Site assessment of Douglas Shoal ship grounding in the Great Barrier Reef

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Abstract

The bulk carrier *Shen Neng 1* ran aground on Douglas Shoal in the Great Barrier Reef Marine Park in April 2010. At over 40 hectares, this is the largest ship grounding scar known in the Great Barrier Reef, and possibly the largest reef-related grounding in the world. Challenges for assessment of the site included its large scale and the remote nature of Douglas Shoal coupled with its high exposure to wind, wave conditions and fauna that may pose safety hazards. Marine surveys used multiple and novel methods including sediment sampling combined with visual and acoustic survey techniques.

Site assessment investigations involved examination of the marine survey data in context of background environment, previous investigation results and relevant guidelines. Analysis showed that almost ten years after the grounding, contamination from the ship's antifouling paint and physical damage from the ship dragging across the shoal, remain as impediments to natural recovery. The assessment delineated remediation priority areas and reduced uncertainty regarding the spatial distribution of contamination and physical damage. Such results are expected to support improved efficiency and effectiveness in remediation activities.

Keywords: reef remediation planning, survey technologies.

1. Introduction

The bulk carrier *Shen Neng 1* ran aground on Douglas Shoal in April 2010 and remained on the shoal for 10-days before being re-floated (Figure 1). Inability to secure the vessel after the initial grounding allowed the vessel to drag across the shoal. The vessel suffered significant underside plate damage and paint loss, including antifouling paint (AFP) containing tributyltin (TBT). An estimated 3 to 4 tonnes of heavy fuel oil was lost [3]. Physical contact between the vessel and the shoal created rubble which is unlike natural sediments. The rubble smothered the shoal substrate, filled natural depressions and reduced habitat diversity.

Other large grounding events recorded in the Great Barrier Reef Marine Park (GBRMP) include the *Bunga Teratai Satu* in 2000 and the *Doric Chariot* in

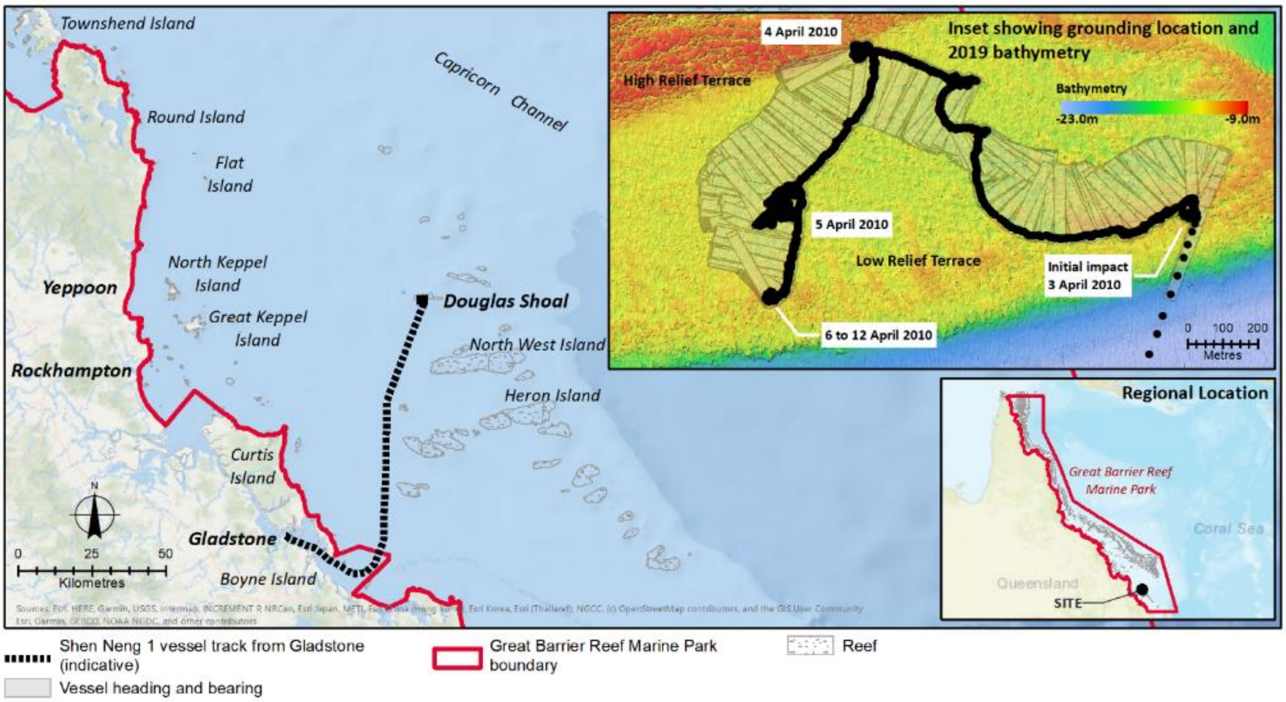

Figure 1 Location of Douglas Shoal. The main inset (top right) indicates the passage of the Shen Neng once grounded.

2002, each distant from Douglas Shoal and with a grounding footprint of less than half a hectare. The grounding footprint of *Shen Neng 1* was about 42ha, which is the largest known in the Great Barrier Reef, and possibly the largest coral reef-related direct shipping impact in the world.

The Great Barrier Reef Marine Park Authority (the Authority) established the Douglas Shoal Remediation Project in 2016 with funds from an out-of-court settlement associated with the grounding. The primary objective of the Project is remediation that supports natural recovery of the shoal.

Assessment of the site is a key step in remediation. It focused on identification of the key concerns for natural recovery of the shoal, primarily AFP contamination and physical damage, and delineation of remediation priority areas. This paper provides an outline of the site assessment undertaken in 2018 and 2019, including the challenges faced, how these were addressed and outcomes for remediation planning.

2. The site and assessment challenges

Douglas Shoal is situated within the southern region of the GBRMP, approximately 90km east of Yeppoon and has a subtropical climate. It is a non-biogenic, 'submerged shoal-reef' [7] located on the widest section of the GBR's continental shelf. It is large (5,180ha [3]), solitary, wholly sub-tidal, and elongated east–west. 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).

Elevated wind and waves frequently impact Douglas Shoal with little protection from these forces from adjacent and nearby shoals and reefs. The significant wave height (Hs) at Douglas Shoal ranged from 0.3 to 4m over measurements taken in 2019 and the wave direction was predominately from the east north-east to south-east, mirroring the prevailing wind direction. Tidal depths measured in January 2019 varied by 4m during spring tidal flows and by 2.8m during neap tidal flows.

The strongest wind and wave conditions at Douglas Shoal are associated with the passage of Tropical Cyclones (TC). Between 1969 and 2018, 17 cyclones passed within 200km of Douglas Shoal. Given the open nature of the ocean surrounding Douglas Shoal, cyclones passing at a distance can adversely affect shoal conditions e.g. TC Oswald (January 2013) and Severe TC Marcia (February 2015) generated 7-8m waves at Douglas Shoal. The passage of cyclones is likely to be a significant driver of rubble and sediment movement.

The presence of potentially dangerous sharks at Douglas Shoal has been identified on several occasions and it is unfortunately notable that a shark-related human fatality occurred in 2020 on North-West Island Reef about twenty kilometres from Douglas Shoal.

In addition to difficult site conditions, lack of data for the shoal challenged the delineation of priority areas. No site-specific data was available regarding the pre-grounding condition of the shoal to support description of habitat and change in response to natural events. Limited comparable information was available from investigations undertaken immediately after the grounding in 2010 [6] to enable analysis of change over time with respect to contamination or physical damage at the shoal.

3. Approach

3.1 Overview

Given the large area requiring survey (over 42ha) and the remote and exposed nature of the shoal, field planning required consideration of usable weather and tidal windows and applied flexible and adaptable survey techniques to minimise in-water time for the survey team. Marine surveys used multiple and novel methods (refer below) to deliver various data inputs for analysis.

Targeted fieldwork was executed in 2019 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 and acoustic 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.

Field data was considered in context of sediment and water quality guidelines (National Assessment Guidelines for Dredging (NAGD [2]) and Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018 [1])) along with information relating to the background environment and previous investigations (Figure 2).

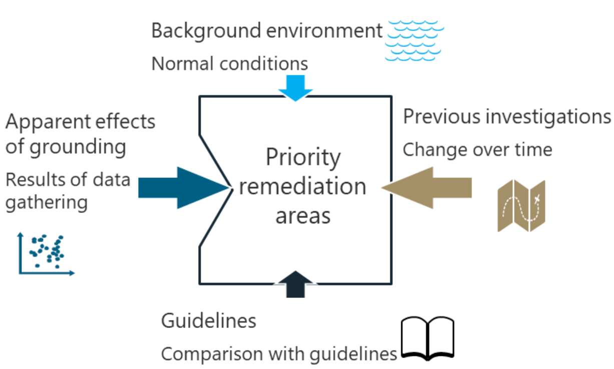

Figure 2 Priority remediation area delineation.

3.2 Novel techniques

Immediately following the grounding incident in 2010, rubble accumulation was identified by diver survey (Figure 3). As such, sonar survey techniques were included as part of the 2019 field survey to provide efficient and effective bottom profiling coverage across the entire grounding area. Sonar survey was undertaken to refine remediation priority areas by investigating:

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

Figure 3 Rubble banks observed during investigations undertaken immediately after the grounding in 2010 [6].

The sonar survey included Multibeam sonar and Sub-Bottom Profiling (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, albeit the results from the SBP survey were ambiguous due to lack of acoustic penetration difference across the survey areas.

Multibeam sonar uses multiple sound signals to map a swath of the sea floor. Sound pulses are transmitted to the sea floor and the characteristics of the returning pulses enable generation of bathymetry and backscatter data. Both the bathymetry and backscatter data provide different insights into changes occurring through time.

Bathymetry data was used to derive the bathymetric profile of the target areas. The slope magnitude of the seabed was also derived from the bathymetry data, and enabled consideration of ‘flattening’ of the seabed. These datasets were used to identify areas potentially impacted by the grounding and were also compared with bathymetry data collected immediately after the grounding to understand possible change over time.

Backscatter data is commonly used to describe sea floor hardness and surficial sediment characteristics [5]. Angle-Range Analysis (ARA) uses backscatter data to analyse sea floor substrate geometry. The ARA technique was derived from investigations [4] and examines the intensity of the backscatter data and correlates this to different types of seabed substrate.

For the backscatter data gathered at Douglas Shoal Angle-Range curves were developed for different areas of the seabed and then compared to empirically derived responses of the seabed for different sediment types as defined in a model [8]. Using this relationship, the backscatter data was used to map the sediment characteristics across the survey area.

A novel method was applied whereby the backscatter data-based mapping was correlated with sediment particle size distribution and habitat characterisation data gathered in field by divers and through underwater video survey respectively, to delineate areas of rubble present on the shoal.

4. Results

4.1 Habitat on the shoal

The site assessment showed that while Douglas Shoal does not comprise a complex benthic marine habitat, there is habitat diversity (Figure 4 and below).

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.

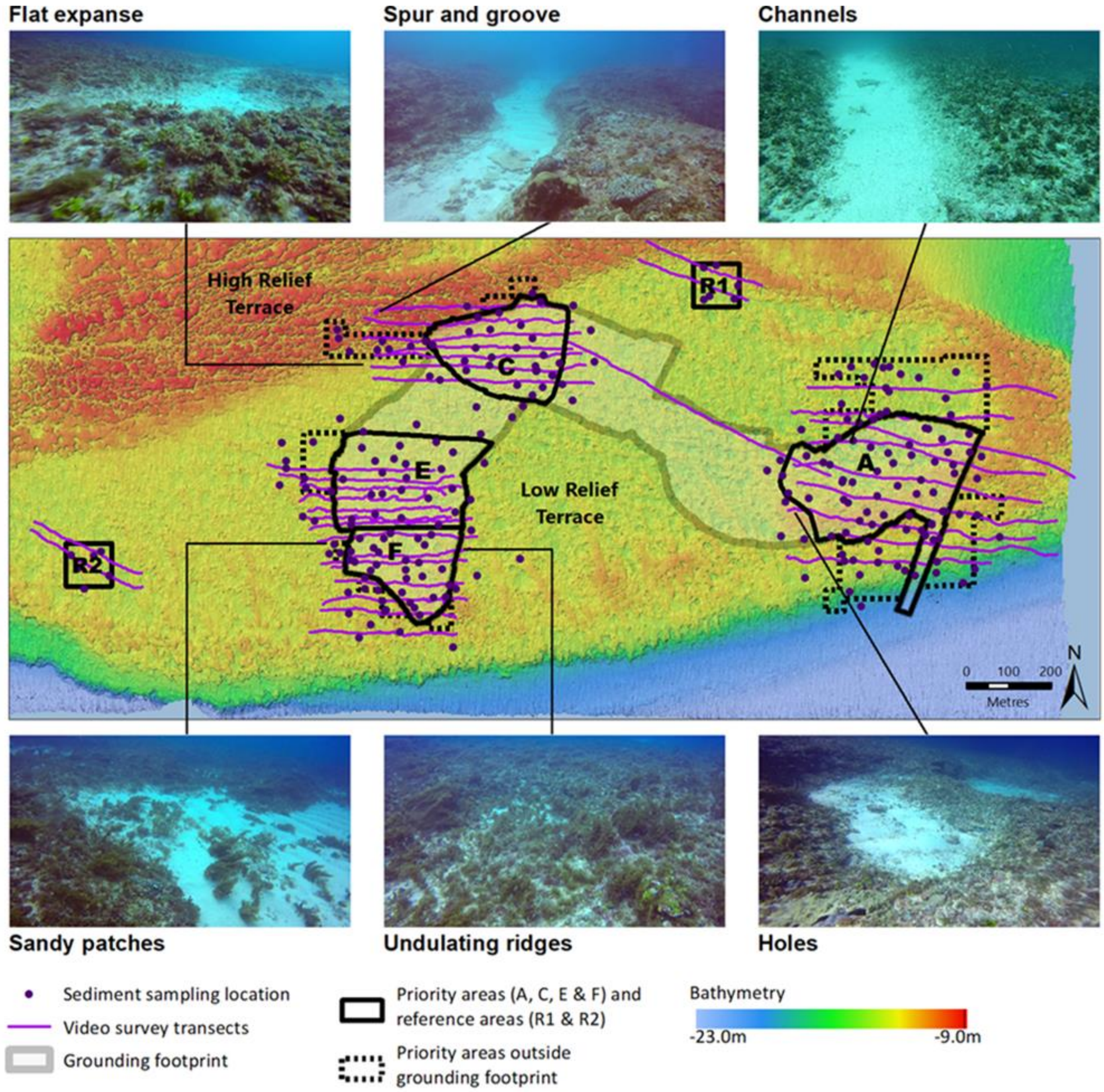

Figure 4 Field survey and habitat types at Douglas Shoal.

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%).

Natural sediment and rubble 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, ranging from 5mm to 400mm, and averaging 73mm.

4.2 Habitat changes

Data collected from underwater video survey were 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 adjacent to the grounding footprint on the Low Relief Terrace of the shoal.

Comparison of 2019 survey benthic habitat data from inside and outside the grounding footprint showed 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. 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%) (refer Figure 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'.

The appearance of the rubble does not appear to have changed significantly since the grounding and remains obviously different (coarser, more angular, and typically without encrusting organisms) to the natural sediments found in 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 immediately after the grounding in 2010 had by 2019 been exposed with westward movement of rubble over time. Undulating substrate found in these areas was devoid of algal growth; however, newly exposed areas may support the settlement and growth of coral recruits and other benthos.

4.3 Contamination

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 breakdown of AFP particles has occurred since the grounding, with no visible AFP particles identified.

Analysis of sediment samples taken during the site assessment focused on the constituents of AFP, particularly copper and TBT. A staged assessment process was applied as set out in the NAGD with laboratory analysis results compared to NAGD screening levels and the 95th and 99th % species protection default guideline values outlined in the ANZG (2018) [1]. Where sediment concentrations of total or potentially bioavailable metals and normalised TBT were near or above the NAGD or ANZG guidelines, these samples were flagged for elutriate testing and the results of this testing were then compared to the ANZG 99% species protection level.

Contamination of sediments exists primarily within part of the previously identified Priority Area A and is principally associated with TBT (Figure 5).

The assessment identified that sediments are not well mixed, with contamination typically associated with remnants of AFP flakes in fine sediment.

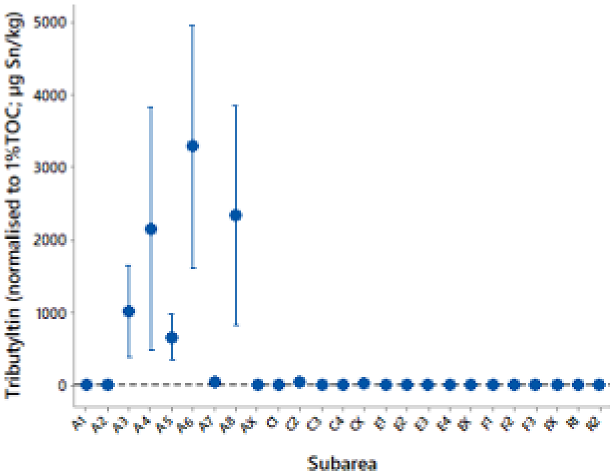

Figure 5 Results of contamination survey in 2019. Mean concentrations of tributyltin (±standard error) by sub-area (ANZG (2018) [1] default guideline value of 9 μg Sn/kg is displayed as a dashed line).

Due to the limited nature of previous investigations direct comparison of contamination analysis was not able to be made; however, 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 weather events. Notwithstanding this, investigation of TBT persistence show it is likely to be a considerable time before TBT ceases to be a contaminant of concern in Priority Area A.

4.4 Physical damage

The rubble is different from naturally occurring sediments as it is coarser, more angular, and typically without encrusting organisms (coralline algae or turf algae, encrusting sponges or coral).

In identification of areas of rubble, good correspondence existed between the independently acquired data sets i.e. data derived from sonar survey, sediment particle size distribution data and habitat characterisation data (Figure 6).

The 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 some locations where the rubble has filled (partially or completely) natural depressions which has altered habitat complexity on the shoal.

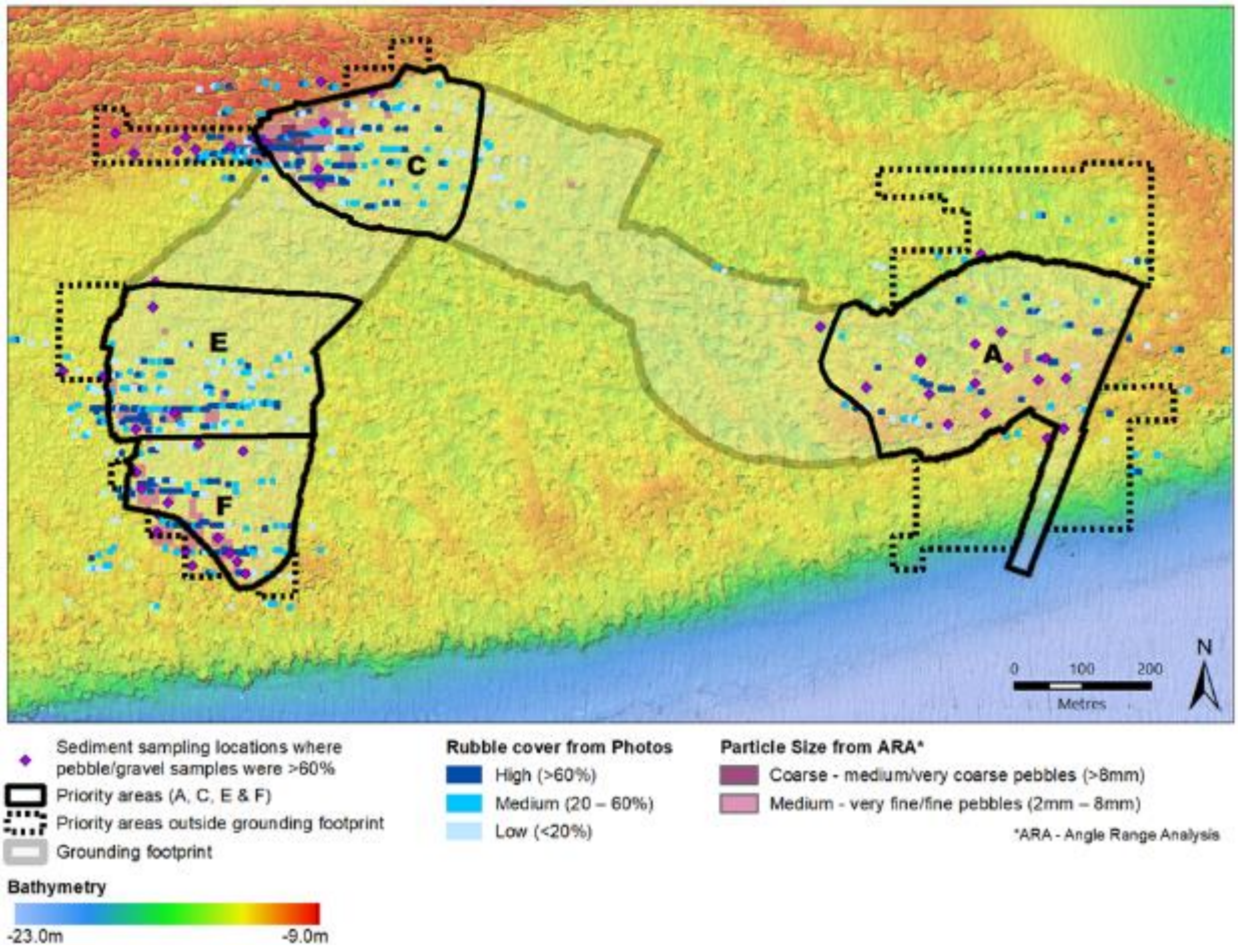

Figure 6 Rubble distribution across the priority areas.

5. Priority areas for remediation

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 supported delineation of priority areas for remediation as follows (Figure 7):

- Remediation priority for contamination in part of Priority Area A:
  - Moderate priority assigned where analysis shows concentrations of contaminants in sediment above default guideline values for ecosystem protection
  - High priority assigned where, in addition to the above, disturbance of the sediment is likely to release water with concentrations of contaminants 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.

Other areas within the grounding footprint, including the remainder of areas A, C, E and F (Figure 7) were not considered to represent a priority for remediation as there is insufficient evidence to show that natural recovery of the shoal is significantly impeded by any ongoing influence of the grounding in these areas.

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 less than the previously identified grounding footprint and estimates of the area of potential remediation priority.

6. Conclusions

The assessment team overcame the site-specific challenges such as the large scale of the grounding and the remote and exposed nature of Douglas Shoal through effective planning, including the use of multiple and novel techniques. Lessons were learned including with respect to application of specific fieldwork and analyses approaches.

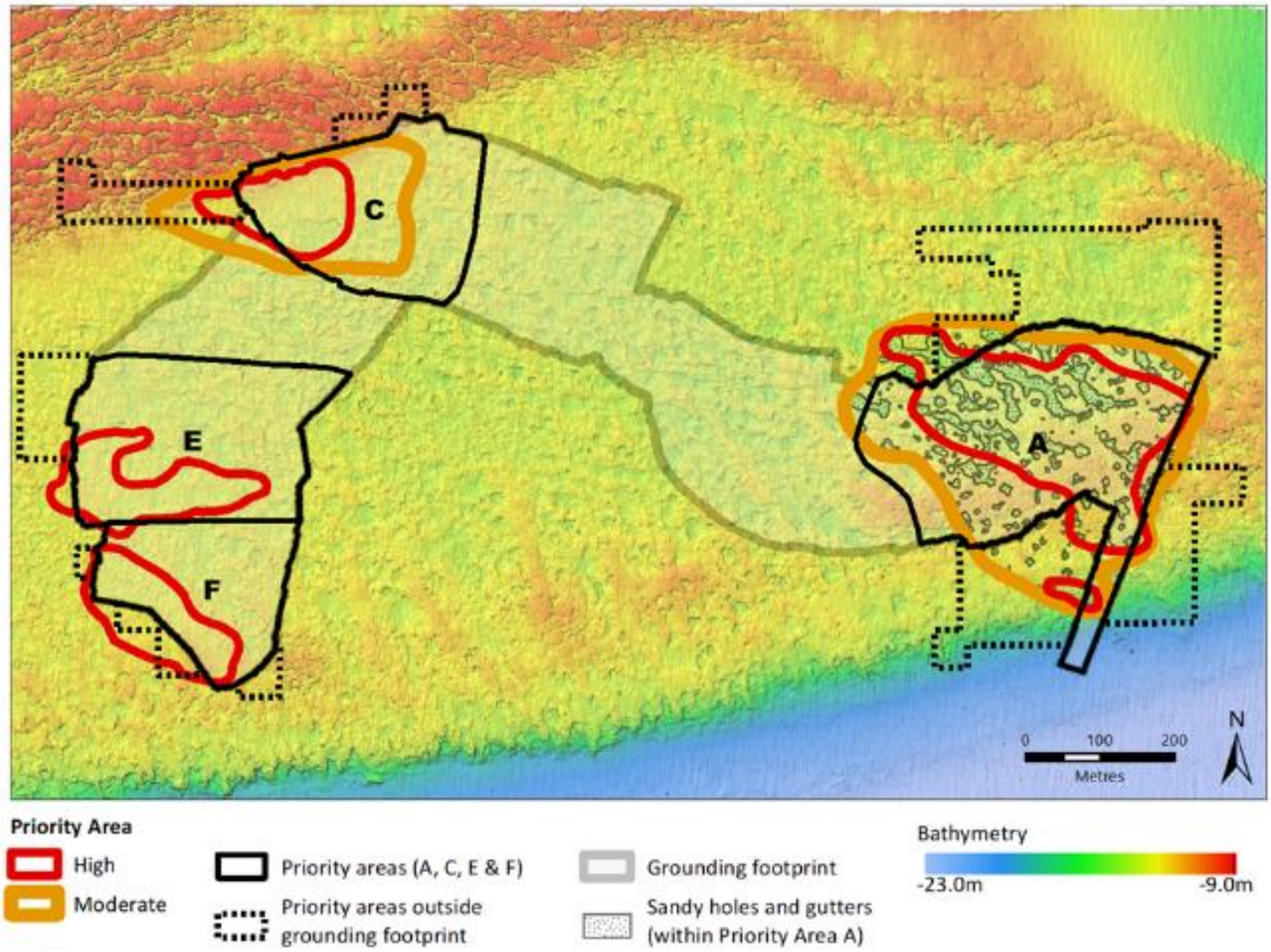

Figure 7 Delineation of high and moderate priority areas.

The assessment delineated remediation priority areas and reduced uncertainty regarding the spatial distribution of contamination and physical damage. This is expected to support improved efficiency and effectiveness in remediation activities. Assessment outcomes underscore the importance of effective and comprehensive planning as the foundation of large-scale marine remediation activity.

7. Acknowledgements

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