, and north of the Capricorn Group of reefs and island (Figure 2-1).

4.1 Geomorphological features

Douglas Shoal is a non-biogenic, 'submerged shoal-reef' (Hopley et al., 2007) located on the widest section of the continental shelf of the GBR, which gradually slopes towards the shelf-edge. The submerged state of non-biogenic shoals such as Douglas Shoal is most often attributed to 'drowning' when rapid post-glacial sea level rises out-paced vertical reef accretion, which was limited by difficult conditions for coral reef growth associated with the last deglaciation (e.g. Fairbanks, 1989; Abbey and Webster, 2011). While most coral reefs within the Capricorn-Bunker group are identified as mature lagoonal or planar platform reefs that reach the surface, this section of the shelf is also lined with numerous submerged (at all tides) reefal platforms or shoals (GBRMPA 1979).

Douglas Shoal is large (5,180ha (Costen et al, 2017)), solitary, wholly sub-tidal, and elongated east – west. The morphology of the shoal is consistent with nearby shoals, such as Haberfield Shoal, and the western section of the shoal is the dominant morphological feature, rising some 45m from the mid-shelf floor to a relatively low relief reefal-shoal top (10 to 15m below MLW). East of this feature, the shoal dips gently for approximately 7km before sharply dipping to the off reefal-shoal floor (Figure 3-2). The following terms are used to describe the geomorphic zones relevant to Douglas Shoal (Costen et al., 2017):

- Off Reefal Shoal Floor
- Reefal Shoal Slope (windward and leeward)
- Reefal Shoal Top
- Low Relief Terrace
- High Relief Terrace.

The physical grounding impacts were confined to two of these zones, the Low and High Relief Terrace (Costen *et al*, 2017).

4.2 Climate and oceanographic conditions

The climate is subtropical with summer occurring between November / December to May and mild winter conditions between June and late October (Costen *et al*, 2017). The bulk of the rainfall occurs in summer; the strongest wind and wave conditions at Douglas Shoal are associated with the passage of Tropical Cyclones (TC). The prevailing currents are driven by the tidal flows and wind driven waves. Douglas Shoal is very exposed to wind and wave conditions with little protection from these forces from Guthrie and Innamincka Shoals to the north-east or the Capricorn Bunker Group to the south-east. More detailed descriptions of the climate and oceanographic conditions at Douglas Shoal are provided in the following sections and in Advisian, 2019f. Data collected by Advisian at ADCP Site 1, between January 2019 and June 2019 (refer to Section 3.1.4) are used to describe the currents, waves and tides specific to the shoal.

4.2.1 Currents

Based on the data gathered between January 2019 and June 2019 current speeds vary from 0m/s during the change in tidal flow to ~0.9m/s during peak flow during the spring tidal periods (Figure 4-1). The general direction of the currents at Douglas Shoal is from the west (260 – 280 degrees) on the flood tide and the east (100 – 120 degrees) on the ebbing tide (Figure 4-2).

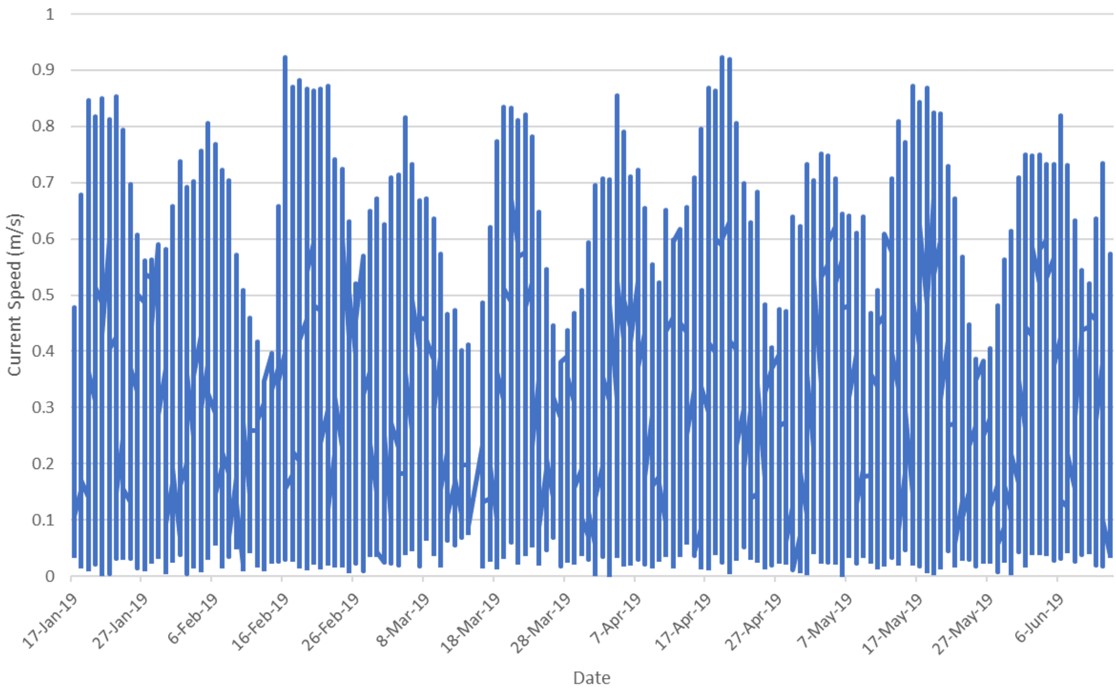

Figure 4-1 Current speeds (m/s) measured at Douglas Shoal between January and June 2019

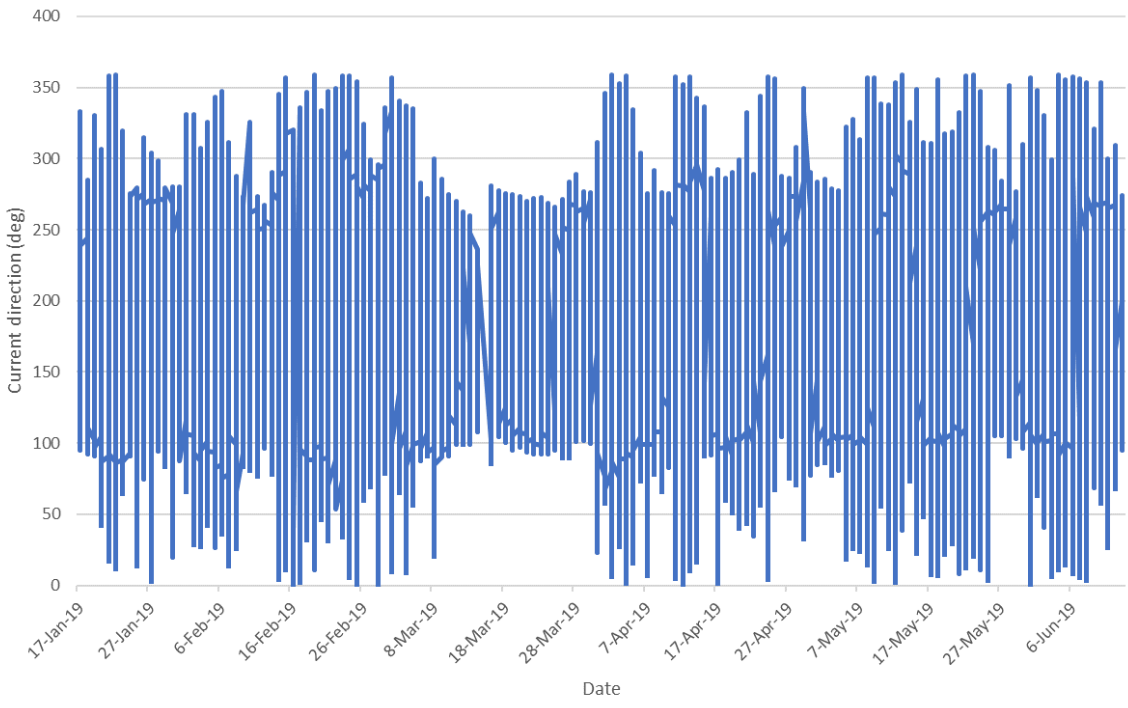

Figure 4-2 Current direction (degrees) measured at Douglas Shoal between January and June 2019

4.2.2 Wind and waves

As site-specific wind direction and wind speed data is not available for Douglas Shoal, information from Heron Island located 30nm to the south-west is considered. Data from the Bureau of Meteorology (BOM) indicate the wind is predominately from the south-easterly and to a lesser extent the easterly direction (Figure 4-3). Mean 3p.m. wind speed is greatest during the cyclone season (between January – May) and lowest during the late winter and spring months (August – November). The strongest winds are associated with the passage of tropical cyclones during the summer (refer to Section 4.2.4).

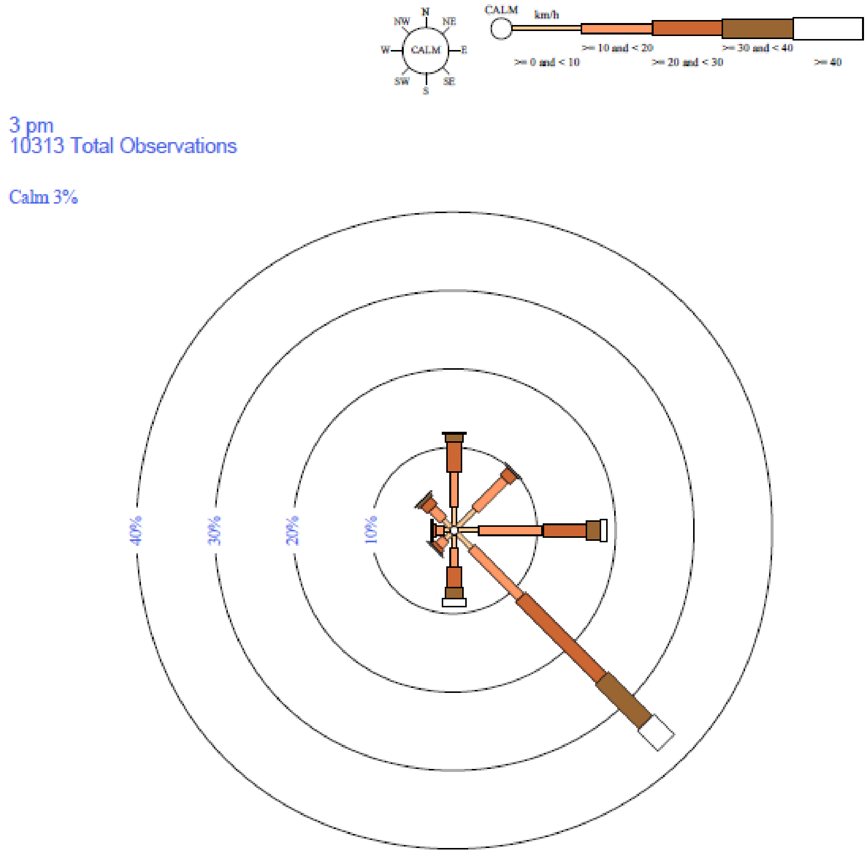

Figure 4-3 Wind Rose for Heron island at 3pm from 1962-2010 (source: BOM – BoMet in GBRMPA, 2018)

Significant wave heights (Hs) is defined as the average wave height, from trough to crest, of the highest one-third of the waves. The Hs measured at Douglas Shoal ranged from 0.3 to 4m over the 6-month period during which measurements were taken (January to June 2019). The wave direction was predominately from the east north-east – south-east (60 – 120 degrees (Figure 4-5)) which mirrors the prevailing wind direction. Occasional northerly winds were experienced during the deployment.

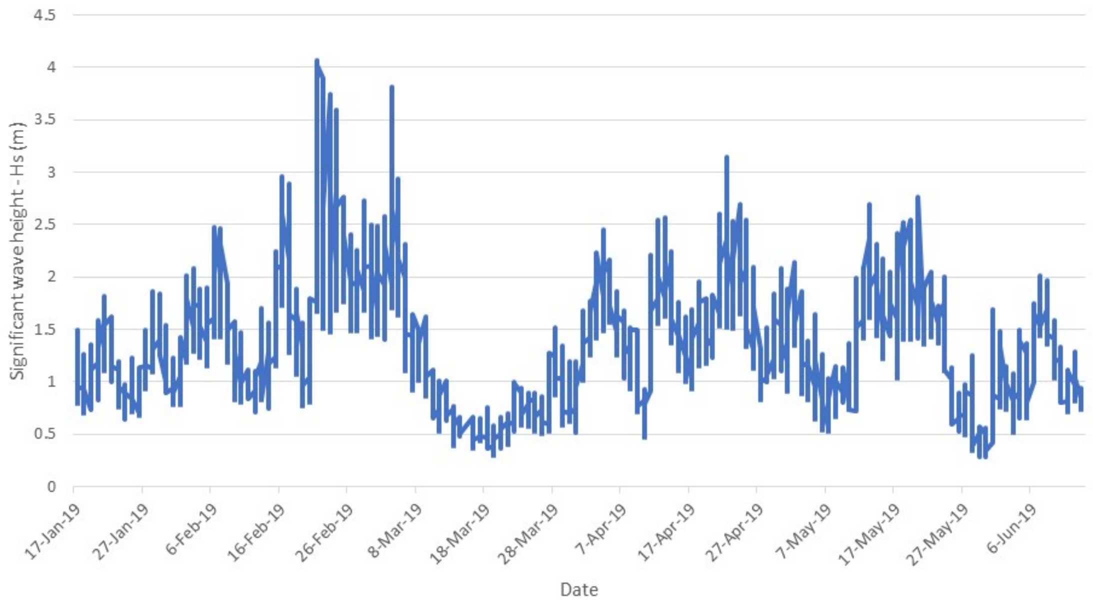

Figure 4-4 Significant wave height (Hs) measured at Douglas Shoal between January and June 2019

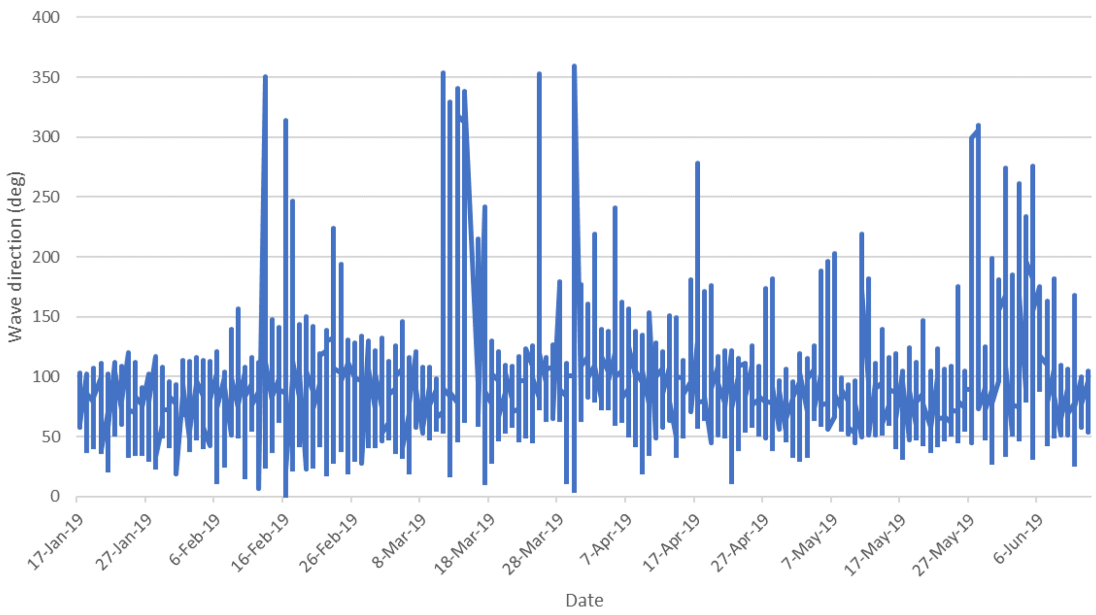

Figure 4-5 Wave direction (degrees) measured at Douglas Shoal between January and June 2019

4.2.3 Tidal depth

Tidal depths during spring tidal flows in January 2019 varied from 16m at high tide to 12m at low tide, a change of 4m. This range varied throughout the measurement period but was below 4m. During the neap tidal flow in January 2019 depths ranged from 15.3m to 12.5m, a change of 2.8m, which was consistent across neap tidal flows during the measurement period.

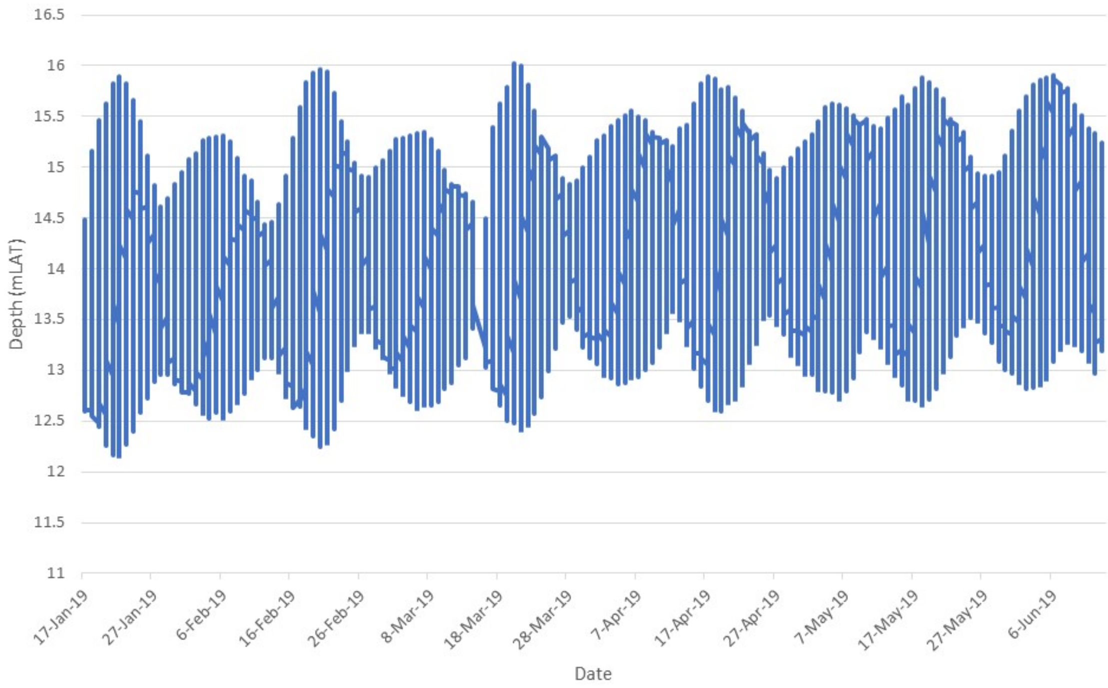

Figure 4-6 Tidal depth (m) measured at Douglas Shoal between January and June 2019

4.2.4 Tropical cyclones

Elevated wind and waves frequently impact Douglas Shoal, noting that extreme weather events created by tropical cyclones have the potential to severely impact benthic habitat. Between 1969 and 2018, 17 cyclones passed within 200km of Douglas Shoal (Table 4-1 and Figure 4-7). Given the open nature of the ocean surrounding Douglas Shoal, cyclones passing at a distance greater than 200km from the shoal can adversely affect conditions on the shoal e.g. TC Oswald (January 2013) and Severe TC Marcia (February 2015) generated 7-8m waves at Douglas Shoal (Kettle, 2015b) with TC Oswald passing at greater than 200km from Douglas Shoal. The passage of cyclones is likely to be a significant driver of sediment movement on the shoal, particularly of the larger fraction of sediment (such as dead coral fragments and rubble) as this is typically transported in high energy conditions. The destructive forces of cyclones also work to create sediment by dislodging and breaking up coral and reef structure.

Table 4-1 Tropical cyclones which have passed within 200km of Douglas Shoal

Cyclone Season	TC name	Pressure at closest point (BOM category)	Approximate distance from Douglas Shoal (km)
1970/1971	Fiona	995	50
1971/1972	Emily	974	30
1975/1976	Beth	994	180
	David	963	120
	Dawn	988	20
	Watorea	980	130
1978/1979	Kerry	999	190
1979/1980	Paul	992	20
	Simon	960	20
1982/1983	Elinor	996	180
1983/1984	Lance	998	170
1984/1985	Pierre	999	5
1991/1992	Fran	980	30
1993/1994	Rewa	980	40
2008/2009	Hamish	948	160
2013/2014	Ita	993	150
2014/2015	Marcia*	931	110

Path of TC 'Marcia' indicated by an arrow on Figure 4-7

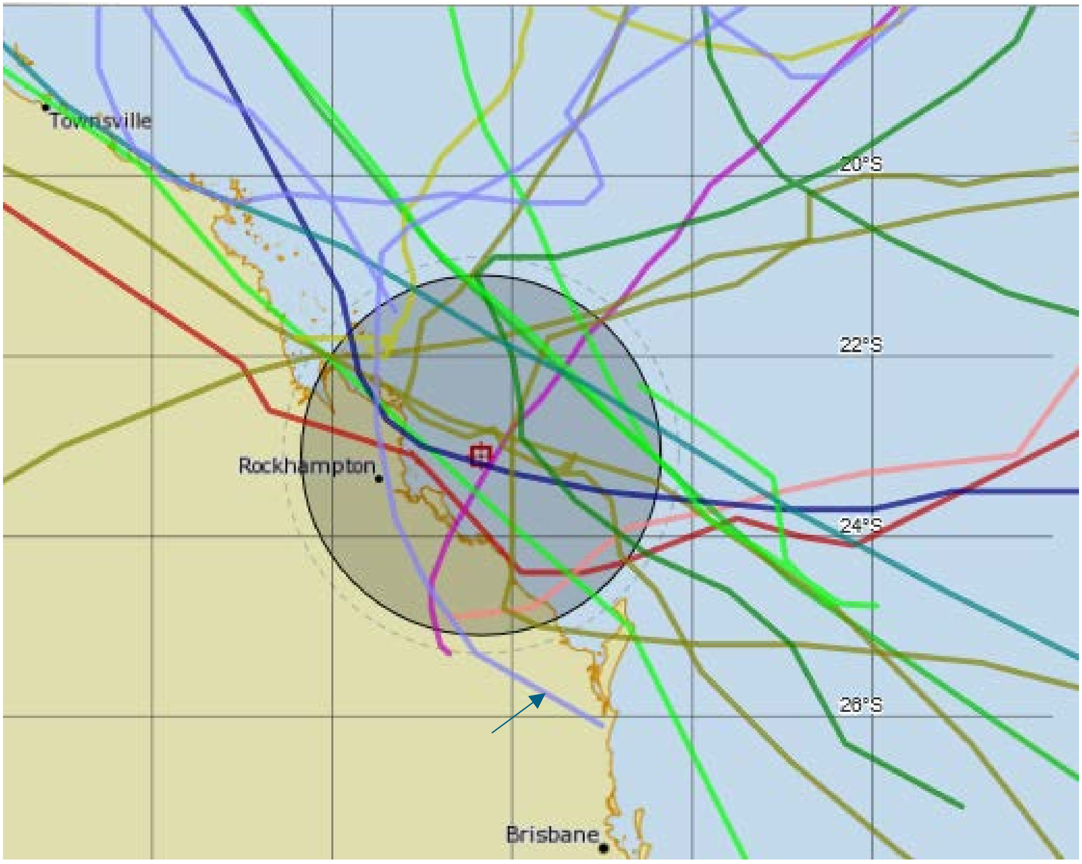

Figure 4-7 Tracks for cyclones passing within 200km (shaded circle) of Douglas Shoal (red square), 1979-2018 (source: BOM, 2018) with path of TC 'Marcia' indicated by an arrow

4.3 Benthic habitat

There is no published information available on the status of the benthic habitat or benthos prior to the grounding event. As such, information drawn from the site assessment fieldwork has been used to broadly describe the habitat types of the Low and High Relief Terraces. Information derived from the towed video survey (with still image capture), along with the sediment characterisation and SBP survey both within and outside the previously defined priority areas has provided an improved understanding of the physical characteristics of the benthic habitat at Douglas Shoal.

A summary of the habitat types is provided below. Given the key concerns for natural recovery of the shoal are related to sediment on the shoal (i.e. contamination of sediment and physical sea floor related impacts) consideration is given here to sediment specifically as a component of benthic habitat (with detailed discussion in Sections 0) followed by analysis of the results of benthic habitat survey.

The sediments created by the action of the grounding are described in the technical note developed by the Authority - *Differentiating natural sediment from incident-generated sediment* (GBRMPA, 2019). Both natural and grounding-related sediments contain different fractions of coarse sand, sand, silt and clay. The primary sediment constituent which distinguished the grounding-related sediments from natural sediments is the presence or absence of large angular sediments or 'rubble'. For consistency with the technical note and to avoid confusion with respect terminology used, this report adopts the following convention:

- Larger fractions of the grounding-related sediments are described as rubble
- Larger fractions of sediment considered to be of natural origin (not related to the grounding) are described as dead coral fragments.

4.3.1 Habitat types

While the Low Relief Terrace at Douglas Shoal does not have a complex range of features relative to other areas of the Shoal, there is a measure of diversity of habitat types which are mirrored in the benthos growing in this area. Survey information and previous studies indicate there are at least four main habitat features on the Low Relief Terrace of Douglas Shoal:

- Undulating expanses of densely covered (predominately with macroalgae) hard reef substrate with occasional sandy patches
- Channels or gutters containing large pieces of dead coral or coarse sand with gently sloping sides
- Flat expanses of low relief corals with minimal sediment (predominately in Priority Area A)
- Holes containing sand or dead coral fragments with densely inhabited steep walls.

The High Relief Terrace found to the north and north-west of Priority Area C contains more complex features:

- Spur and groove outcrops rising several meters from the sea floor with moderate coral cover
- Deeper channels with large fragments of dead coral fragments and coarse sand with sparse tufts of macroalgae growing within the sediment
- Diverse range of benthic organisms growing in the sheltered embayments within the groove structure
- The spur and groove structure which provides ideal habitat for diverse and abundant fish life.

Figure 4-8 illustrates the range of habitat on the Low Relief Terrace along with a small section of the High Relief Terrace.

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- Flat expanses of low relief corals with minimal sediment (predominately in Priority Area A)
- Holes containing sand or dead coral fragments with densely inhabited steep walls.

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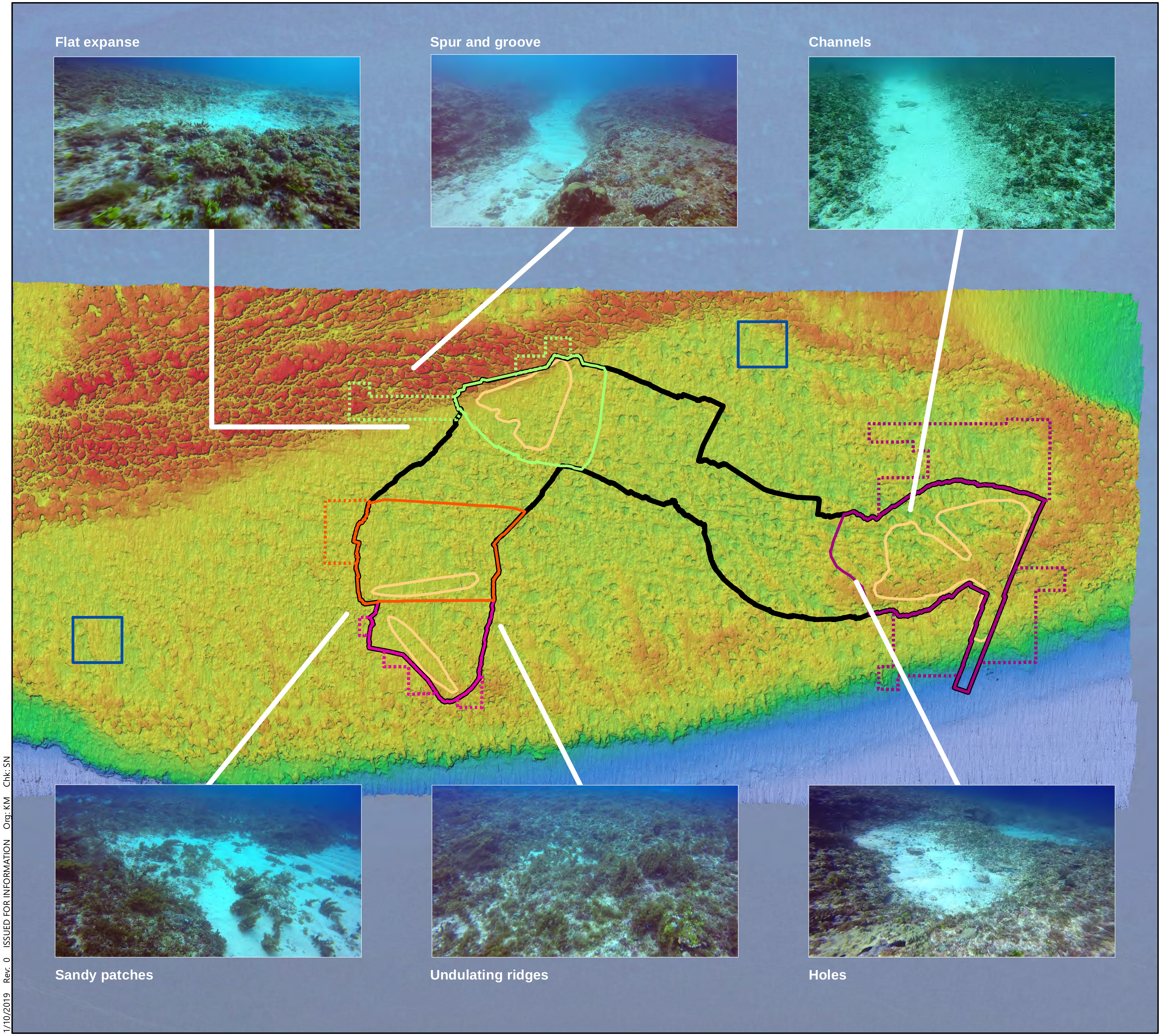


Douglas Shoal Remediation Planning
Site Assessment Report

Figure 4-8
Examples of habitat types found across Douglas Shoal

Grounding footprint
2010 Impact scars

Priority Area

A
A - outside grounding footprint
C
C - outside grounding footprint
E
E - outside grounding footprint
F
F - outside grounding footprint
Reference areas

Bathymetry (2019)

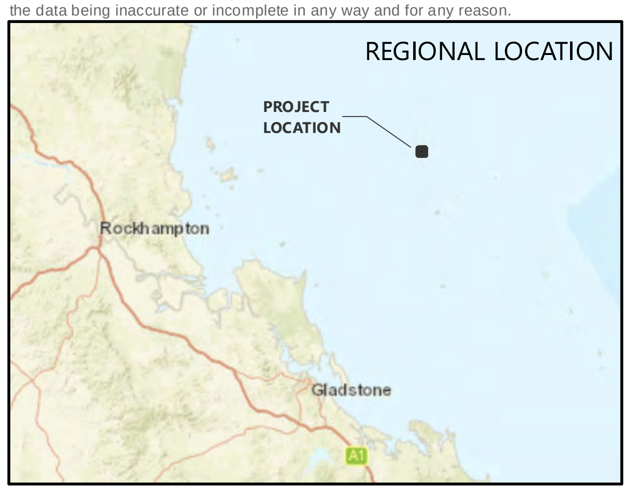
-23.0m — -9.0m

Source Information:
Priority areas, Grounding footprint
Cardno 2017
2019 Bathymetry (50cm LAT)
Acoustic Imaging 2019
Images
GeoOceans 2019
2010 Impact scars
AIMS 2019

0 50 100 150 200
Metres

Coordinate System: GCS GDA 1994
Datum: GDA 1994
Scale at A3 - 1:8,000

N



Advisian
Worley Group

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4.3.2 Sediment

Sediment is not uniformly distributed across Douglas Shoal. It is typically located in depressions across each of the habitat types, as patches in undulating areas, and in channels, gutters and holes. It is not a dominant component of the shoal substrate. Results of the towed video survey (discussed in Section 4.3.3) indicate the Low Relief Terrace habitat consists of large expanses of turf algae on rock (32.6%), macroalgae growing predominately on rock (38.5%), hard and soft coral growing on rock (5.8%). Areas of rubble, dead coral fragments and sand account for around 20% of the Low Relief Terrace area.

Results of the SBP survey and depth measurements taken during sampling provide further information to understand the area and volume of sediments on the shoal. The SBP survey provided limited information regarding the location and depth of sediments across survey transects. An example of the SBP output from surveys in Priority Area F is provided in Figure 4-9. In this example, the grounding footprint is evident as a depression and the depth of penetration of the acoustic signal is very limited indicating there is very little overlaying sediment on a hard surface at this location. This was typical of the results of the SBP survey, indicating few areas of sediment and generally limited sediment depth.

A sound indication of sediment depth across the survey area is provided by diver measurements (Figure 4-10). Depth of sediment at each of the sampling sites ranged from 5mm to 400mm, averaging 73mm across all sites (Table 4-2 and Figure 4-11). Areas AX and FX contained the deepest sediments on average, with 99.5mm and 114.8mm depth respectively. These sampling sites were located outside of a priority area, and in some cases in deeper water. Sediment depths may be greater at these sites due to the lower energy environment of the deeper water which may allow for more settlement.

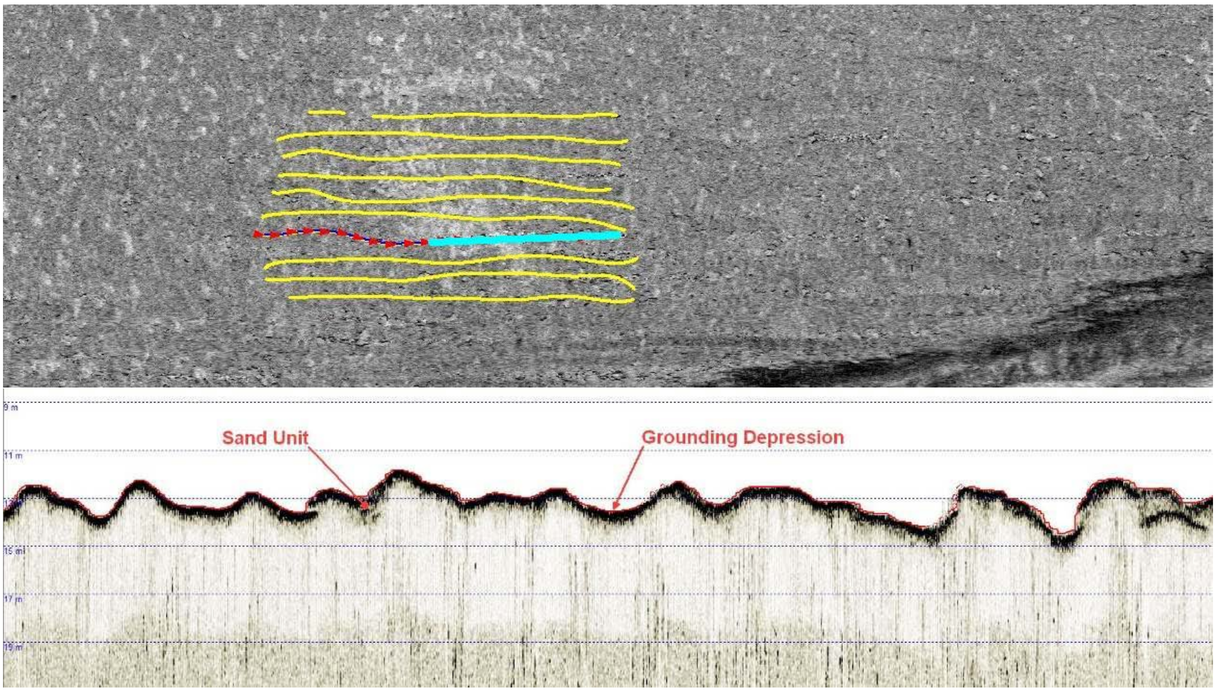


Figure 4-9 SBP transects in Priority Area F with cross-section of the blue line transect section in the lower image

Of the areas sampled, Priority Area A had the shallowest sediment on average. This may reflect the structure and location of the area. This is the most uniform of the priority areas in terms of sea floor structure and is the most exposed of the priority areas to prevailing winds and swell. This may cause resuspension rather than accumulation of sediments in this area.

Figure 4-10 Diver hammering scaled stainless steel rod in Priority Area F to measure sediment depths

Table 4-2 Summary statistics for the depths of sea floor sediment measured by divers

Survey Area ID	Number of samples	Mean (mm)	Median (mm)	95th Percentile	Minimum (mm)	Maximum (mm)	Standard Deviation	Standard Error
A	425	60.2	50	150	5	350	43.9	4.8
AX	60	99.5	100	200	20	200	49.1	14.2
C	165	76.2	50	200	5	400	72.3	12.6
CX	60	69.3	50	150	5	250	44.2	12.8
E	130	65.3	50	150	5	350	37.2	7.3
EX	60	67.1	50	150	25	200	43.5	12.5
F	165	85.6	100	200	5	250	47.3	8.2
FX	60	114.8	100	250	20	300	48.1	13.9
Reference	60	78.1	75	150	10	150	38.1	11.0
Summary	1185	73.0	50	200	5	400	50.3	3.3

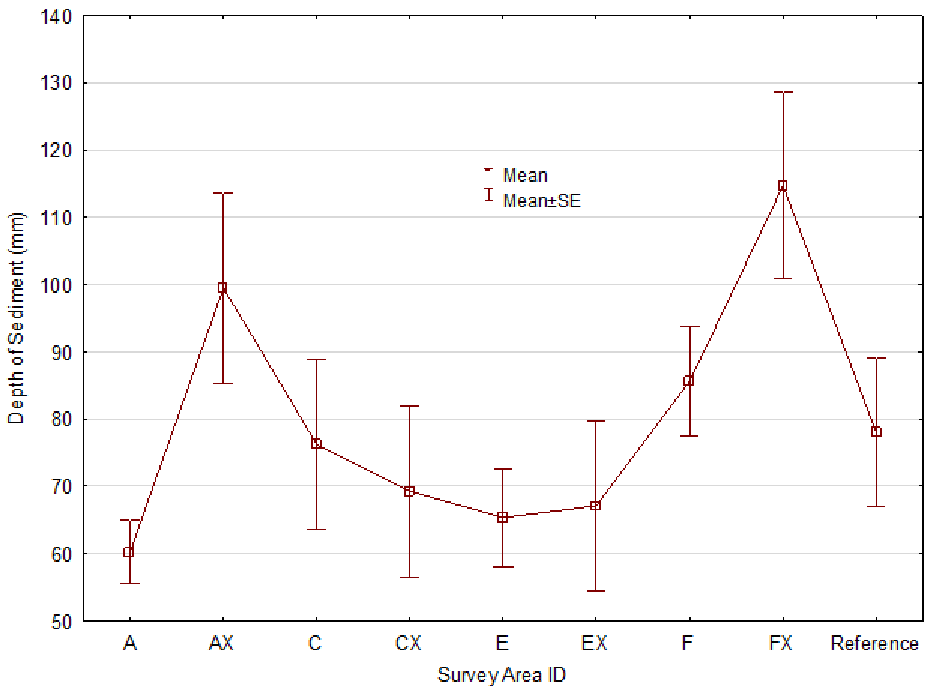


Figure 4-11 Graphical representation of the mean depths of sediments (mm) in each sampling area

Discussion of the volume of sediment within each of the priority remediation areas is provided in Section 0.

4.3.3 Benthic habitat survey

Information from previous investigations in 2010 indicates that impacts associated with the grounding were mostly limited to the Low Relief Terrace of Douglas Shoal. The 2010 towed video survey provided information on the spatial extent of the benthic habitat and benthos across this area immediately after the grounding. To account for potential habitat differences due to the grounding, the 2019 analysis differentiates between images captured inside the 'impacted' areas as defined by the AIMS sonar surveys in 2010 (Negri et al, 2010) and those images along transects captured outside this 'impacted' area. This assumes that impacts associated with the grounding (such as reduction in coral cover) were isolated to these 'impacted' areas and as time progressed any naturally occurring change to benthic habitat (e.g. due to high energy conditions associated with tropical cyclones) will have occurred equally both inside and outside these areas.

The 2019 results from inside and outside the 'impacted' areas are presented below along with those from the reference areas. In addition, and as shown in Table 4-3, image analysis data from three areas outside the priority areas in deeper or shallower water are presented separately due to their characteristics. These include:

- The sections of transects which traversed the High Relief Terrace to the north of Priority Area C are presented as Area C (S)
- The sections of transects which traversed the deeper areas to the south and east of Priority Area A are presented as Area A (DS)

- The entire Transect 35 which traverses Priority Area B is presented as Area B.

Categories such as sponge, coralline algae, cyanobacteria, turf algae (on large dead coral) and other organisms (generally with <3% cover) are grouped into the 'Other' category or are removed from the graphical representations to allow for a more targeted discussion on the major differences between more significant groupings. Removal of the data from these low categories still left >95% of all data available for comparisons.

4.3.3.1 Across Douglas Shoal

The benthic habitat within and surrounding the priority areas at Douglas Shoal in 2019 are dominated by macroalgae (38.5%) and turf algae growing on hard substrate (32.6%) (Table 4-3 and Figure 4-12). Hard coral (3.8%) and soft coral (2.0%) are sparse and low in abundance. Rubble and sandy areas devoid of benthos cover 10.2% and 9.3% of the area respectively. Dead coral fragments cover <1% of the shoal while coralline algae, sponge, and other organisms represent the remaining 3% cover. Examples of the benthos found on Douglas Shoal are provided in Figure 4-13. A full list of hard and soft coral families and genera observed during the analysis is provided at Table 4-6.

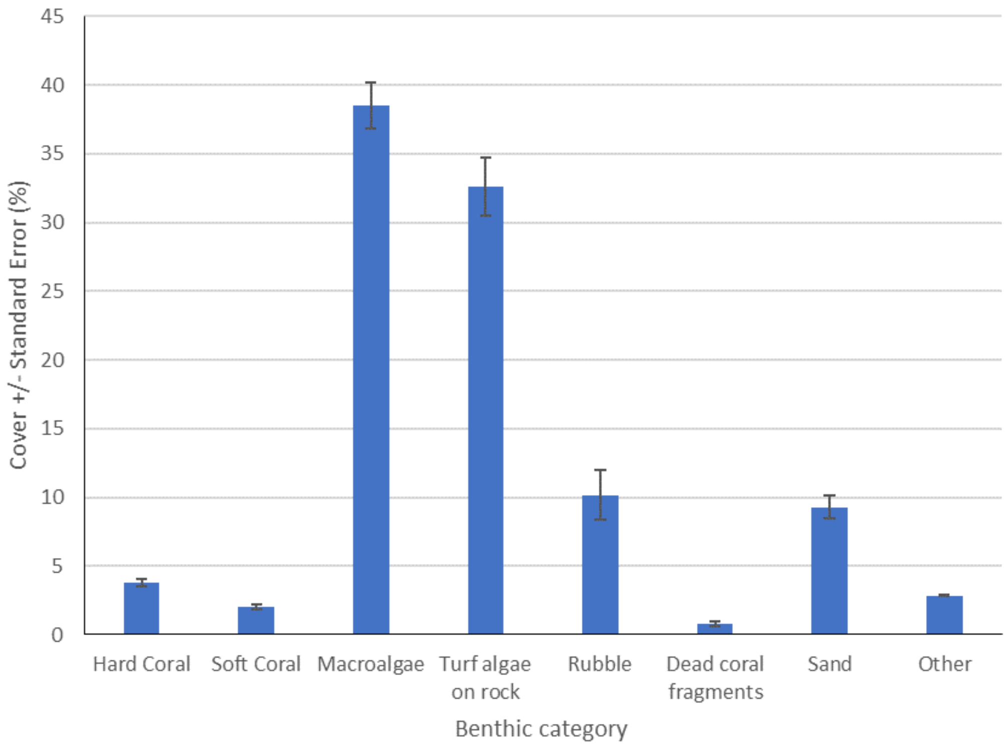
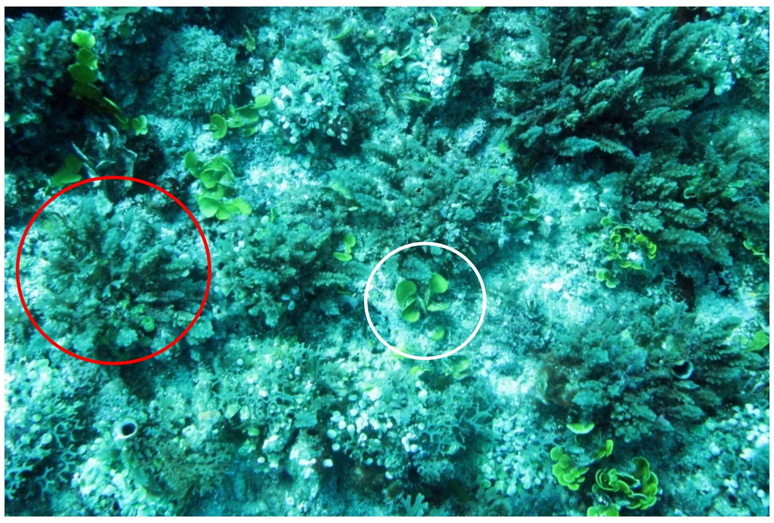


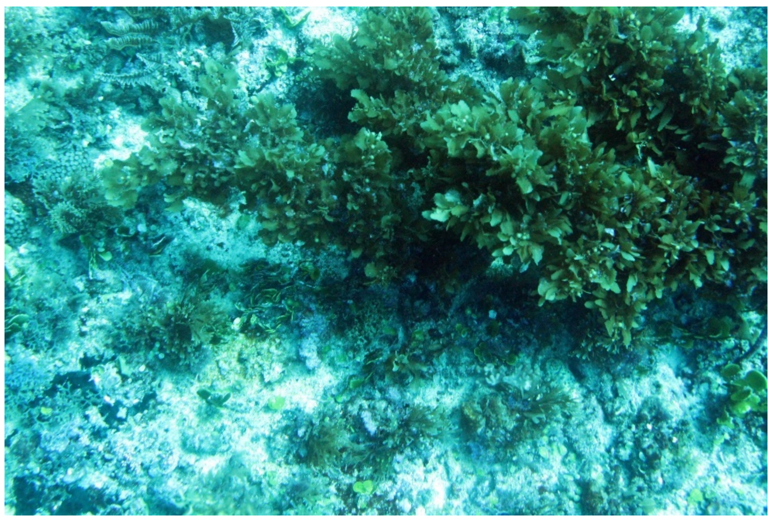
Figure 4-12 Percentage covers (+/- standard error) of broad benthic groups at Douglas Shoal



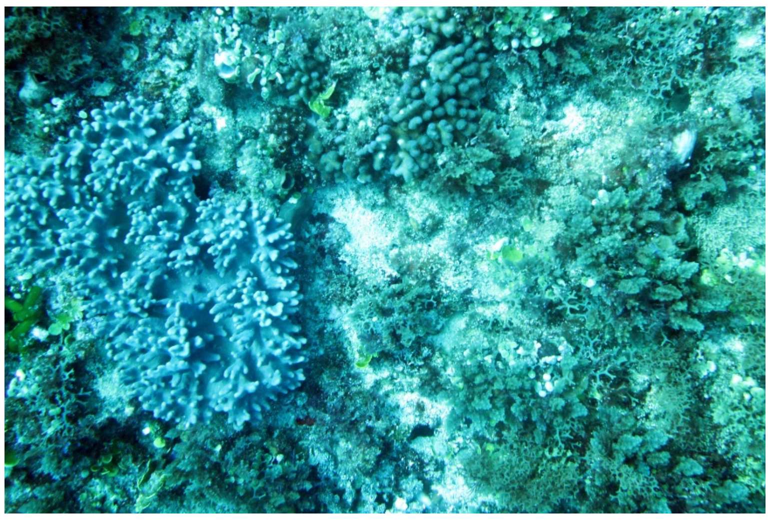
Asparagopsis (red circle) and *Halimeda* (white circle) *spp.*

Dictyota (red circle) and young *Sargassum* (white circle) *spp.*

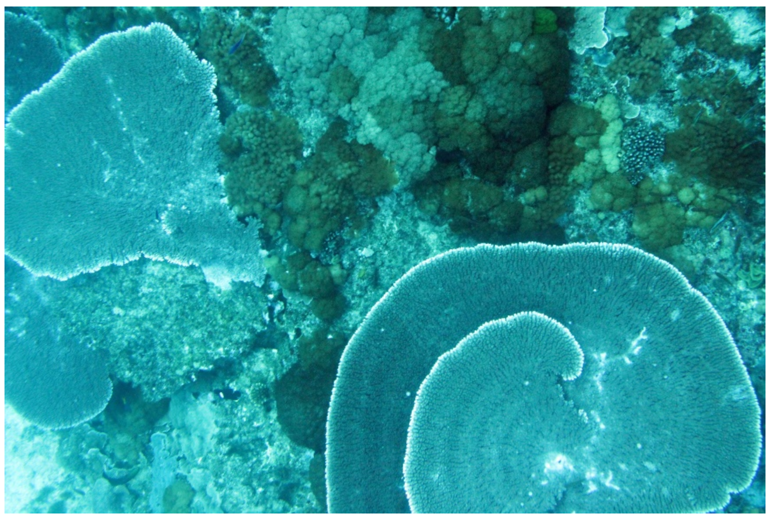
Complex benthic organisms



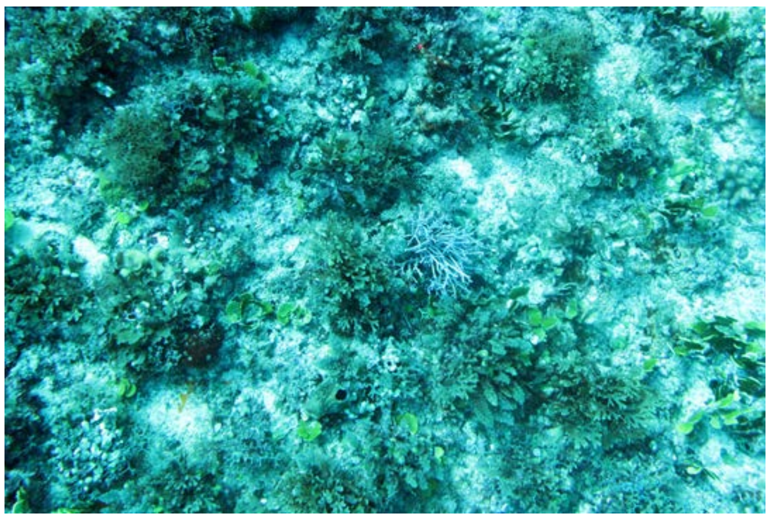
Mature *Sargassum spp.*



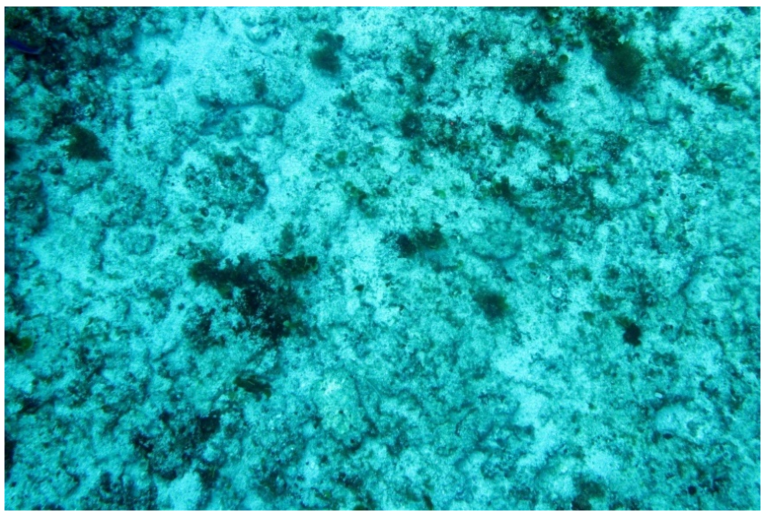
Soft corals and macroalgae assemblages



Tabulate *Acropora* and soft corals



Calcareous algae (center) and macroalgae assemblages



Turf Algae on rock

Figure 4-13 Examples of benthic organisms growing on the hard reef structure

Table 4-3 Percentage cover of focus benthic groups from towed underwater stills analysis

Priority Area (zone)	N (sample points)	Hard coral	Soft coral	Sponge	Macroalgae (Total)	Macroalgae subcategories						Turf algae on rock	Turf algae	Coralline algae	Cyanobacteria	Rubble	Sand	Dead coral fragments	Other
						Macroalgae assemblage	*Sargassum spp.*	*Dictyota spp.*	*Halimeda spp.*	*Asparagopsis spp.*	Macroalgae other								
Area A (I)	1415	3.3	2.7	0.6	44.9	1.0	5.7	18.8	12.4	3.8	3.2	30.5	2.7	0.1	0.4	10.4	3.5	0.2	0.8
Area A (O)	5244	3.8	2.6	1.0	29.3	5.2	1.0	10.0	9.1	2.4	1.5	51.2	1.0	0.2	1.1	2.3	6.2	0.5	0.8
Area C (I)	1426	2.2	0.9	0.4	41.7	3.6	17.2	7.0	10.9	1.2	1.8	22.1	0.2	0.1	2.0	23.5	6.5	0.0	0.4
Area C (O)	2167	3.3	1.5	0.8	45.1	6.2	15.3	10.8	7.6	2.4	2.8	21.8	0.0	0.2	0.3	16.4	9.9	0.1	0.7
Area E (I)	860	2.8	1.7	0.7	35.5	7.7	14.1	5.0	6.3	1.6	0.8	22.6	0.0	0.0	1.0	31.4	3.0	0.0	1.3
Area E (O)	3526	3.8	1.3	0.7	46.7	8.8	18.8	8.3	6.8	2.5	1.4	24.7	0.1	0.1	1.0	10.9	10.0	0.6	0.3
Area F (I)	420	1.2	0.2	1.2	29.3	3.1	15.2	2.9	6.9	1.0	0.2	18.6	0.0	0.0	1.0	47.9	0.7	0.0	0.0
Area F (O)	3821	4.0	1.6	0.6	42.5	8.5	16.4	7.9	6.9	1.9	0.9	29.0	0.0	0.1	0.9	9.3	9.9	0.9	1.1
Ref 1	688	3.3	2.6	0.7	27.0	9.9	4.7	1.7	7.3	3.1	0.4	46.9	0.4	0.1	1.9	0.0	14.0	2.8	0.1
Ref 2	908	2.9	1.7	0.6	46.3	12.8	18.5	6.1	5.8	1.5	1.5	20.8	0.0	0.0	0.2	0.0	22.9	4.5	0.2
Area A (DS)	615	4.9	6.7	1.8	4.7	0.0	0.0	4.4	0.2	0.0	0.2	60.2	0.0	0.0	1.5	2.6	16.9	0.2	0.7
Area B	752	1.9	1.9	0.9	44.9	15.4	5.6	5.5	12.4	5.3	0.8	31.6	0.1	0.0	0.7	0.9	14.2	2.3	0.5
Area C (S)	783	15.2	6.4	0.8	19.9	5.0	1.4	5.2	5.1	1.5	1.7	45.5	0.1	0.3	0.9	7.8	2.0	0.0	1.1
Average		3.8	2.0	0.4	38.5							32.6	0.4	0.1	0.1	10.2	9.3	0.8	0.7

Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas

4.3.3.2 *Inside and outside impacted areas*

Comparisons between the broad categories of benthic habitat and benthos inside and outside the impacted areas are shown in Figure 4-14 and Table 4-4. Outside the impacted areas, hard and soft coral, macroalgae, turf algae on rock, sand and other benthos were more abundant. The impacted areas were characterised by a very high cover of rubble. Closer examination of the rubble / sand / dead coral fragments categories (Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas)
Figure 4-15) show the cover of rubble is highest inside the impacted areas in Priority Area F (47.9%), followed by Priority Area C (23.5%), Area E (31.4%) then Area A (10.4%). Dead coral fragments are predominately found outside the impacted areas and in reference areas (Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas)

Figure 4-16). The visual differences between rubble and dead coral fragments are discussed in Section 6.1.1.

Comparison of the 2019 towed video survey results with results derived from the survey in 2010 (Negri et al. 2010) are challenged by differences between the surveys in terms of coverage and analysis undertaken. Notwithstanding this, a qualitative comparison shows that results from both surveys found low cover of hard coral (<8%) and high abundance of macroalgae and 'bare' reef pavement. Care must be taken when considering macroalgae cover as the majority of the macroalgae observed was *Sargassum spp.*, the abundance of which is highly seasonal. Both surveys were undertaken at similar times of the year (mid-April in 2010 and late May in 2019) and therefore the abundance of macroalgae is reasonably comparable.

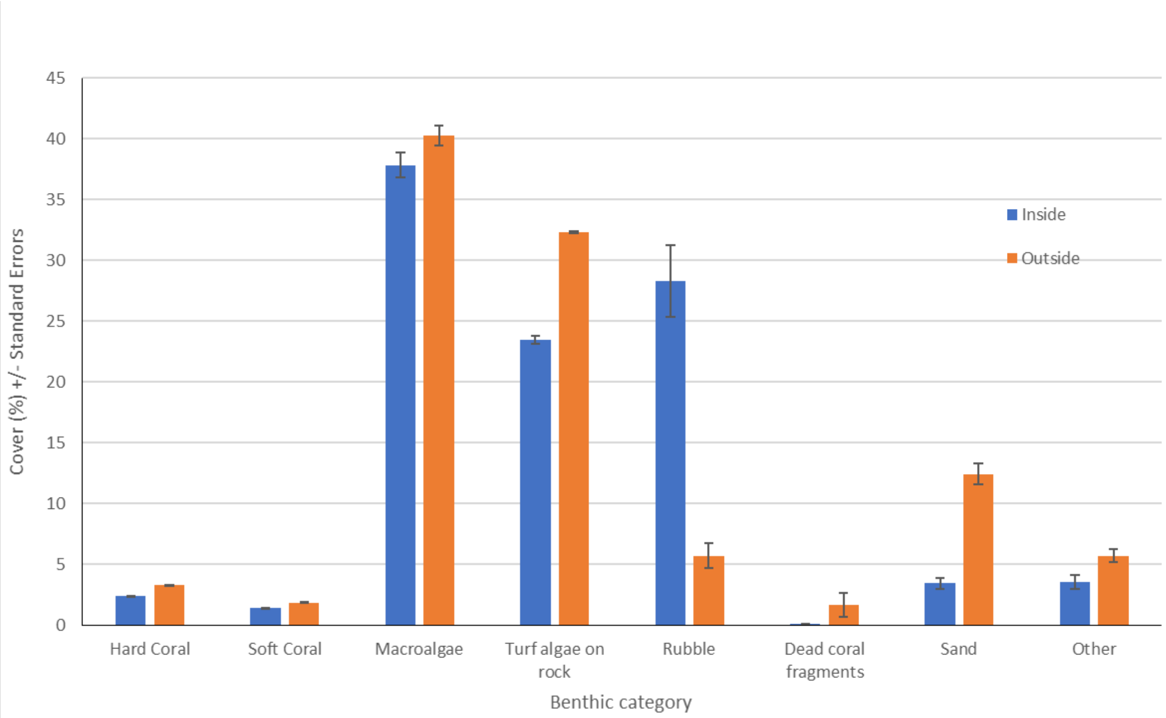


Figure 4-14 Percentage covers (+/- standard error) of benthic groups inside and outside the impacted areas

Table 4-4 Percentage covers of benthic groups inside and outside the impacted areas

Zone	Hard Coral	Soft Coral	Macroalgae	Turf algae on rock	Rubble	Sand	Dead coral fragments	Other
Inside	2.4	1.4	37.8	23.4	28.3	3.4	0.1	3.6
Outside	3.3	1.9	40.3	32.3	5.7	12.4	1.7	5.7

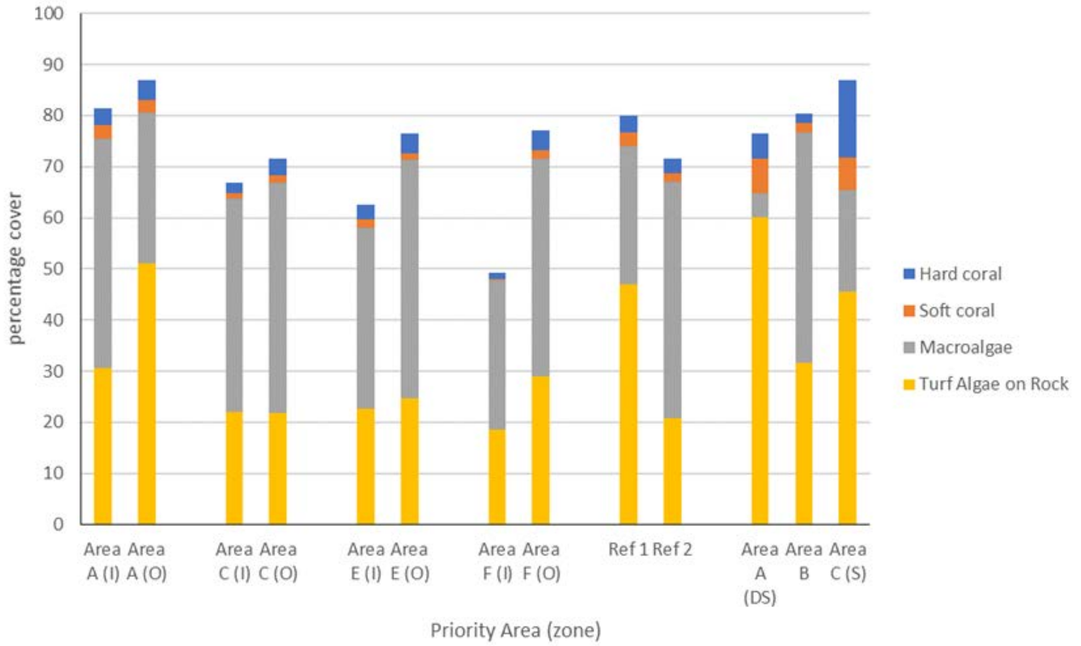
4.3.3.3 Priority areas and surrounds

Hard coral cover was highest on the High Relief Terrace (15.2%) and lowest inside the grounding footprint at Area F (1.9%). Hard coral cover was below 5% at all sites including the reference areas but slightly higher in areas outside the grounding footprint compared to those inside the footprint across all priority areas. Hard corals, where found, were dominated by corals from the genus *Acropora* and *Stylophora*, with very sparse (<1%) cover of *Seriatopora*, *Pocillopora* and *Montipora.*

Soft coral cover was highest in the deeper areas outside of Priority Area A (6.7%) and lowest inside the grounding footprint of Priority Area F (0.2%). Soft coral cover inside the grounding footprint was similar or lower than outside the footprint.

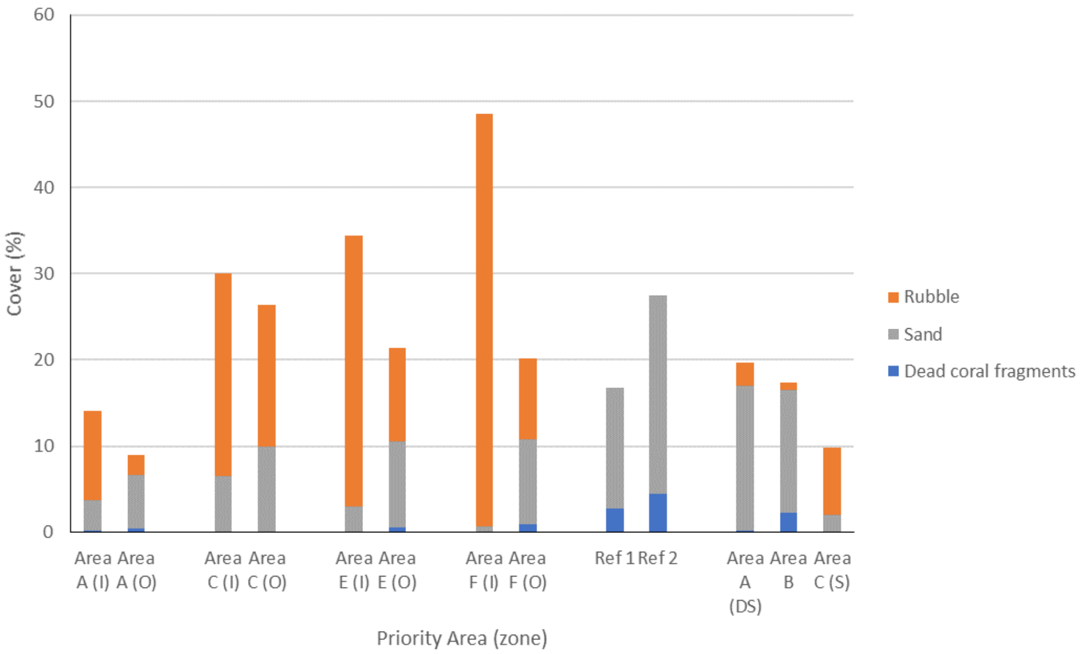
Turf algae growing on the reefal structure (rock) represented the highest category of benthos, ranging from 60.2% cover in the deeper sections outside of Priority Area E to 18.6% inside the grounding footprint of Priority Area F. The cover of turf algae on rock was generally higher outside of the grounding footprint.

Macroalgae is most abundant outside Priority Area E (46.7%), but similarly abundant at several locations. The lowest abundance of macroalgae occurred in the deeper areas outside of Priority Area A (4.7%). Macroalgae cover was generally higher outside of the grounding footprint except in Priority Area A. Macroalgal communities were dominated by the genus *Sargassum, Dictyota* and *Halimeda spp*.



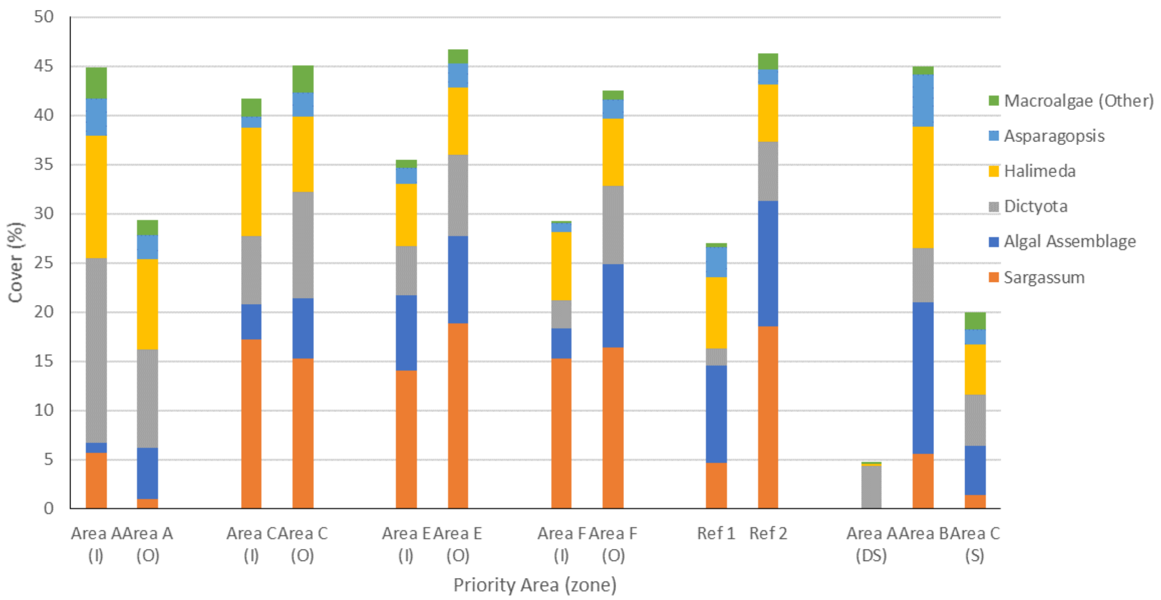
Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas)

Figure 4-15 Selected live benthic habitat percentage covers across all priority areas and impacted areas



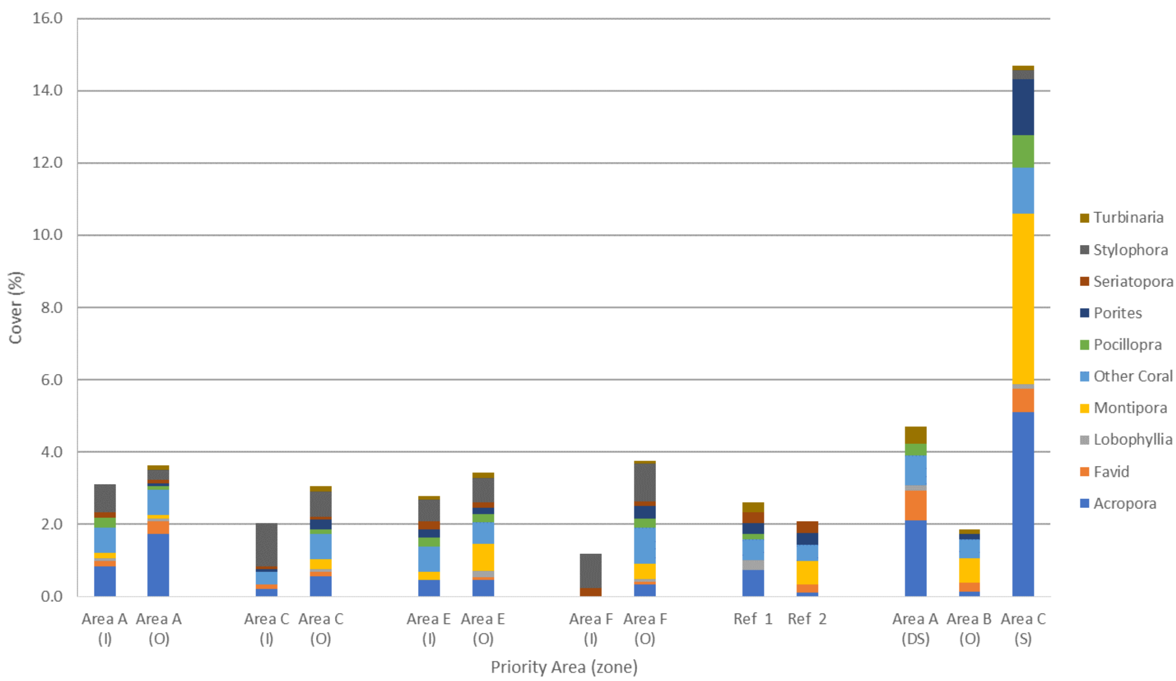
Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas)

Figure 4-16 Selected dead (abiotic) benthic habitat percentage covers across all priority areas and impacted areas



Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas)

Figure 4-17 Macroalgae categories percentage cover across all priority areas and impacted areas



Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas)

Figure 4-18 Percentage cover of the major coral categories across all priority areas and impacted areas

Table 4-5 Selected coral cover categories and their percentage cover across all priority areas and impacted areas

Priority Area (zone)	*Acropora spp.*	*Favid spp.*	*Lobophyllia spp.*	*Montipora spp.*	Other Coral	*Pocillopora spp.*	*Porites spp.*	*Seriatopora spp.*	*Stylophora spp.*	*Turbinaria spp.*
Area A (I)	0.85	0.14	0.07	0.14	0.71	0.28	0.00	0.14	0.78	0.00
Area A (O)	1.74	0.36	0.06	0.10	0.71	0.10	0.10	0.10	0.27	0.11
Area C (I)	0.21	0.14	0.00	0.00	0.35	0.00	0.07	0.07	1.19	0.00
Area C (O)	0.57	0.13	0.06	0.28	0.69	0.13	0.28	0.06	0.69	0.16
Area E (I)	0.47	0.00	0.00	0.23	0.70	0.23	0.23	0.23	0.58	0.12
Area E (O)	0.45	0.09	0.17	0.77	0.60	0.23	0.17	0.14	0.68	0.14
Area F (I)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.95	0.00
Area F (O)	0.34	0.08	0.08	0.42	0.99	0.26	0.34	0.13	1.05	0.08
Ref 1	0.73	0.00	0.29	0.00	0.58	0.15	0.29	0.29	0.00	0.29
Ref 2	0.11	0.22	0.00	0.66	0.44	0.00	0.33	0.33	0.00	0.00
Area A (DS)	2.11	0.81	0.16	0.00	0.81	0.33	0.00	0.00	0.00	0.49
Area B (O)	0.13	0.27	0.00	0.66	0.53	0.00	0.13	0.00	0.00	0.13
Area C (S)	5.11	0.64	0.13	4.73	1.28	0.89	1.53	0.00	0.26	0.13

Note: (I)= Inside impacted areas, (O) = Outside impacted areas, (DS)= Deep Shelf outside impacted areas, (S)= Shallow Shelf outside impacted areas

Table 4-6 List of families, genera and growth forms of hard and soft coral, macroalgae and other organisms found during the towed underwater video analysis

Group	Family or description	Genus	Growth Form
Hard Coral	ACROPORIDAE	*Acropora spp.*	Corymbose Acropora
	ACROPORIDAE	*Montipora spp.*	Foliose non-Acropora
	ACROPORIDAE	*Montipora spp.*	Encrusting non-Acropora
	ACROPORIDAE	*Montipora spp.*	Massive non-Acropora
	ACROPORIDAE	*Acropora spp.*	Staghorn Acropora
	ACROPORIDAE	*Acropora spp.*	Tabulate Acropora
	ACROPORIDAE	*Acropora spp.*	Branching Acropora
	ACROPORIDAE	*Isopora spp.*	Submassive Acropora
	ACROPORIDAE	*Acropora spp.*	Digitate Acropora
	DENDROPHYLLIIDAE	*Turbinaria spp.*	Encrusting non-Acropora
	DENDROPHYLLIIDAE	*Turbinaria spp.*	Foliose non-Acropora
	EUPHYLLIDAE	*Euphyllia spp.*	Massive non-Acropora
	FAVIIDAE	*Favia spp.*	Massive non-Acropora
	FAVIIDAE	*Echinopora spp.*	Encrusting non-Acropora
	FAVIIDAE	*Cyphastrea spp.*	Massive non-Acropora
	FAVIIDAE	*Favid spp.*	Massive non-Acropora
	FAVIIDAE	*Goniastrea spp.*	Massive non-Acropora
	FAVIIDAE	*Platygyra spp.*	Massive non-Acropora

Group	Family or description	Genus	Growth Form
	FAVIIDAE	*Cyphastrea spp.*	Massive non-Acropora
	FAVIIDAE	*Cyphastrea spp.*	Encrusting non-Acropora
	FAVIIDAE	*Echinopora spp.*	Foliose non-Acropora
	MERULINIDAE	*Hydnophora spp.*	Massive non-Acropora
	MERULINIDAE	*Merulina spp.*	Foliose non-Acropora
	MUSSIDAE	*Scolymia vitiensis*	Solitary coral
	MUSSIDAE	*Lobophyllia spp.*	Massive non-Acropora
	OCULINIDAE	*Galaxea spp.*	Massive non-Acropora
	PECTINIIDAE	*Echinophyllia spp.*	Encrusting non-Acropora
	PECTINIIDAE	*Echinophyllia*	Encrusting non-Acropora
	POCILLOPORIDAE	*Pocillopora verrucosa/meandrina*	Submassive non-Acropora
	POCILLOPORIDAE	*Stylophora pistillata*	Submassive non-Acropora
	POCILLOPORIDAE	*Pocillopora damicornis*	Submassive non-Acropora
	POCILLOPORIDAE	*Seriatopora hystrix*	Branching non-Acropora
	PORITIDAE	*Goniopora spp.*	Submassive non-Acropora
	PORITIDAE	*Porites spp.*	Branching non-Acropora
	PORITIDAE	*Porites spp.*	Encrusting non-Acropora
	PORITIDAE	*Goniopora spp.*	Massive non-Acropora
	PORITIDAE	*Alveopora spp.*	Massive non-Acropora

Group	Family or description	Genus	Growth Form
	PORITIDAE	*Porites spp.*	Massive non-Acropora
	SIDERASTREIDAE	*Coscinaraea spp.*	Massive non-Acropora
Macroalgae	ALGAL ASSEMBLAGE	*Algal Assemblage*	N/A
	BROWN MACROALGAE	*Sargassum spp.*	N/A
	BROWN MACROALGAE	*Dictyota spp.*	N/A
	BROWN MACROALGAE	*Padina spp.*	N/A
	BROWN MACROALGAE	*Colpomenia spp.*	N/A
	BROWN MACROALGAE	*Lobophora spp.*	N/A
	GREEN MACROALGAE	*Chlorodesmis fastigiata*	N/A
	GREEN MACROALGAE	*Halimeda spp.*	N/A
	MACROALGAE	Macroalgae Other	N/A
	RED MACRO ALGAE	*Asparagopsis*	N/A
	RED MACRO ALGAE	Calcareous algae	N/A
Soft Coral	ALCYONIIDAE	*Sinularia spp.*	Arb & Enc Soft Coral
	ALCYONIIDAE	*Lobophytum spp.*	Encrusting Soft Coral
	ALCYONIIDAE	*Sarcophyton spp.*	Capitate Soft Coral
	ELLISELLIDAE	*Junceella spp.*	Soft coral
	GORGONIAN	*Gorgonia spp.*	Arborescent Soft Coral
	NEPHTHEIDAE	*Nephtha spp.*	Arborescent Soft Coral

Group	Family or description	Genus	Growth Form
	XENIIDAE	*Xenia spp.*	Capitate Soft Coral
Sponge	SPONGE	*Sponge spp.*	Sponge Encrusting
	SPONGE	*Sponge spp.*	Sponge
Other	MILLEPORIDAE	*Millepora spp.*	Millepora
	OTHER	*Ascidian*	Other organisms
	OTHER	*Zoanthid*	Zoanthid
	OTHER	*Hydroid*	Other organisms

Key points

Douglas Shoal does not have a complex range of features; however, some habitat diversity is evident. Habitat areas of the Low Relief Terrace of the shoal include:

- Undulating expanses of densely covered (predominately macroalgae) hard reef substrate with occasional sandy patches
- Channels or gutters containing large pieces of dead coral or coarse sand with gently sloping sides
- Flat expanses of low relief corals with minimal sediment
- Holes containing sand or dead coral fragments with densely inhabited steep walls.

The High Relief Terrace to the north and north-west of the shoal contains more complex features:

- Spur and groove outcrops with moderate coral cover rising several metres from the sea floor
- Deep channels with large fragments of broken coral and coarse sand with sparse tufts of macroalgae growing within the sediment.

The surveyed area of the Low Relief Terrace consists of large expanses of turf algae on rock (32.6%), macroalgae growing predominately on rock (38.5%) and hard (3.8%) and soft coral (2.0%) growing on rock, areas of grounding related rubble (10.2%), dead coral fragments (~1%) and sand (9.3%).

Sediment is not a dominant component of the substrate and is typically located in depressions as patches in undulating areas and in channels, gutters and holes. The depth of sediment is limited across the surveyed area of the shoal, ranging from 5mm to 400mm, and averaging 73mm.

Surveys undertaken immediately after the grounding in 2010 and in 2019 both found low cover of hard coral (<8%) and high abundance of macroalgae and 'bare' reef pavement outside the grounding footprint on the Low Relief Terrace.

Comparison of 2019 survey benthic habitat and benthos data from inside and outside the area assumed to be impacted by the grounding shows that outside the impacted areas, hard and soft coral, macroalgae, turf algae on rock, sand and other benthos were more abundant. The impacted areas were characterised by having very high cover of rubble. The cover of rubble is highest inside the impacted area in Priority Area F (47.9%), followed by Priority Area C (23.5%), Area E (31.4%) then Area A (10.4%). It is considered likely that the grounding caused habitat changes on the shoal including replacement of areas of 'turf algae on rock' and areas of 'sand' with 'rubble'.

5 Contamination

Sediment sampling undertaken immediately after the grounding incident in 2010 at Douglas Shoal was focused on the concentrations of metals, metalloids and organotins in response to evidence of significant loss of AFP from the hull of the *Shen Neng 1* due to the grounding event. Sampling effort was concentrated along areas where either AFP paint flecks / sheets were found, or reef damage was observed. Sampling and visual assessments of the hull of the *Shen Neng 1* showed variable damage along the boat's length, and in some locations, especially along the base of the hull, the top AFP coat, barrier coat, and historic AFP coat were exposed and / or lost (Monkivitch, 2010).

Evidence of AFP contamination was identified through these initial investigations in the form of smears on substrate and fractured substrate and as flakes, chips and microscopic particles. These initial investigations form the basis of the identification of contamination as one of the key concerns for natural recovery of the shoal.

5.1 Current contamination status

Sediment sampling undertaken in 2019 at Douglas Shoal as part of the site assessment was concerned with the spatial distribution and concentrations of metals, metalloids and organotins in the four priority remediation areas set out in Costen et al (2017). The sediment collected were also tested for physical characteristics including PSD and settleability, and sea floor sediment depths were measured at each sampling location.

The location of sampling sites had a sound statistical basis as described in the SAP (Advisian, 2019a), which required the subdivision of the priority areas into sub-areas to allow for specific areas or 'hotspots' to be identified and targeted for further investigation. The parameters analysed are listed in Section 3.1.1 and include the main constituents of the AFP paint that was applied to the vessel including TBT, copper and zinc oxides and the biocide zineb. An additional suite of metals and metalloids was analysed to enable consideration of the background conditions at the shoal.

As noted at Section 3.1.1, during the execution of fieldwork, visual observations were made to identify the location of any AFP smears (on substrate and fractured substrate) and AFP flakes or chips. No visible evidence of AFP smears, flakes or chips was identified during the survey, which may be due to erosion of particles over time. As part of the reporting of remediation trial activity (focused in three depressions within Priority Area A) Kettle (2015a) observed that neither flakes nor 'smeared' aggregates of paint were evident in intervening ridge areas between depressions, where previously they had been identified, and that deposits of 'smeared' AFP have progressively eroded. Kettle (2015a) did observe paint flakes or particles in the sediments collected by the diver operated vacuum apparatus when these sediments were closely examined onboard the vessel.

Tabulated laboratory and QA/QC results along with the statistical analyses of all chemical and physical results from sediment collected at Douglas Shoal in 2019 are provided in full in the Sediment Characterisation Report provided in Appendix A. The full set of laboratory results and summary tables are provided in Appendix B. The key results of the analysis with respect AFP contamination in sediment are discussed below including with reference to:

- Maps of each of the priority and reference areas showing the locations of the sampling sites and sub-areas
- Two different metal concentration analyses performed on the sediment samples:
  - Total extractable metals analysis to provide the overall concentration of metals in each sample
  - Weak acid digest analysis intended to approximate the fraction of the total metals concentration which is potentially bioavailable.

The main results of the laboratory analysis presented below are focused on bioavailable copper and zinc, TBT (normalised to 1% TOC), and zineb. Graphical representations of all results from each sub-area for total and bioavailable copper and zinc and organotins are provided in sections 5.1.1, 5.1.2 and 5.1.3, respectively.

In **Priority Area A** (Figure 5-1) sediment was collected from 97 sites and sent to the laboratory for analysis. TBT was detected at 48 sites; 35 sites were above the ANZG (2018) guideline of 9µgSn/kg. Copper was detected at 55 sites; five sites were above the ANZG (2018) guideline of 65mg/kg. Zinc was detected at 48 sites; no sites were above the ANZG (2018) guideline of 200mg/kg. Elutriate testing of samples from Priority Area A which exceeded the ANZG (2018) guidelines found 15 samples (of the 48 tested) with TBT concentrations (ng Sn/L) above the ANZG 99% Species Protection Guideline. Three (of the five elutriate tested for elevated copper) samples had copper (µg/L) above the ANZG 99% Species Protection Guidelines. No zineb was detected in samples tested.

In **Priority Area C** (Figure 5-2) sediment was collected from 45 sites. TBT was detected at 22 sites; three sites were above the ANZG (2018) guideline of 9µgSn/kg. Copper was detected at 15 sites; no sites were above the ANZG (2018) guideline of 65mg/kg. Zinc was detected at 19 sites; no sites were above the ANZG (2018) guideline of 200mg/kg. Elutriate testing of the 22 samples from priority Area C where TBT was detected found one sample (site CX-8) had a TBT concentration (ng Sn/L) above the ANZG 99% Species Protection Guideline. No zineb was detected in samples tested.

In **Priority Area E** (Figure 5-3) sediment was collected from 38 sites. TBT was detected at three sites; one site was above the ANZG (2018) guideline of 9µgSn/kg. Copper was detected at three sites, no sites were above the ANZG (2018) guideline of 65mg/kg. Zinc was detected at nine sites, no sites were above the ANZG (2018) guideline of 200mg/kg. Elutriate testing of the three samples where TBT was detected found no sites had a TBT concentration (ng Sn/L) above the ANZG 99% Species Protection Guideline. No zineb was detected in samples tested.

In **Priority Area F** (Figure 5-4) sediment was collected from 45 sites. TBT was not detected. Copper was detected at one site, below the ANZG (2018) guideline of 65mg/kg. Zinc was detected at six sites; no sites were above the ANZG (2018) guideline of 200mg/kg. Elutriate testing was not undertaken and therefore no analysis for zineb was undertaken in this priority area.

In **reference areas** (Figure 5-5) sediment was collected from 12 sites. TBT, copper and zinc was not detected in any of the samples. Elutriate testing was not undertaken and therefore no analysis for zineb was undertaken in these areas.

Visual inspection of the data suggests that Priority Area A is a 'hotspot' for AFP contamination.

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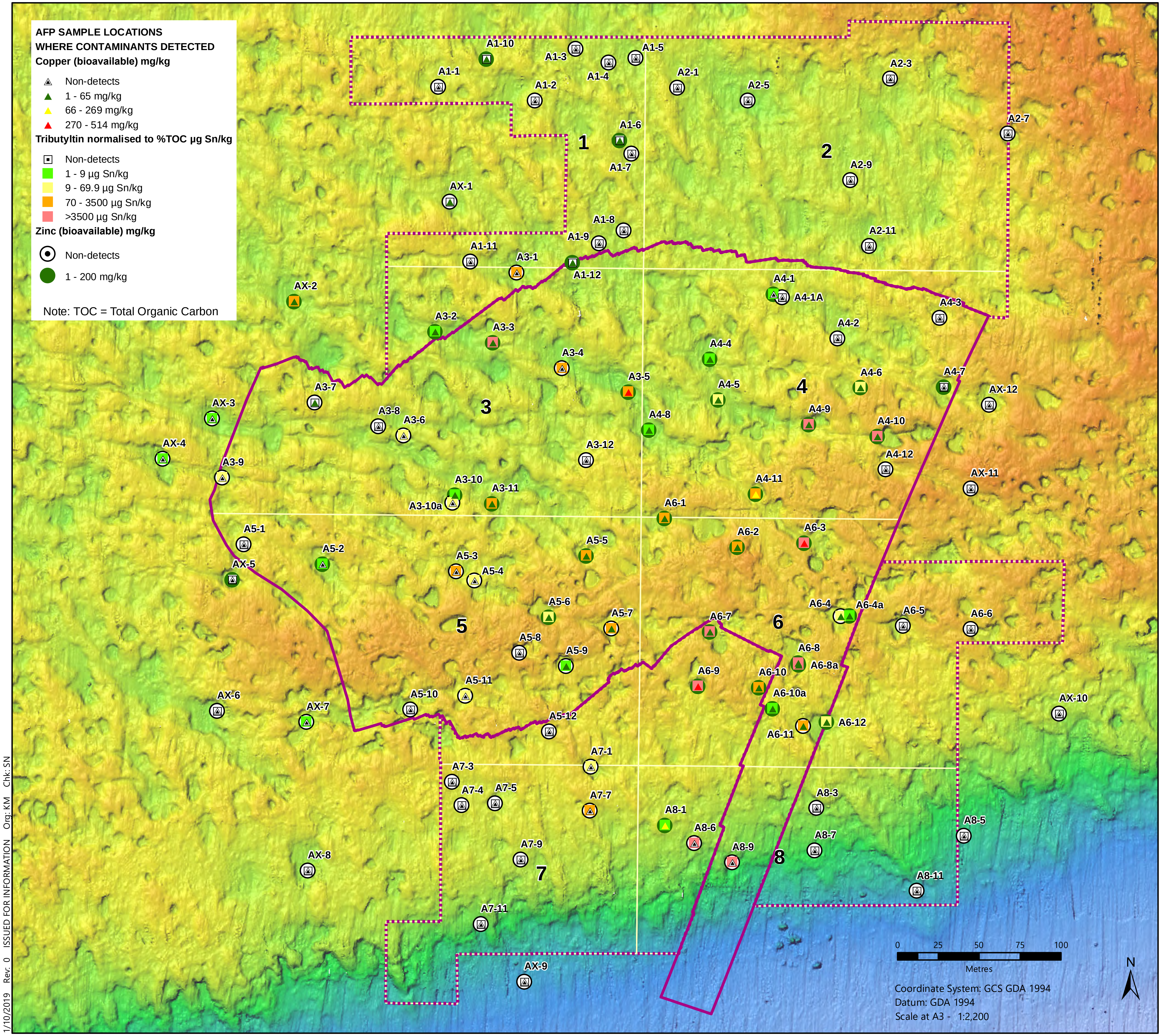
Figure 5-1
AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area A

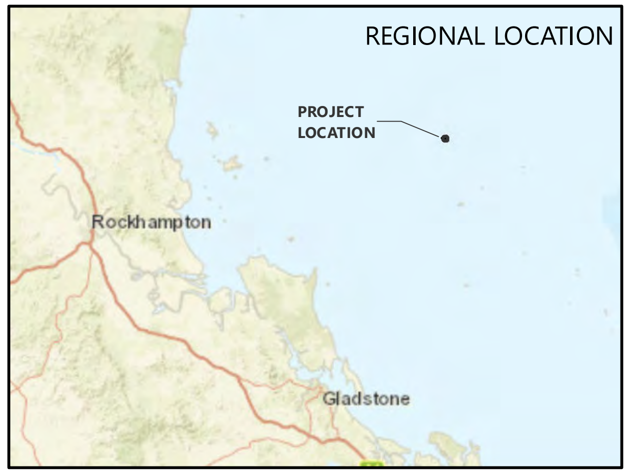


Priority Area
A
A - outside grounding footprint
Priority area A sampling subarea

Bathymetry
-23.0m -9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019



Advisian
Worley Group

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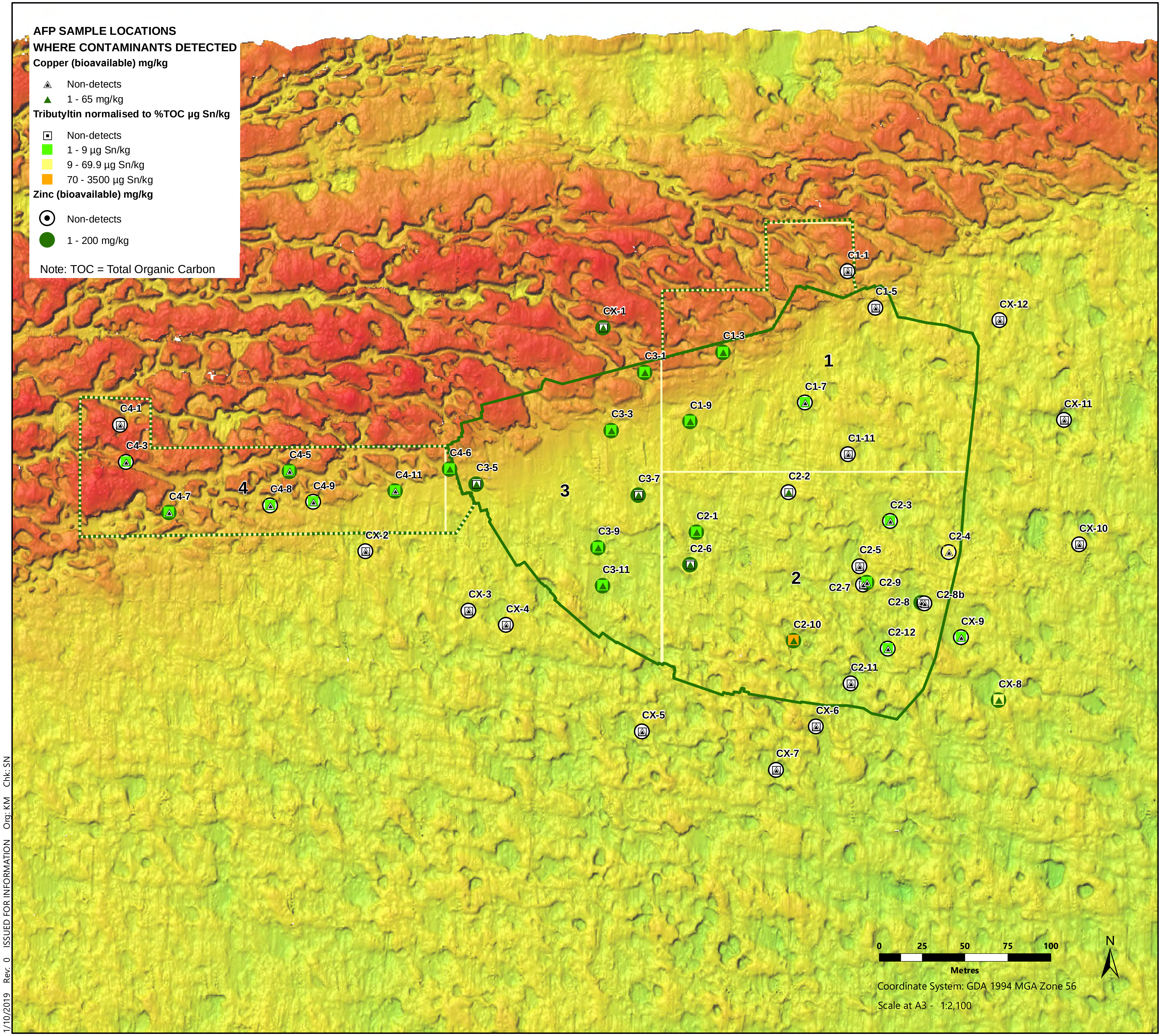
Figure 5-2
AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area C



Priority Area

C

C - outside grounding footprint

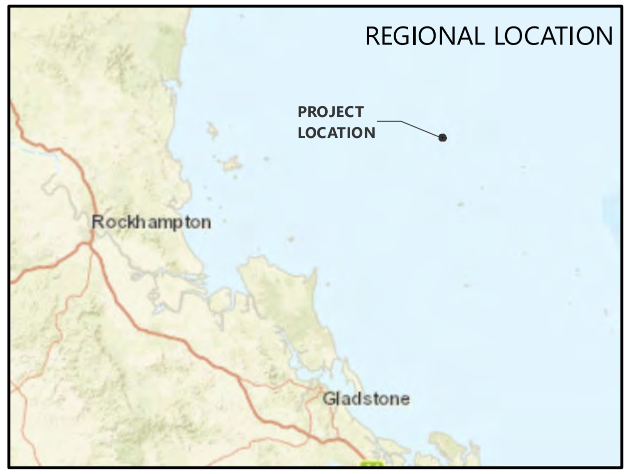
Priority Area C Sampling Sub-area

Bathymetry

-23.0m -9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019



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Worley Group

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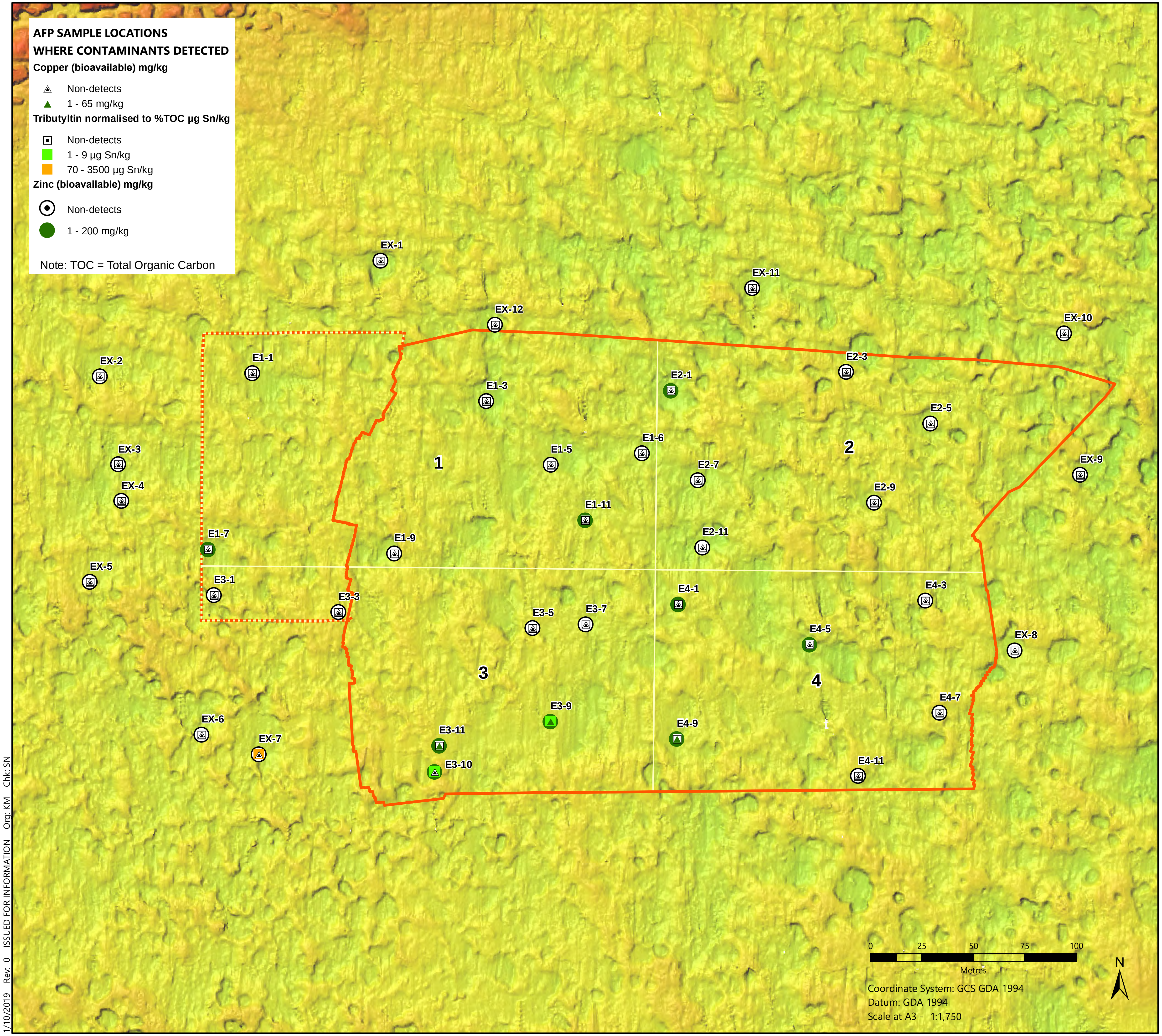
Figure 5-3
AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area E



Priority Area
E
E - outside grounding footprint
Priority Area E Sampling Sub-area

Bathymetry
-23.0m
-9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019

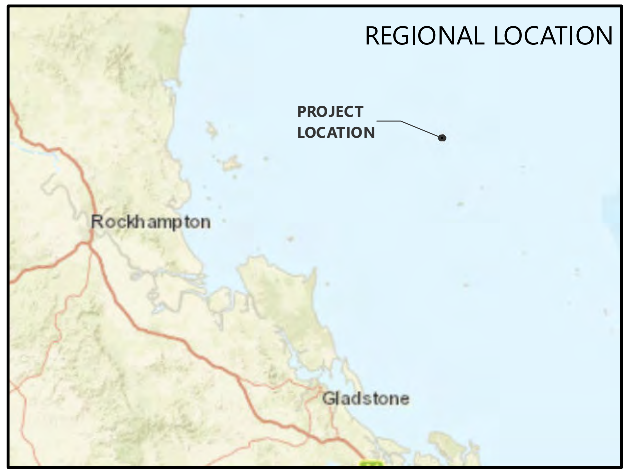


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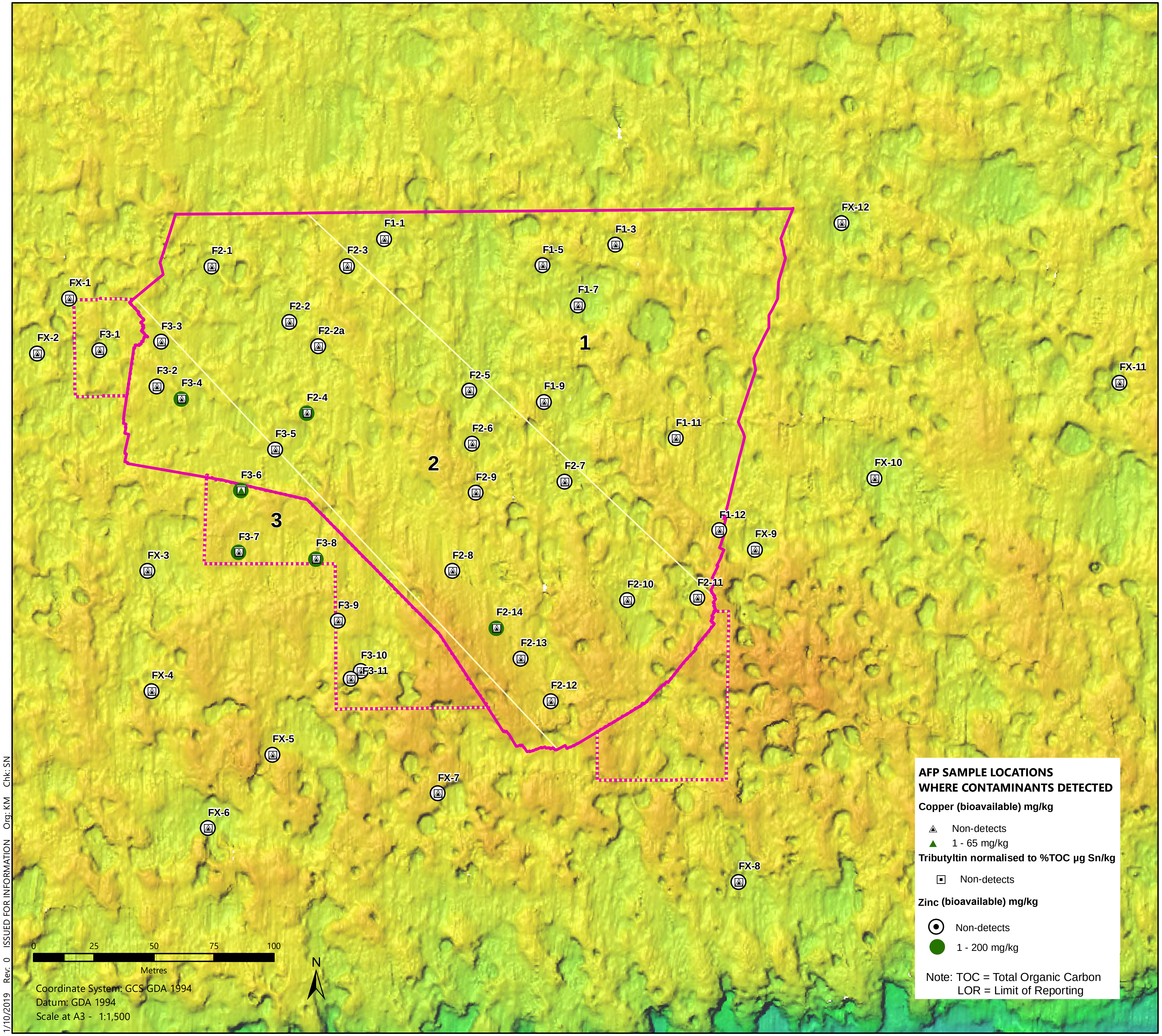
Figure 5-4
AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area F



Priority Area

F

F - outside grounding footprint

Priority Area F Sampling Sub-area

Bathymetry

-23.0m -9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019

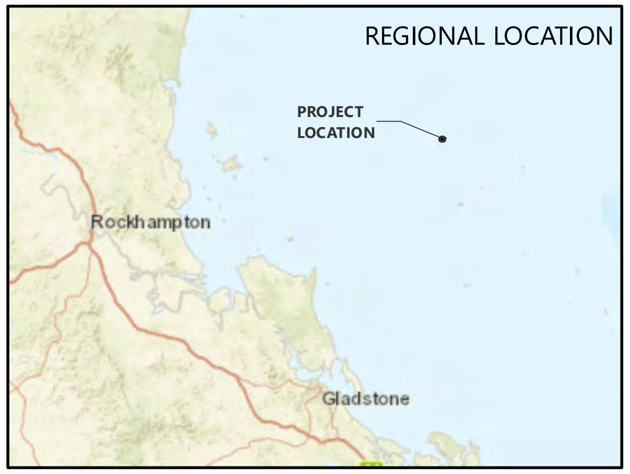


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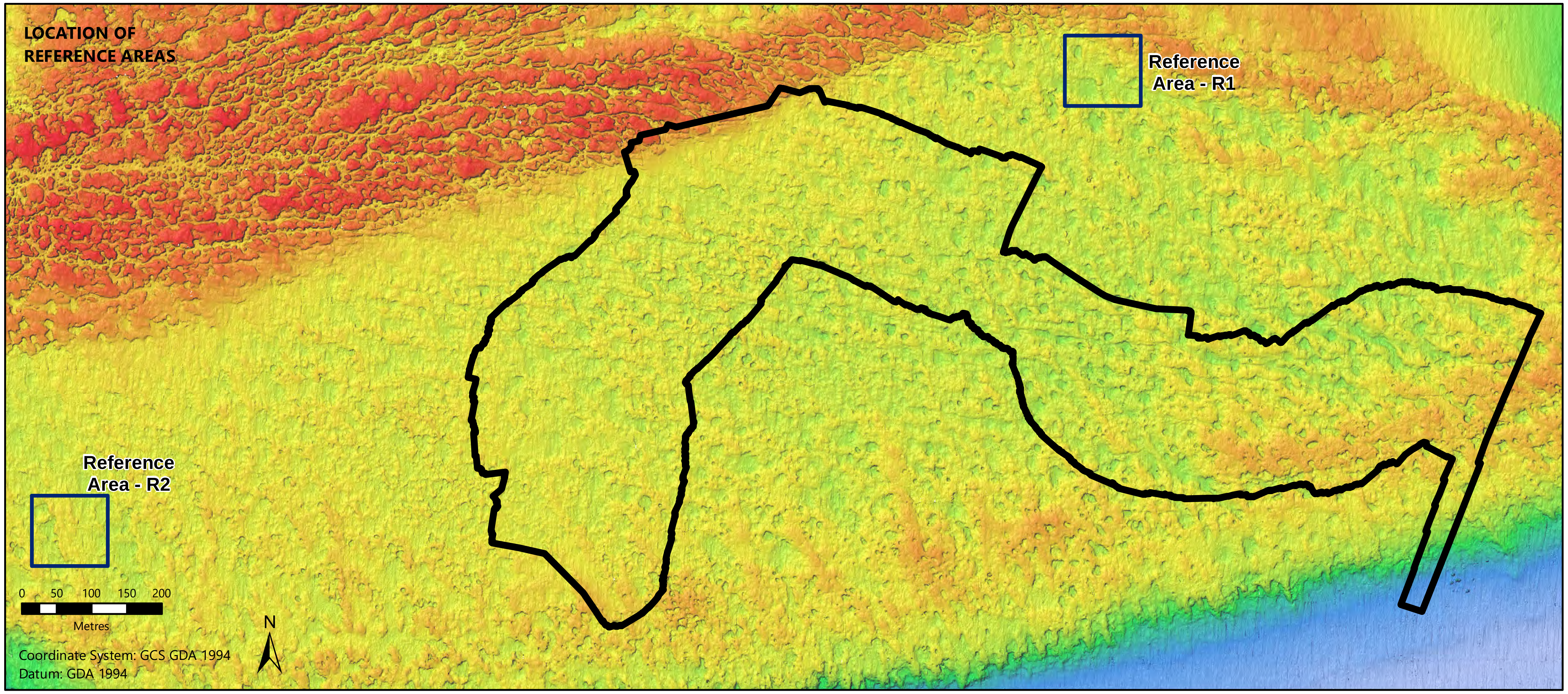
Figure 5-5
AFP* Constituent Concentrations at Sediment Sampling Sites in the Reference Areas



Reference areas
Grounding footprint

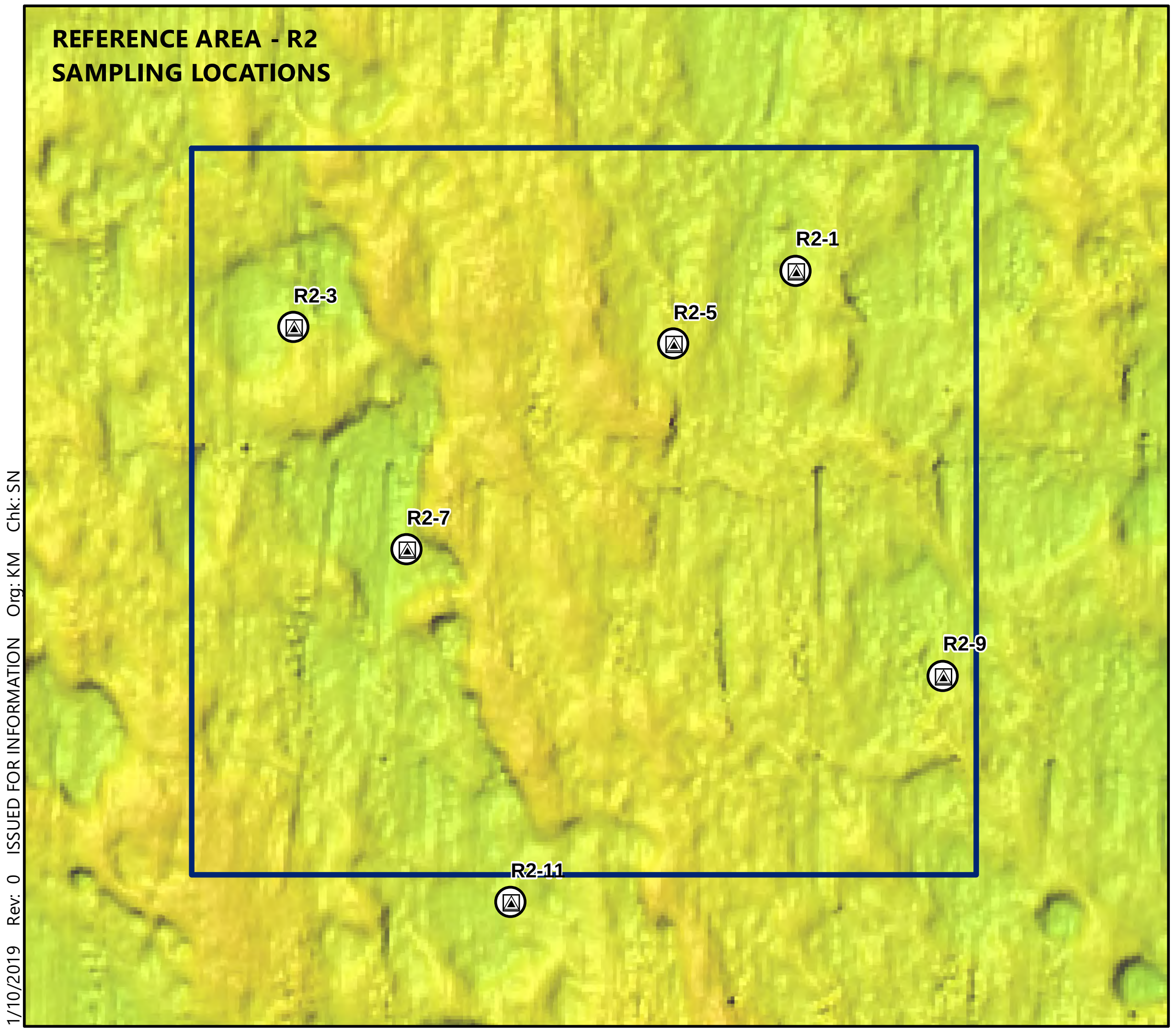
Bathymetry
-23.0m -9.0m

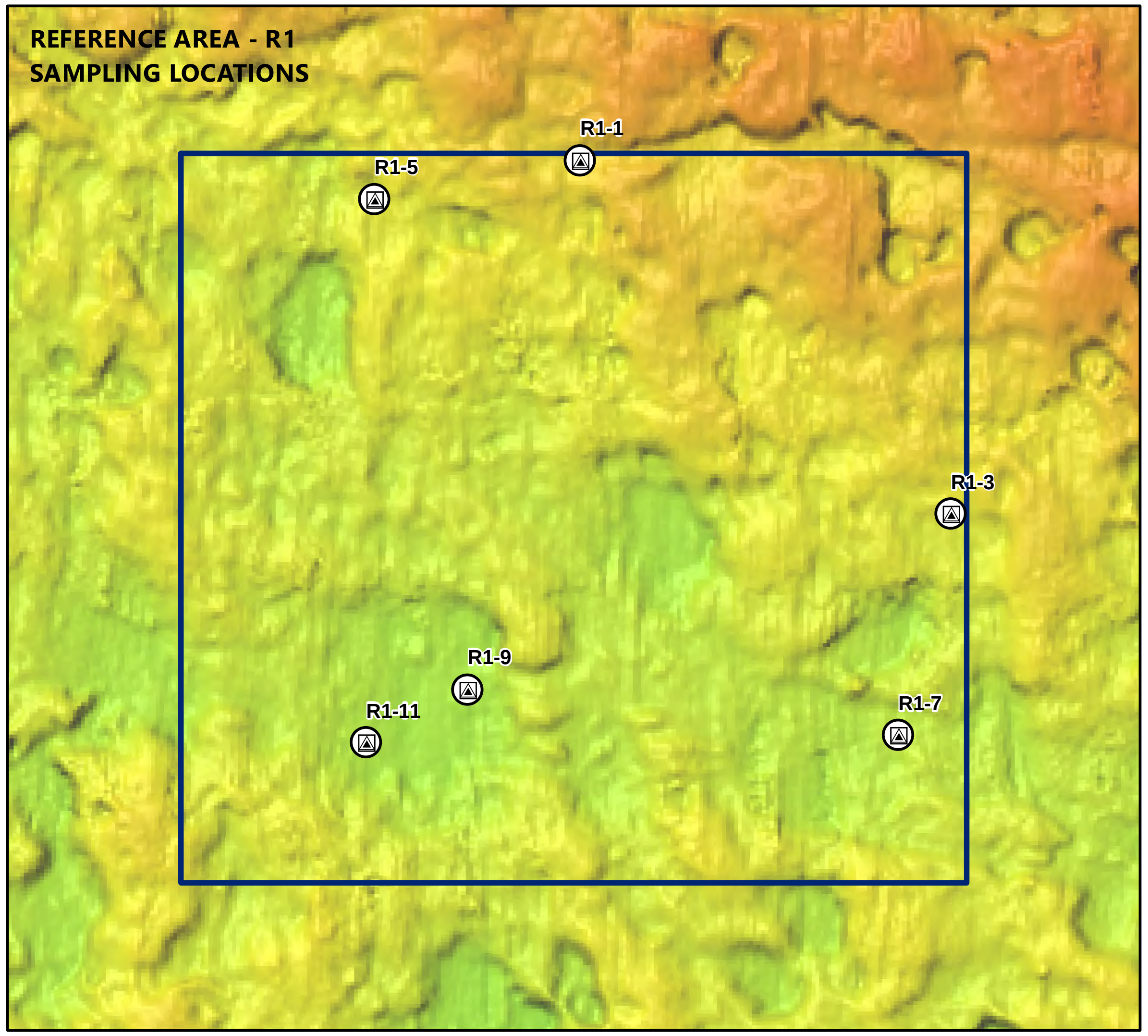
AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (bioavailable) mg/kg
Non-detects

Tributyltin normalised to %TOC μg Sn/kg
Non-detects

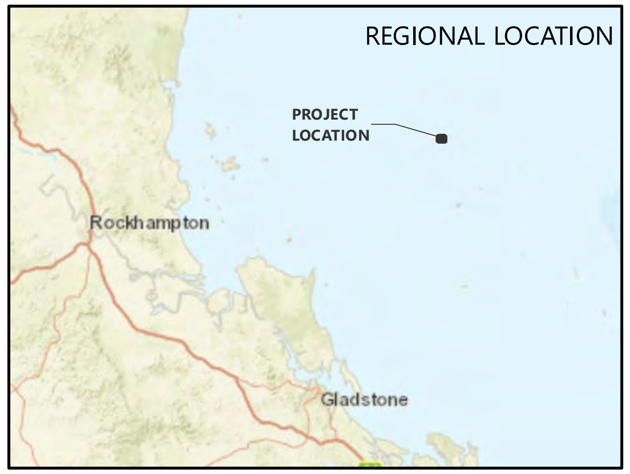
Zinc (bioavailable) mg/kg
Non-detects





AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019



Advisian
WorleyParsons Group

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5.1.1 Total copper and zinc

The mean concentrations of total copper and total zinc were graphed to compare across sub-areas and priority areas and to identify where samples exceeded the ANZG (2018) default guideline value. These graphs are shown in Figure 5-6 and Figure 5-7, with ± standard deviation in each sub-area shown by vertical blue lines, and concentration scales varying between contaminants.

Elevated mean concentrations of total copper and zinc were found in sub-areas within the priority areas compared to the reference areas; however, results for these sub-areas also showed a high standard error. The variation was due to higher concentrations in only one or two of the sampling sites of those sub-areas. Significant results include:

- The mean concentration of total copper (mg/kg) was higher at sub-areas A4 and A6 in comparison to the reference areas (R1 and R2) and all other sub-areas (Figure 5-6). The elevated mean concentrations at A4 and A6 were due to high values in one of 13 sampling sites in sub-area A4 and one of 15 sampling sites in sub-area A6.
- The mean concentration of total zinc (mg/kg) was highest at sub-area A6 in comparison to reference areas R1 and R2 and all other sub-areas (Figure 5-7). The elevated mean concentration was due to a high value in one of 15 sampling sites in sub-area A6.

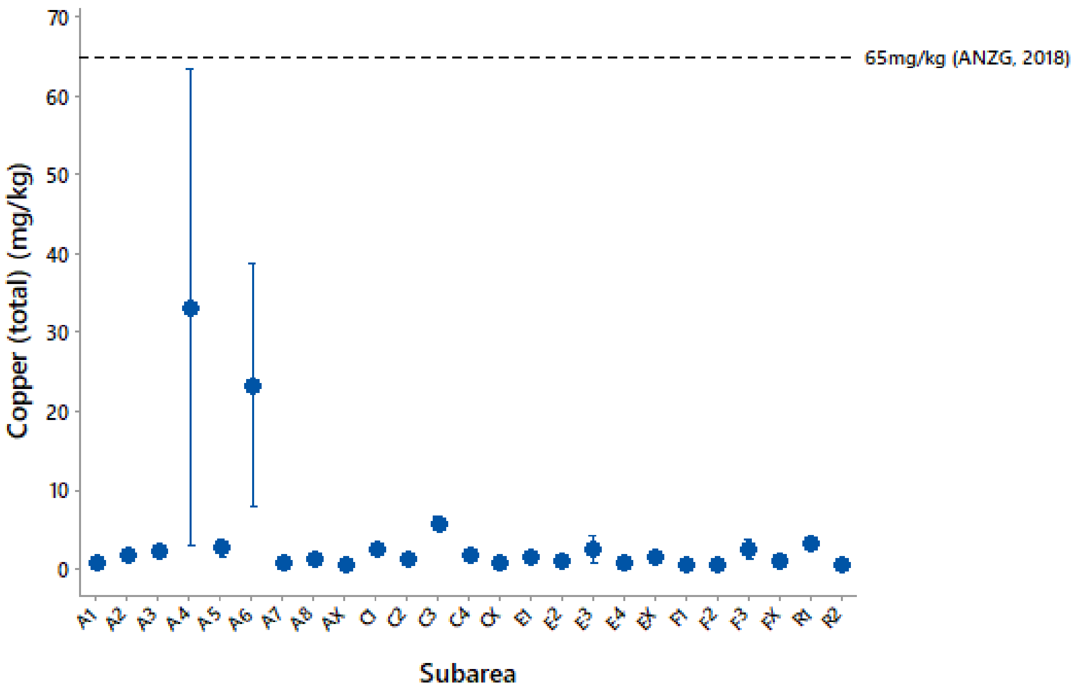

Figure 5-6: Mean concentrations of total copper (mg/kg) (+/- standard error) by sub-area with the ANZG (2018) default guideline value of 65mg/kg

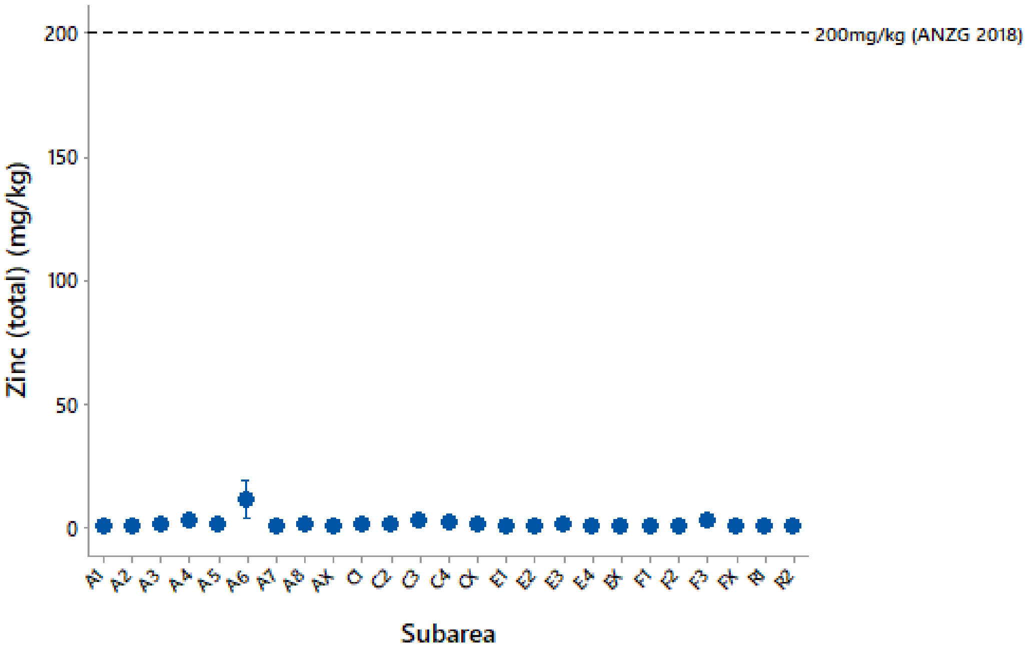

Figure 5-7: Mean concentrations of total zinc (mg/kg) (+/- standard error) by sub-area, with the ANZG (2018 default guideline value of 200mg/kg

5.1.2 Bioavailable copper and zinc

The mean concentrations (± standard error represented as blue vertical bars on each graph) of bioavailable metals and metalloids were plotted to compare across sub-areas and priority areas and to identify where samples exceeded the ANZG (2018) default guideline value.

Mean concentration of bioavailable copper (Figure 5-8) was higher at sub-areas A3 and A6 in comparison to reference areas R1 and R2 in which all sample concentrations were below the LOR. The elevated mean concentration in sub-areas A3 and A6 was due to one or two samples from sub-areas A3 and A6 which had concentrations above the ANZG (2018) guideline of 65 mg/kg. Mean concentration of bioavailable zinc (Figure 5-9) was higher at sub-areas A1, A3, A4, A6 and A8 in comparison to reference areas R1 and R2. The elevated mean concentration was due to high values in one or two sampling sites in each sub-area.

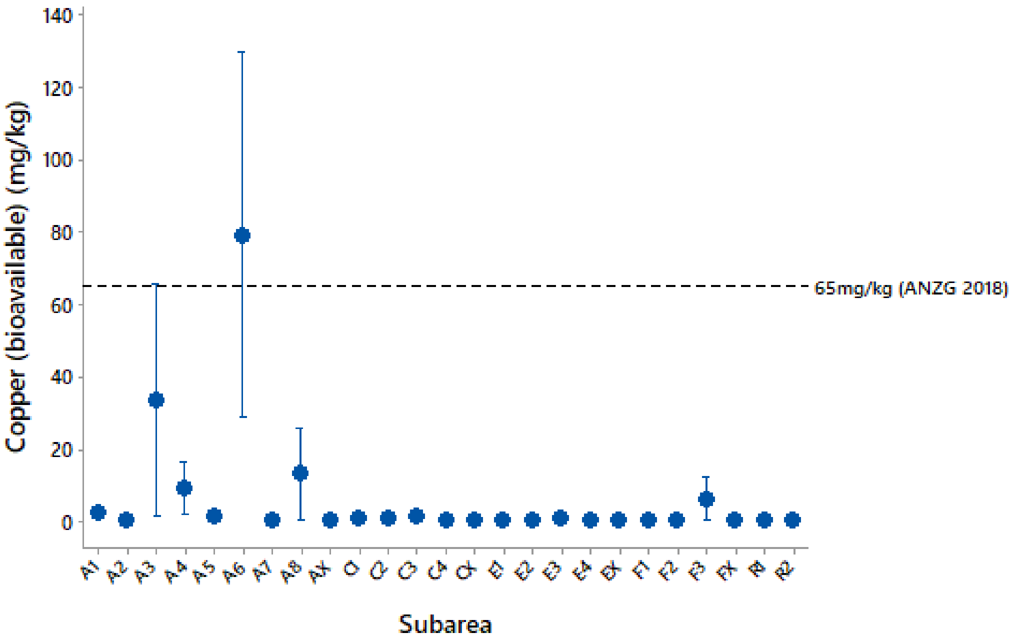

Figure 5-8 Mean concentrations (+/- standard error) of bioavailable copper (mg/kg) by sub-area with the ANZG (2018) default guideline value of 65mg/kg

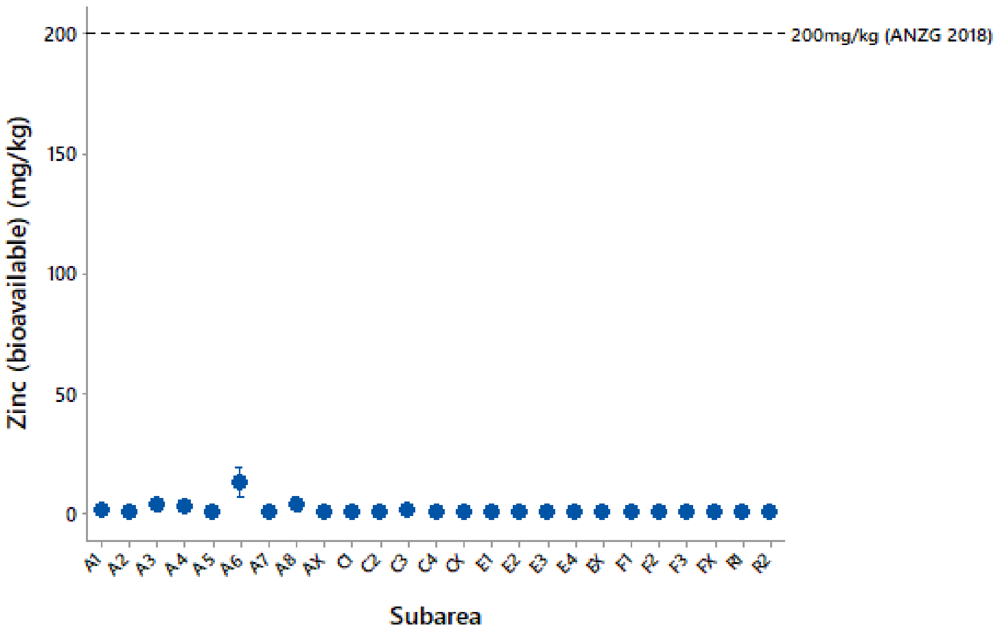

Figure 5-9 Mean concentrations (+/- standard error) of bioavailable zinc (mg/kg) by sub-area with the ANZG (2018) default guideline value of 200mg/kg

5.1.3 Organotins

The organotin, TBT, was a constituent of the AFP applied to the hull of the *Shen Neng 1* and is a highly toxic compound when ingested by marine organisms (Garg *et al* 2009). TBT will eventually breakdown into the organotins DBT and then MBT over time due to natural processes.

To provide a more accurate approximation of the concentration of TBT in sediments which is bioavailable, the measured concentrations of TBT in the sediment were normalised to the percentage of TOC in that sample (NAGD, 2009). Most sediment samples from Douglas Shoal contain small amounts of TOC (<1%) meaning that once TBT concentrations are normalised to 1% TOC the TBT concentrations are increased by up to 5 times the measured concentration.

There was high 'within sub-area variability' of organotin concentration as shown by the high standard errors in Figure 5-10, Figure 5-11 and Figure 5-12. This is likely due to the nature of the sediments at Douglas Shoal having high heterogeneity i.e. a large range of different sediment fractions from large to small in each sample with TBT potentially present in the form of minute paint flakes. It is possible that laboratory sample mixing and subsampling may lead to smaller sized fractions being over represented and analysed. Concentrations of the breakdown organotins MBT (μg Sn/kg) (Figure 5-10) and DBT (μg Sn/kg) (Figure 5-11) along with TBT (μg Sn/kg) (Figure 5-12) are higher in sub-areas A3, A4, A5, A6 and A8, and to a lesser degree A7, in comparison to all other sub-areas, including reference areas R1 and R2. Note the variation in the y axis scale for each organotin graph.

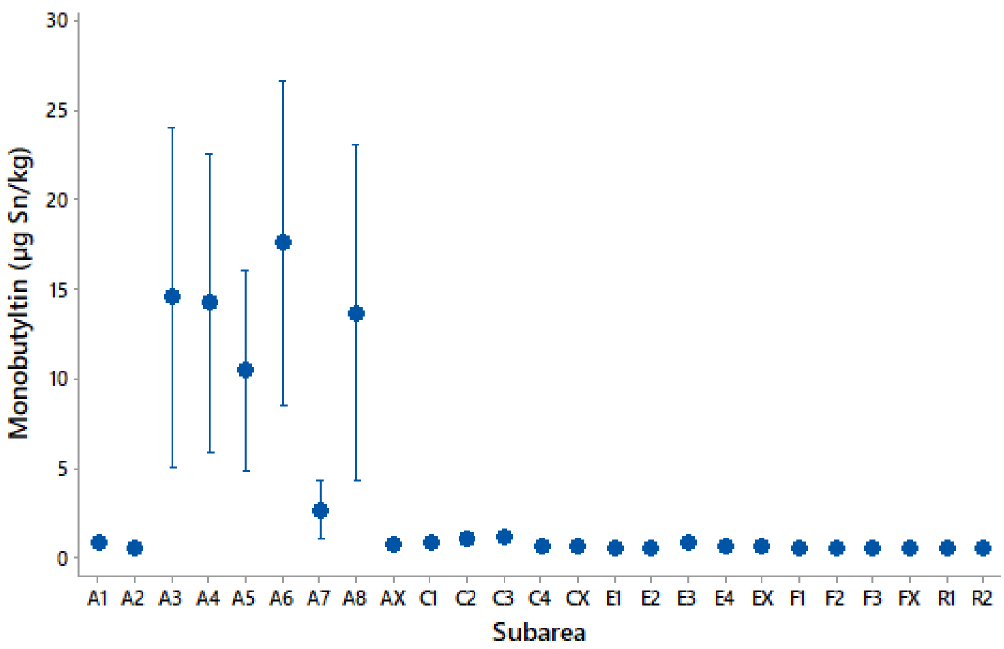

Figure 5-10 Mean concentrations (+/- standard error) of monobutyltin (μgSn/kg) by sub-area

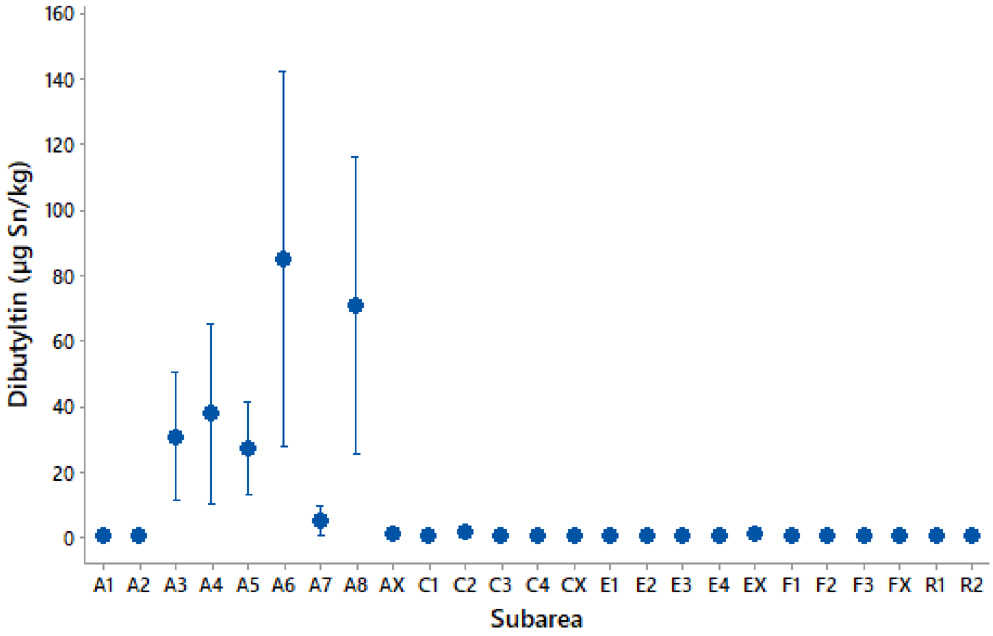

Figure 5-11 Mean concentrations (+/- standard error) of dibutyltin (µgSn/kg) by sub-area

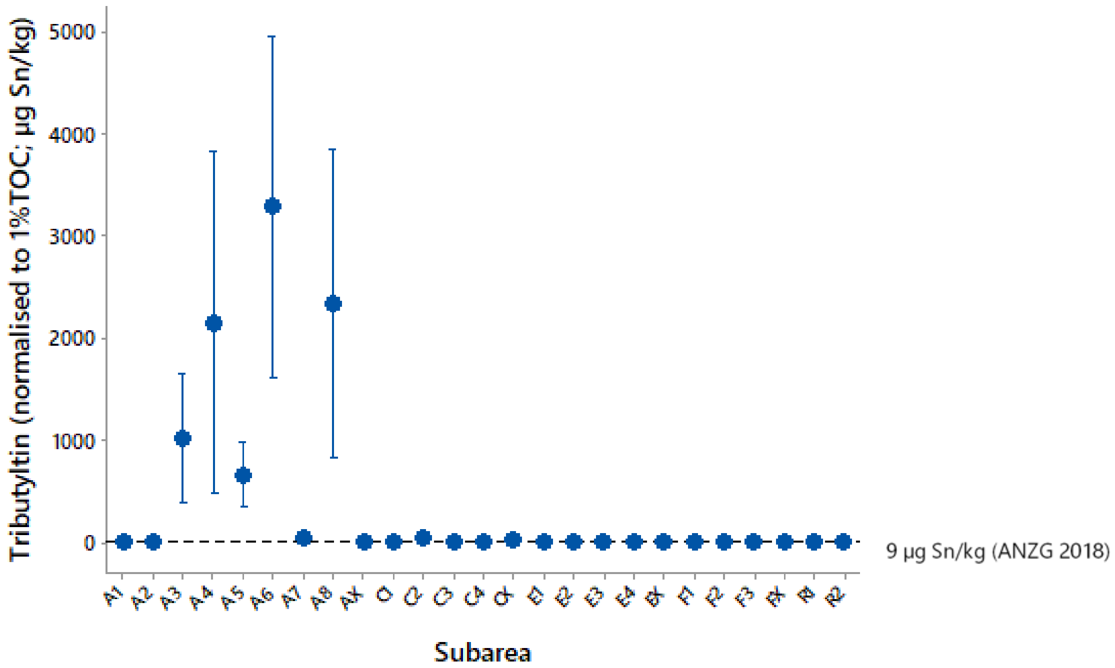

Figure 5-12 Mean concentrations (+/- standard error) of tributyltin (normalised to 1% TOC) (µgSn/kg) by sub-area with the ANZG (2018) default guideline value of 9µgSn/kg

5.2 Statistical analysis

A range of statistical analyses were undertaken on AFP contamination data for all sub-areas within each priority area. The objectives of this analysis were to determine the significant differences between remediation priority areas and reference areas, and if possible to detect any contamination hotspots within each priority area. Specific details on the methods used to determine these objectives and results are provided in the Sediment Characterisation Report (Appendix A).

The spatial patterns of the AFP contamination across the four priority areas are best graphically represented by the Non-metric Multi-Dimensional Scaling (nMDS) plots and bubble plots as follows.

5.2.1 nMDS plots

The nMDS plots were completed to identify the priority areas and sub-areas that are different in terms of their contamination profile and the specific contaminants driving these differences. There are three main groups / clusters of priority areas showing contamination due to organotins (Figure 5-13). These groups or clusters are comprised predominantly of sub-areas from Priority Area A. The results suggest:

- Priority Area A is most different from the other priority areas due to the elevated concentrations of organotins as well as (to a lesser extent) bioavailable copper and zinc (Figure 5-13).
- Sub-areas A3, A4, A5 and A6 are the most different from other sub-areas, again due to elevated concentrations of organotins as well as (to a lesser extent) bioavailable copper and zinc (Figure 5-14).
- There was one sampling site within each of sub-areas C2, CX and EX that were different from other Priority Area C and E sub-areas due to bioavailable aluminium and iron (Figure 5-14).
- There were two sampling sites within sub-area F3 that were different due to higher concentrations of total arsenic, cadmium, cobalt, lead and nickel (Figure 5-14).

The nMDS analysis showed that differences for sub-areas in Priority Areas C, E and F were driven by elevated concentrations of metals in one or two samples within the priority area. For sub-areas within Priority Area A, the nMDS analysis indicated that differences are due to elevated organotin, copper and zinc concentrations, all of which are a component of AFP associated with the grounding.

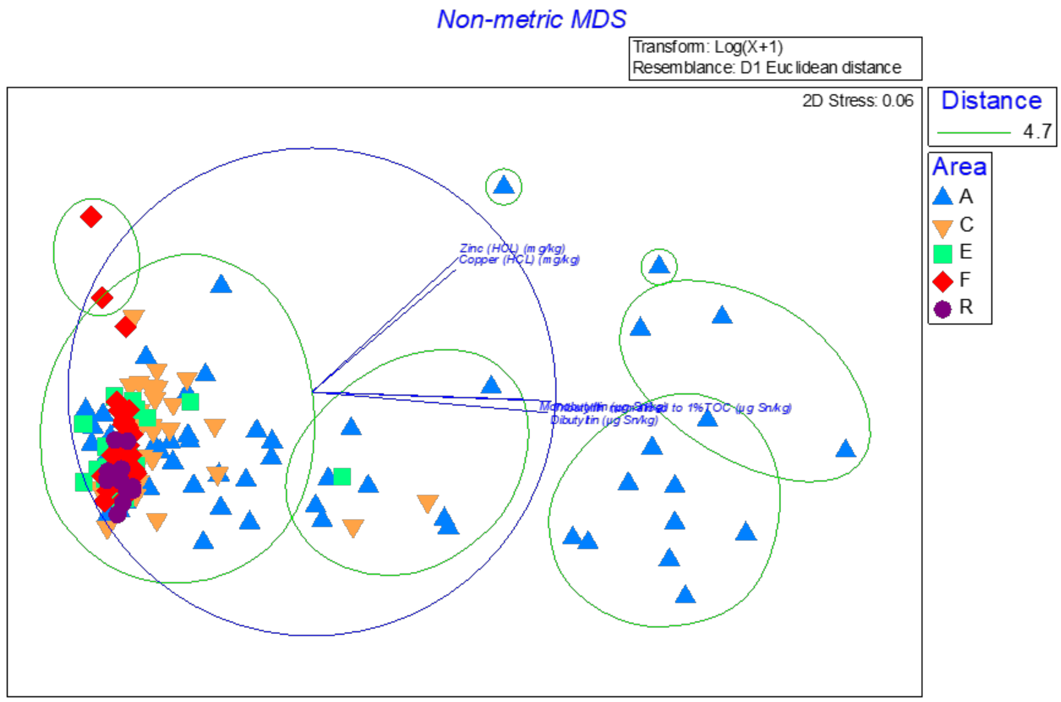

Figure 5-13 nMDS plot of the contaminant data matrix overlaid with the factor of area (sub-areas that are clustered together and most similar are circled)

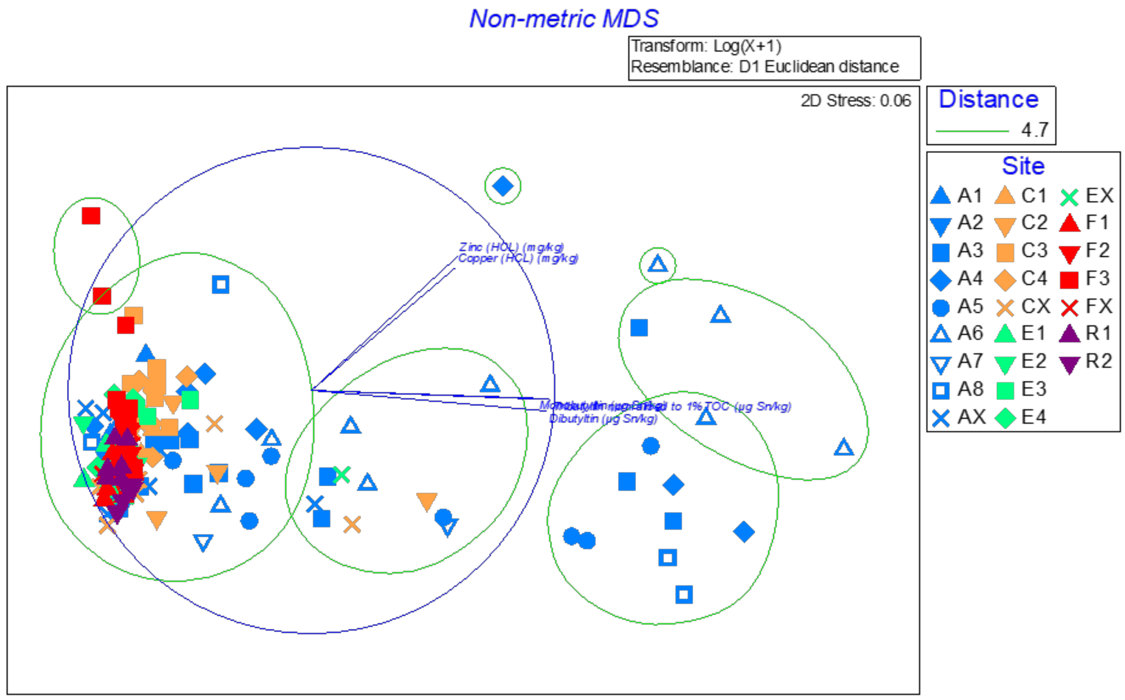

Figure 5-14 nMDS plot of the contaminant data matrix overlaid with the factor of sampling site (sampling sites that are clustered together and most similar are circled)

5.2.2 Bubble plots for Priority Area A hotspot

The contamination levels and locations of TBT (normalised), total copper and total zinc within Priority Area A were examined in greater detail using bubble plots to visualise contamination concentrations at each sampling site within Priority Area A. Sites with higher concentrations are represented by larger bubbles and bubbles with the same colour are sites from the same sub-area. The plots show that:

- There were many exceedances of the ANZG (2018) guideline for TBT (Figure 5-15). The highest concentrations (normalised to 1% TOC) were seen in sub-areas A4 (19,800 µg Sn/kg), followed by A6 (17,905 µg Sn/kg), A8 (8,750 µg Sn/kg), A3 (7,350 µg Sn/kg) and A5 (2,845 µg Sn/kg).
- Similar patterns to that of TBT were observed for concentrations of DBT and MBT.
- Concentrations of total copper (mg/kg) were most elevated in two sub-areas (A4 and A6) due to only one sample in each site exceeding the ANZG (2018) guideline of 65 mg/kg (Figure 5-16). These samples were 365 mg/kg in A4 and 175 mg/kg in A6.
- Similar patterns to that of copper were observed for total zinc (mg/kg) concentrations which were elevated in two sub-areas (A4 and A6) due to one sample in each sub-area (Figure 5-17). No values exceed the ANZG (2018) sediment guideline of 200 mg/kg for zinc.

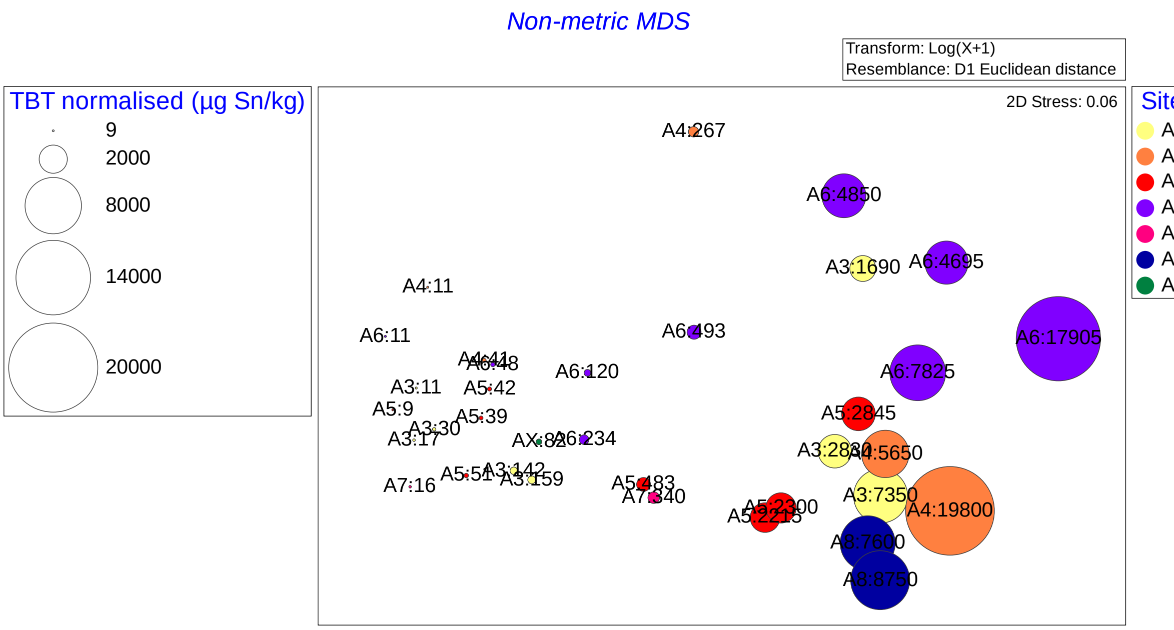

Figure 5-15 Concentrations of TBT (normalised to 1% TOC) which exceeded the ANZG (2018) guideline of 9µgSn/kg within Priority Area A.

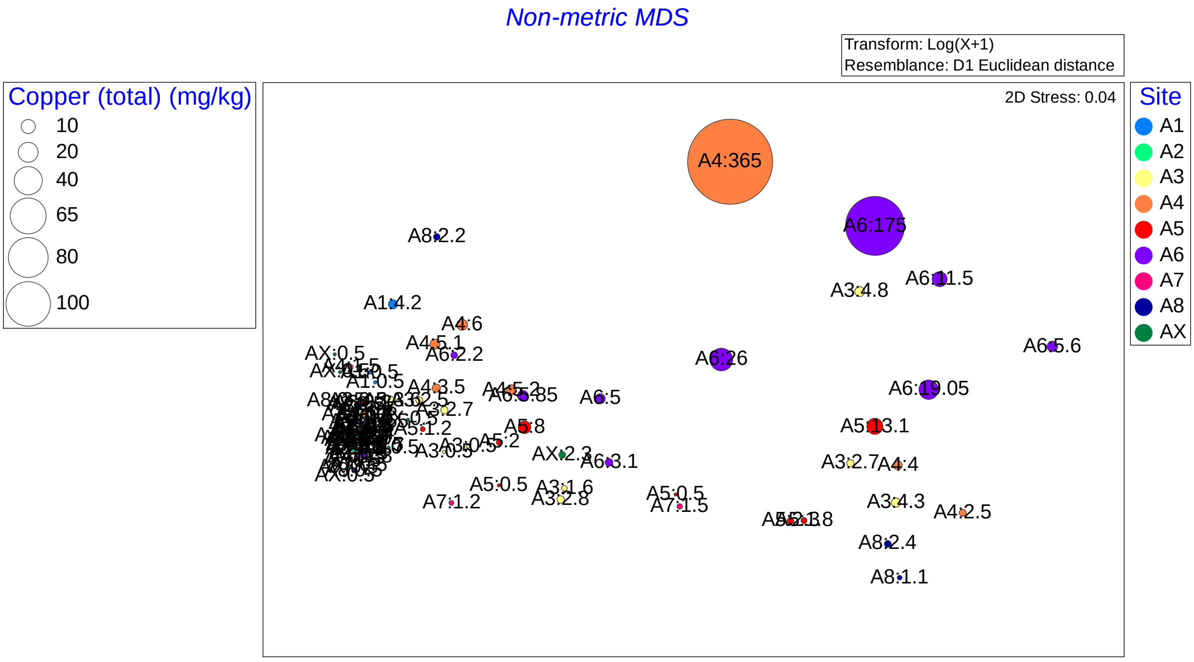

Figure 5-16: Concentrations of total copper within Priority Area A (only one sample in sub-area A4 and one in sub-area A6 were above the ANZG (2018) sediment guideline of 65mg/kg).

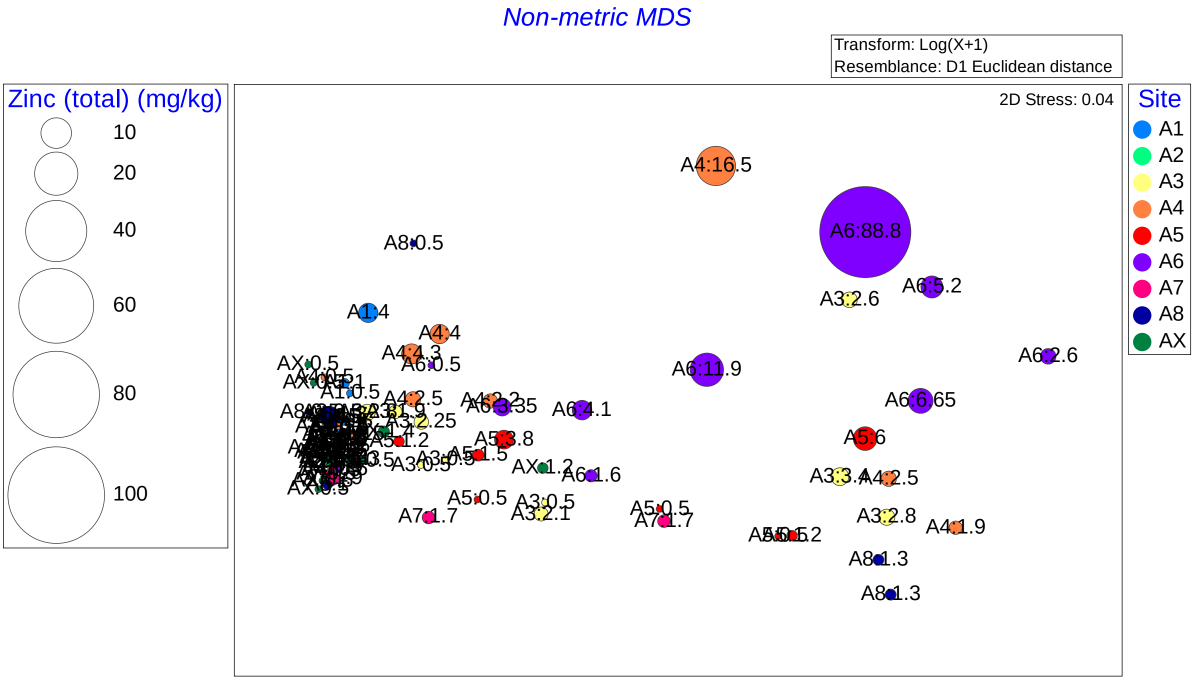

Figure 5-17: Concentrations of total zinc within Priority Area A (no samples exceeded the ANZG (2018) sediment guideline of 200mg/kg)

5.3 Comparison to historical data

The comparison of sampling results from previous investigations is confounded by several factors. Marshall *et al* (2010) undertook a preliminary site inspection to assess the state of contamination (total metals in sediments) within the grounding footprint of the *Shen Neng 1* at Douglas Shoal. This sampling was undertaken immediately following the grounding incident as a rapid assessment of key impacts, and as such was not based on a comprehensive sampling and analysis plan. Sampling was targeted based on visual observation of AFP paint chips and as such it is considered the results of this sampling do not provide a clear picture regarding the relative levels of contamination within the areas assessed.

It is considered likely that larger quantities of AFP were abraded from the vessel within Priority Area A than within other areas of the grounding site. Priority Area A includes the first point of contact between the vessel and shoal so there was more AFP 'available' to be abraded in this area. In addition, during the initial stages of contact the vessel was under full steam across the shoal and therefore likely to create a larger abrasive force on the shoal than during later stages of the grounding. Notwithstanding this, the relative differences in levels of AFP contamination across different areas of the grounding footprint (e.g. concentrations in Priority Area A versus Priority Area F) were not identified during the initial site assessments due to the sparsity of sampling (and the focused nature), and so comparison with this earlier data is challenged.

In addition, the sediments at Douglas Shoal in the grounding footprint are highly heterogenous (i.e. not well mixed) with contamination associated with remnants of paint flakes in the finer fractions. This presents issues with smaller sampling efforts spread across large areas and implies a further challenge to quantitative comparison between sampling events. It is notable that a more precise sampling site positioning system was used in 2019 with accuracy of less than 1m compared to 2010 assessments which had accuracy of typically less than 20m. This challenges further quantitative comparisons of data.

A semi-quantitative comparison is discussed below to provide a broad indication of change over time in terms of the contamination profile. Summary statistics for the primary constituents of AFP for the 2010 data are compared to the 2019 dataset in Table 5-1. Maps comparing the spatial distribution and concentrations of AFP contaminants between samples collected in 2010 versus those collected in 2019 are provided for Priority Area A (Figure 5-18), Priority Area C (Figure 5-19), Priority Area E (Figure 5-20) and Priority Area F (Figure 5-21). The TBT data presented in these figures (for 2010 and 2019) is not normalised to 1% TOC and care should be taken when comparing these values to the guidelines which are for normalised data. These comparisons suggest that generally the concentrations of the AFP contaminants present on the shoal have decreased over time, especially in Priority Area C, E and F.

- Mean total copper concentrations were higher in 2010 due to several outliers (2,552.3mg/kg ± 16,710.1mg/kg) in comparison to 2019 (6.8mg/kg ± 53.4mg/kg):
  - Removing these three outliers measured in 2010 (152,300mg/kg, 116,500mg/kg and 52,700mg/kg) reduces the 2010 mean total copper concentration to 261.5mg/kg ± 1,119.2mg/kg, still well above the concentrations of total copper measured in 2019
- Mean total zinc concentrations were higher and more variable in 2010 (450.5mg/kg ± 2,748.1mg/kg) in comparison to 2019 (2.5mg/kg 25.5mg/kg)

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- All three organotin parameters had higher mean concentrations and were more variable during 2010 (e.g. TBT was 6,245.7µgSn/kg ± 53,372.9µgSn/kg) in comparison to 2019 (TBT was 89.9µgSn/kg ± 427.2µgSn/kg).

Table 5-1: Comparison of statistical parameters for total metals and non-normalised organotins in sediment (2010 to 2019 dataset)

Parameter	Sample Year	n	Min	Max	Mean	Stdev	20% ile	50% ile	80% ile	95% ile
Copper (total) (mg/kg)	2010	140	0.5	152,300	2,552.3	16,710.1	0.5	0.5	0.5	4,045
	2019	251	0.5	647.0	6.8	53.4	0.5	1.1	2.6	11
Zinc (total) (mg/kg)	2010	140	0.5	22,000	450.5	2,748.1	0.5	0.5	0.5	1,105
	2019	251	0.5	150	2.5	25.5	0.5	0.5	2.4	5.2
Tributyltin (µgSn/kg)	2010	140	0.3	545,000	6,245.7	53,372.9	0.3	0.7	25.7	3,376.8
	2019	251	0.3	3,960	89.9	427.2	0.3	0.3	1.7	534.2
Monobutyltin (µgSn/kg)	2010	140	0.5	1,710	16.0	147.5	0.5	0.5	0.5	2.1
	2019	251	0.5	114	3.9	27.6	0.5	0.5	1.0	26.7
Dibutyltin (µgSn/kg)	2010	140	0.5	31,600	268.0	2,691.6	0.5	0.5	1.0	29.8
	2019	251	0.5	646	11.7	60.1	0.5	0.5	0.5	75.2

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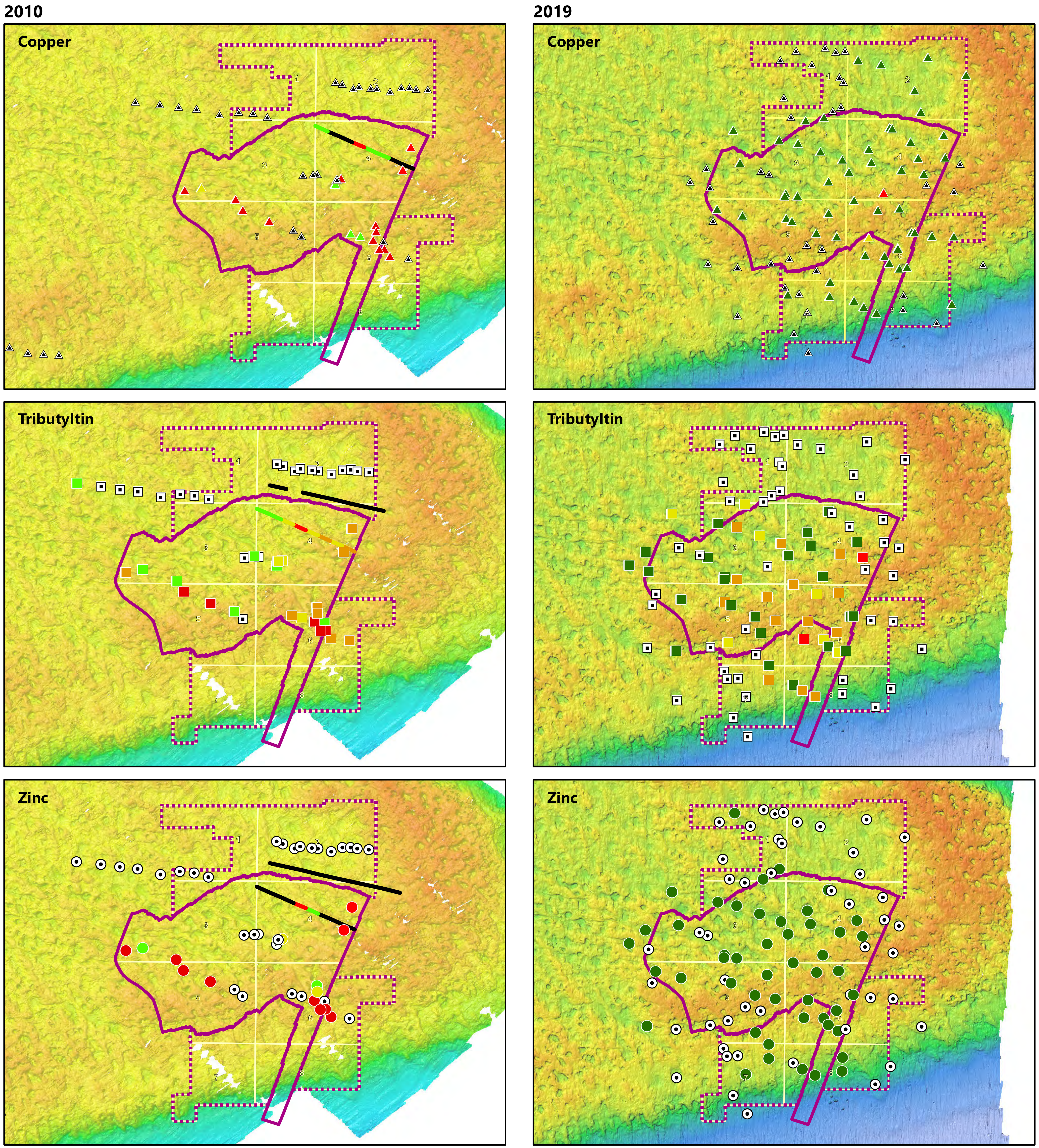
Figure 5-18
Comparison of AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area A



2019 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 0.5 - 65
- 65 - 269
- 270 - 365

TBT µg Sn/kg (non-normalised)
- Non-detects
- < 9
- 9 - 69.9
- 70 - 3500
- > 3500

Zinc (total) mg/kg
- Non-detects
- 1 - 200

2010 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 0.5 - 65
- 65 - 270
- > 270
- Non-detects
- 0.5 - 65
- > 270

TBT µg Sn/kg (non-normalised)
- Non-detect
- < 9
- 9 - 69.9
- 70 - 3500
- > 3500
- Non-detects
- < 5
- 5 - 69.9
- 70 - 3500
- > 3500

Zinc (total) mg/kg
- Non-detects
- 1 - 200
- 200 - 410
- > 410
- Non-detects
- 1 - 200
- > 410

0 50 100 150 200
Metres
Scale at A3 - 1:6,807

N

Coordinate System: GCS GDA 1994
Datum: GDA 1994

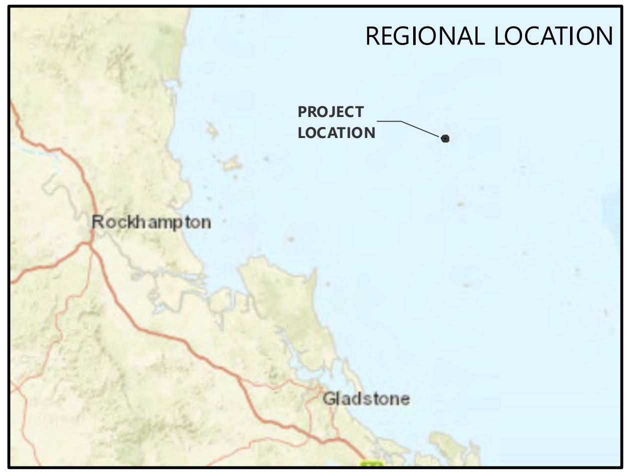
Priority Area
- A
- A - outside grounding footprint

Priority Area A Sub-area

Bathymetry
-23.0m -9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
2010 AFP sampling
Costen et al 2017
Sampling locations and contaminant concentration
Advisian - March 2019
2010 Bathymetry (Negri et al)
Cardno 2017
2019 Bathymetry (50cm LAT)
Acoustic Imaging 2019



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Worley Group

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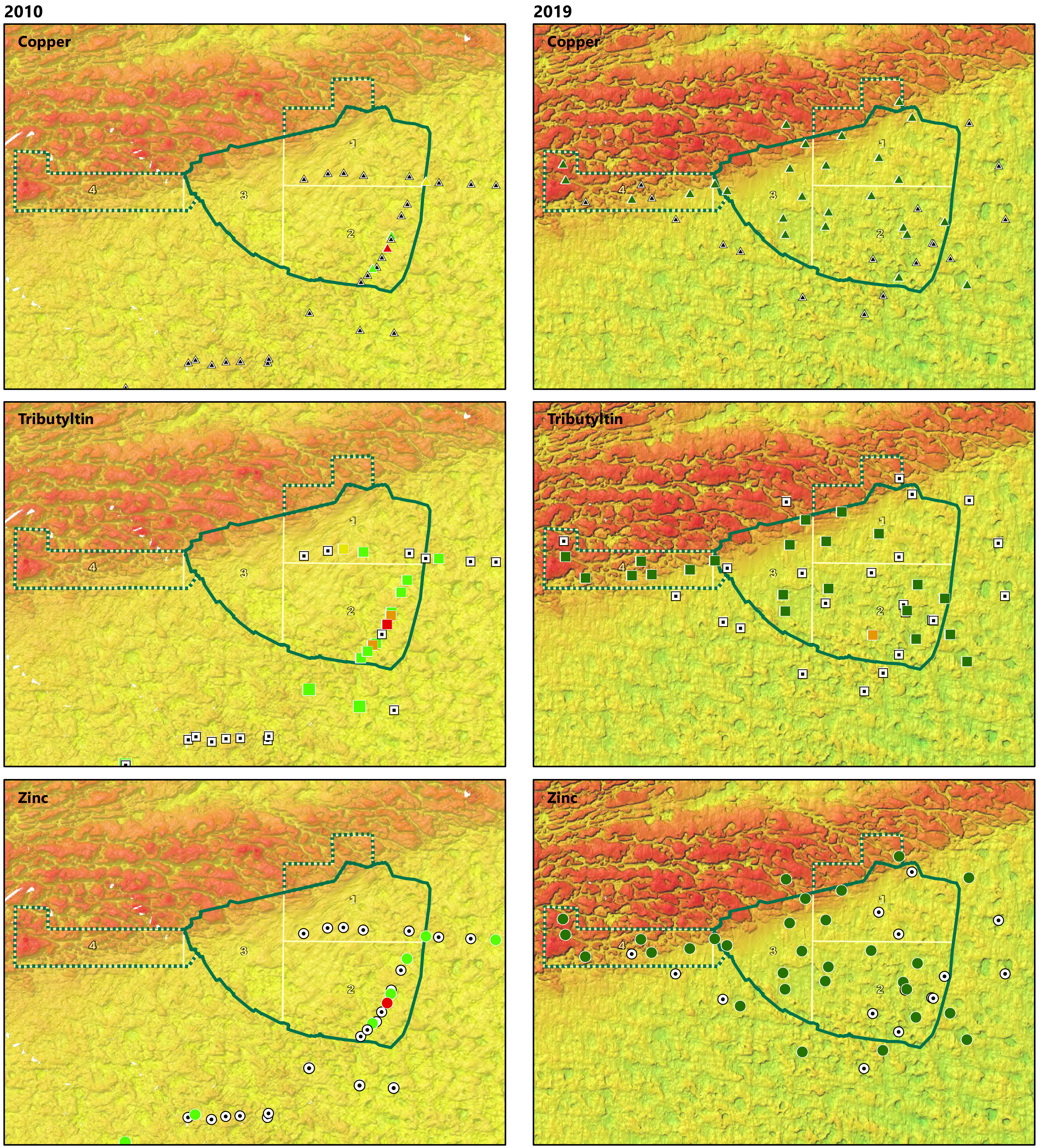
Figure 5-19
Comparison of AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area C



2019 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 0.5 - 65

TBT µg Sn/kg (non-normalised)
- Non-detects
- < 9
- 70 - 3500

Zinc (total) mg/kg
- Non-detects
- 1 - 200

2010 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 0.5 - 65
- 65 - 270
- > 270

TBT µg Sn/kg (non-normalised)
- Non-detects
- < 9
- 9 - 69.9
- 70 - 3500
- > 3500

Zinc (total) mg/kg
- Non-detects
- 1 - 200
- > 410

Priority Area
- C
- C - outside grounding footprint

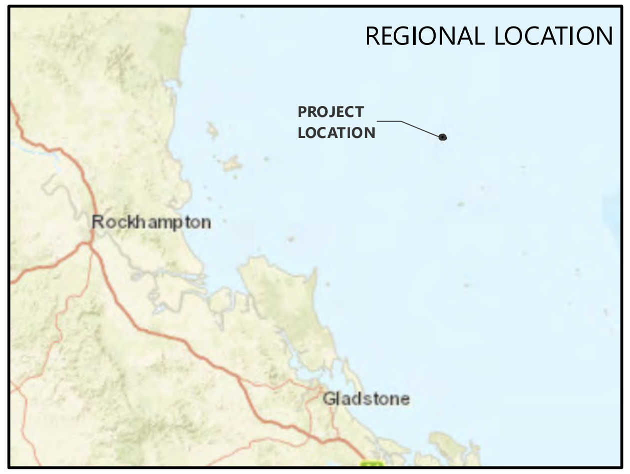
Priority Area C Sampling Sub-area

Bathymetry

-23.0m   -9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
2010 AFP sampling
Costen et al 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019



0 50 100 150 200
Metres
Scale at A3 - 1:5,500
N

Coordinate System: GCS GDA 1994
Datum: GDA 1994

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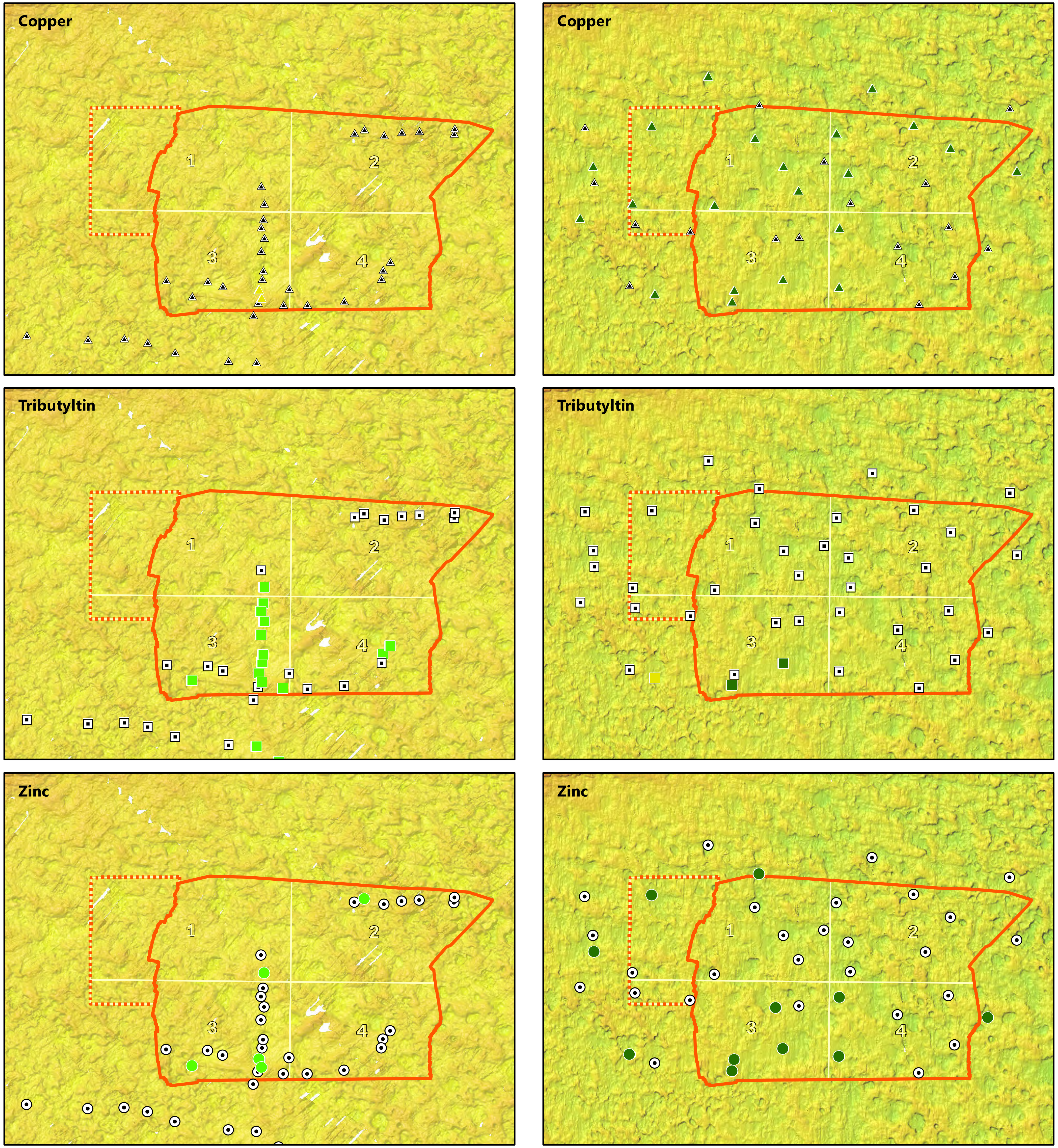

2019 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 0.5 - 65

TBT µg Sn/kg (non-normalised)
- Non-detects
- < 9
- 9 - 69.9

Zinc (total) mg/kg
- Non-detects
- 1 - 200

2010 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 65 - 270

TBT µg Sn/kg (non-normalised)
- Non-detects
- < 9

Zinc (total) mg/kg
- Non-detects
- 1 - 200

0 50 100 150 200
Metres

Scale at A3 - 1:4,500

N

Coordinate System: GCS GDA 1994
Datum: GDA 1994

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Figure 5-20
Comparison of AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area E

Priority Area
- E
- E - outside grounding footprint

Priority Area E Sub-area

Bathymetry
-23.0m -9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
2010 AFP sampling
Costen et al 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019

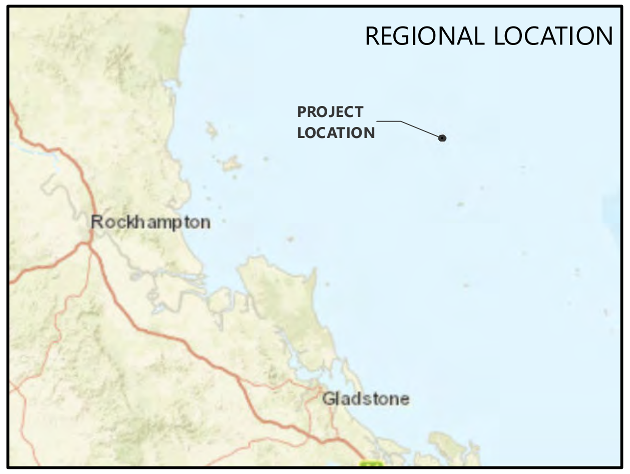

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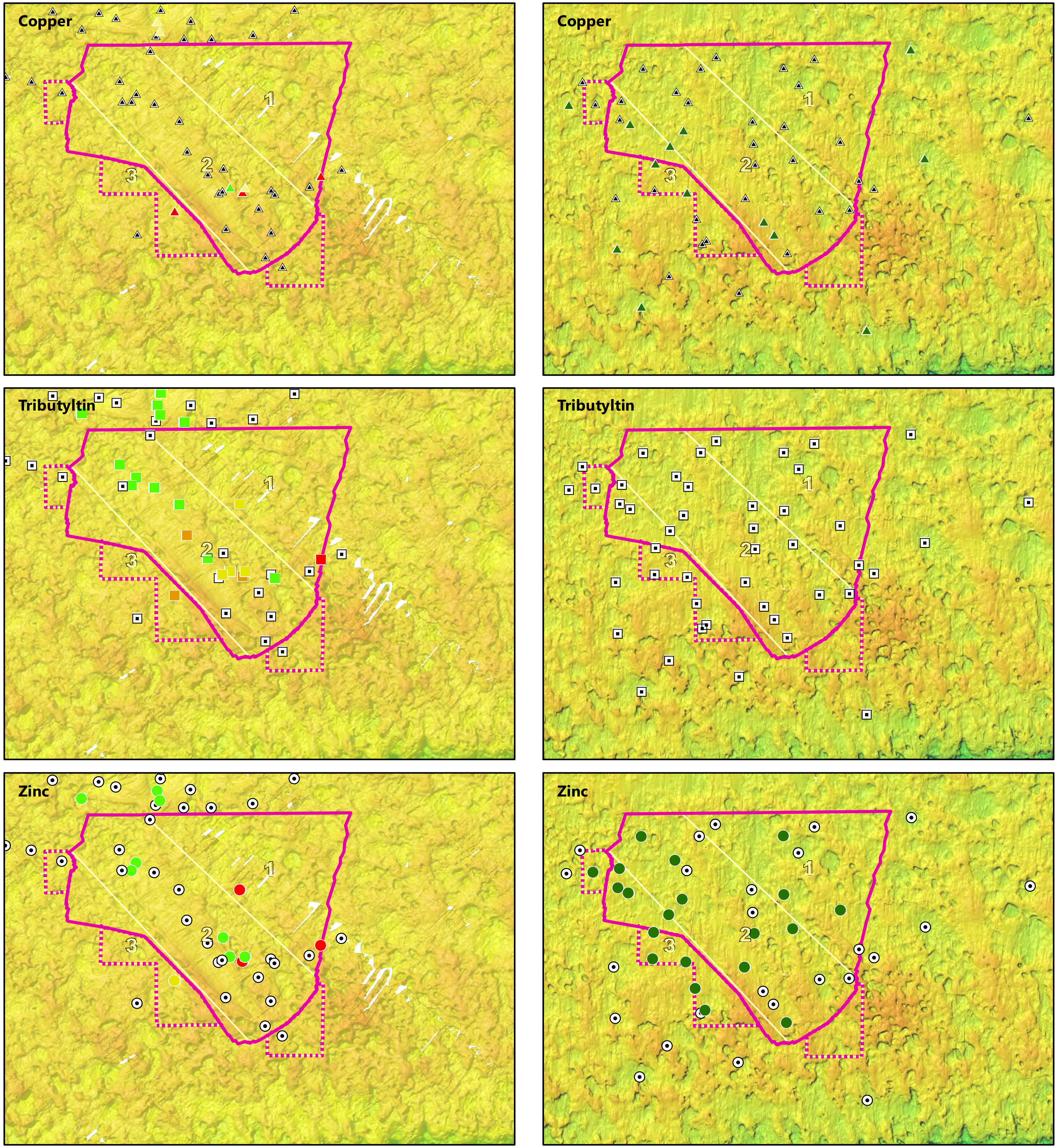
Figure 5-21
Comparison of AFP* Constituent Concentrations at Sediment Sampling Sites in Priority Area F

2010 | 2019



2019 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 0.5 - 65 mg/kg

Tributyltin µg Sn/kg
- Non-detects

Zinc (total) mg/kg
- Non-detects
- 1 - 200 mg/kg

2010 AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (total) mg/kg
- Non-detects
- 0.5 - 65
- 65 - 270
- > 270

TBT µg Sn/kg (non-normalised)
- Non-detect
- < 9
- 9 - 69.9
- 70 - 3500
- > 3500

Zinc (total) mg/kg
- Non-detects
- 1 - 200
- 200 - 410
- > 410

Priority Area
- F
- F - outside grounding footprint
- Priority Area F Sub-area

Bathymetry
-23.0m — -9.0m

AFP* - Anti Fouling Paint

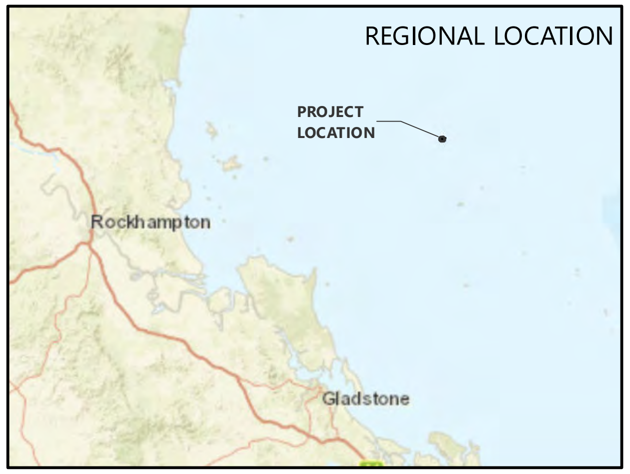
Source Information:
Grounding footprint, Priority areas
Cardno 2017
2010 AFP sampling
Costen et al 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019

N

0 50 100 150 200
Metres

Scale at A3 - 1:4,000

Coordinate System: GCS GDA 1994
Datum: GDA 1994



Advisian
Worley Group

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5.4 TBT degradation

Kettle (2014) collected sediments for contamination analysis at five locations on Douglas Shoal within the grounding footprint (five different depth replicates per location) approximately three and a half years after the grounding. None of these locations were within the same areas previously sampled in 2010 shortly after the grounding. As noted in Kettle (2014) comparison of TBT concentrations detected on the shoal over time is confounded by differences in sampling location and method.

Kettle (2014) used the most comparable dataset available to consider the change in TBT concentration over time and concluded that while maximum TBT concentrations observed in 2013 were lower than those reported from sampling one month after the grounding (GBRMPA 2011), the proportion of extreme levels of TBT contaminants (described in Kettle (2014) as 'more than 50 times the guideline maximum') had increased in the sampled areas. Kettle (2014) opined that portions of the site where the most extreme contaminant loadings exist are being continually exposed to 'fresh' contaminants through sediment movement and abrasion. Subsequent studies (Kettle 2015a) found little evidence of large AFP flakes, indicating the gradual erosion of large flakes to smaller flakes or particles.

The 2019 surveys found no visible evidence of AFP flakes. This may indicate that AFP flakes have eroded since the grounding and AFP now exists as small particles not observable by the naked eye.

To provide a measure of the potential degradation of TBT over time the sediment contamination datasets from 2010, 2013 and 2019 were collated and interrogated. The Butyltin Degradation Index (BDI) as described in Garg et al 2009 was used to examine TBT degradation to Dibutyltin (DBT) and Monobutyltin (MBT) using the formula below:

$$BDI = \frac{(\mathrm{DBT} + \mathrm{MBT})}{\mathrm{TBT}}$$

Noting that the sampling method and location was different during each sampling campaign (2010, 2013 and 2019) the results from sampling where concentrations of MBT, DBT and TBT were detected through laboratory analysis are shown in Table 5-2. Data with non-detections or that was less than the limit of reporting for MBT and DBT were removed to provide a more accurate estimate of degradation. An alternate approach of altering the data to half the limit of reporting when it is below that limit (e.g. <1 to 0.5) is likely to bias the calculation of the BDI.

As shown in Table 5-2, except for sites A3-10a and A7-1 sampled in 2019, all other sites show a BDI value of less than 1. These results indicate the TBT reported during each sampling campaign was likely to have been associated with a 'fresh' source of TBT i.e. exposure of TBT through sediment movement and abrasion, breaking down larger to smaller particles of AFP and releasing TBT in the process. Kettle (2014) reviewed several publications in relation to TBT degradation half-lives and found that TBT degradation half-lives in sediment as determined by laboratory experiments in aerobic environments is in the order of 1 to 3 years but this may increase to between 10 to 15 years in anaerobic sediments.

The use of historical data to estimate timeframes within which elevated TBT, MBT and DBT concentrations may be reduced below relevant guidelines is confounded by several factors including:

- Different sampling methods and locations used across sampling campaigns
- Uncertainty regarding the introduction of 'fresh' sources of TBT as AFP has broken down over time

- Variability of environmental conditions at the shoal affecting sediment movement and abrasion
- TBT data used is not normalised to 1% TOC.

Initial surveys in 2010 found large smears and flakes of paint were present on the shoal. As these flakes broke down 'new' layers of AFP paint were exposed providing fresh sources of TBT. Field investigations undertaken in 2019 indicate that significant break-down of AFP particles has occurred since the grounding, with no visible AFP particles identified. Due to the microscopic size of the remaining AFP particles, it is likely that limited (if any) 'fresh' sources of TBT remain at the shoal. In addition, the most recent investigations clearly indicate a reduction of TBT concentration in sediments over time. The historical data may provide a reasonable indication of likely timeframes for future reduction of elevated TBT concentrations to below relevant guidelines.

Table 5-2 Concentrations of MBT, DBT and TBT in sediments collected in the grounding footprint over time.

Site Name	Date collected	Monobutyltin (MBT) µgSn/kg	Dibutyltin (DBT) µgSn/kg	Tributyltin (TBT) µgSn/kg	BDI
004-AA	11-May-2010	2	5	32	0.22
008-AA	11-May-2010	1	7	28.5	0.28
128-AA	11-May-2010	8	305	23,300	0.01
122-AA	11-May-2010	2	46	804	0.06
040-AA	11-May-2010	7	322	7,860	0.04
038-AA	11-May-2010	1,710	31,600	545,000	0.06
039-AA	11-May-2010	8	23	234	0.13
042-AA	11-May-2010	322	1,880	29,200	0.08
041-AA	11-May-2010	1	28	512	0.06
078-AA	11-May-2010	8	158	4,020	0.04
080-AA	11-May-2010	93	2,730	43,100	0.07
110-AA	12-May-2010	2	8	68.5	0.15
147-AA	12-May-2010	3	6	25	0.36
SED1-AS	11-Oct-2013	28	131	535	0.30
SED1-BS	11-Oct-2013	51	289	1,390	0.24
SED1-BD	11-Oct-2013	2	6	71	0.11
SED1-CD	11-Oct-2013	100	492	2,350	0.25
SED2-AS	11-Oct-2013	6	11	41.9	0.41
SED2-CS	11-Oct-2013	1	2	7.1	0.42
SED2-BD	11-Oct-2013	4	3	9	0.78

Site Name	Date collected	Monobutyltin (MBT) µgSn/kg	Dibutyltin (DBT) µgSn/kg	Tributyltin (TBT) µgSn/kg	BDI
SED3-AS	11-Oct-2013	38	198	2,170	0.11
SED3-BS	11-Oct-2013	341	985	7,080	0.19
SED3-CS	11-Oct-2013	365	641	5,920	0.17
SED3-AD	11-Oct-2013	40	217	2,640	0.10
SED3-BD	11-Oct-2013	464	1,020	7,800	0.19
SED3-CD	11-Oct-2013	413	1,190	6,550	0.24
SED4-AS	11-Oct-2013	605	1,920	10,900	0.23
SED4-BS	11-Oct-2013	466	1,460	9,670	0.20
SED4-CS	11-Oct-2013	1,140	3,010	15,600	0.27
SED4-AD	11-Oct-2013	643	1,340	9,800	0.20
SED4-BD	11-Oct-2013	228	746	5,940	0.16
SED4-CD	11-Oct-2013	2,070	3,720	14,200	0.41
A3-3	10-Mar-2019	36	233	1,470	0.18
A3-5	10-Mar-2019	16	70	338	0.25
A3-10a	20-Mar-2019	4	2	3	2.00
A3-11	11-Mar-2019	114	59	566	0.31
A4-9	11-Mar-2019	91	116	1,130	0.18
A4-10	20-Mar-2019	56	324	3,960	0.10
A4-11	11-Mar-2019	14	8	53.3	0.41
A5-3	12-Mar-2019	14	71	443	0.19
A5-4	18-Mar-2019	3	2	8.3	0.60
A5-5	14-Mar-2019	67	158	569	0.40
A5-6	19-Mar-2019	3	2	7.7	0.65
A5-7	14-Mar-2019	26	77	460	0.22
A5-9 (T2)	14-Mar-2019	22	33	375	0.15
A6-1	10-Mar-2019	8	15	98.6	0.23
A6-2	10-Mar-2019	7	7	23.9	0.59
A6-3	10-Mar-2019	27	94	939	0.13
A6-4 (T3)	10-Mar-2019	1	2	17.1	0.18

Site Name	Date collected	Monobutyltin (MBT) µgSn/kg	Dibutyltin (DBT) µgSn/kg	Tributyltin (TBT) µgSn/kg	BDI
A6-8	10-Mar-2019	49	154	1,300	0.16
A6-8a	18-Mar-2019	38	88	1,830	0.07
A6-9	10-Mar-2019	99	646	3,760	0.20
A6-11	10-Mar-2019	2	5	46.7	0.15
A7-1	16-Mar-2019	4	1	3.1	1.61
A7-7	16-Mar-2019	12	33	81.7	0.55
A8-6	18-Mar-2019	28	241	1,520	0.18
A8-9	16-Mar-2019	65	252	1,750	0.18
AX-2	19-Mar-2019	3	8	16.3	0.67
C2-4	09-Mar-2019	1	2	6.3	0.48
C2-10	09-Mar-2019	3	10	93.7	0.14
EX-7	12-Mar-2019	2	7	31.6	0.28

To support approximation of the rate of degradation and reduction of TBT, MBT and DBT concentrations to below relevant guidelines (ANZG, 2018) for all the data in Table 5-2, the mean and maximum concentrations of TBT, MBT and DBT were calculated for each sampling period (Table 5-3)

Table 5-3 Summary statistics for each survey period for each organotin constituent

Month since grounding	n	Organotin constituent	Mean concentrations (µgSn/kg)	Maximum concentrations (µgSn/kg)
1	13	MBT	167	1,710
		DBT	2,855	31,600
		TBT	50,322	545,000
42	19	MBT	369	2,070
		DBT	915	3,720
		TBT	5,404	15,600
108	29	MBT	28	114
		DBT	94	646
		TBT	721	3,960

Graphical representations of the mean and maximum values for each sampling period (months since grounding) are provided in Figure 5-22 and Figure 5-23. Note the y-axis uses a logarithmic scale. An exponential goodness of fit line is fitted to the data for the organotin constituents.

The line of best fit equation for TBT and the R^2 value are provided on each graph. The R^2 value is a measure of the goodness of fit, with the closer this value is to 1 the better the fit. For TBT using the mean and maximum the R^2 values is 0.9735 and 0.8592, respectively. The equation which best describes the line of best fit for the TBT concentrations over time are provided on each graph. These equations can be used to calculate the future TBT concentrations (x-value) for a given time in months (y-value) or vice versa.

The line of best fit for the change in mean concentration of TBT over time is:

$y = 40984e^{-0.039x}$ or when rearranged $x = \frac{1}{-0.039} * ln(\frac{y}{40984})$

The line of best fit for the change in maximum concentration of TBT over time is:

$y = 290431e^{-0.044x}$ or when rearranged $x = \frac{1}{-0.044} * \ln\left(\frac{y}{290431}\right)$

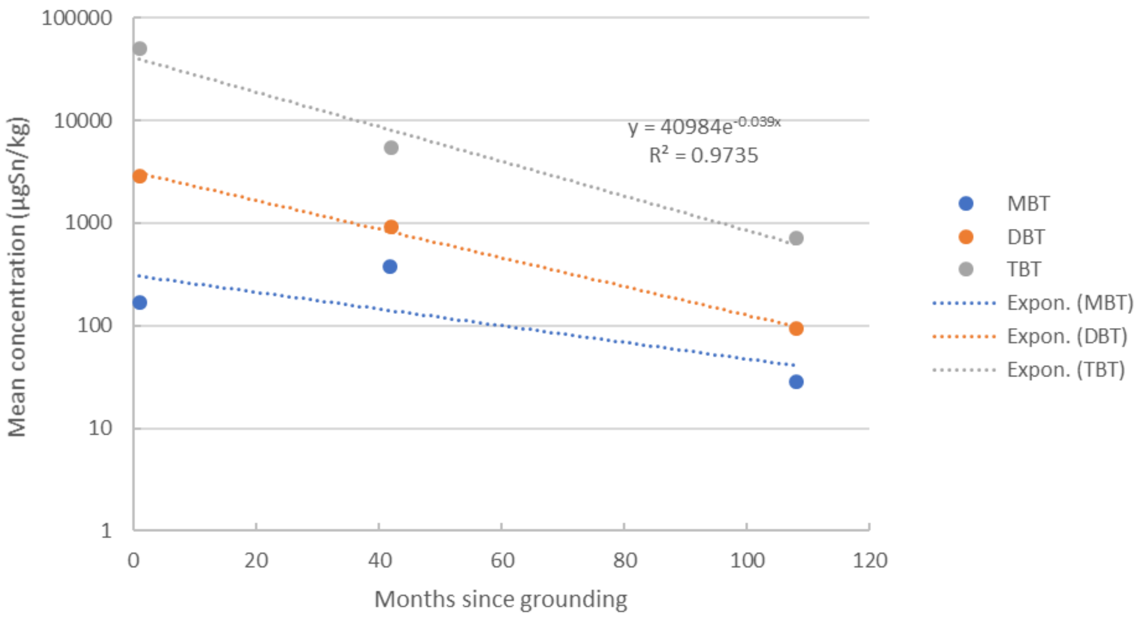


Figure 5-22 Mean concentration of MBT, DBT and TBT over time with line of best fit (equation and R^2 for TBT)

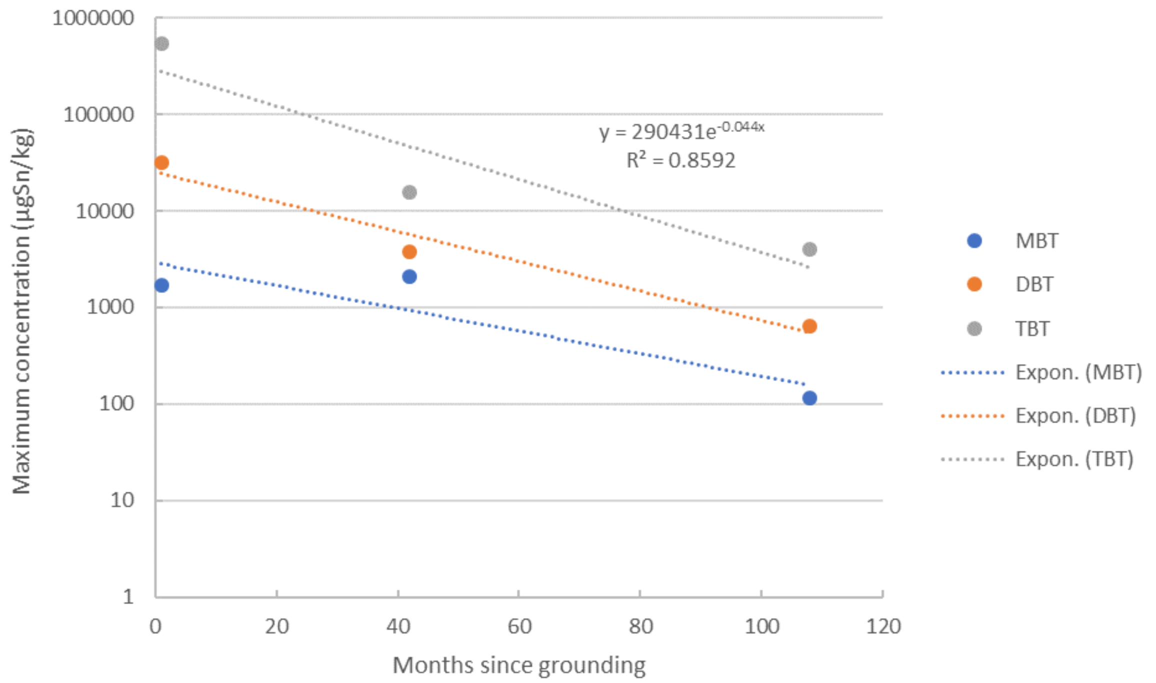


Figure 5-23 Maximum concentration of MBT, DBT and TBT over time with line of best fit (equation and R^2 for TBT)

The estimated time (x-value) until TBT concentrations (non-normalised to 1% TOC) in sediments are below the ANZG guideline value of 9µgSn/kg (y-value) is provided in Table 5-4. The mean and maximum concentrations of TBT may be reduced below the guideline value within approximately 18 years and 20 years of the grounding respectively. No threshold or trigger values are available for MBT and DBT. As such an estimate for when they may cease to be of potential concern is not made. Notwithstanding this, it is likely that once concentrations of TBT are below the guideline value, remaining MBT and DBT will not pose a significant environmental risk.

Table 5-4 Estimated TBT (non-normalised) degradation period to below relevant guidelines

Statistic	y value (µgSn/kg)	x value (months)	Years	Date
Mean	9	216	18.0	2028
Max	9	236	19.7	2030

5.5 Contamination priority areas

Based on the analysis described above part of Priority Area A is the only remediation priority area for contamination. Contamination in other priority areas occurs at isolated sites or in some cases a single site and further analysis (Phase III) of those samples via elutriation found no residual concentrations above the relevant guidelines. Elevated concentrations of TBT are evident at many sites in Priority Area A and it is considered that TBT is likely to remain a contaminant of concern in this area for another decade. Consideration should be given to the address of TBT contaminated sediments in this area.

The sea floor of Priority Area A includes areas dotted with deep and shallow holes and long interconnected channels or gutters containing shallow layers of sediments (Figure 5-24) with sediment depths between 5mm and 350mm (average 60mm) (Section 4.3.2). Most of the grounding footprint in Priority Area A is hard substrate covered in layers of encrusting benthos such as turf algae on rock (30.5%), macroalgae (44.9%) with only small areas of sand (3.5%) and rubble (10.4%) (Section 4.3.3).

Figure 5-24 Deep and shallow holes, channels or gutters in the grounding footprint of Priority Area A

Detailed analysis of the physical characterisation of sediments collected in Priority Area A is provided in Appendix A. The results indicate that most of the variability in the contaminant multivariate dataset can be explained by TOC (10.4%) and PSD (16.9%). Within the factor of PSD (when using full range PSD), more variability is described by the smaller fractions (<+300µm) compared to the larger fractions (>+425µm). A higher proportion of larger particles and of the finest sediments was identified for sediments within the grounding footprint compared to outside the footprint. Further analysis found that within the contaminated sub-areas of Priority Area A, contamination is strongly associated with the finest sediment fraction (<75µm in particular) and TOC. As is well established in literature (ANZG 2018), sediment samples with higher proportions of the sediment fraction <75µm or higher TOC are more likely to have higher concentrations of contaminants.

Delineation of the high priority remediation areas for contamination considered the following:

- Sites which had elutriate concentrations that exceeded the ANZG (99% species protection) guidelines for TBT, copper or zinc which indicates that when agitated the sediments at these sites may release pore water containing harmful (above the 99% species protection guideline value) concentrations of TBT into the water column
- Sites identified in the 'hot spot' analysis (refer to Section 5.2.2)
- Sites not sampled during the sediment survey that were adjacent to those sampled sites where contamination results exceeded the guidelines or were identified in the 'hotspot' analysis
- Sediment areas which are connected via channels or holes to sites where elutriate samples exceeded the ANZG (99% species protection) guidelines for TBT, copper or zinc
- The total area which contains sediment (holes or channels) based on analysis of images and videos of each site.

Delineation of the moderate priority remediation areas for contamination considered the following:

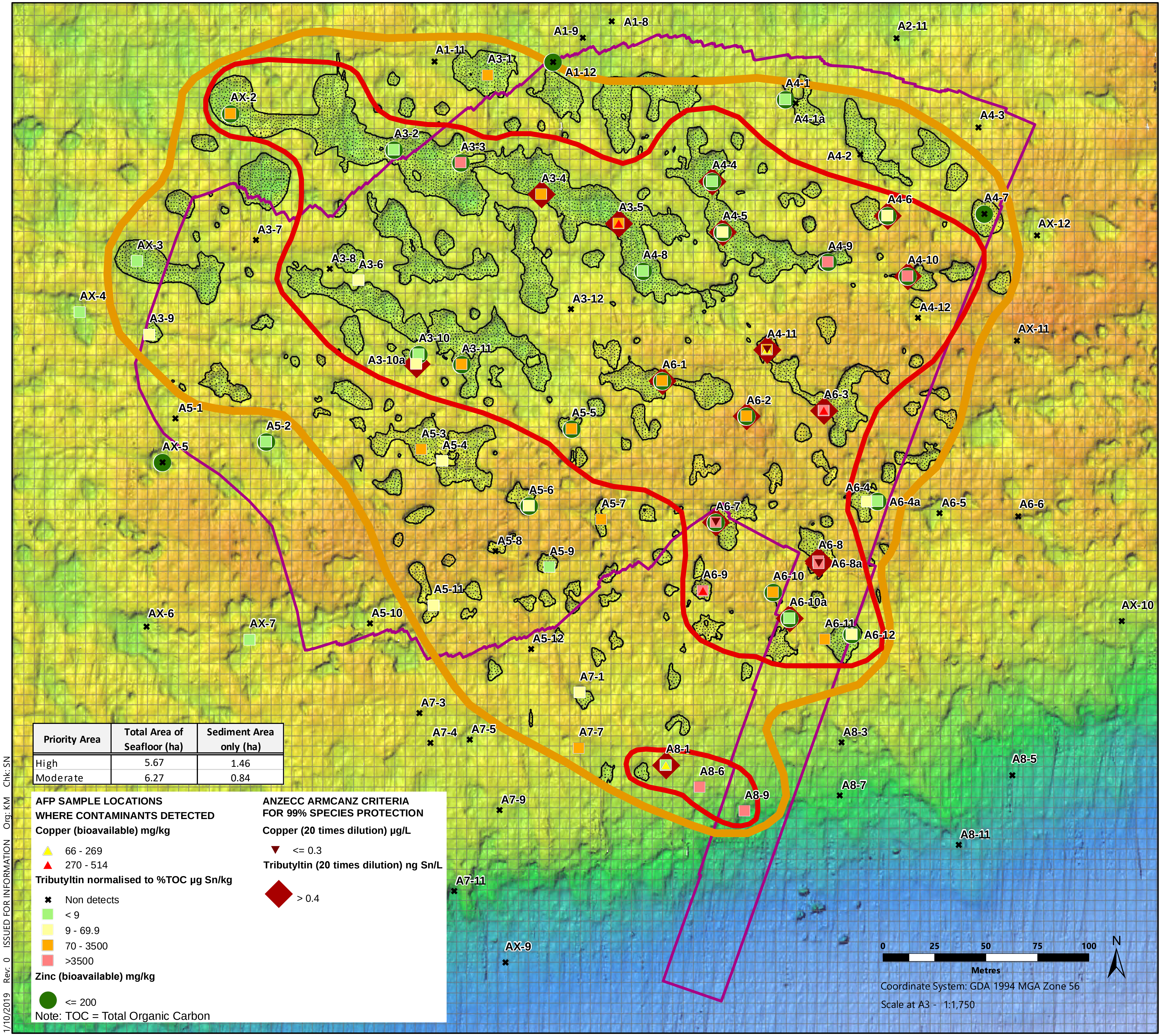
- Sites which had elevated concentrations of TBT, copper, or zinc above ANZG Guidelines
- Sediment areas which were connected to via channels or holes to sites where ANZG guidelines were exceeded
- Sites adjacent to those that exceeded the guidelines
- The total area which contains sediment (holes or channels) based on analysis of images and videos of each site.

The results of the priority remediation area delineation are presented in Figure 5-25.

The total area encompassed within the high priority remediation area for contamination is 5.67ha and the area within this identified as containing sediment is 1.46ha. In addition, the total area encompassed within the moderate priority remediation area is 6.27ha and the area within this identified as containing sediment is 0.84ha.

Douglas Shoal Remediation Planning
Site Assessment Report

Figure 5-25
Priority remediation areas for contamination Priority Area A



Priority Area	Total Area of Seafloor (ha)	Sediment Area only (ha)
High	5.67	1.46
Moderate	6.27	0.84

AFP SAMPLE LOCATIONS WHERE CONTAMINANTS DETECTED

Copper (bioavailable) mg/kg

- 66 - 269
- 270 - 514

Tributyltin normalised to %TOC µg Sn/kg

- Non detects
- < 9
- 9 - 69.9
- 70 - 3500
- >3500

Zinc (bioavailable) mg/kg

- <= 200

Note: TOC = Total Organic Carbon

ANZECC ARMCANZ CRITERIA FOR 99% SPECIES PROTECTION

Copper (20 times dilution) µg/L

- <= 0.3

Tributyltin (20 times dilution) ng Sn/L

- > 0.4

Priority Area

- A
- 5m x 5m reference grid

Sandy holes and gutters (within Priority Area A)

Priority Area

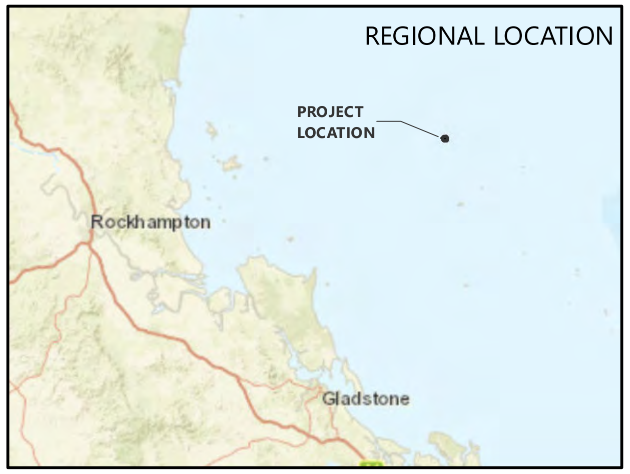
- High
- Moderate

Bathymetry

-23.0m -9.0m

AFP* - Anti Fouling Paint

Source Information:
Grounding footprint, Priority areas
Cardno 2017
Sampling locations and contaminant concentration
Advisian - March 2019
Bathymetry (50cm LAT)
Acoustic Imaging 2019



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User

Advisian
Worley Group

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1/10/2019 Rev: 0 ISSUED FOR INFORMATION Org: KM Chk: SN

Key points

No visible evidence of antifouling paint smears, flakes or chips was identified by the naked eye during the survey.

Contamination of sediments exists primarily within part of the previously identified Priority Area A and is principally associated with tributyltin. Tributyltin was detected at 48 sites in Priority Area A; 35 sites were above the ANZG (2018) default guideline value of 9µgSn/kg. Elutriate testing of samples from Priority Area A which exceeded the ANZG (2018) guidelines found 15 samples (of the 48 tested) with tributyltin concentrations above the ANZG (2018) 99% species protection default guideline value (0.4ngSn/L).

Remediation planning and monitoring should recognise that sediments are not well mixed, with contamination typically associated with remnants of antifouling paint flakes in fine sediment. As such, contamination of sediments may occur outside of the priority remediation areas; however, these areas are likely to be small, isolated and with lower levels of contamination.

It is likely that both the extent and level of contamination has reduced at the grounding site over time, with contributing factors to the reduction including exposure to erosive forces (e.g. ocean currents and waves) through normal conditions and extreme events.

Investigation of the persistence of tributyltin shows that it may be another decade before tributyltin ceases to be a contaminant of concern in parts of Priority Area A. As such, it is considered that addressing antifouling paint-related contamination should remain a priority for remediation.

The total area encompassed within the high priority remediation area for contamination is 5.67ha and the area within this identified as containing sediment is 1.46ha. In addition, the total area encompassed within the moderate priority remediation area is 6.27ha and the area within this identified as containing sediment is 0.84ha.

6 Physical Damage

Immediately after the grounding incident Negri et al (2010) observed extensive physical damage to the benthic habitat along the path of the grounding, primarily in the Low Relief Terrace. The benthic habitat and organisms that colonise the habitat in these areas were abraded and compacted. Where the vessel remained for longer periods the upper layers of the reef substrate were crushed and displaced leading to the creation of large angular calcium carbonate sediments or rubble (see Section 4.3 regarding definitions of vessel generated sediments compared to natural sediments).

The abrasive damage to the upper layers of benthic habitat led to flattening of large areas and the exposure and/or dislodgement of the calcium carbonate reef structure below. The physical damage caused by the vessel's grounding is summarised as including generation and persistence of rubble and flattening of the shoal's topography. The main areas of abrasion and rubble generation occurred where the vessel first ran aground and three additional locations where the vessel was stationary for six to ten hours or more. These areas form part of the priority areas A, C, E and F as described in Costen et al (2017) and are the focus of the discussion of physical damage below.

6.1 Rubble

The impacts associated with the vessel grounding included the creation of large amounts of rubble caused by the hull of the vessel abrading the solid reef surface layers. Negri et al (2010) found the spatial extent of the rubble was confined to the grounding footprint and particularly areas where the vessel remained aground for periods of days. Previous investigations have identified differences between rubble generated by the grounding incident and sediment (including dead coral fragments) which occurs naturally at the shoal, with a comparison provided in Table 6-1 (GBRMPA, 2019).

The surveys undertaken to support the site assessment found evidence of large areas of grounding-related rubble and identified areas of 'natural' sediment (dead coral fragments) as described by previous investigations.

Table 6-1 Review of grounding sediment characteristics (reproduced from GBRPMA, 2019)

Report	Page	Relevant finding
Negri et al 2010	14-15	In undamaged areas, natural sediment is present in gutters and holes as calcium carbonate-dominated gravel and sand. In damaged areas, incident-generated rubble is composed of unconsolidated limestone gravel from 5mm to 50mm in diameter.
McCook 2011	25-27	Recent incident-generated rubble is composed of finger-sized pieces of dead coral and limestone rock which is recognisable from natural sediments by: • Whiter colour • Presence of bright green filamentous slimy algae • Absence of established turf algae

Report	Page	Relevant finding
		• Absence of boring organisms • Lack of erosion of coral skeletal structure.
McCook 2011	25-27	Compacted benthos is distinguished from natural limestone pavement by being 'packed flat,' lacking open pockets, bio-erosion or vertical structure.
McCook 2011	27	Extensive unconsolidated gravels were only observed on Douglas Shoal within the grounding footprint.
Kettle 2014a	12-14	Incident-generated gravel is differentiated from natural gravel by: • Being coarser and more angular, with little abrasion of sharp edges • Being paler in colour • Having less epiphytic growth. Sub-surface rubble exhibits these differences more clearly than surface rubble. Surface rubble sometimes has a light cover of epiphytic algae, even when angular surfaces suggest it is incident-generated rubble.
Kettle 2014a	12, 34	Differences in distribution of incident-generated rubble: • Area A – Deposited into natural depressions in the reef surface, filling or partially filling these but not obscuring surrounding areas of higher relief. May be overlain in these depressions by finer natural sediment (sand to fine gravel). • Areas C, E and F – Spread across extensive flat areas, covering and obscuring the natural topography beneath.
Kettle 2015b	12-13	Tropical Cyclone Oswald (January 2013) and Severe Tropical Cyclone Marcia (February 2015) generated 7-8m waves at Douglas Shoal. This appears to have disturbed and moved natural sand, but not to have significantly mobilised incident-generated gravel.

Images captured soon after the grounding (Negri et al, 2010) showed large rubble banks (up to 1m high) either side of the main grounding sites (Figure 6-1, left image). Subsequent surveys (Kettle 2014) found these rubble banks had disappeared, and rubble had spread out and was filling in depressions.

The surveys undertaken to support the site assessment found no evidence of rubble banks. It is likely the rubble banks previously identified have spread out across the flattened areas forming shallow (5-200mm) layers of rubble (Figure 6-2, right image) and potentially filling depressions in these areas.

Figure 6-1 Rubble banks observed during the initial assessment in April 2010 (left) and March 2019 (right) (note locations are not the same)

Figure 6-2 Rubble across the grounding footprint in 2019 from Priority Area C (T14)

The rubble (Figure 6-3) typically appears to be bereft of encrusting organisms (coralline algae or turf algae, encrusting sponges or coral), indicating the rubble is mobile in some areas.

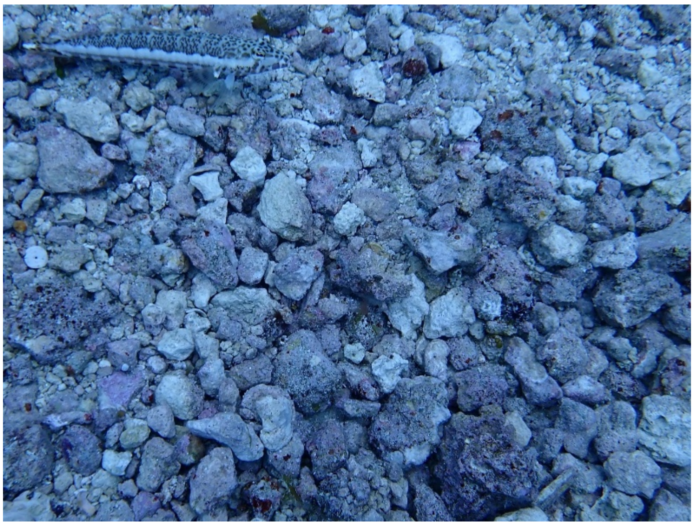


Figure 6-3 Close-up of rubble in 2019 from Priority Area F

6.1.1 Natural versus grounding sediments

The surveys undertaken to support the site assessment identified large expanses of dead coral fragments in reference areas and outside the priority areas (Figure 6-4, Figure 6-6 and Figure 6-6). These sediments were generally made up of different sized coral fragments, fresh or rounded and covered in red coloured coralline algae. Coralline algal rhodoliths (spherical or lumpy shaped coralline algae structures) and different sized shell fragments were also found in these sediments. This contrasts with the large expanses of rubble found in priority areas C, E and F (Figure 6-7 and Figure 6-8). Images of all collected sediments prior to homogenisation and preservation are provided in Appendix A.

The appearance of the rubble has not changed significantly since the grounding and remains obviously different to the natural sediments found in the reference or unaffected areas. Some areas of rubble do support benthic organisms and have consolidated over time (Figure 6-9).

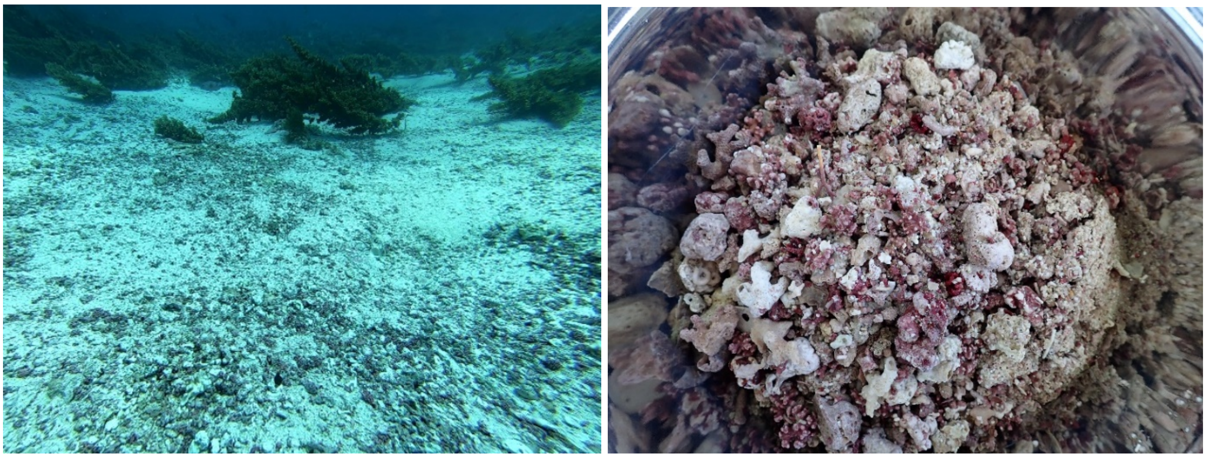


Figure 6-4 Expanses of sand and dead coral fragments and collected sediment from Reference Area 2 (Site R2-11)

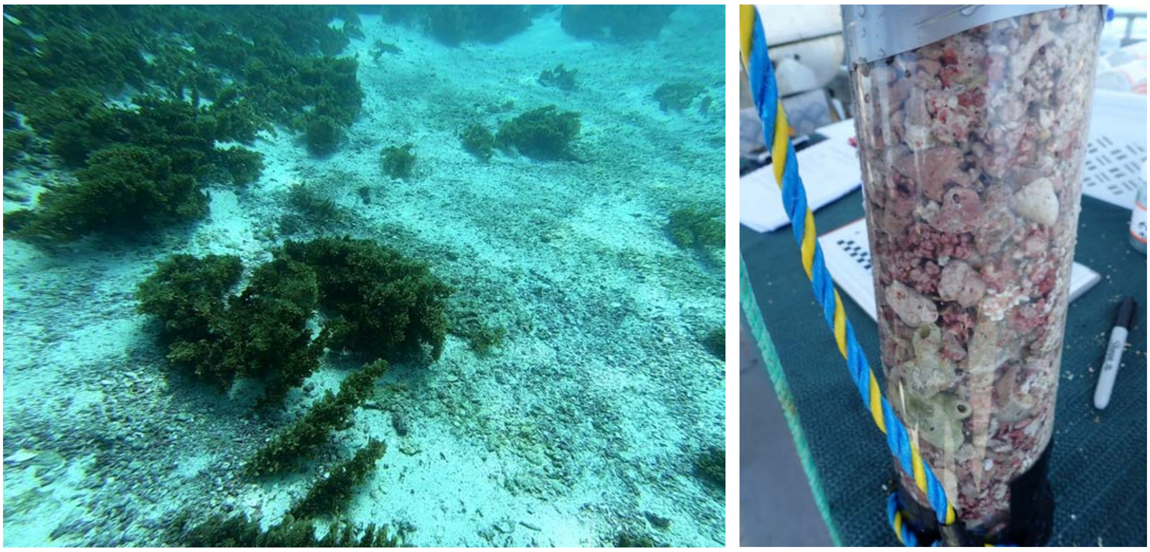


Figure 6-5 Natural sediments (in situ and collected) from outside Area E (Site EX-2)

Figure 6-6 Natural sediments (collected) with a close-up of rhodoliths (circled) from outside Area E (Site EX-2)

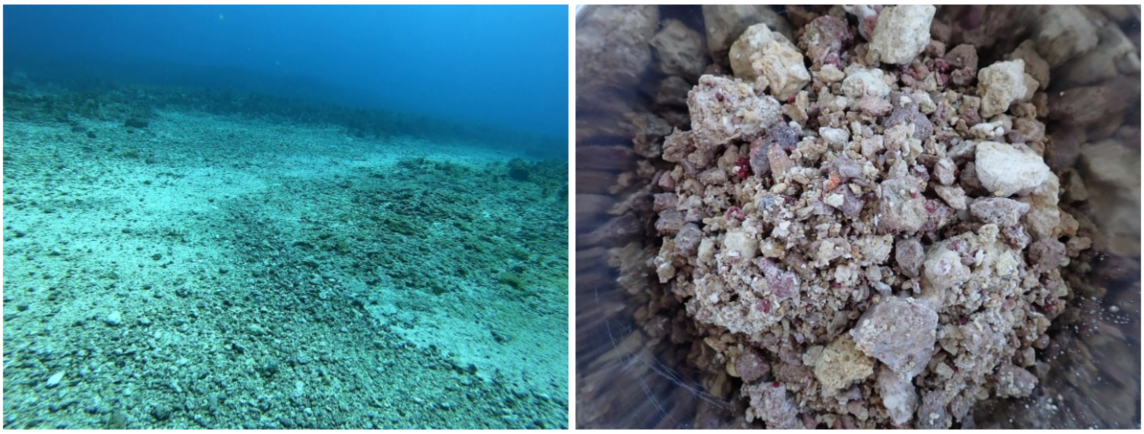
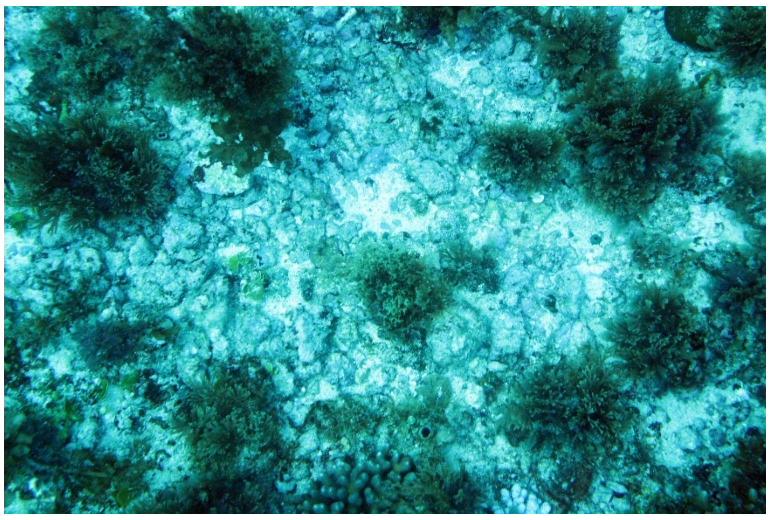


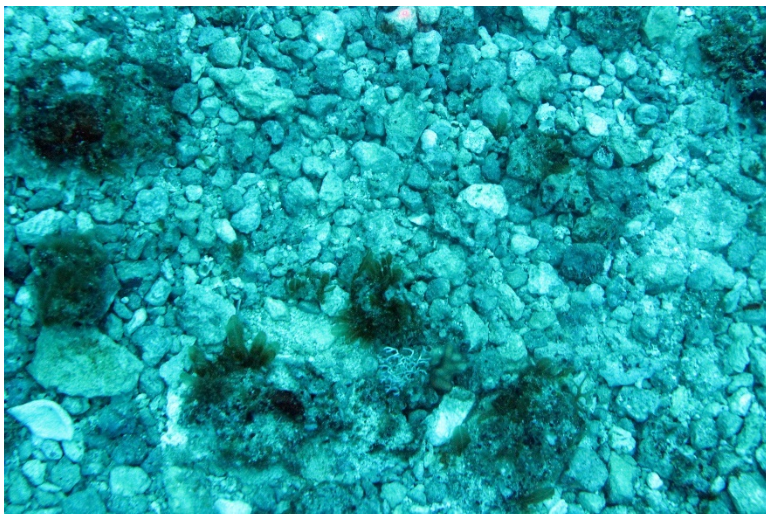
Figure 6-7 In-situ rubble areas and collected sediments from Area C (Site C3-3)

Figure 6-8 In-situ rubble areas and collected sediments from Area E (Site E3-10)

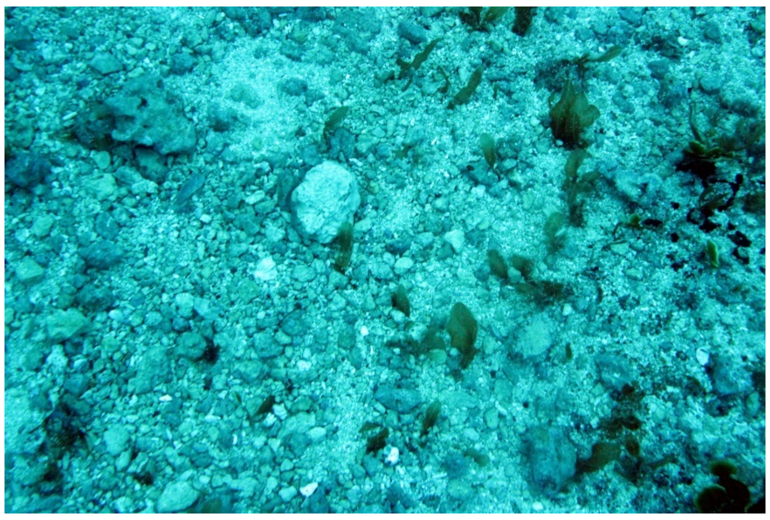


Consolidated rubble and macroalgae growth.

Loose rubble and juvenile *Sargassum spp*.

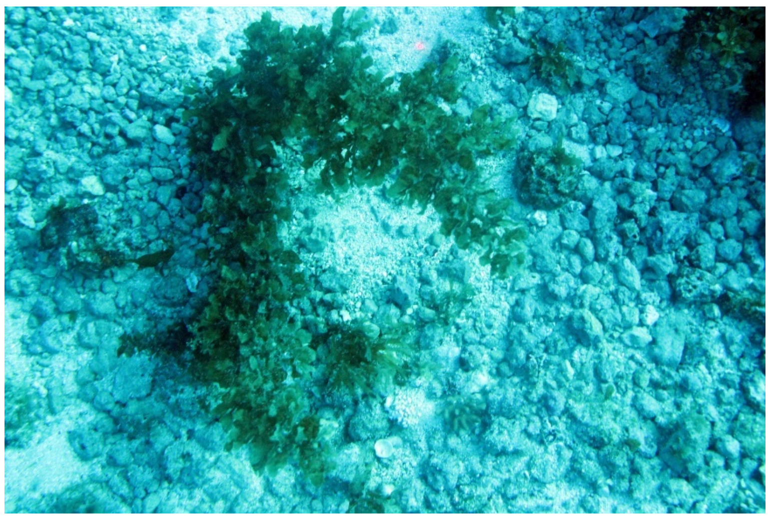


Loose rubble and macroalgae.



Loose rubble and juvenile *Sargassum spp.*

Consolidated rubble covered in turf algae.



Loose rubble and mature *Sargassum spp.*

Loose rubble and mature and juvenile S*argassum spp.*

Loose rubble and adult *Sargassum spp.*

Figure 6-9 Areas of rubble which show consolidation and/or support benthos such as Sargassum spp.

6.1.2 Movement of rubble

Evidence of the movement of rubble in a generally westerly direction is supported by slope analysis data (Section 6.2). Further evidence in the form of imagery from key locations in the eastern and middle section within the footprint of Priority Area C (Figure 5-19) appear to support this analysis. Images captured from site C1-3 (Figure 6-10), C1-9 (Figure 6-11, Figure 6-12) and C3-3 (Figure 6-13) show areas of rubble and areas of undulating depauperate substrate devoid of algae growth (indicated by arrows and circles) which may have been smothered by mobile rubble banks originating from the grounding, and subsequently exposed over time. These exposed areas devoid of rubble may now be able to support the settlement and growth of coral recruits and other benthos.

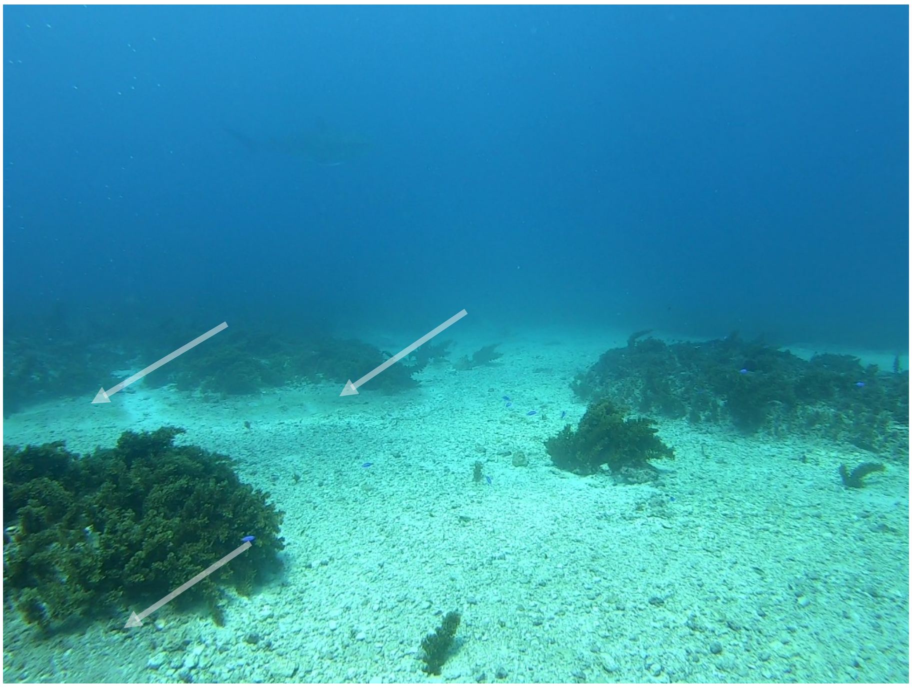


Figure 6-10 Images of rubble and exposed substrate from Priority Area C (site C1-3)

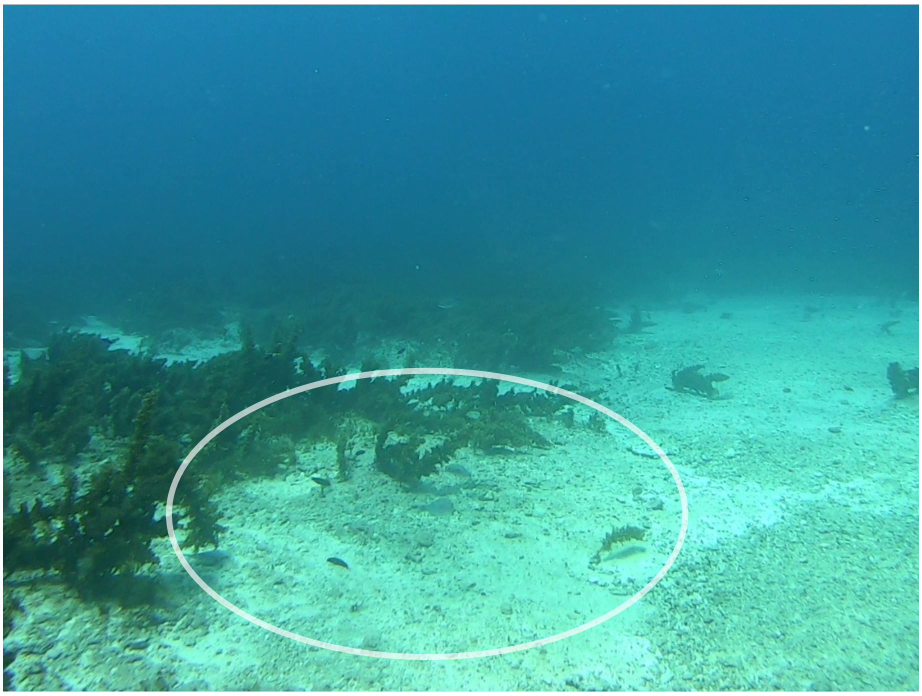


Figure 6-11 Images of rubble and exposed substrate from Priority Area C (site C1-9)

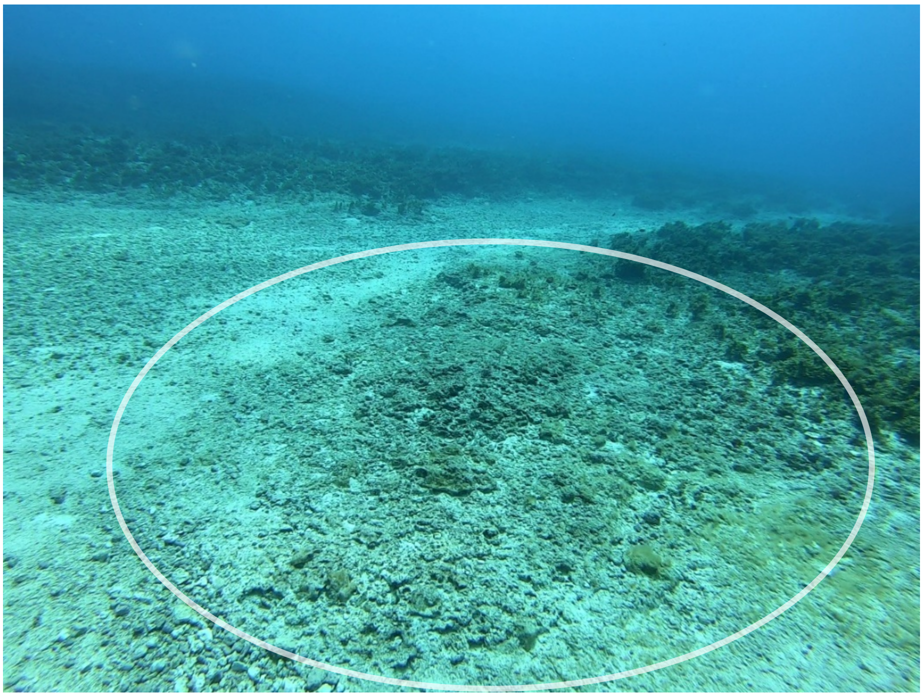


Figure 6-12 Image of rubble and exposed substrate from Priority Area C (site C3-3)

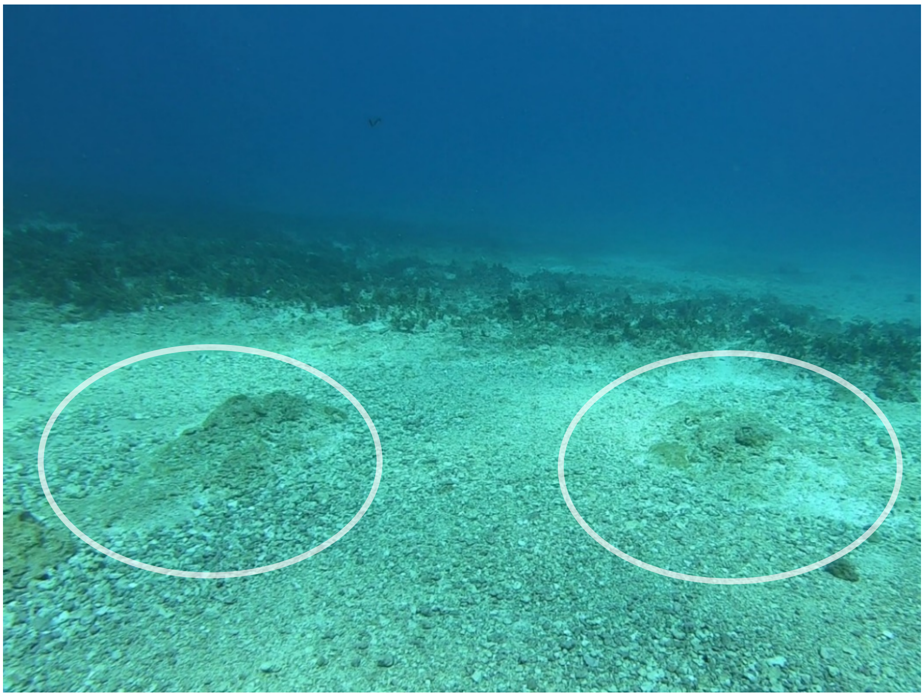


Figure 6-13 Images of rubble and exposed substrate from Priority Area C (site C3-3)

6.1.3 Sediment physical characterisation

A full description of the analysis of the physical characteristics of sediment collected across all priority areas is provided in the Sediment Characterisation Report (Appendix A). Physical characteristics were assessed using the results from laboratory analyses of PSD, TOC, soil particle density, moisture content, and settleability. A summary of the main results for PSD is provided below.

PSD varied considerably between priority areas and between sub-areas within priority areas for percent (%) clay, silt, sand and gravel (Figure 6-14).

- The mean proportion of clay was highest in sub-area C2 (16.7%), and across all sub-areas the mean proportions ranged from 1%-16.7%
- The mean proportion of silt was highest at sub-areas A6 (4.7%), F3 (4.3%) and R2 (4%) and across all sub-areas the mean proportions ranged from 0%-4.7%
- The mean proportion of sand was highest in sub-area A8 (80%) and across all sub-areas the mean proportion ranged from 2-95%
- The mean proportion of gravel was highest at sub-area C4 (74.1%), and across all sub-areas the mean proportions ranged from 61-83%.

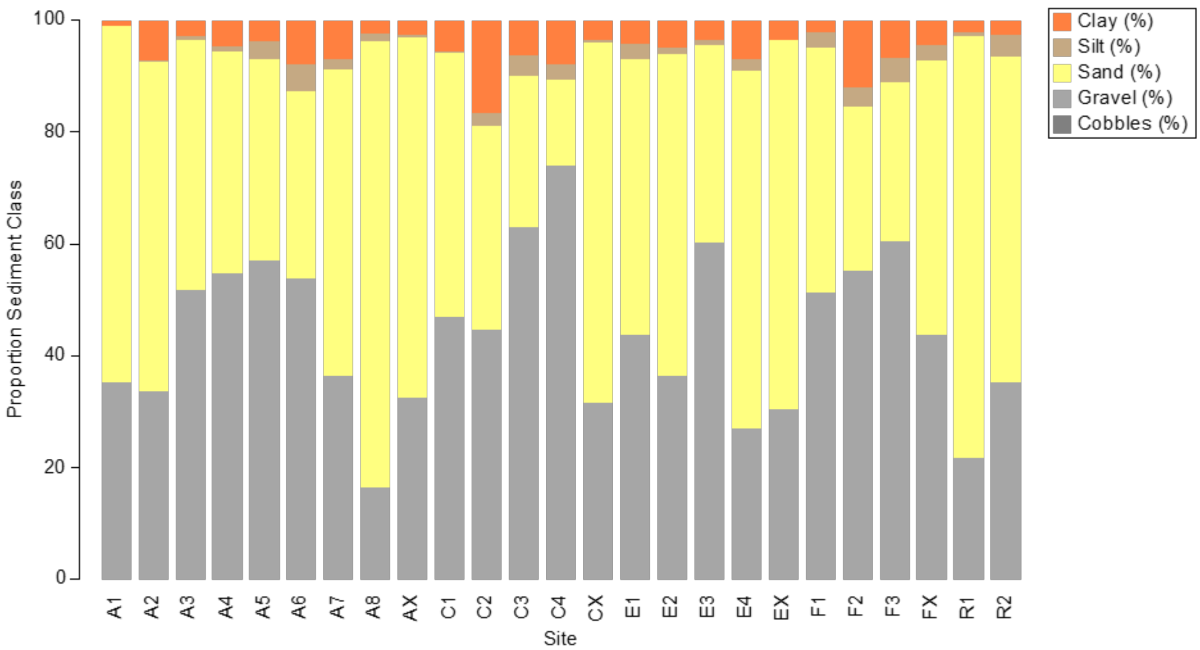


Figure 6-14 PSD (%) shown by sub-area

The backscatter from the multibeam surveys provides an excellent correlation with the results from the PSD analysis. The backscatter images are overlaid with results from all sites where PSD information was collected for gravel fractions (upper image) and sand fractions (lower image) in Figure 6-15. The lighter areas in the backscatter images represent flattened areas. For each figure the larger the symbols the higher is the percentage of each fraction found at each site when compared to all other fractions (cobbles, silt and clay). Figure 6-15 shows the larger rubble class were confined to the areas where the grounding occurred, and the more 'natural' sand fractions occurred outside the grounding footprint.

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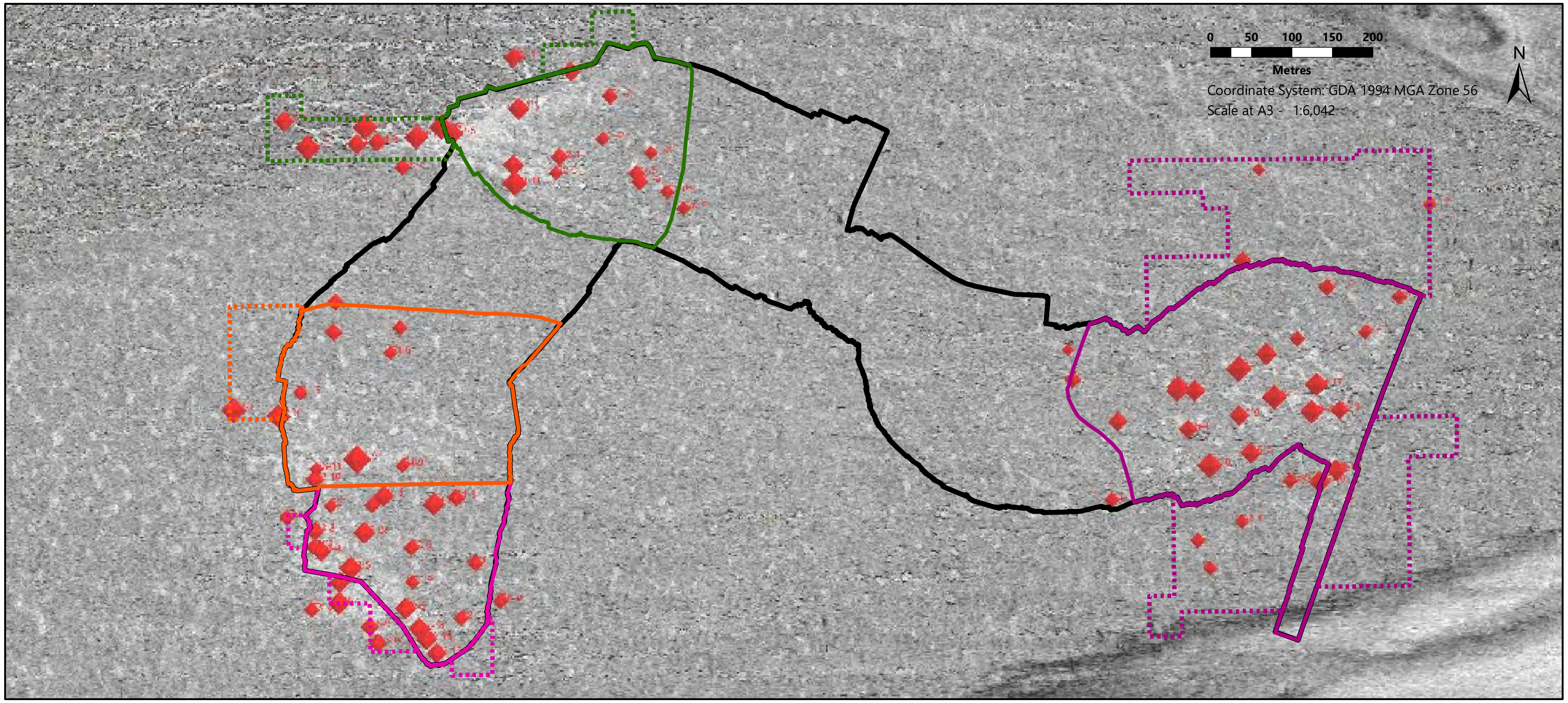
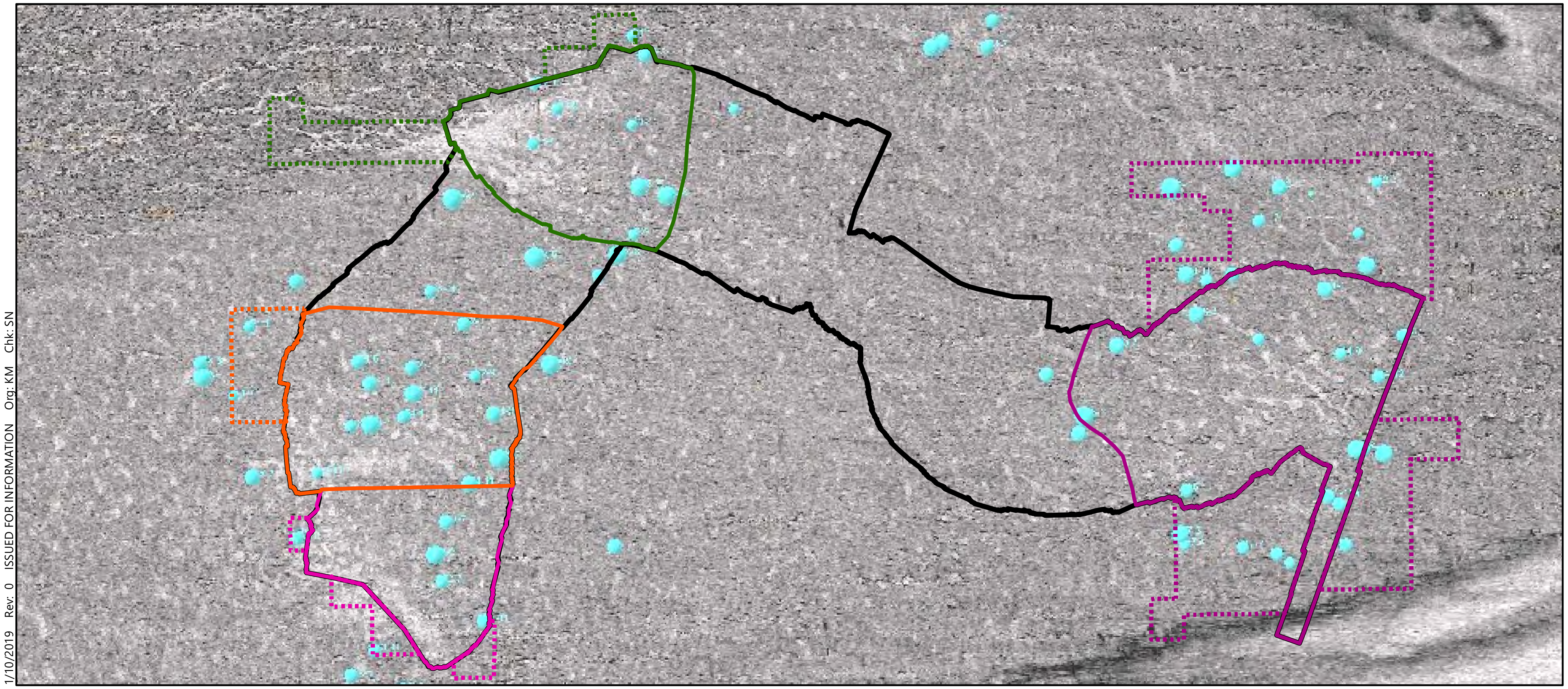
Figure 6-15
Backscatter mosaic (300Hz) overlaid with sites containing gravel and sand fractions





Gravel
Sand
Grounding footprint

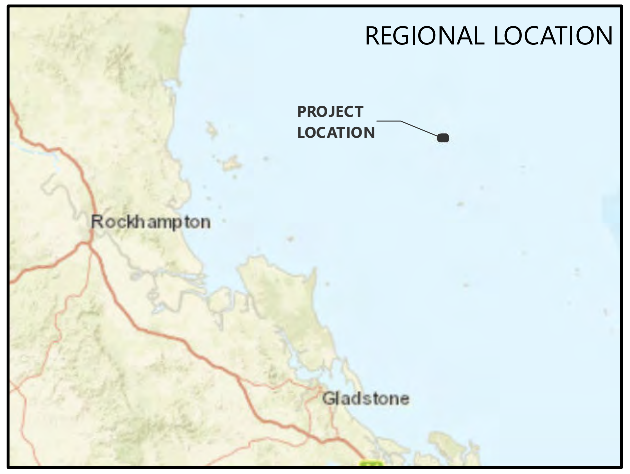
Priority Area

- A
- A - outside grounding footprint
- C
- C - outside grounding footprint
- E
- E - outside grounding footprint
- F
- F - outside grounding footprint

Bathymetry

-23.0m -9.0m

Source Information:
Grounding footprint, Priority areas Cardno 2017
Bathymetry (50cm LAT), Acoustic Imaging 2019



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User

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6.1.4 Rubble priority remediation areas

The approach used to quantify the spatial extent of the rubble and to produce mapping that delineates high and moderate priority remediation areas is described in Section 3 and relied on multiple data sources including:

- The PSD data collected during the sediment sampling along with video panoramas and still images at each site
- The characterisation of each still image collected along the towed video transects to quantify the different rubble percentage cover categories along each transect and in each 5m x 5m georeferenced grid
- The MBES data, including the results of the ARA used to model areas where the data indicates areas of larger grain sizes and which are indicative of the spatial extent of the rubble coverage in each priority area and surrounds.

6.1.4.1 Priority Area A

Mapping of the rubble areas using all sources of information from Priority Area A found small patches of rubble spread throughout the grounding footprint in isolated patches within holes and gutters (Figure 6-16 and Figure 6-17). When the contamination-related high and moderate priority remediation areas are superimposed onto Figure 6-17, all areas where the ARA modelling of the MBES data that show rubble (represented by light and dark brown squares on each figure) lie within the high priority remediation area for contamination, as do many of the grids where PSD and towed video data indicate sediment with rubble characteristics. For Priority Area A, the rubble and contamination issues may be dealt with concurrently. The total area of grounding-related rubble is likely to be similar to the area of contamination.

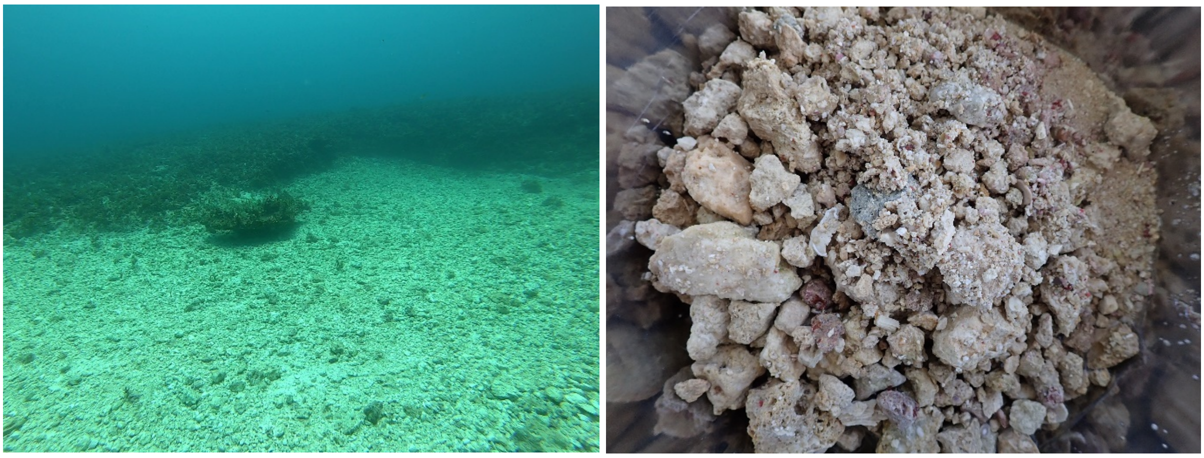

Figure 6-16 Rubble areas in situ and collected from Priority Area A (site A4-11)

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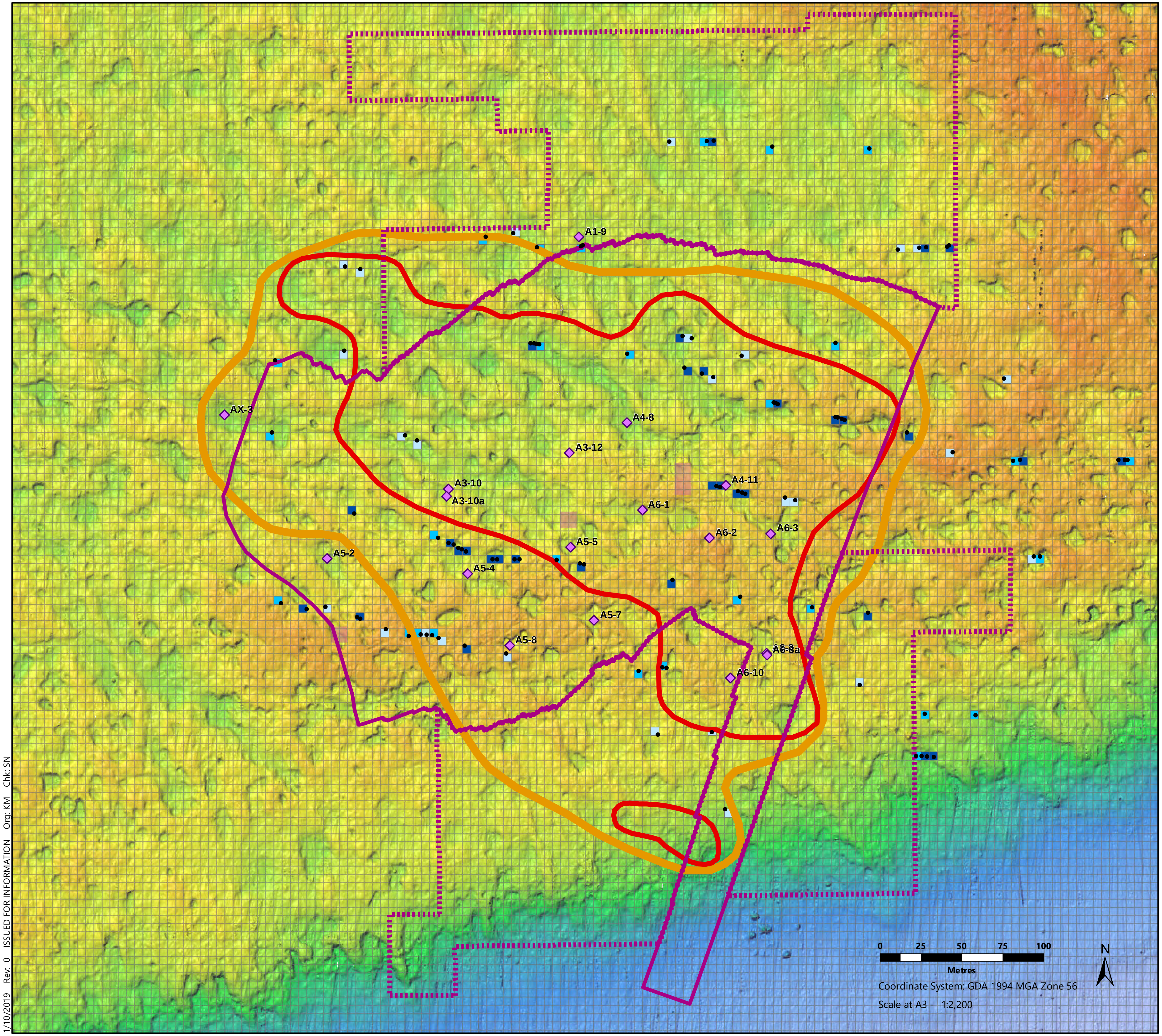
Figure 6-17
Distribution of Rubble in Priority Area A



- • Photo locations where rubble was present
- ◇ Sediment sampling locations where pebble/gravel samples were >60%
- 5m x 5m reference grid

Priority Area

- A
- A - outside grounding footprint

Rubble cover from Photos

- High (>60%)
- Medium (20 – 60%)
- Low (<20%)

Particle Size from ARA*

- Medium - very fine/fine pebbles (2mm – 8mm)

Contamination Priority sub areas

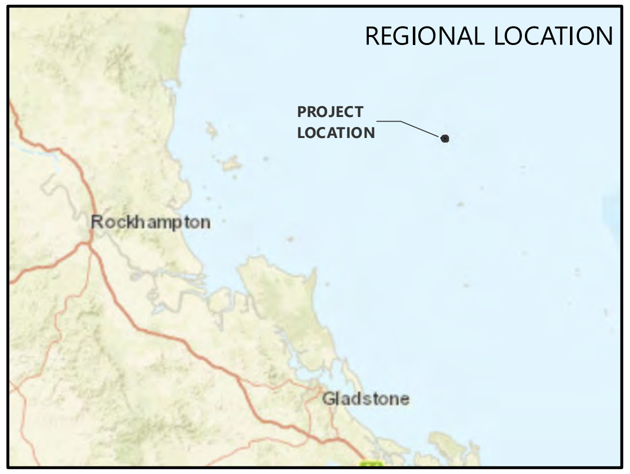
- High
- Moderate

Bathymetry

-23.0m – -9.0m

Note: ARA - Angle Range Analysis

Source Information:
Grounding footprint, Priority areas Cardno 2017
2010 Impact Zones AIMS
Bathymetry (50cm LAT) Acoustic Imaging 2019
Rubble Distribution (ARA Phi FP) Acoustic Imaging 2019



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User

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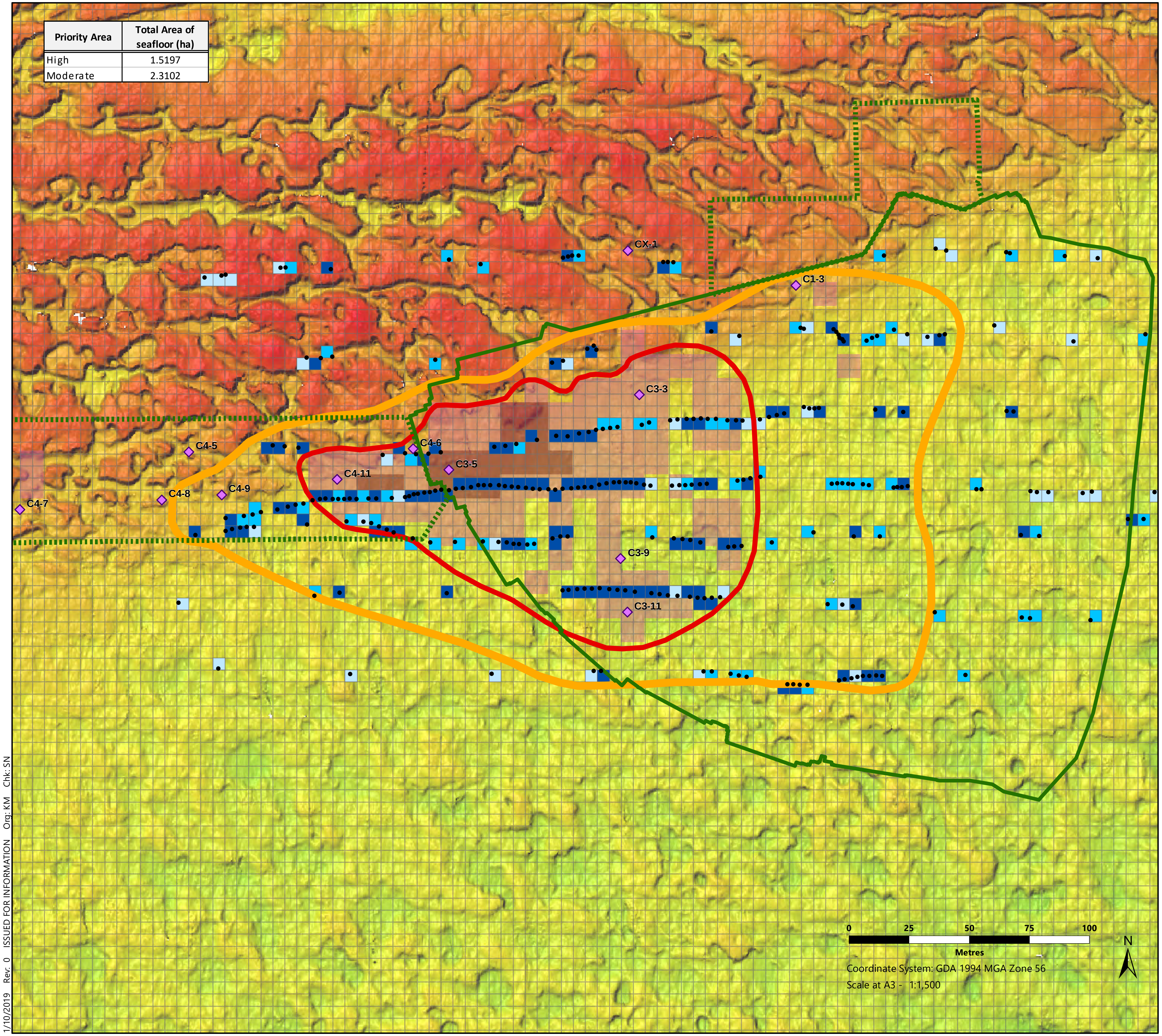
6.1.4.2 Priority Area C

Priority Area C contains large expanses of rubble. The vessel sat up against the shallow shelf of the High Relief Terrace and abraded the sea floor in this area for approximately two days. Using the data captured during the site assessment, a map was developed to combine data sources and to delineate the proposed high and moderate priority remediation areas for rubble (Figure 6-20). The area of focus for remediation activities (i.e. the high priority remediation area) is highlighted in red and covers an area of 1.52ha. The moderate priority remediation area (orange polygon) measures approximately 2.31ha and encompasses areas where smaller amounts of rubble were detected using the towed video imagery and PSD analysis of collected sediments.

The rubble appears to have shifted westward with the prevailing wave climate along the edge of the upper shelf to outside the grounding footprint. An example of the in-situ area and sediment collected from within the high priority remediation area for rubble (site C3-5) and from an area outside the grounding footprint to the west (Site C4-9) is provided in Figure 6-18 and Figure 6-19, respectively.

Figure 6-18 Rubble areas in-situ and collected from the high priority remediation area within the grounding footprint of Priority Area C (site C3-5)

Figure 6-19 Rubble areas in-situ and collected from outside the grounding footprint of Priority Area C (C4-9)



Priority Area	Total Area of seafloor (ha)
High	1.5197
Moderate	2.3102

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Figure 6-20 Distribution of Rubble in Priority Area C

Photo locations where rubble was present

Sediment sampling locations where pebble/gravel samples were >60%

5m x 5m reference grid

Priority Area

C

C - outside grounding footprint

Rubble cover from Photos

High (>60%)

Medium (20 – 60%)

Low (<20%)

Particle Size from ARA*

Coarse - medium/very coarse pebbles (>8mm)

Medium - very fine/fine pebbles (2mm – 8mm)

Priority Area

High

Moderate

Bathymetry

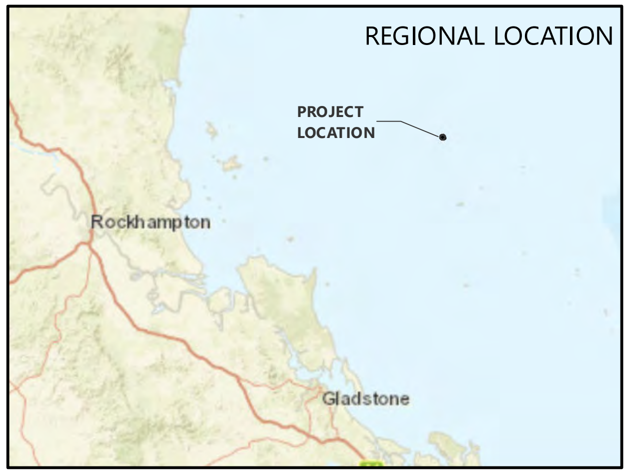
-23.0m

-9.0m

Note: ARA - Angle Range Analysis

Source Information:
Grounding footprint, Priority areas
Cardno 2017
2010 Impact Zones
AIMS

Bathymetry (50cm LAT)
Acoustic Imaging 2019
Rubble Distribution (ARA Phi FP)
Acoustic Imaging 2019



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User

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6.1.4.3 Priority Area E

The vessel was grounded in Priority Area E for a day and the abrasion of the reef rock here produced large areas of rubble. Using the data captured during the site assessment, a map was developed to combine data sources and to delineate the proposed high rubble priority remediation area for Priority Area E (Figure 6-23). The area of focus for remediation activities (i.e. the high priority remediation area) is highlighted in red and covers an area of 1.83ha. No moderate priority remediation area is proposed as the high priority area encompasses the area where significant amounts of rubble was found during the surveys.

As with Priority Area C, though to a lesser extent, the rubble appears to have shifted westward with the prevailing wave climate to outside the grounding footprint. An example of the in-situ area and sediment collected from within the high priority remediation area site E3-9 and site E3-11 is provided in Figure 6-21 and Figure 6-22, respectively.

Figure 6-21 Rubble areas in-situ and collected from the high priority remediation area within the grounding footprint of Priority Area E (site E3-9)

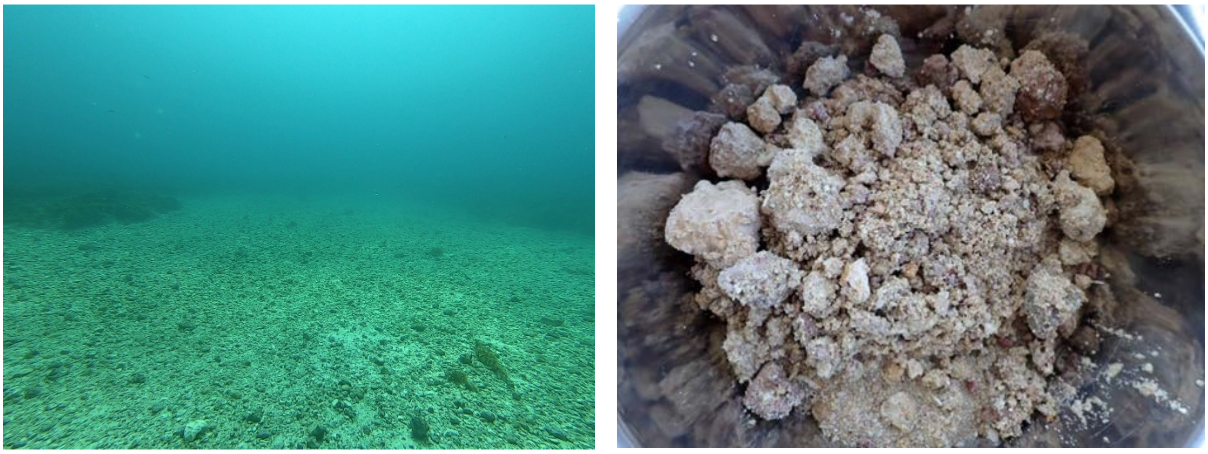

Figure 6-22 Rubble areas in-situ and collected from the high priority remediation area within the grounding footprint of Priority Area E (site E3-11)

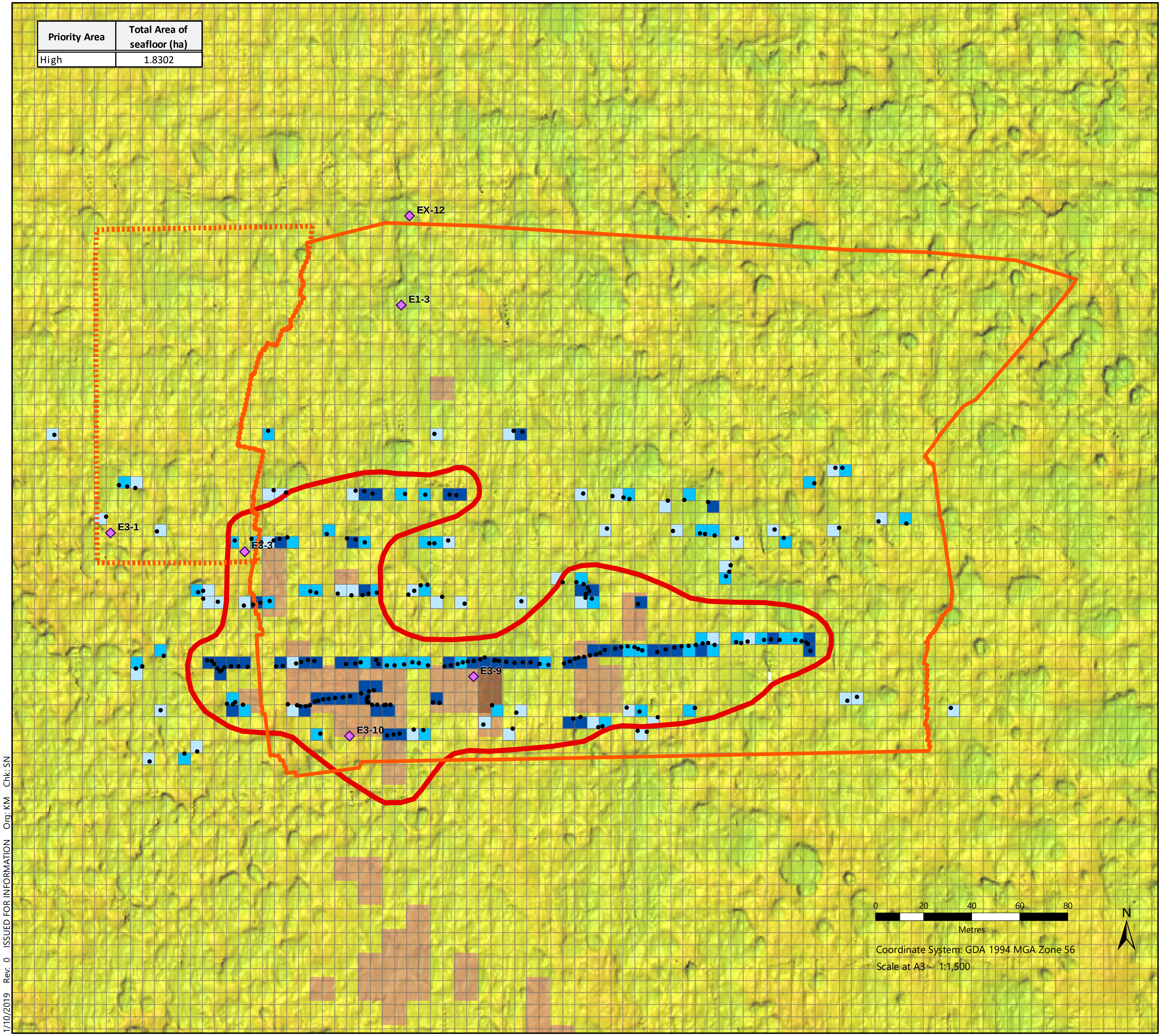

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Figure 6-23
Distribution of Rubble in Priority Area E

Photo locations where rubble was present

Sediment sampling locations where pebble/gravel samples were >60%

5m x 5m reference grid

Priority Area
- E
- E - outside grounding footprint

Rubble cover from Photos
- High (>60%)
- Medium (20 – 60%)
- Low (<20%)

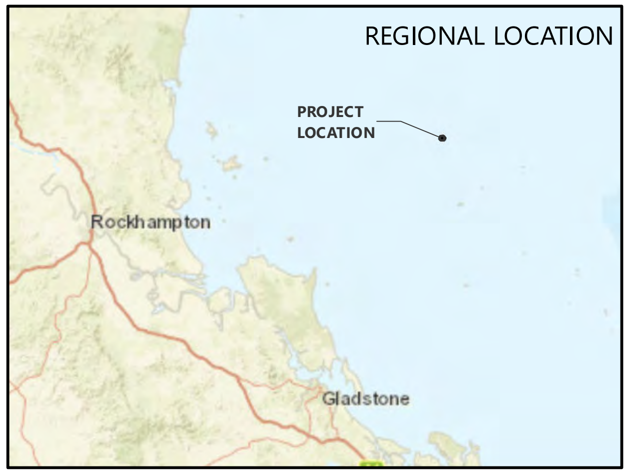
Particle Size from ARA*
- Coarse - medium/very coarse pebbles (>8mm)
- Medium - very fine/fine pebbles (2mm – 8mm)

Priority Area
- High

Bathymetry
-23.0m
-9.0m

Note: ARA - Angle Range Analysis

Source Information:
Grounding footprint, Priority areas
Cardno 2017
2010 Impact Zones
AIMS
Bathymetry (50cm LAT)
Acoustic Imaging 2019
Rubble Distribution (ARA Phi FP)
Acoustic Imaging 2019



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User

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6.1.4.4 Priority Area F

The vessel was grounded in Area F for seven days and the abrasion of the reef rock at this site produced large areas of rubble. Using the data captured during the site assessment, a map was developed to combine data sources and to delineate the proposed high priority remediation area for rubble for Priority Area F (Figure 6-26). The area of focus for remediation activities (i.e. the high priority remediation area) is highlighted in red and covers an area of 1.83ha. No moderate priority remediation area is proposed as the high priority area encompasses where significant amounts of rubble was found during surveys.

As with Priority Area E, the rubble originating from the grounding footprint appears to have shifted westward with the prevailing wave climate to outside the grounding footprint. An example of the in-situ area and sediment collected from within the high priority remediation area site F2-8 and from site F3-7 outside the grounding footprint is shown in Figure 6-24 and Figure 6-25 respectively.

Figure 6-24 Rubble areas in-situ and collected from the high priority remediation area within the grounding footprint of Priority Area F (site F2-8)

Figure 6-25 Rubble areas in-situ and collected from outside the high priority remediation area (site F3-7)

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Figure 6-26
Distribution of Rubble in Priority Area F

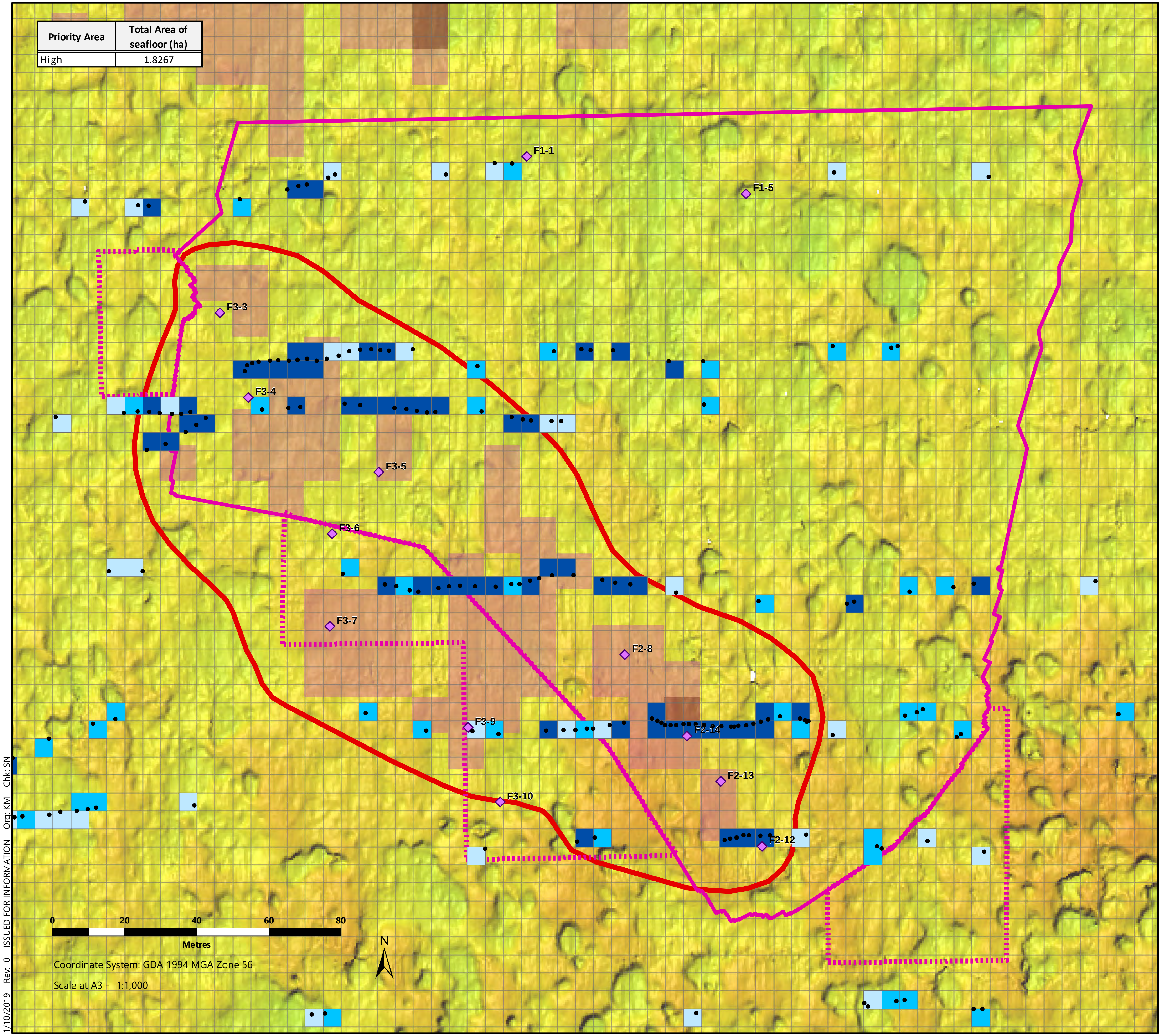


Photo locations where rubble was present

5m x 5m reference grid

Sediment sampling locations where pebble/gravel samples were >60%

Priority Area

F

F - outside grounding footprint

Rubble cover from Photos

High (>60%)

Medium (20 – 60%)

Low (<20%)

Particle Size from ARA*

Coarse - medium/very coarse pebbles (>8mm)

Medium - very fine/fine pebbles (2mm – 8mm)

Priority Area

High

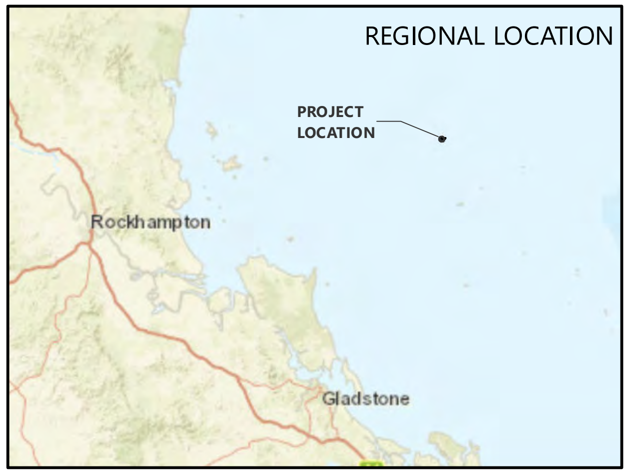
Bathymetry

-23.0m — -9.0m

Note: ARA - Angle Range Analysis

Source Information:
Grounding footprint, Priority areas
Cardno 2017
2010 Impact Zones
AIMS

Bathymetry (50cm LAT)
Acoustic Imaging 2019
Rubble Distribution (ARA Phi FP)
Acoustic Imaging 2019



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6.2 Flattening and compaction

6.2.1 Changes over time

Comparisons between the high resolution multibeam bathymetry data collected in 2010 (Negri et al, 2010) and that collected for the site assessment for each priority area and reference area are provided in Figure 6-29 (Priority Area A and C), Figure 6-30 (Priority Area E and F) and Figure 6-31 (reference areas). Slope analysis calculations for each of the two datasets identify areas with differing slope angles (0-5, 5-10 and >10 degrees) and are provided in Figure 6-32 (Priority Area A and C) and Figure 6-33 (Priority Area E and F). Changes in the rugosity of the grounding footprint and surrounds is compared over time in these figures. The areas where evidence of flattening remains is in Priority Area C, E and F. Diver investigations of these areas confirm this. Little evidence of significant flattened areas can be found in Priority Area A.

Evidence of flattening is clearly shown in Area F where the vessel sat for seven days. Investigations by divers in the grounding footprint of Priority Area F found large expanses of rubble covering worn down calcium carbonate reef structure. Within this structure, remnants of the coral matrix formed over time can be seen (Figure 6-27). In nearby areas, potential evidence of rubble created by the grounding being compacted was found (Figure 6-28).

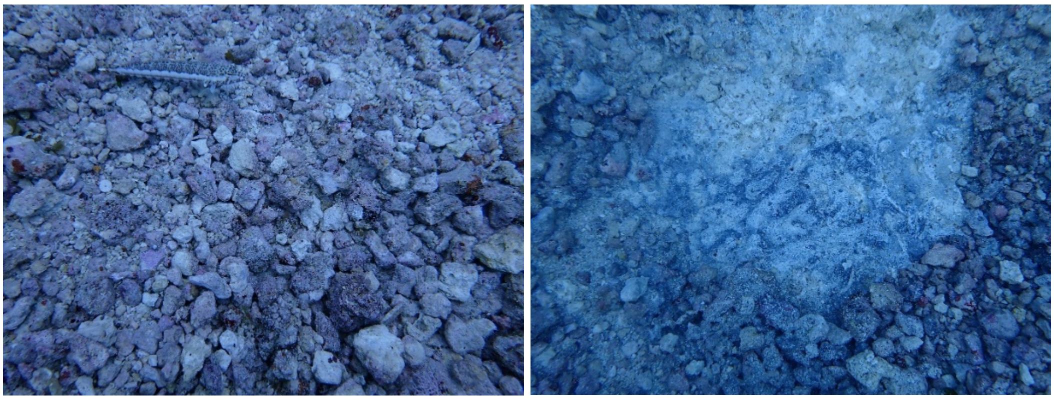

Figure 6-27 Flattened reef structure in Priority Area F grounding footprint with rubble layer and after removal

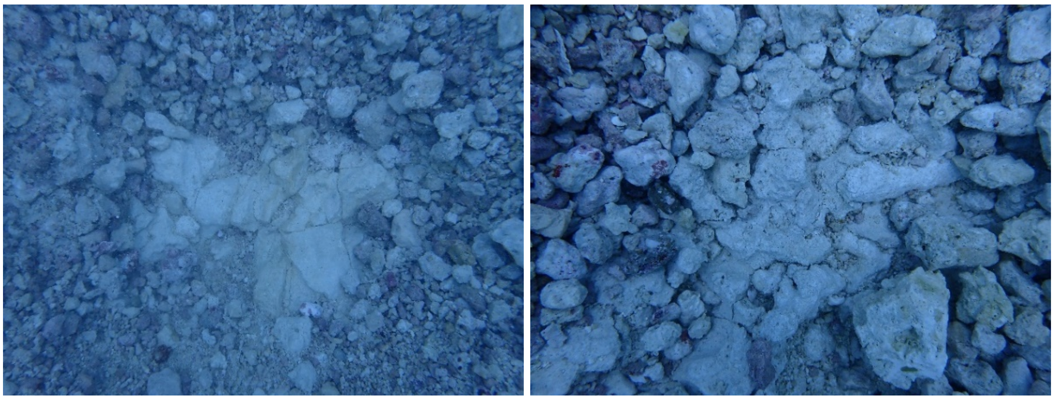

Figure 6-28 Areas where compaction was found in Priority Area F

Maps are provided which highlight all areas where the slope is between 0-5 degrees, or flat areas, for Priority Area C (Figure 6-34), Priority Area E (Figure 6-35) and Priority Area F (Figure 6-36). The impacted areas polygon from sonar (Negri et al, 2010) are included in these figures, along with the 2019 remediation priority areas for rubble (Section 6.1.4). Three estimates of the extent of flattened areas are provided on each figure as follows:

- Total flat (0-5 degrees) sea floor areas (ha) within the entire grounding footprint for the 2019 data
- Total sea floor area (ha) within the impacted areas from sonar (Negri et al 2010)
- Total estimated flat (0-5 degrees) sea floor areas (ha) within the impacted areas from sonar (Negri et al 2010).

The estimates of flattened areas for each priority area are provided in Table 6-2. The largest flattened areas within the impacted areas occur in Area C (1.59ha).

Table 6-2 Estimates of flattened areas (0-5 degrees slope) calculated from 2019 slope analysis

Flattened area locations	Priority Area C (ha)	Priority Area E (ha)	Priority Area F (ha)
Entire grounding footprint	3.5	4.10	2.6
Impacted areas from sonar	1.59	0.46	0.48

The change in flattened extent over time shown in this analysis suggests the grounding-related flattened areas are at least in part associated with rubble filling in depressions and ‘flattening’ the profile of the shoal. This is supported by the slope analysis of the 2010 bathymetry compared to the 2019 bathymetry i.e. the ridges of rubble evident in 2010 are missing in 2019, especially in the impacted areas in Priority Area F. To the west of Priority Area F, the more complex bathymetry (holes and channels) observed in the 2010 slope analysis appears to be ‘flattened’ or filled / covered and now appear to contain rubble which has shifted to the west. The high priority area for rubble extends to the west to capture this migration of rubble.

The extent of abrasive flattening and compaction (i.e. areas which the substrate is intact but ‘flattened’ and compacted) is unclear as these areas are obscured by the presence of rubble. These areas are considered to be of lesser importance with respect remediation, given the areas are small, within identified areas of rubble and ‘natural’ areas outside of the grounding footprint are likely to offer habitat of similar value to these abraded flattened areas. It is proposed that these abraded flattened areas are not a priority for remediation.

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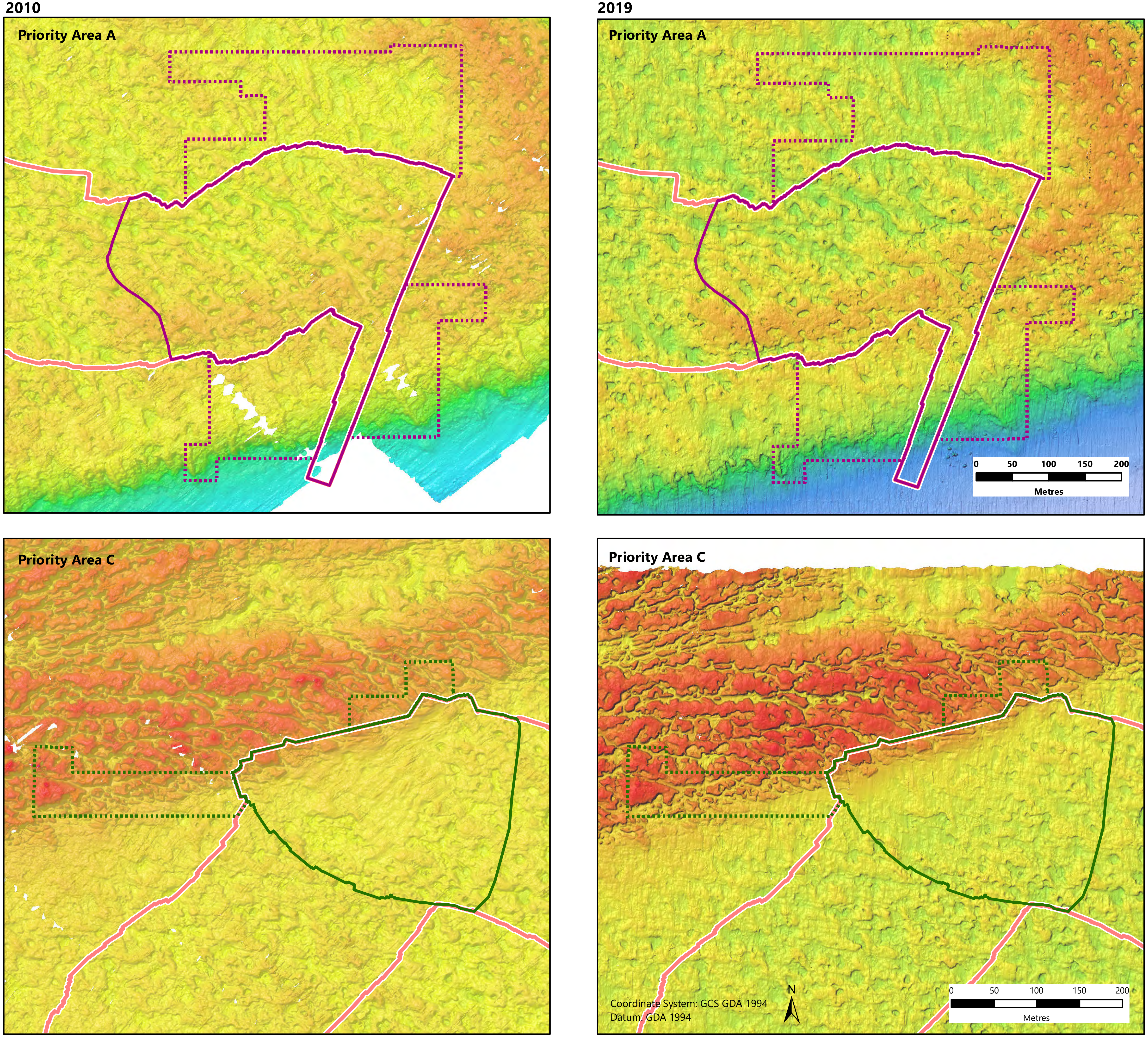
Figure 6-29
Comparisons between 2010 and 2019 bathymetry in Priority Areas A and C



Grounding footprint

Priority Area

A

A - outside grounding footprint

C

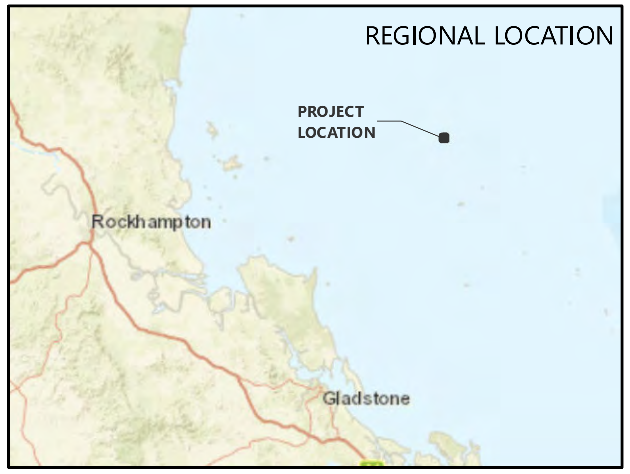
C - outside grounding footprint

Bathymetry

-23.0m

-9.0m

Source Information:
Priority areas, Grounding footprint, 2010 Bathymetry (Negri et al) Cardno 2017
2019 Bathymetry (50cm LAT) Acoustic Imaging 2019



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User

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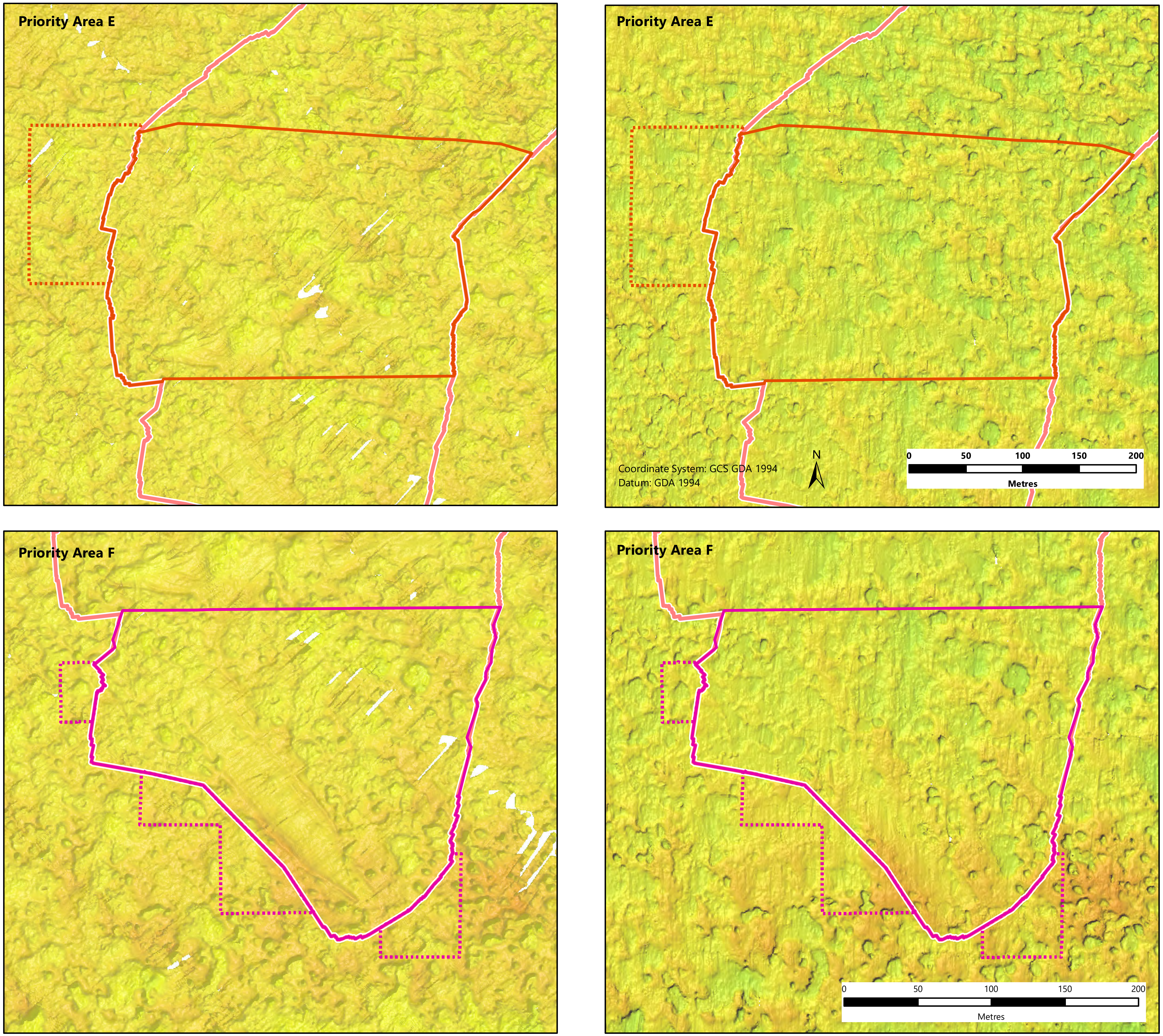
Figure 6-30
Comparisons between 2010 and 2019 bathymetry in Priority Areas E and F



Grounding footprint

Priority Area

E

F

E - outside grounding footprint

F - outside grounding footprint

Bathymetry

-23.0m — -9.0m

Source Information:
Priority areas, Grounding footprint, 2010 Bathymetry (Negri et al)
Cardno 2017
2019 Bathymetry (50cm LAT)
Acoustic Imaging 2019

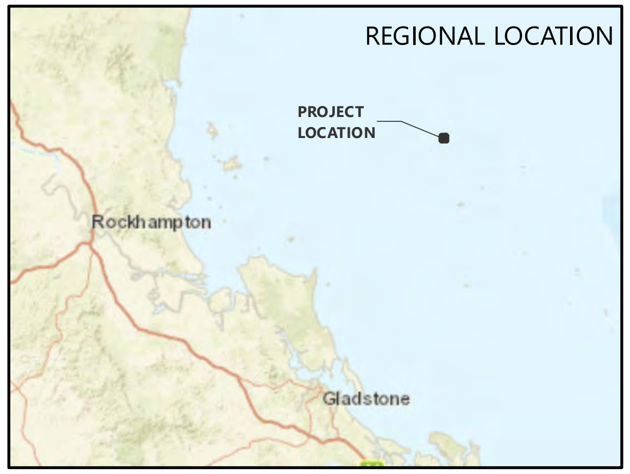


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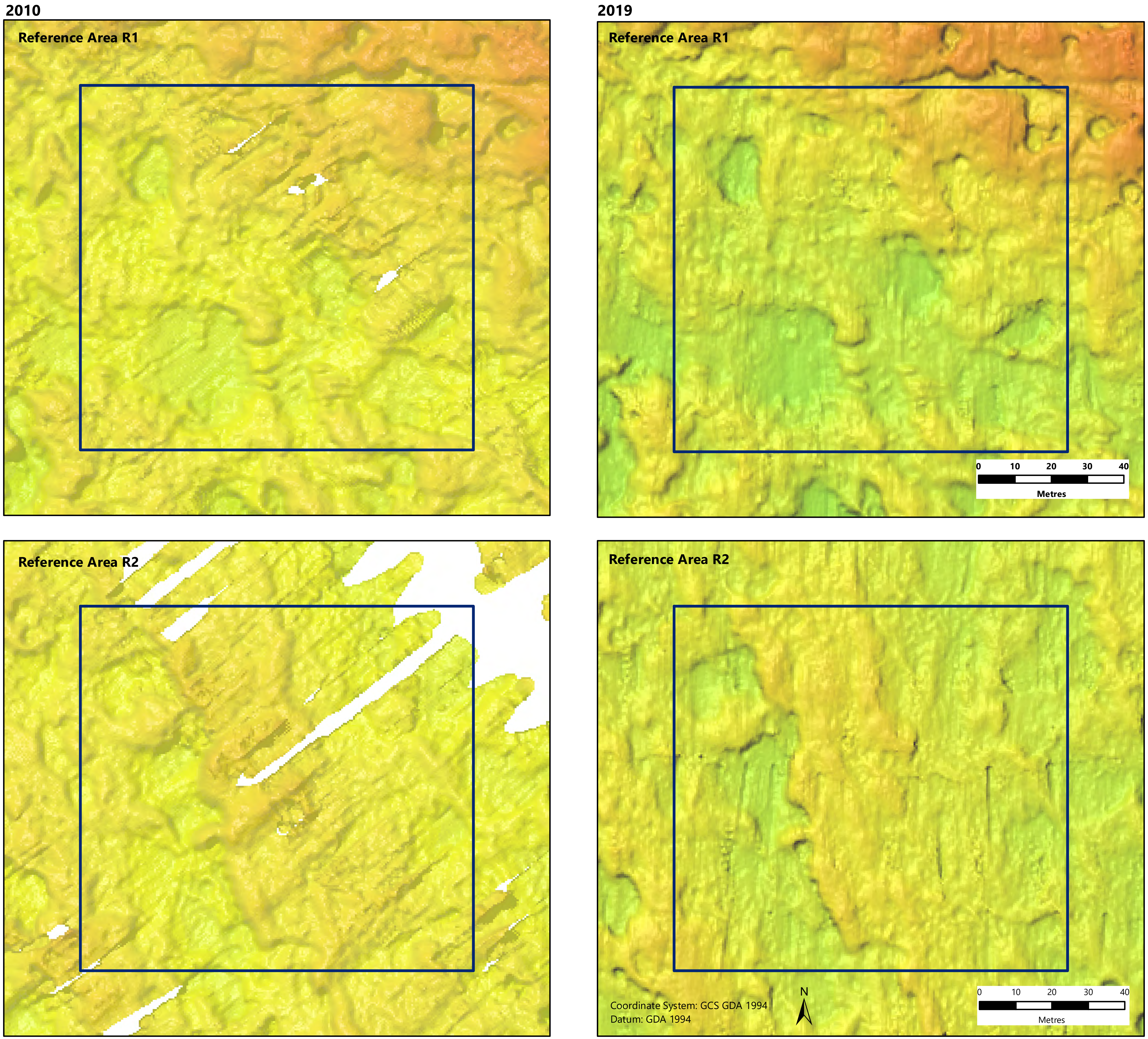
Figure 6-31
Comparisons between the 2010 and 2019 bathymetry in Reference Areas R1 and R2

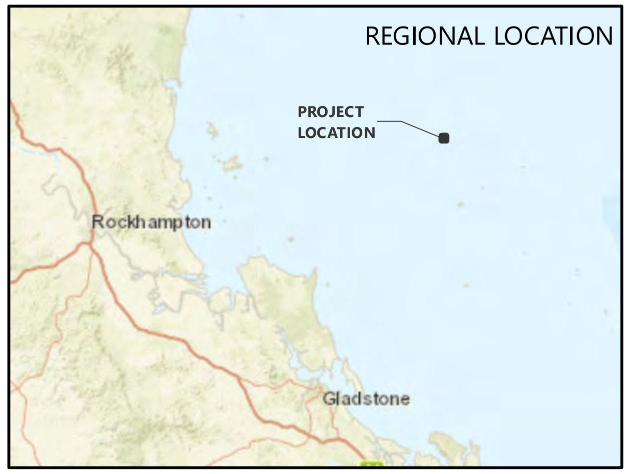


Reference Area

Bathymetry

-23.0m — -9.0m

Source Information:
Priority areas, Grounding footprint, 2010 Bathymetry (Negri et al)
Cardno 2017
2019 Bathymetry (50cm LAT)
Acoustic Imaging 2019



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User

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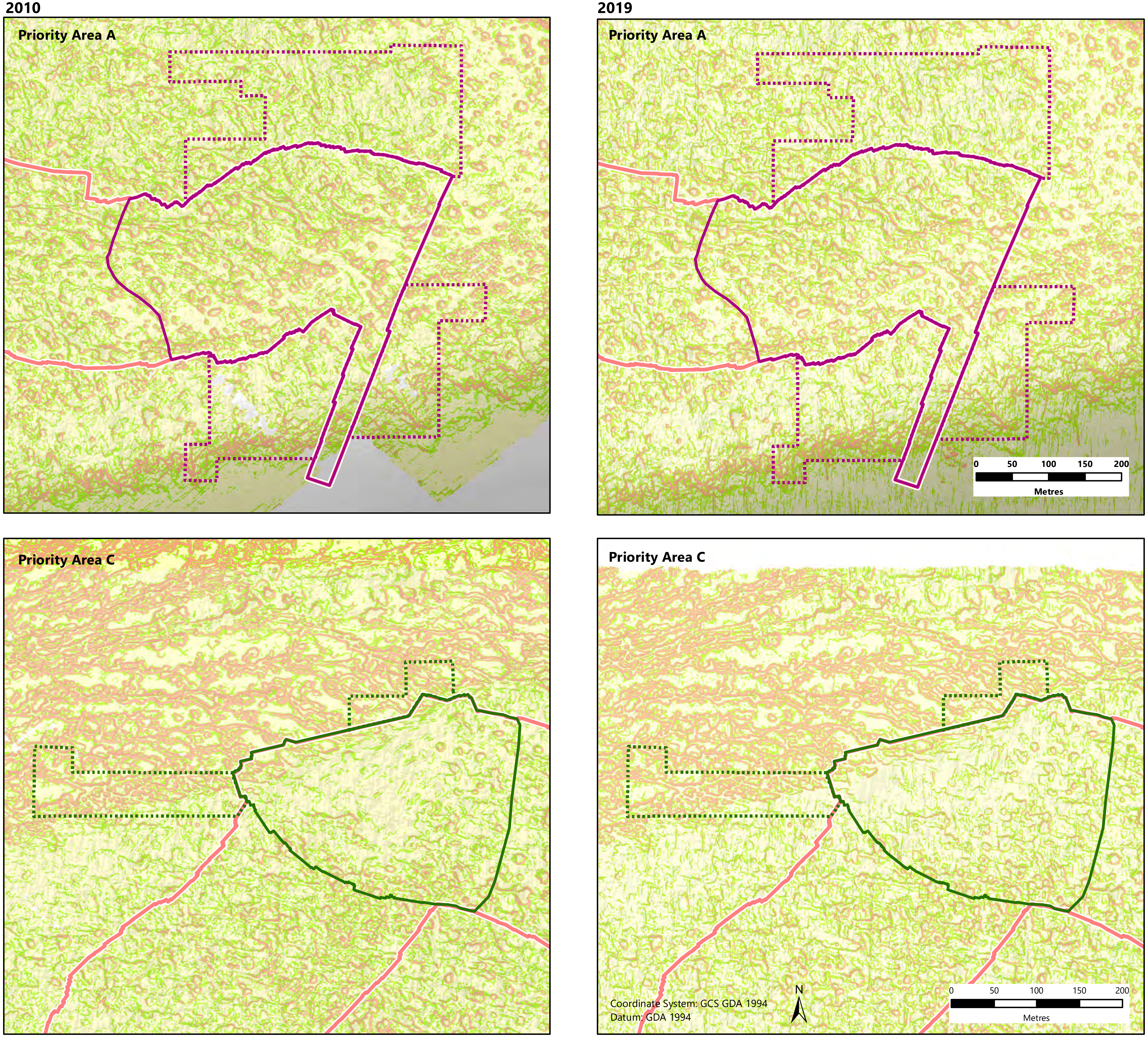
Figure 6-32
Comparisons between 2010 and 2019 slope analysis of the MBES bathymetry in Priority Areas A and C



Degrees Slope
- 0 - 5
- 5 - 10
- > 10

Grounding footprint

Priority Area
- A
- A - outside grounding footprint
- C
- C - outside grounding footprint

Source Information:
Priority areas, Grounding footprint
Cardno 2017
2010/2019 Slope Analysis
Acoustic Imaging 2019

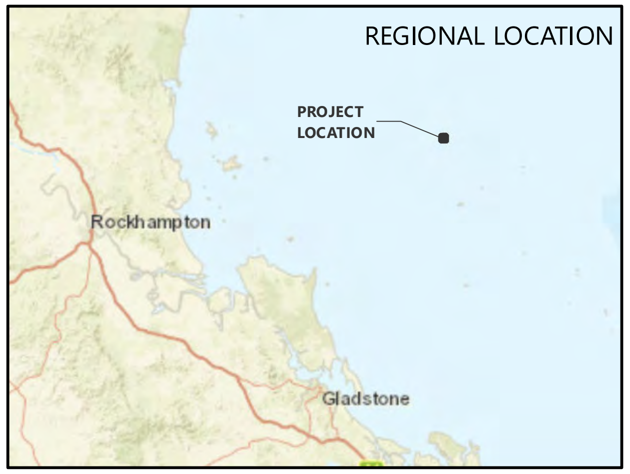


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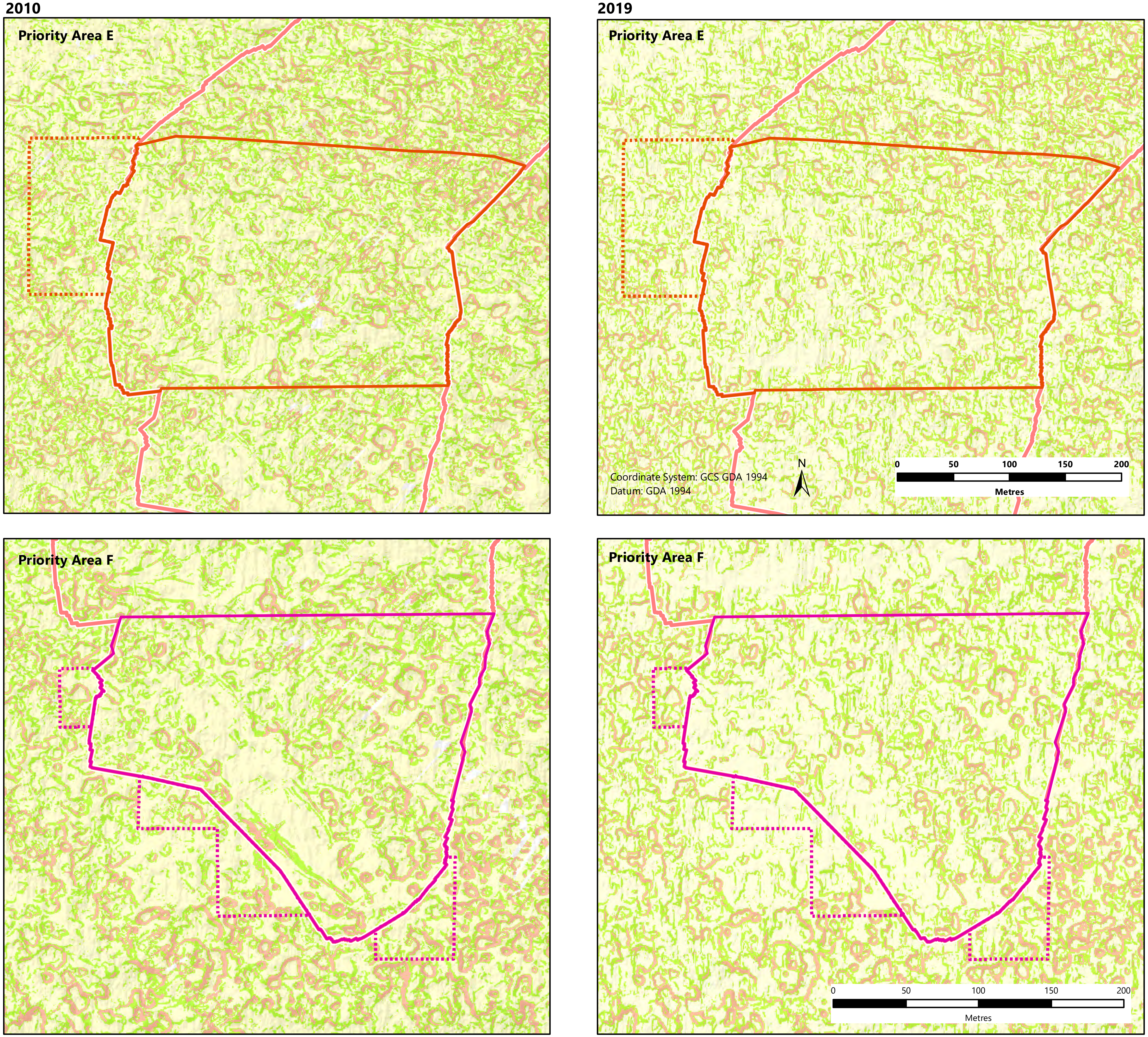
Figure 6-33
Comparisons between the 2010 and 2019 slope analysis of the MBES bathymetry in Priority Areas E and F

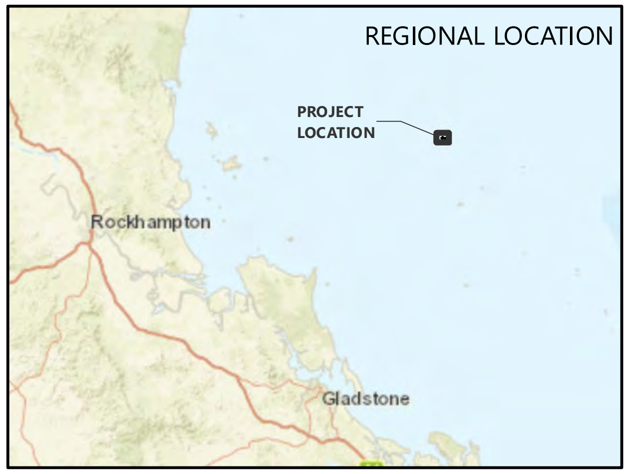


Degrees Slope
- 0 - 5
- 5 - 10
- > 10

Grounding footprint

Priority Area
- E
- E - outside grounding footprint
- F
- F - outside grounding footprint

Source Information:
Priority areas, Grounding footprint
Cardno 2017
2010/2019 Slope Analysis
Acoustic Imaging 2019



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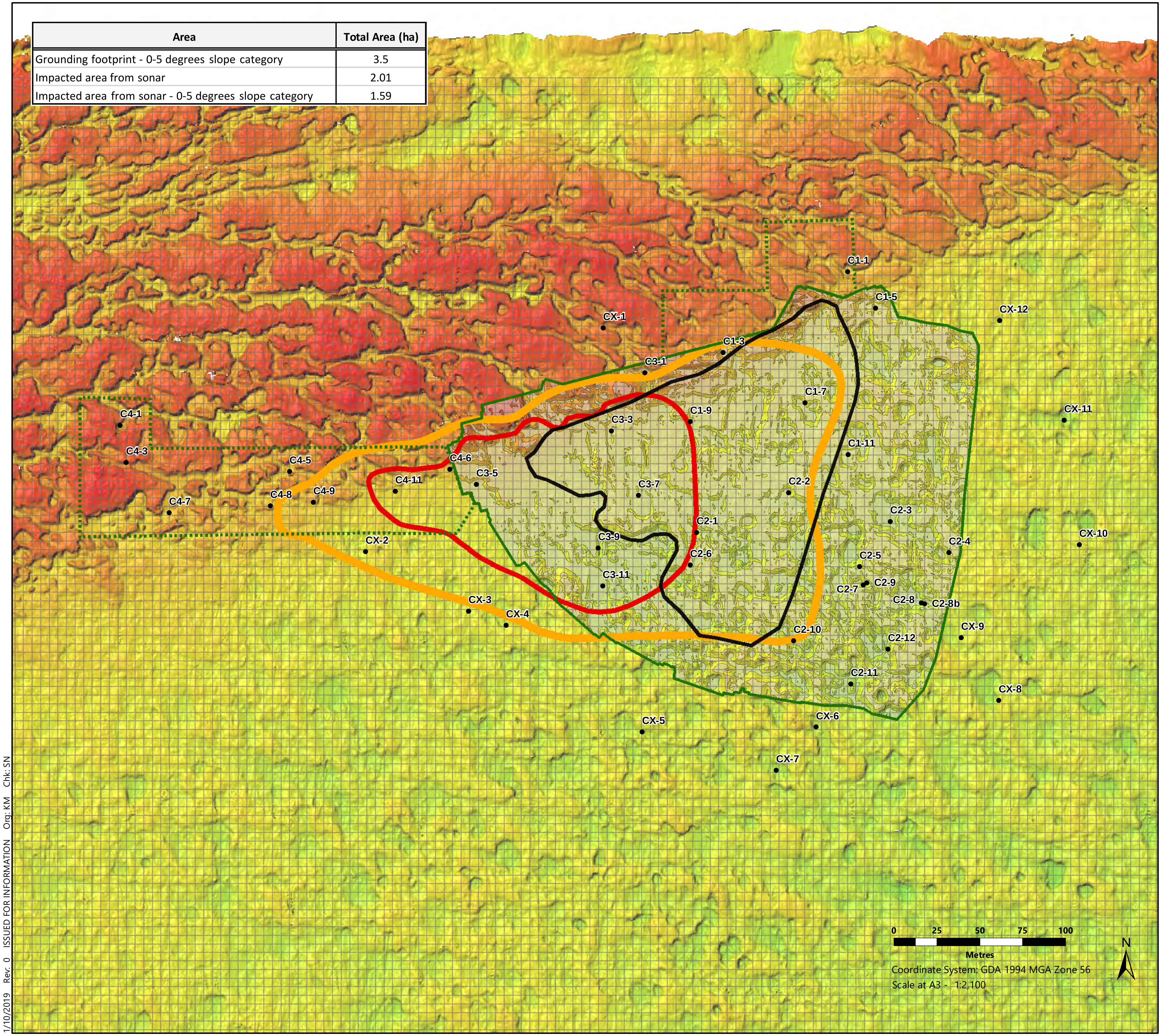
Area	Total Area (ha)
Grounding footprint - 0-5 degrees slope category	3.5
Impacted area from sonar	2.01
Impacted area from sonar - 0-5 degrees slope category	1.59



Coordinate System: GDA 1994 MGA Zone 56
Scale at A3 - 1:2,100

Douglas Shoal Remediation Planning Site Assessment Report

Figure 6-34
Flattened Extents due to Hull Abrasion in Priority Area C

- Sediment sampling location
- 5m x 5m reference grid
- Impacted area from sonar (Negri et al 2010)

Priority Area
- C
- C - outside grounding footprint

Slope catagory
- 0-5 degrees

Rubble Priority Area
- High
- Moderate

Bathymetry
-23.0m -9.0m

Source Information:
Grounding footprint, Priority areas
Cardno 2017

Impacted areas from sonar
Negri et al 2010

Bathymetry (50cm LAT), 2019 Slope Analyses
Acoustic Imaging 2019

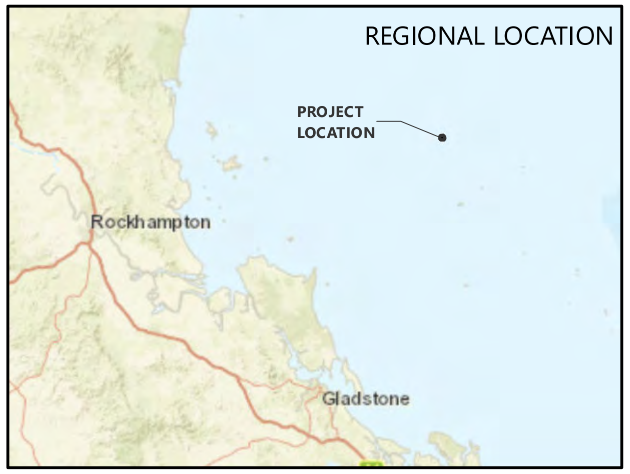


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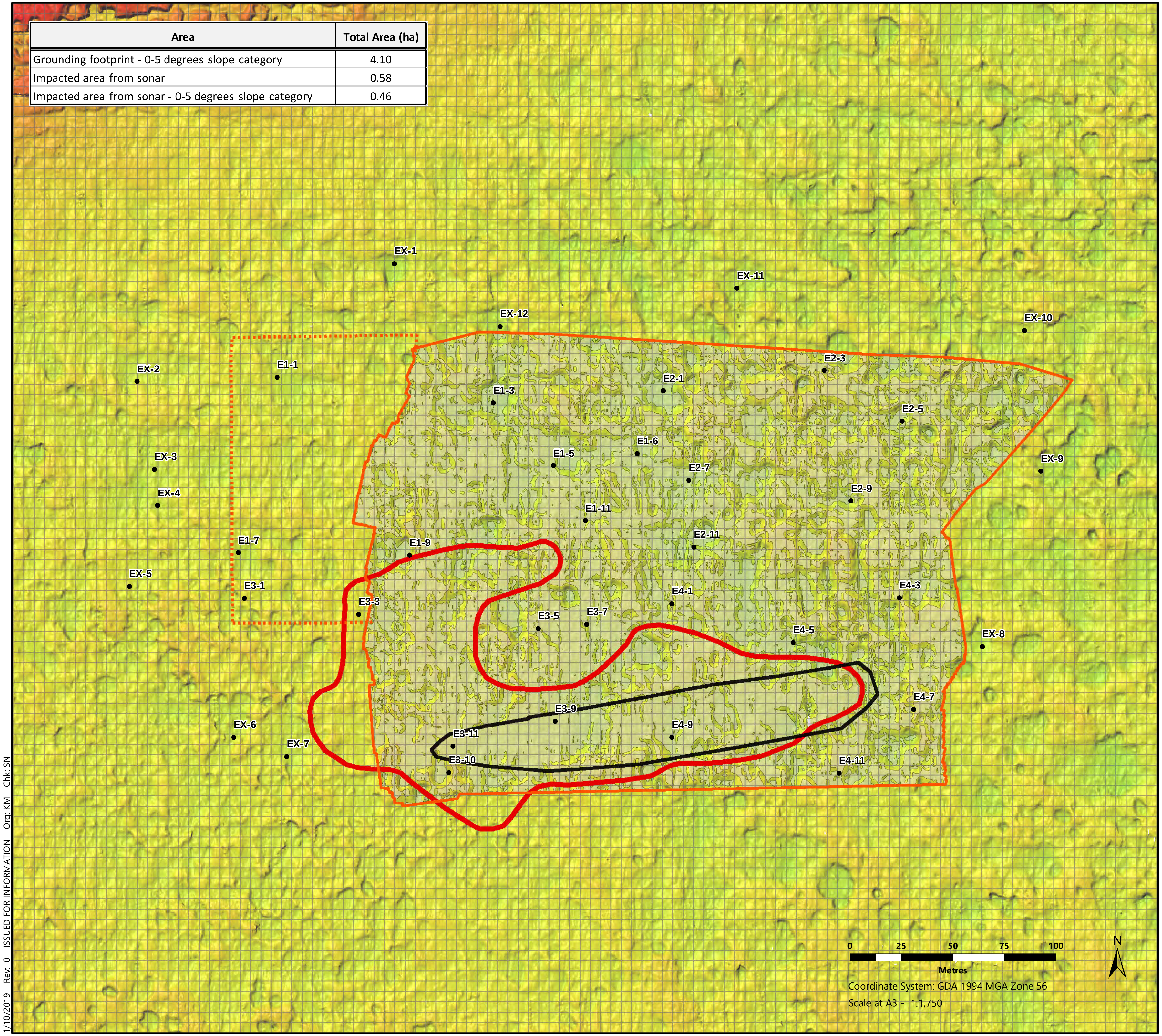
Figure 6-35
Flattened Extents due to Hull Abrasion in Priority Area E

Area	Total Area (ha)
Grounding footprint - 0-5 degrees slope category	4.10
Impacted area from sonar	0.58
Impacted area from sonar - 0-5 degrees slope category	0.46



Coordinate System: GDA 1994 MGA Zone 56

Scale at A3 - 1:1,750

Sediment sampling location

5m x 5m reference grid

Impacted area from sonar (Negri et al 2010)

Priority Area

E

E - outside grounding footprint

Slope catagory

0-5 degrees

Rubble Priority Area

High

Bathymetry

-23.0m — -9.0m

Source Information:
Grounding footprint, Priority areas Cardno 2017
Impact ed area from sonar(Negri et al 2010)

Bathymetry (50cm LAT), 2019 Slope Analyses Acoustic Imaging 2019

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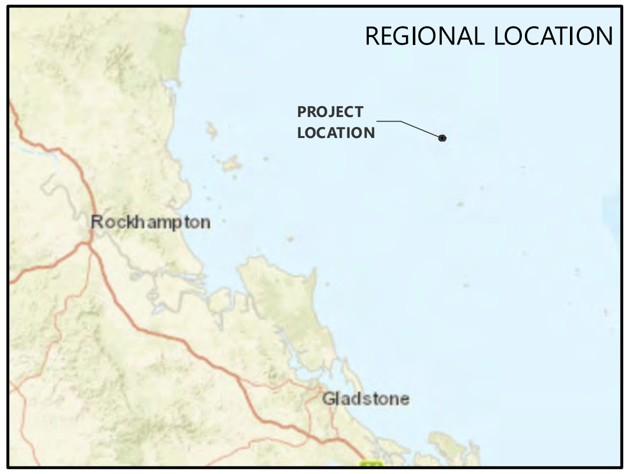

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Douglas Shoal Remediation Planning
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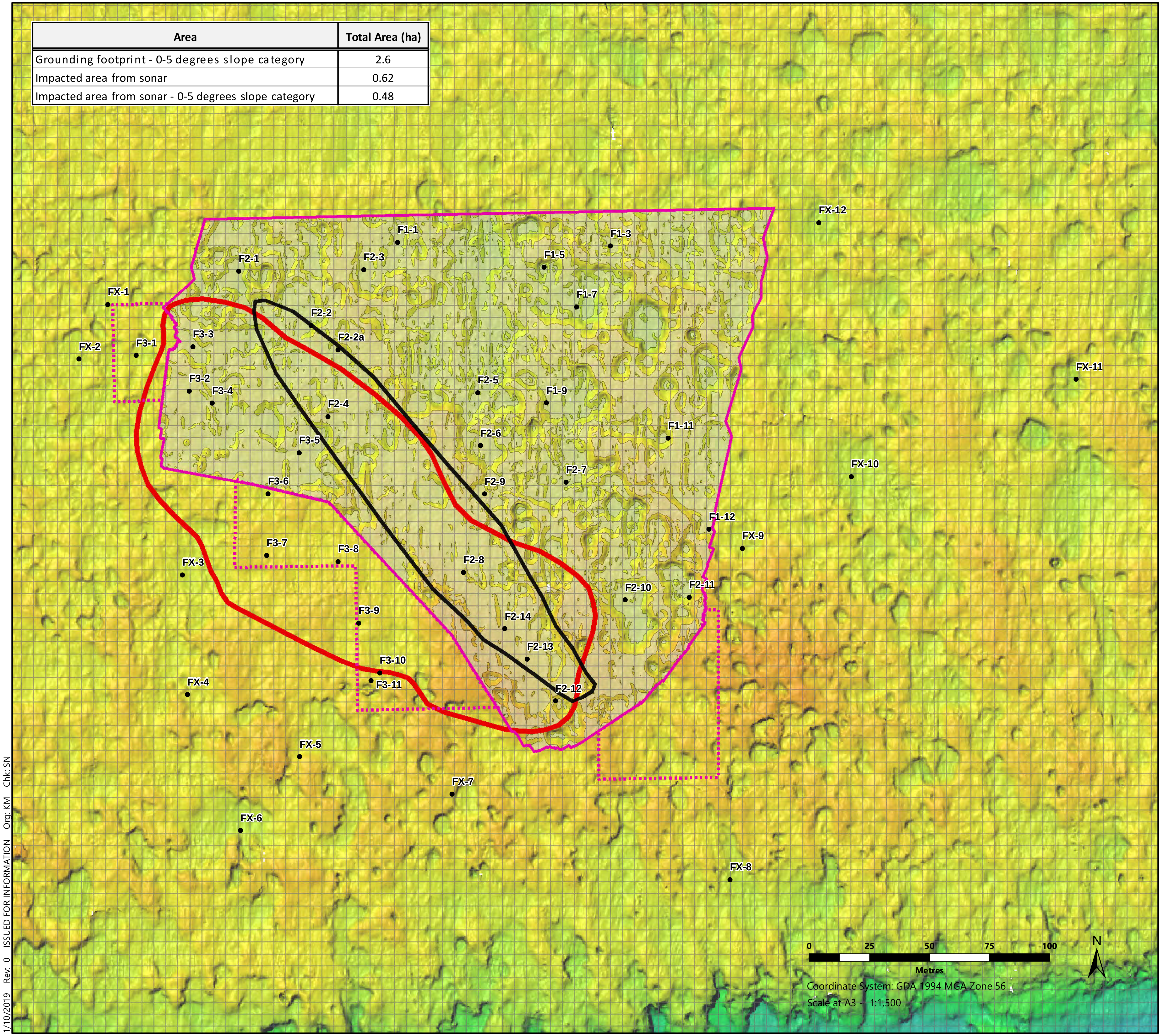
Figure 6-36
Flattened Extents due to Hull Abrasion in Priority Area F

Area	Total Area (ha)
Grounding footprint - 0-5 degrees slope category	2.6
Impacted area from sonar	0.62
Impacted area from sonar - 0-5 degrees slope category	0.48



Sediment sampling location
5m x 5m reference grid
Impacted area from sonar (Negri et al 2010)

Rubble Priority Area
High

Priority Area
F
F - outside grounding footprint

Slope catagory
0-5 degrees

Bathymetry
-23.0m -9.0m

Source Information:
Grounding footprint, Priority areas Cardno 2017
Impacted area from sonar Negri et al 2010
Bathymetry (50cm LAT), 2019 Slope Analyses Acoustic Imaging 2019

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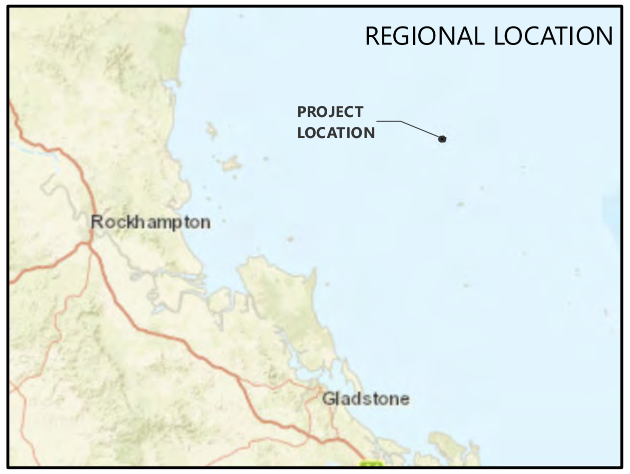

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Key points

Physical contact between the vessel and the shoal created rubble. The rubble is different from naturally occurring sediments (including dead coral fragments) as it is coarser, more angular, and typically without encrusting organisms (coralline algae or turf algae, encrusting sponges or coral).

The form of the rubble does not appear to have changed significantly since the grounding and remains obviously different to the natural sediments found in the reference or unaffected areas; however, some areas of rubble do support benthic organisms and have consolidated over time.

Rubble is commonly unconsolidated and its movement over time appears to impede natural recovery. Unconsolidated rubble appears to have moved generally in a westerly direction and has affected habitat on the shoal beyond the grounding footprint. In some locations the rubble has filled (partially or completely) natural depressions and therefore altered habitat complexity on the shoal.

It appears that some areas of substrate previously smothered by rubble following the grounding have been exposed with the westward movement of rubble over time. Undulating substrate was found in these areas to be devoid of algal growth; however, now exposed these areas may support the settlement and growth of coral recruits and other benthos.

The persistence of rubble obscures the extent of abrasive flattening and compaction damage on the shoal; however, these areas of abrasive flattening and compaction are considered to be of lower importance for remediation, given the areas are small, within identified areas of rubble and that 'natural' areas outside of the grounding footprint are likely to offer habitat of similar value to these abraded flattened areas.

7 Volumes of sediment

Estimates of the volumes of sediment in each of the high and moderate priority areas will be important when evaluating remediation options. Data available to support volume estimates includes:

- Five replicate measurements at each sediment collection site within the Priority Areas resulting in 885 individual measurements of sediment depth. noting that in some areas divers struggled to collect sediment for analysis due to the sparsity of sediment (Section 4.3.2, Table 4-2)
- Consideration of PSD information from 193 individual sites across all priority areas (Table 7-1)
- SBP data showing shallow sediments overlaying a hard substrate across the survey extent which encompasses all priority areas and surrounds.

To obtain estimates of the volumes of sediment in each high and moderate priority area, sediment depth data from that area is used.

Table 7-1 PSD Results from all priority areas and surrounds (AX, CX, EX, FX) and reference areas

Priority Area	n	Clay (%) <2µm	Silt (%) (2-60µm)	Sand (%) (0.06-2mm)	Gravel (%) (>2mm – 60mm)	Cobbles (%) (>60mm)
A	66	4.7	1.8	49.9	43.7	0.0
AX	6	2.5	0.5	64.5	32.5	0.0
C	29	9.8	2.2	32.4	55.7	0.0
CX	8	4.3	0.8	61.3	33.8	0.0
E	24	4.8	1.7	50.2	43.4	0.0
EX	7	3.6	0.0	66.0	30.4	0.0
F	29	8.1	3.6	31.9	56.3	0.0
FX	11	4.4	2.7	49.0	43.9	0.0
Reference	11	2.5	2.5	66.4	28.7	0.0

Using the mean (± standard deviation) values of sediment depth (refer to Section 4.3.2, Table 4-2 and Table 7-2), the estimate of the total volume of sediments in the high priority rubble areas of Priority Area C, E and F are 1,158 ± 1,129m^3 , 1,196 ± 908m^3 and 1,564 ± 1,060m^3 respectively. The mean volume of contaminated sediment found in the holes and channels of the high priority area of Priority Area A represents approximately 880 ± 737m^3.

Values for the median and 95th percentile depths of sediments (and volumes) are provided for comparison in this table. The 95th percentile represents a depth which 95% of all sediment depth measurements taken in each Priority Area were less than. Using this statistic, the upper estimate of volumes of sediment in the high priority rubble and contaminated areas combined is 11,628 m^3, and the moderate priority areas contain 5,880m^3 (Table 7-2).

Consideration of grain size may also be important for remediation options, particularly in Priority Area A where the AFP particles have eroded and are very small and likely to be a component of the finer sediment fractions (clay and or silt). These finer fractions of sediment in Priority Area A make up less than 7% of the total sediment. As such, if targeted during the remediation process, the total volume of sediment to be addressed may be approximately 10% of the estimate provided in Table 7-2.

Conversely in priority areas C, E and F the larger proportions of sediment (rubble) may be targeted. Targeting of remediation activities to grain size (if feasible) may enable reduction in the volume of sediment to be addressed.

.

Table 7-2 Estimates of volumes (median, 95th percentile, mean and standard deviation) of sediment in the high or moderate priority areas

Priority Area	Areas of Contamination (m^2)		Areas of Rubble (m^2)		Sediment Depth (m)				Total Sediment Volumes (m^3)							
	Moderate	High	Moderate	High	Median	95th Percentile	Mean	Standard Dev.	Moderate				High			
									Median	95th Percentile	Mean	Standard Dev.	Median	95th Percentile	Mean	Standard Dev.
A	8,400	14,600	N/A	N/A	0.050	0.150	0.060	0.050	420	1,260	506	424	730	2,190	880	737
C	N/A	N/A	23,102	15,197	0.050	0.200	0.076	0.074	1,155	4,620	1,761	1,716	760	3,039	1,158	1,129
E	N/A	N/A	N/A	18,302	0.050	0.150	0.065	0.050	N/A	N/A	N/A	N/A	915	2,745	1,196	908
F	N/A	N/A	N/A	18,267	0.100	0.200	0.086	0.058	N/A	N/A	N/A	N/A	1,827	3,653	1,564	1,060
Totals	**8,400**	**14,600**	**23,102**	**51,766**	**0.050**	**0.200**	**0.073**	**0.057**			**2,267**				**4,798**	

Key points

As shown in the table below (using the average measured sediment depth for each area):

- The volume of sediment within the high and moderate remediation priority areas (contamination and physical damage) is estimated to be 7,065m^3
- An estimated 1,386m^3 of sediment is considered to be of high and moderate remediation priority for contamination within part of Priority Area A
- An estimated 5,679m^3 of rubble is considered to be of high and moderate remediation priority for physical damage across part of priority areas C, E and F.

Priority area	Impediment to natural recovery	Estimated area (ha)			Estimated volume of sediment (m^3)		
		High	Moderate	Total	High	Moderate	Total
A	Contamination	1.5	0.8	2.3	880	506	1,386
C	Physical damage	1.5	2.3	3.8	1,158	1,761	2,919
E	Physical damage	1.8	-	1.8	1,196	-	1,196
F	Physical damage	1.8	-	1.8	1,564	-	1,564
Totals	**Contamination and physical damage**	**6.6**	**3.2**	**9.8**	**4,798**	**2,267**	**7,065**

8 Discussion

8.1 Information gaps and uncertainty

In line with previous investigations undertaken for the Project, the site assessment identified several information gaps which create uncertainty for effective remediation planning. With the Project's primary desired outcome being that remediation activities support natural recovery at Douglas Shoal, it is important to understand what the natural state of the shoal is, how it was affected by the grounding incident, and how it has subsequently recovered (if at all). In this context a significant source of uncertainty is associated with the information available to address these questions:

- There are no published reports, papers of reviews specifically relating to the pre-grounding incident condition of Douglas Shoal to provide information regarding substrate and habitat type (and health) and how this may change seasonally and in response to natural events that affect the shoal, including the movement of sediment
- While there is information available from several investigations post-grounding, the focus and nature of these investigations does not provide a consistent or comparable set of information regarding contamination or physical damage (amongst other things) to enable a quantitative analysis of change over time and therefore if and how natural recovery has occurred since the incident.

Further discussion with respect to how this uncertainty relates to the assessment of physical damage and contamination is provided below.

8.1.1 Background condition

The grounding footprint is fully located within the Low Relief Terrace. This undulating area is exposed to the tidal current flow and wave action which affect the benthic organisms. Based on the field investigations undertaken post-grounding, it appears the 'natural' habitat of the Low Relief Terrace is dominated by turf and macroalgae growing on hard calcium carbonate substrate; however, differences in habitat are evident across the shoal, which are likely due to local differences with respect geomorphological features and oceanographic condition. These areas are affected variously by seasonal and event-based change; however, given the absence of information regarding background condition the extent or importance of this change is not clear.

The abundance of macroalgae is known to be seasonally influenced, e.g. *Sargassum spp.* is largely absent during the winter months and highly abundant and ubiquitous in the summer months. Hard and soft coral colonies grow sparsely and are generally small. Extreme weather events are likely to impact habitat across the shoal, including through the destruction of habitat such as coral colonies and subsequent generation and transport of sediment (including rubble); however, the extent and importance of this 'natural' change is unclear. As such the importance of the grounding-related physical damage relative to 'natural' change is unclear.

Notwithstanding this uncertainty, almost ten years after the grounding incident, sufficient evidence of the grounding related impacts exists to enable differentiation between habitat within and outside of the grounding footprint. The difference between the habitat within and outside the grounding footprint is primarily the abundance of grounding-related angular rubble inside the footprint compared to outside.

Change to the profile of rubble on the shoal has clearly occurred since the grounding, with the rubble banks found immediately after the grounding shown to have flattened and the rubble has shifted in a direction which appears to be influenced by the prevailing wind and waves. The larger connected areas of rubble do not appear to support the growth of hard and soft corals and macroalgae, and the abundance of these benthos are lower inside the grounding footprint.

It appears the main change in habitat associated with the grounding is the increase in the amount of rubble on the shoal due to grounding has likely reduced the areas of turf algae on rock habitat and areas of sand habitat. The loss of areas of turf algae on rock, a habitat on which hard and soft corals can grow, is evident in the lower percentage covers of hard and soft coral inside the grounding footprint compared to outside. The ongoing movement of unconsolidated rubble may be causing smothering of reef substrate at the advancing front and allowing recovery at the receding edge.

It is likely that over time the rubble will spread or consolidate to an extent that no further smothering will occur, however, the timing associated with unassisted natural recovery may be dependent on oceanographic conditions experienced at the shoal amongst other things.

8.1.2 Contamination

While there is no baseline sediment contamination data available for the shoal it is reasonable to assume the AFP-related contamination identified through the site assessment is associated with the grounding incident, noting that, no contamination was found in the reference areas outside of the grounding footprint. Key areas of uncertainty with respect to contamination are associated with:

- Change in the contamination profile over time
- The heterogenous nature of the contamination
- The toxicity and persistence of the contamination.

8.1.3 Change over time

As described in Section 5.3, comparison with the results of/from previous sampling is confounded by factors including the nature and scope of the previous investigations. This affects consideration of change to both the area and profile (level) of contamination over time.

Due to the nature of the incident it is considered likely that larger quantities of AFP were abraded from the vessel within Priority Area A than within other areas of the grounding site. Investigations to support the site assessment demonstrate that contamination of sediments at levels above relevant guidelines now exists primarily within Priority Area A. Desktop investigation of the persistence of TBT (Section 5.4) suggests it is likely to be another decade before breakdown of TBT occurs to a point where TBT ceases to be a contaminant of concern and concentrations do not exceed the ANZG (2018) guidelines. This is broadly consistent with the findings reported in Kettle (2014), which indicated the persistence of high levels of TBT at the shoal, particularly within sediment that was less exposed to the effect of currents (e.g. buried and/or in depressions).

While quantitative comparison is not possible, it is considered highly likely that both the extent and level of contamination has reduced to a varying degree at the grounding site over time, with contributing factors to the reduction including the local geomorphic features (e.g. exposure to erosive forces) and oceanographic conditions such as normal and extreme event conditions.

Given the source of AFP contamination (flakes, chips and smears of paints that break down to finer particles over time and may be transported dependent on location of deposition and erosive forces), the nature of the grounding-related contamination is highly heterogenous. This presents challenges for sampling and analysis, and dependent on the measures of success for rehabilitation, has the potential to confound the remediation work. It is considered likely that contamination above relevant guidelines may occur outside of the high and moderate priority remediation areas identified (Priority Area A); however, given the comprehensive nature of the sediment characterisation and the physical characteristics of the shoal the priority areas identified represent the areas where the majority of the high-level contamination is likely to exist. Any areas of contamination outside the identified priorities are likely to be small, isolated and with lower levels of contamination.

8.1.4 Toxicity

The sediment in Priority Area A contain concentrations of TBT well above the ANZG (2018) guidelines. Further analysis of these sediments via laboratory controlled elutriate testing simulated the agitation or action of removal of these sediments by mixing contaminated sediments with the seawater collected from the site. This analysis found concentrations of the TBT which may be liberated from these sediments as being above the ANZG (2018) 99% species protection guidelines.

Should removal of contaminated material be proposed the spatial extent of areas with water quality that may be above the ANZG (2018) 99% species protection guidelines is likely to be highly variable at Douglas Shoal and dependent on the currents and tidal flow at the time of removal activities. Trialing of remediation techniques by removal (Kettle 2015b) indicated that TBT contamination liberated into the water column by a vacuum removal technique may cause elevated TBT concentrations in the water column down-current of this activity. Careful consideration is required of the method used to address remediation of contaminated sediments.

8.1.5 Physical damage

Key areas of uncertainty with respect to physical damage are associated with:

- Sediment volume and movement across the shoal over time and how this affects habitat
- Fine-scale differences in habitat provision between the rubble and dead coral fragments.

As described in Section 6, the grounding incident created large volumes of rubble. Where sediment exists in the grounding footprint it primarily consists of this rubble and sand, while outside the grounding footprint, sediment is primarily comprised of sand and natural dead coral fragments. There is little information available regarding natural change (including sediment transport) and how this affects habitat across the shoal.

Acoustic surveys of the shoal and quantitative analysis including backscatter, slope analysis and ARA demonstrate the movement of rubble since 2010. Rubble transport across the shoal appears to be driven by the prevailing winds and waves, although this may vary due to the passage of extreme weather events.

The rubble has likely filled natural depressions and smothered benthic habitat, noting the natural benthic habitat on the Low Relief Terrace is primarily turf algae on rock. Fine-scale differences in habitat provision between the rubble and dead coral fragments are unclear. Where the rubble is stable, there is evidence of consolidation and these areas are shown to support growth of turf algae and macroalgae communities. Furthermore, rubble deposition has created habitat on the Low Relief Terrace. Large areas of rubble are utilised by fish life specifically adapted to live in or utilise these areas for feeding (e.g. goatfish, blennies, lizard fish and trigger fish).

The shape of the rubble may alter over time as natural processes work to smooth and break it up. There appears to be some evidence of this occurring in areas outside the main grounding footprint where more rounded, pebble like rubble was observed. The time-frame and extent to which this can occur for the rubble is unknown.

Notwithstanding that sediment transport across the shoal is not well understood, ten years after the grounding there remains clear evidence of rubble on the shoal. Where the rubble is non-consolidated it appears to be moving due to oceanographic conditions and this movement continues to effect habitat on the shoal at a local scale. It is considered possible that due to the grounding, rubble is in excess on the shoal compared to ‘natural’ condition. In some instances, the rubble has filled (partially or completely) natural depressions and therefore removed complexity from the shoal. It is considered these areas of rubble are impeding natural recovery to some extent and are therefore considered to be a priority for remediation.

Physical damage associated with rubble is more obvious than areas affected by abrasive flattening and compaction as these areas are obscured by the rubble. They are considered to be of lesser importance for remediation because the areas are small, within identified areas of rubble and that ‘natural’ areas outside of the grounding footprint are likely to offer habitat of similar value to these flat areas.

8.2 Remediation priorities

As described in Section 2.1.3, the Authority identified key concerns for natural recovery of the shoal as contamination and physical damage caused by the vessel’s grounding. The investigations undertaken to support the site assessment show that almost ten years after the grounding these concerns remain as potential impediments to natural recovery, albeit the magnitude of the concerns may be diminished, and the area identified as being of priority for remediation is of significantly lesser extent than previously described. It is possible that contaminants are more widely dispersed, however, sediment contamination characterisation surveys in 2019 outside the previously defined priority remediation areas (Costen et al, 2017), found little evidence of dispersion of contaminants at detectable levels or levels exceeding ANZG (2018) guidelines.

The site assessment investigations support delineation of priority areas for remediation as follows:

- Areas of high and moderate remediation priority with respect to contamination in part of the previously identified Priority Area A
- Areas of high and moderate remediation priority with respect to persistence of grounding-related rubble in part of the previously identified Priority Area C
- An area of high remediation priority with respect to persistence of grounding-related rubble in part of the previously identified Priority Area E
- An area of high remediation priority with respect to persistence of grounding-related rubble in part of the previously identified Priority Area F
- Areas of abrasive flattening and compaction damage in parts of previously identified priority areas C, E and F are not considered to be a priority for remediation.

Visual representation and comparison with the priority remediation areas identified in Costen et al (2017) is provided in Figure 8-1 and Table 8-1.

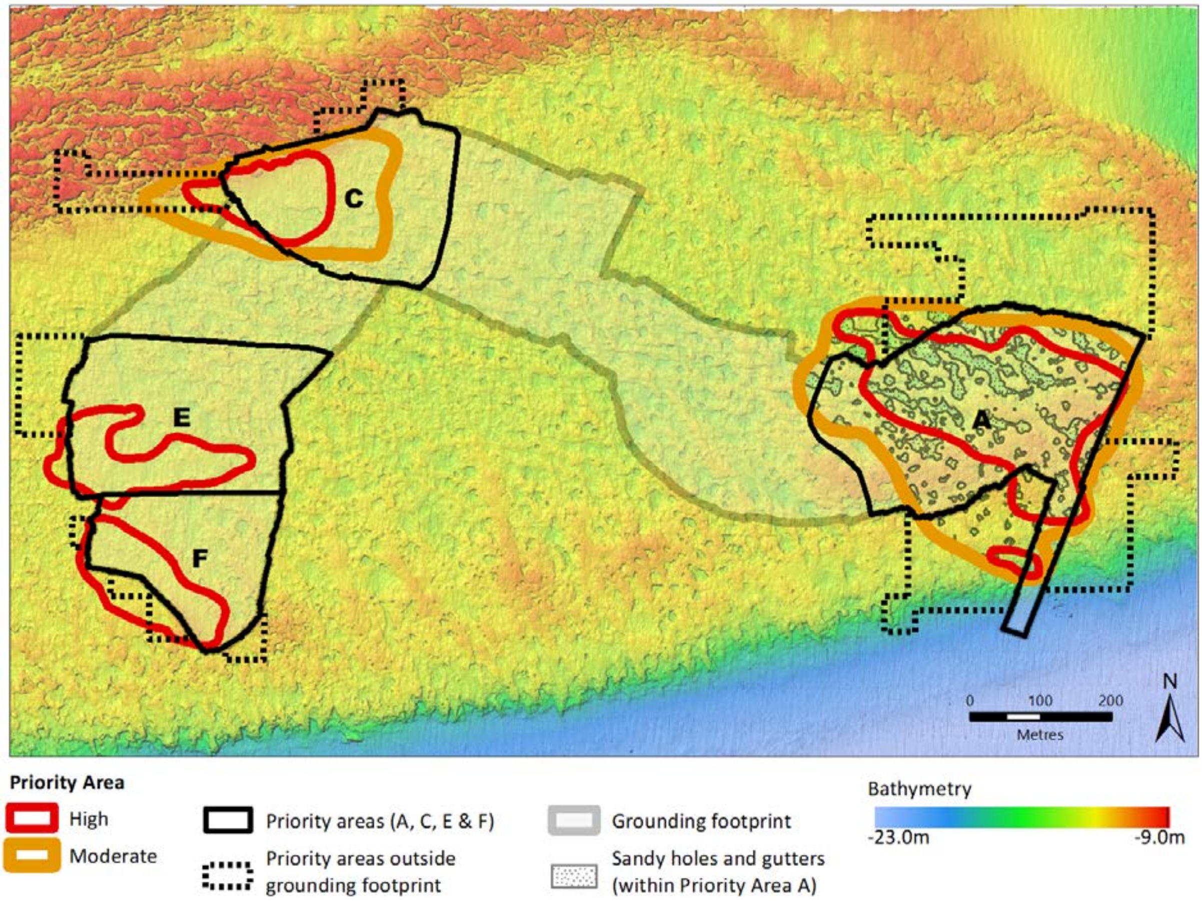

Figure 8-1 Priority remediation areas

Table 8-1 Remediation area estimates

Priority area	Costen et al (2017) estimates - Contamination and physical damage (ha)	Advisian estimates (ha)			
		Impediment to natural recovery	High	Moderate	Total
A	20.3	Contamination	1.5	0.8	2.3
C	8.2	Physical damage	1.5	2.3	3.8
E	8.1	Physical damage	1.8	-	1.8
F	5.2	Physical damage	1.8	-	1.8
Totals	**41.7**	**Contamination and physical damage**	**6.6**	**3.2**	**9.8**

The priority areas developed by Costen et al (2017) were based on the information available from studies undertaken immediately after the grounding and several years later. This delineation contained many areas of uncertainty regarding the spatial distribution of contamination and physical damage caused by the grounding, due to the lack of information. The present study has further delineated the priority areas based on detailed studies designed to reduce the uncertainty around the spatial distribution of the physical damage and contamination.

Key points

The site assessment delineates and describes the remediation priorities at Douglas Shoal despite limitations such as:

- There are no data relating to the pre-grounding incident condition of the shoal to provide information on habitat and how this may change seasonally and in response to natural events
- There is not a consistent or comparable set of information regarding contamination or physical damage to enable detailed quantitative analysis of change over time including natural recovery.

Noting these information gaps the site assessment focuses on the current state of the shoal. Contamination and physical damage remain as potential impediments to natural recovery of the shoal, albeit their significance within the survey area may have diminished over time.

The site assessment investigations support delineation of priority areas for remediation as follows:

- Areas of high and moderate remediation priority for contamination in part of Priority Area A:
  - Moderate remediation priority was assigned for areas of sediment where analysis showed that concentrations of tributyltin, copper or zinc in sediment were predominantly above guidelines for ecosystem protection, with contaminant levels in sediment likely to remain above the guidelines for about ten years
  - High remediation priority was assigned for areas of sediment where, in addition to the above, analysis showed that disturbance of the sediment is likely to release water with concentrations of tributyltin, copper or zinc that are above guidelines for the protection of a high ecological or conservation value system.
- Areas of high and moderate remediation priority for persistence of rubble in part of priority areas C, E and F:
  - High remediation priority was assigned for areas where analysis showed that most of the substrate is rubble
  - Moderate remediation priority was assigned for areas where analysis showed that a significant part of the substrate is rubble.

Areas of abrasive flattening and compaction damage are not considered to be a priority for remediation.

It is considered that other areas within the grounding footprint, including the remainder of priority areas A, C, E and F do not represent a priority for remediation as there is insufficient evidence to show that natural recovery of the shoal is impeded by any ongoing influence of the grounding in these areas.

The total area of high and moderate remediation priority (both contamination and physical damage) is 9.8 hectares which is significantly less than the area identified as a being of remediation priority in the preliminary site assessment (42 hectares).

9 References

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10 Glossary of terms and acronyms

Acronym or term	Definition
ADCP	Acoustic Doppler Current Profilers (ADCP) provide current speed and direction, and wave height data for the water column.
AFP	Antifouling Paint (AFP) is applied to marine vessels to control biofouling (build-up of living organisms and organic or inorganic compounds) and as a corrosion barrier. AFP contains biocides (commonly including copper compounds) and prior to 2003, tributyltin was a common constituent.
AIMS	The Australian Institute of Marine Science (AIMS) is an Australian tropical marine research agency.
ANZG	The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) provide guidance on the management of water and sediment quality in Australia and New Zealand.
ARA	Angle-Range Analysis (ARA) uses data from multibeam sonar surveys to analyse sea floor substrate geometry.
Authority	The Great Barrier Reef Marine Park Authority.
BDI	The Butyltin Degradation Index (BDI) is a ratio of tributyltin to its breakdown products monobutyltin and dibutyltin and provides some information regarding the degradation of tributyltin over time.
BOM	The Bureau of Meteorology (BOM) provides observational, meteorological, hydrological and oceanographic services including forecasts, warnings, monitoring and advice throughout the Australian region.
Dead Coral Fragments	Dead Coral Fragments are naturally occurring calcium carbonate sediment fractions comprised of different sized dead coral fragments which form the sediments found at Douglas Shoal.

Acronym or term	Definition
dbRDA	Distance-based Redundancy Analysis (dbRDA) plots are used in statistical analysis to show the factors driving variability in a data set and where significant differences occur between factors.
DBT	Dibutyltin (DBT) is a breakdown product of tributyltin.
DistLM	Distance Based Linear Modelling (DistLM) is used to identify combinations of factors driving variability in a data set. Factors are fitted against data according to a multiple linear regression.
GBR	The Great Barrier Reef (GBR) is in the Coral Sea off Queensland's coast and is the world's largest coral reef system. Douglas Shoal is in the GBR.
GBRMPA	The Great Barrier Reef Marine Park Authority (the Authority) is the lead management agency of the GBR, responsible for long-term protection and conservation of the reef's environment, biodiversity and heritage values.
Heterogeneous sediments	Heterogeneous sediments are non-uniform in composition and character including shape, size, colour, texture and chemical composition.
Homogeneous sediments	Homogenous sediments are uniform in composition or character including shape, size, colour, texture and chemical composition.
Hs	Significant Wave Height (Hs) is the average wave height, from trough to crest, of the highest one-third of all waves measured.
LAT	The Lowest Astronomical Tide (LAT) is the lowest tide level predicted to occur under average meteorological conditions and any combination of astronomical conditions.
LOR	The Limit of Reporting (LOR) is the lowest concentration of an analyte that can practically reported by the laboratory.

Acronym or term	Definition
LTMP	The Long-term Monitoring Program (LTMP) is a monitoring program run by AIMS on the GBR for over 30 years and represents a long continuous record of change in reef communities over a large geographical area.
MBES	The Multibeam Echo Sounder (MBES) is a common offshore surveying tool that uses multiple sound signals to detect and map the sea floor.
MBT	Monobutyltin (MBT) is a breakdown product of tributyltin.
MLW	Mean Low Water (MLW) is the average of all low water levels observed over a long period of time.
MSL	Mean Sea Level (MSL) is the average level of the sea's surface observed over a long period of time.
NAGD	The National Assessment Guidelines for Dredging (NAGD) set a framework for environmental impact assessment and permitting of ocean disposal of dredged material in Australia.
nMDS	Non-metric Multi-Dimensional Scaling (nMDS) plots are used in statistical analysis to show the position of data in multi-dimensional space where points that are closer together are more similar. Vectors (arrows) on plots show the important factors driving differences between points.
Normalised to 1% TOC	Concentrations of tributyltin may be normalised to 1% total organic carbon (TOC) to facilitate comparison with guideline values.
PERMANOVA	Permutational Analysis of Variance (PERMANOVA) is a statistical analysis technique that examines significant differences or interactions between factors across multivariate data, using multiple variables (a data cloud).
Priority Area	Priority Area refers to the four possible priority areas (A, C, E and F) identified by Costen el al. (2017) on which this site assessment focused to delineate proposed high and moderate priorities for remediation.

Acronym or term	Definition
PSD	Particle Size Distribution (PSD) is a measure of the distribution of particle sizes within a sediment sample.
QA/QC	Quality Assurance/Quality Control (QA/QC) refers to processes and procedures applied to ensure quality of assessment.
Rubble	Rubble is the angular sediment generated by the vessel grounding.
SAP	The Sampling and Analysis Plan (SAP) sets out the fieldwork, analysis and reporting that was planned.
SBP	Sub Bottom Profiling (SBP) is a sonar survey technique that sends sound pulses sent into the sea floor to determine physical properties and to image and characterise geological information.
Sediment	Sediment is solid material that is moved and deposited in a new location. Sediment can consist of rocks and minerals, as well as the remains of plants and animals.
Sub-areas	Within each Priority Area, sub-areas were developed as part of the Sampling Analysis Plan to ensure statistical rigour in the contamination assessment. Multiple discrete sampling sites are included in each sub-area.
TBT	Tributyltin (TBT) is a highly toxic organotin that was a common constituent of AFP applied to marine vessels prior to 2003.
TC	A Tropical Cyclone (TC) is a rotating storm system with a low-pressure centre that produces strong winds, rain and surging seas.
TOC	Total Organic Carbon (TOC) is the amount of organic carbon found in sediment.

Acronym or term	Definition
Total metals analysis	Total metals analysis uses acid digestion to fully dissolve the metal analytes within a sample and the subsequent analysis provides estimates of the total concentrations of metal analytes in the sample.
1M HCl analysis	A 1 mole of hydrochloric acid (HCl) per litre of solution (1M HCl) dilution is a weak acid digestion extraction test which provides a measure of bioavailability of analytes. Concentrations of the bioavailable analytes are generally less than the concentrations measured using total metals analysis.

Appendix A
Sediment Characterisation Report

Appendix B
Laboratory Analysis Report

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Appendix C
Acoustic Imaging Technical Report