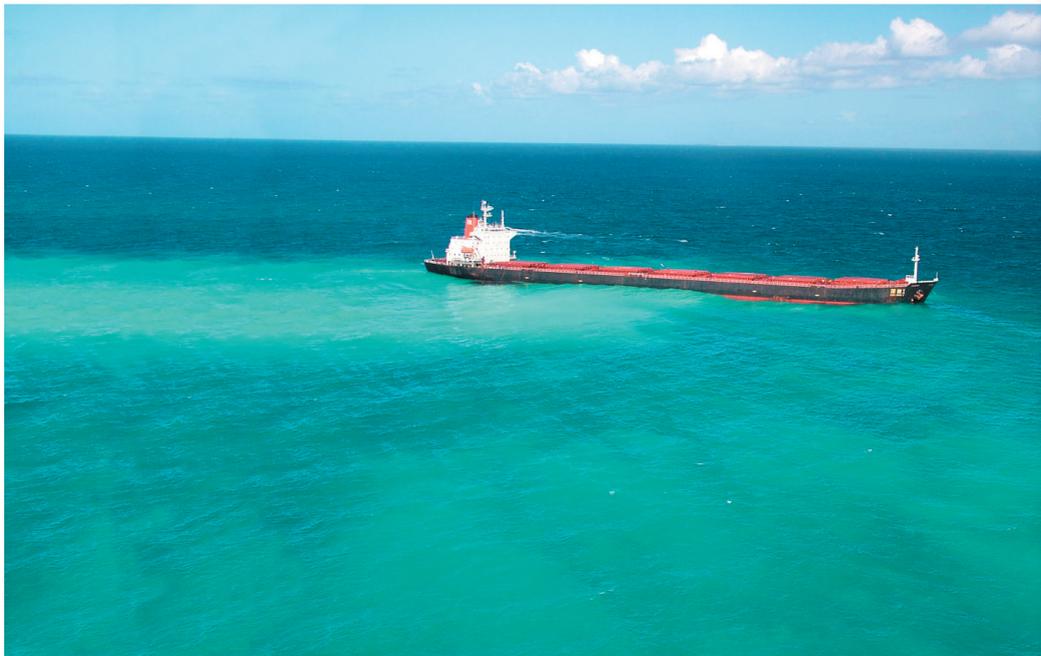




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# Grounding of the *Shen Neng 1* on Douglas Shoal, April 2010: Impact assessment report



June 2011





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**Grounding of the *Shen Neng 1*  
on Douglas Shoal, April 2010:  
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June 2011

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**National Library of Australia Cataloguing-in-Publication entry**

Grounding of the Shen Neng 1 on Douglas Shoal, April 2010 [electronic resource] : impact assessment report / Great Barrier Reef Marine Park Authority.

ISBN 9781921682391 (pdf)

Shen Neng 1(Cargo ship)  
Stranding of ships—Environmental aspects--Queensland--Douglas Shoal.  
Marine accidents—Environmental aspects--Queensland--Douglas Shoal.  
Marine habitats--Environmental aspects--Queensland—Douglas Shoal.  
Environmental impact analysis--Queensland--Douglas Shoal.  
Great Barrier Reef Marine Park Authority.

333.916409943

This publication should be cited as:

Great Barrier Reef Marine Park Authority 2011, *Grounding of the Shen Neng 1 on Douglas Shoal, April 2010: Impact assessment report*, GBRMPA, Townsville.

**Acknowledgements**

This report was compiled and edited by Dr Laurence McCook of the Great Barrier Reef Marine Park Authority, with assistance and technical input from a number of other GBRMPA staff. The GBRMPA also acknowledges the contribution of scientific knowledge and advice by staff of the Australian Institute of Marine Science.

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## Executive Summary

On 3 April 2010, the Chinese bulk coal carrier *Shen Neng I* ran aground on Douglas Shoal in the southern Great Barrier Reef. The vessel remained on the shoal until 12 April 2010, during which time it moved significantly due to winds and tides. This report provides a summary assessment of the impacts of the ship grounding on the marine habitats of Douglas Shoal, based on three site visits. Data are provided for:

- Direct and photographic assessments by divers of damage
- Chemical analyses of sediments samples for antifoulant paint contamination
- Multibeam sonar and towed video surveys provided by the Australian Institute of Marine Science.

Based on these assessments, the vessel grounding caused significant impacts to the habitats of Douglas Shoal, with extensive areas of severe physical damage to, and destruction of, the shoal habitats and considerable contamination by toxic chemicals. The shoal habitats and organisms, especially the corals, are likely to be significantly affected within the damaged areas for many years. This is due to i. the mortality of corals and other organisms directly due to the physical damage; ii. the toxic effects of the antifoulant paint on remaining corals and other organisms; iii. the effects of antifoulant paint in inhibiting settlement and growth of new corals etc; and iv. the inhibition of settlement and growth of new corals on unconsolidated rubble on the shoal seafloor, created by the grounding.

Overall, in terms of direct physical damage, it is estimated that 115,000 m<sup>2</sup> of the shoal were severely damaged or completely destroyed. Further, patchy or moderate damage occurred over much of the rest of the 400,000 m<sup>2</sup> that the ship covered during this incident. These values provide minimum and maximum estimates of the area damaged by physical contact with the shoal.

Contamination of sediments by tributyltin, a highly toxic component of antifoulant paint now banned in Australia for current use, was severe, although highly patchy. Of 166 sediment samples collected on the third site visit, 35 samples were above the low trigger level for Australia and New Zealand Environment and Conservation Council (ANZECC) guidelines, 21 samples were above the high guideline level, 9 samples were more than 50 times the high guideline level, and one sample was more than 7500 times the high guideline level. Patterns of contamination by copper and zinc from antifoulant paint were similar. Strong mixing of the waters over the shoal will mean that the effects of this contamination may be spread very widely, well beyond the area of direct contact with the ship's hull.

The patterns of physical damage and chemical contamination are strongly related to the path of the vessel during the grounding, with very little damaged seafloor or contamination recorded at sites more than 50 m distant from the path of the vessel.

There was also significant pollution by oil, and by oil dispersants, at the time of the grounding. This pollution apparently affected a large area, as oil was found on islands in the Capricorn Bunker group, 20-25 km from the grounding site.

When assessed against the Significant Impact Guidelines 1.1 for Matters of National Environmental Significance under the *Environment and Biodiversity Conservation Act 1999 (EPBC Act)*, these results demonstrate that the ship grounding meets several of the criteria for impacts on the Great Barrier Reef, including in particular:

- *"modify, destroy, fragment, isolate or disturb an important, substantial, sensitive or vulnerable area of habitat or ecosystem component such that an adverse impact on marine ecosystem health, functioning or integrity in the Great Barrier Reef Marine Park results"*
- *"result in a substantial change in air quality or water quality (including temperature) which may adversely impact on biodiversity, ecological health or integrity or social amenity or human health"*
- *"result in persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, or social amenity or human health may be adversely affected."*

## **Table of Contents**

Executive Summary .....	1
List of Figures .....	4
Introduction.....	5
Overview of Site Assessment .....	8
Remote Sensing .....	10
Objectives .....	10
Personnel and Expertise .....	10
Methods.....	10
Results.....	11
Site Assessment 3: 11 - 12 May 2010 .....	15
Objectives .....	15
Personnel and Expertise .....	15
Sampling Approach and Methods.....	18
Sampling approach .....	18
Methods: Surveys of physical damage and sampling of sediment pollution.....	21
Georeferencing.....	22
Sampling Procedures: Scuba based surveys.....	23
Sampling Procedures: Manta surveys .....	24
Benthic analyses.....	24
Chemical analyses.....	26
Results.....	26
Physical Damage .....	27
Pollution by antifoulant paint constituents .....	32
Overall Damage Assessment .....	33
Relationship between damage and ship position during grounding. ....	33
Estimated extent of damage .....	35
Distribution of chemical pollution within the shoal environment.....	39
Oil and dispersant pollution .....	44
Conclusions.....	46
Assessment against Criteria for Significant Impact Guidelines .....	46
References .....	48
Appendices	
Appendix A: Map showing locations of photographs in Figures in this report.	
Appendix B: Report based on site visit 1: Preliminary Impact Assessment Report Grounding of the Shen Neng I on Douglas Shoal.	
Appendix C: Report based on site visit 2: Douglas Shoal Ship Grounding Survey: Habitat Damage Monitoring using Multibeam Sonar and Towed Video (TVA) Assessments	
Appendix D: Report of hull sampling for antifoulant paint constituents	

## **List of Figures** (see actual figure for full title)

Figure 1: Photograph of the <i>Shen Neng I</i> aground on Douglas Shoal in the southern Great Barrier Reef.	5
Figure 2: Maps showing the location of Douglas Shoal on the southern Great Barrier Reef and the surrounding bathymetry.	6
Figure 3: Map showing the path of the <i>Shen Neng I</i> whilst grounded on Douglas Shoal.	7
Figure 4: Map showing vessel speed of movement whilst on Douglas Shoal.	9
Figure 5: WorldView2 satellite image showing patterns of light colour in the shoal seafloor.	12
Figure 6: QuickBird satellite image captured April 2008 showing absence of light coloured areas on shoal seafloor prior to the ship grounding.	13
Figure 7: QuickBird satellite image captured 7 April 2010 showing presence of light coloured areas on shoal seafloor immediately after the ship grounding.	14
Figure 8: Map showing tracks of all survey scuba dives and manta tows for Site Assessment Trip 3.	20
Figure 9: Snorkel diver undertaking manta tow surveys.	19
Figure 10: Photographs showing divers collecting sediment and paint smears on the shoal seafloor.	22
Figure 11: Photographs showing undisturbed shoal habitats, remote from the grounding site, and damaged site, with coral rubble.	28
Figure 12: Photographs showing diversity of seaweeds, corals and other invertebrates, and fishes in an undisturbed shoal habitat and growth of ephemeral algae on damaged site.	29
Figure 13: Divers sampling sediments within a swathe of disturbed benthos on the shoal.	30
Figure 14: Map showing extent of damage to reef, based on assessments of photographs and manta tow observations.	31
Figure 15: Map showing relationships between the grounding path and damage assessments from all site visits.	34
Figure 16: Comparison of estimated damage to the shoal benthos within the area of the ship's path and outside that area.	33
Figure 17: Map showing relationships between the severity of damage and the location of the vessel when stationary.	36
Figure 18: Map showing relationships between the detailed bathymetric analyses based on multibeam sonar and direct observations of damage from the first and third site visits.	37
Figure 19: Map showing estimates of area of damage integrated from all three site visits. 3	38
Figure 20: Map showing concentrations of tributyltin (TBT), an antifoulant paint contaminant, compared to the path of the vessel during the grounding.	40
Figure 21: Comparisons of TBT concentrations in samples collected outside the area of the ship's path and inside that area.	41
Figure 22: Map showing concentrations of copper, an antifoulant paint contaminant, and the path of the vessel during the grounding.	42
Figure 23: Map showing concentrations of zinc, an antifoulant paint contaminant, and the path of the vessel during the grounding.	43

Locations of all photographic Figures are shown in Appendix 1.

## Introduction

On 3 April 2010, the 225m long Chinese bulk coal carrier *Shen Neng I* ran aground on Douglas Shoal in the southern Great Barrier Reef (Fig. 1). Initially carrying approximately 68,000 tonnes of coal, and approximately 950 cubic metres of oil, the vessel remained on the reef until 12 April 2010, when it was refloated. This report provides a summary assessment of the impacts of the ship grounding on the marine habitats of Douglas Shoal.

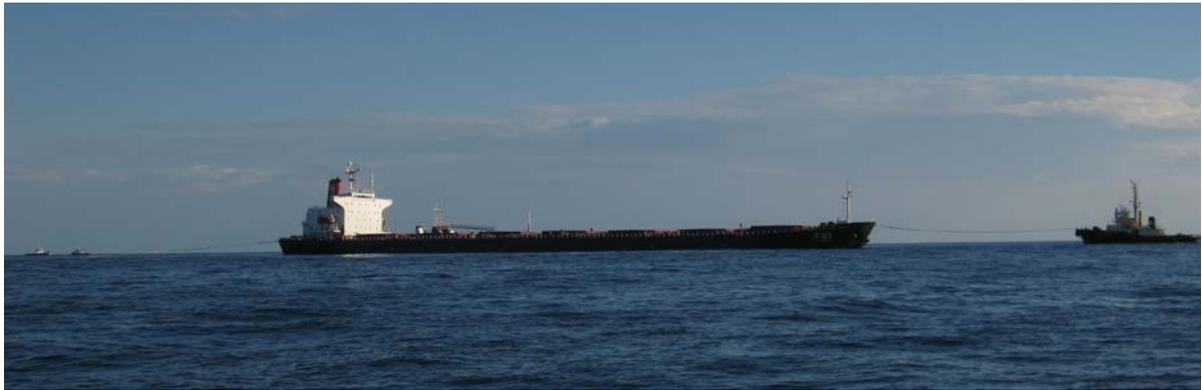


Fig. 1: Photograph of the *Shen Neng I* aground on Douglas Shoal in the southern Great Barrier Reef.

Douglas Shoal is a large, discrete shoal in the southern Great Barrier Reef (151°40'E, 23°5'S), approximately 90 km east of Yeppoon, and north of the Capricorn Group (Fig. 2<sup>1</sup>), and approximately 890 hectares in area. The shoal is relatively deep, rising to a minimum depth of about 11 m below the surface from a surrounding seafloor of approximately 25-30 m. (In contrast, many of the coral reefs in the Capricorn Group reach the surface). The shoal is exposed to strong tidal currents, predominantly towards the north-west during the flooding phase of the tide and towards the southeast during ebb (Negri et al 2010); maximum tidal range in the area is greater than 3.5 m. The shoal has a relatively flat, low relief topography with similarly low relief benthic<sup>2</sup> communities, dominated by large seaweeds, and benthic invertebrates such as sponges, soft and hard corals (Marshall 2010). Fish life on the shoal is abundant and diverse, including a range of species targeted by fishers. Seas snakes and marine turtles are also abundant (Marshall 2010).

The vessel initially struck in the south-east corner of the shoal, but shifted position considerably before salvage was completed (Fig. 3<sup>3</sup>). Vessel movement depended on tides raising and lowering

---

<sup>1</sup> Fig. 2 (over): Maps showing the location of Douglas Shoal on the southern Great Barrier Reef and the surrounding bathymetry.

<sup>2</sup> "Benthic" refers to organisms of the benthos, i.e. organisms that inhabit the seafloor in an area or zone (e.g. corals, seaweeds), in contrast to pelagic organisms, which inhabit the water column above the seafloor (e.g. plankton, whales).

<sup>3</sup> Fig. 3 (over): Map showing the path of the *Shen Neng I* whilst grounded on Douglas Shoal. Data are sourced from Australian Marine Safety Authority, and derived from the vessel's automatic identification system (AIS). The track of the vessel's AIS transmitter, located near the stern of the ship, is shown as black squares. Shading indicates the position of the vessel based on the AIS transmitter location and heading, and the vessel length of 225 m and beam of 30 m (assumes AIS transmitter located in centre of vessel at 15m from stern).



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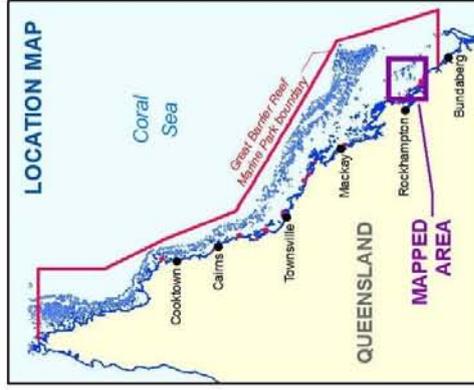
### Shen Neng 1 Grounding Douglas Shoal 23-044 3-12 April 2010

Figure 2

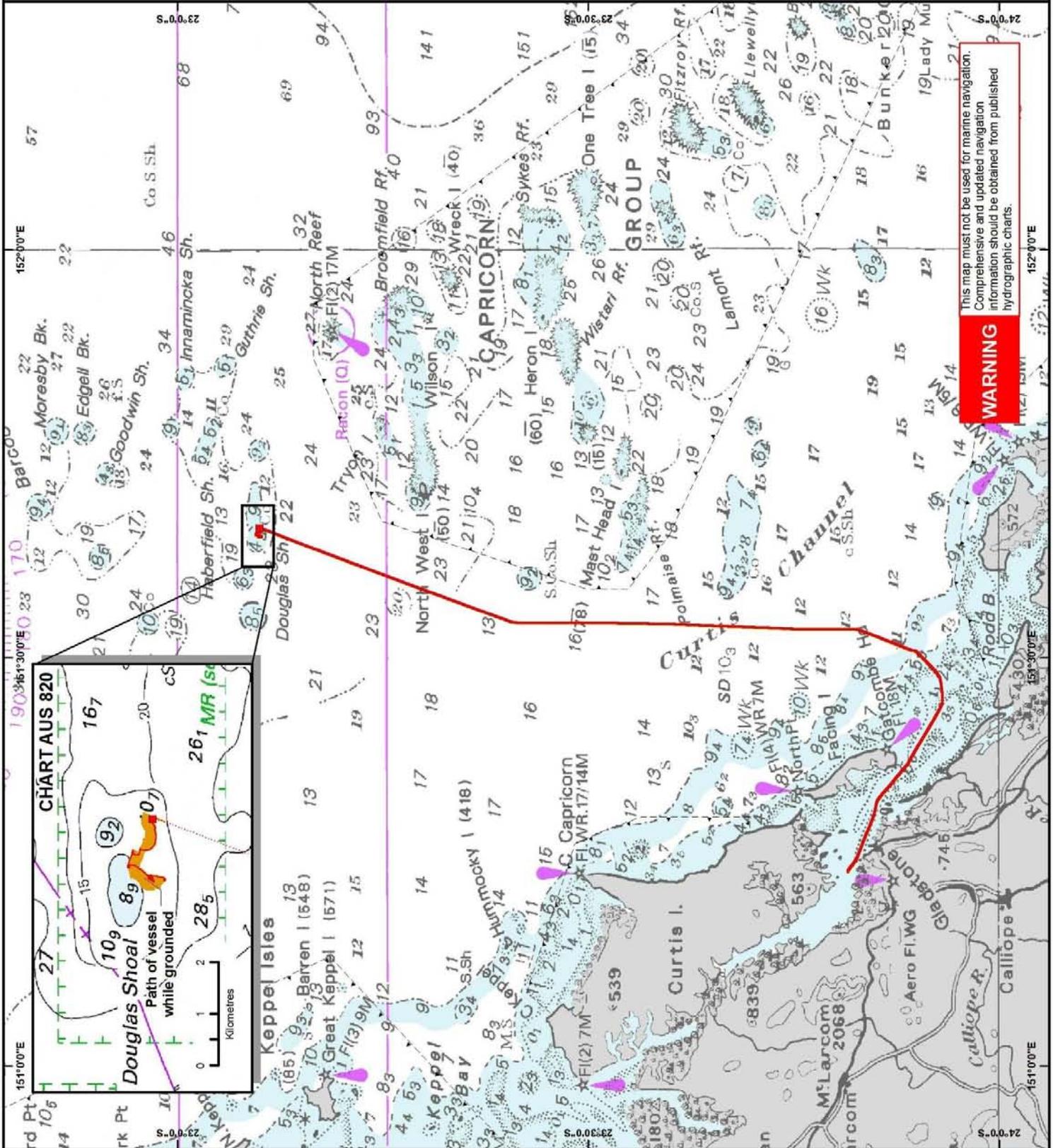
### Location of Douglas Shoal

#### LEGEND

- Grounding Location
- AIS position of vessel (AMSA)
- Designated Shipping Area boundary
- ▲ Shipping



Map Projection: Unprojected Geographics  
 Horizontal Datum: World Geodetic System 1984  
 Raster source: Chart AUS 428  
 SDC100405-3A3 12 November 2010



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Shen Neng 1 Grounding  
Douglas Shoal 23-044  
3-12 April 2010

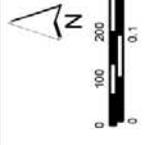
Figure 3  
Vessel Path  
LEGEND

- AIS position of vessel (AMSA)
- Heading of vessel (derived from AIS headings)
- Path of vessel

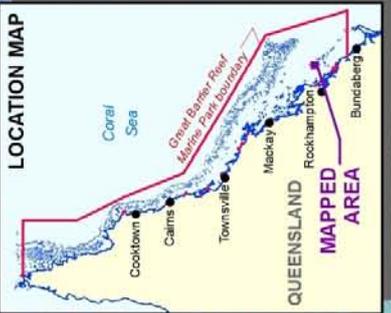
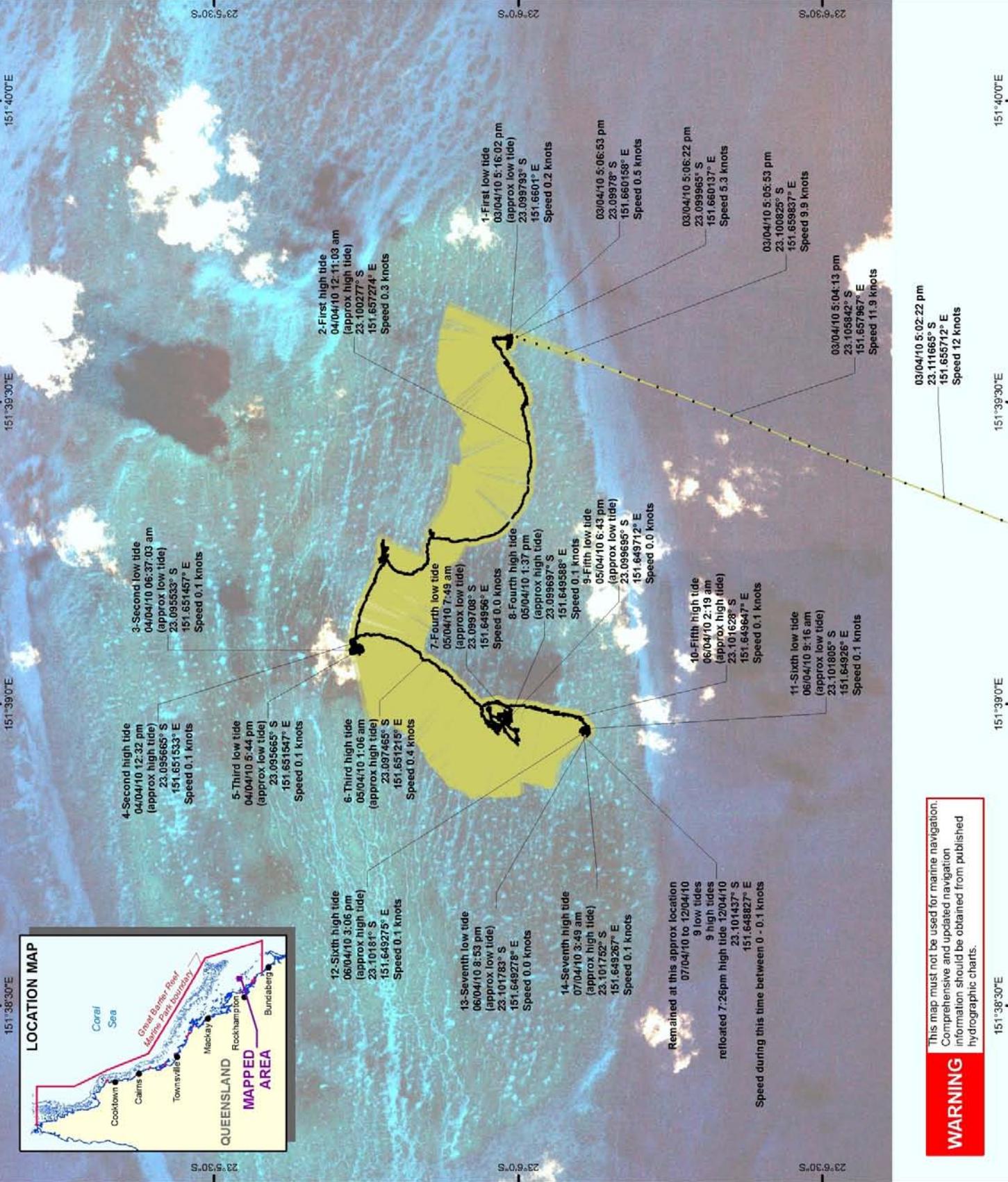
**Tryon Island Tides**

(approximately 21 km SE of Douglas Shoal)

Sat Apr 3	Low 5:16 pm 1.3m
Fri Apr 9	High 5:50 am 3.6m Low 12:10 pm 1.2m High 6:18 am 3.4m
Sun Apr 4	High 12:11 am 3.5m Low 6:37 am 1.5m High 12:32 pm 2.9m Low 5:44 pm 1.6m
Mon Apr 5	High 1:06 am 3.5m Low 7:49 am 1.7m High 1:37 pm 2.7m Low 6:43 pm 1.8m
Tue Apr 6	High 2:19 am 3.3m Low 9:16 am 1.7m High 3:06 pm 2.7m Low 8:53 pm 1.9m
Wed Apr 7	High 3:49 am 3.3m Low 10:35 am 1.6m High 4:37 pm 2.9m Low 10:29 pm 1.8m
Thurs Apr 8	High 4:59 am 3.4m Low 11:29 am 1.4m High 5:35 pm 3.1m Low 11:32 pm 1.6m
Mon Apr 12	High 1:27 am 1.1m Low 7:36 am 3.8m High 1:45 pm 0.8m Low 7:57 pm 3.9m



Map Projection: Unprojected Geographics  
Horizontal Datum: World Geodetic System, 1984  
Raster Source: Quickbird Image Prior To Grounding, 2008  
SOC 100405-3A1 16 November 2010



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the vessel, and hence affecting the contact between the vessel and the shoal seafloor. The locations of the vessel during periods it was stationary are shown in Fig. 4<sup>4</sup>.

### **Overview of Site Assessment**

Assessment of the impact of the grounding on the Douglas Shoal has involved three separate site visits, involving collaborations between the Great Barrier Reef Marine Park Authority (GBRMPA), the Queensland Parks and Wildlife Service (QPWS), the Australian Institute of Marine Science (AIMS) and James Cook University (JCU). These site visits used standard methods for marine ecological surveys, including scuba surveys, manta-towed surveys, and towed video surveys, adapted to the circumstances and purposes of this assessment, and integrated with satellite imagery using GPS and spatial mapping tools.

The first site visit, led by the GBRMPA, took place on 12-13 April 2010, as the *Shen Neng I* was being removed from the Shoal, and involved scuba and snorkel based assessments of damage to the shoal habitats, as well as sampling of sediments and paint specimens from the shoal seabed. The Preliminary Impact Assessment Report on physical damage to the shoal is included at Appendix 2; the results of chemical analyses of sediment and paint samples collected on that site visit are included in the present report.

The second site visit was led by AIMS, and mapped fine-scale bathymetry of the impact site, along with towed underwater video surveys of the shoal bottom; the report from that assessment is provided at Appendix 3.

The third site visit took place on 12-13 May 2010, and involved sampling for sediment pollutants and scuba-based surveys of damage to the shoal habitats in the area of the grounding. The results of that assessment are included in this report.

This report also provides a synthesis of information from all three site visits.

Of particular concern is the documentation of any pollution of the shoal seafloor by antifoulant paint scraped off the vessel during the grounding. These antifoulant paints are specifically formulated to be toxic to marine organisms, and include the chemicals tributyltin (TBT), copper and zinc, which can inhibit invertebrate recruitment and reef recovery (Reichelt-Brushett and Harrison 2000; Negri and Heyward 2001; Haynes et al. 2002; Smith et al 2003; Reichelt-Brushett and Michalek-Wagner 2005; Negri and Marshall 2009). These chemicals are incorporated into the paint because they are toxic to marine organisms, and so prevent fouling of the hull. TBT is particularly toxic, to the extent that it has been banned from use as an antifoulant on vessels in accordance with the International Convention on the Control of Harmful Anti-fouling Systems on Ships (IMO 2001) and Australia's Oceans Policy (Commonwealth of Australia 1998).

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<sup>4</sup> Fig. 4 (over): Map showing vessel speed of movement whilst on Douglas Shoal, as recorded by the vessel GPS ("speed over ground"). Red areas indicate vessel was stationary at that location.



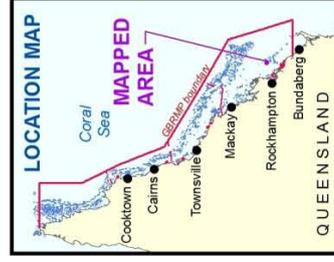
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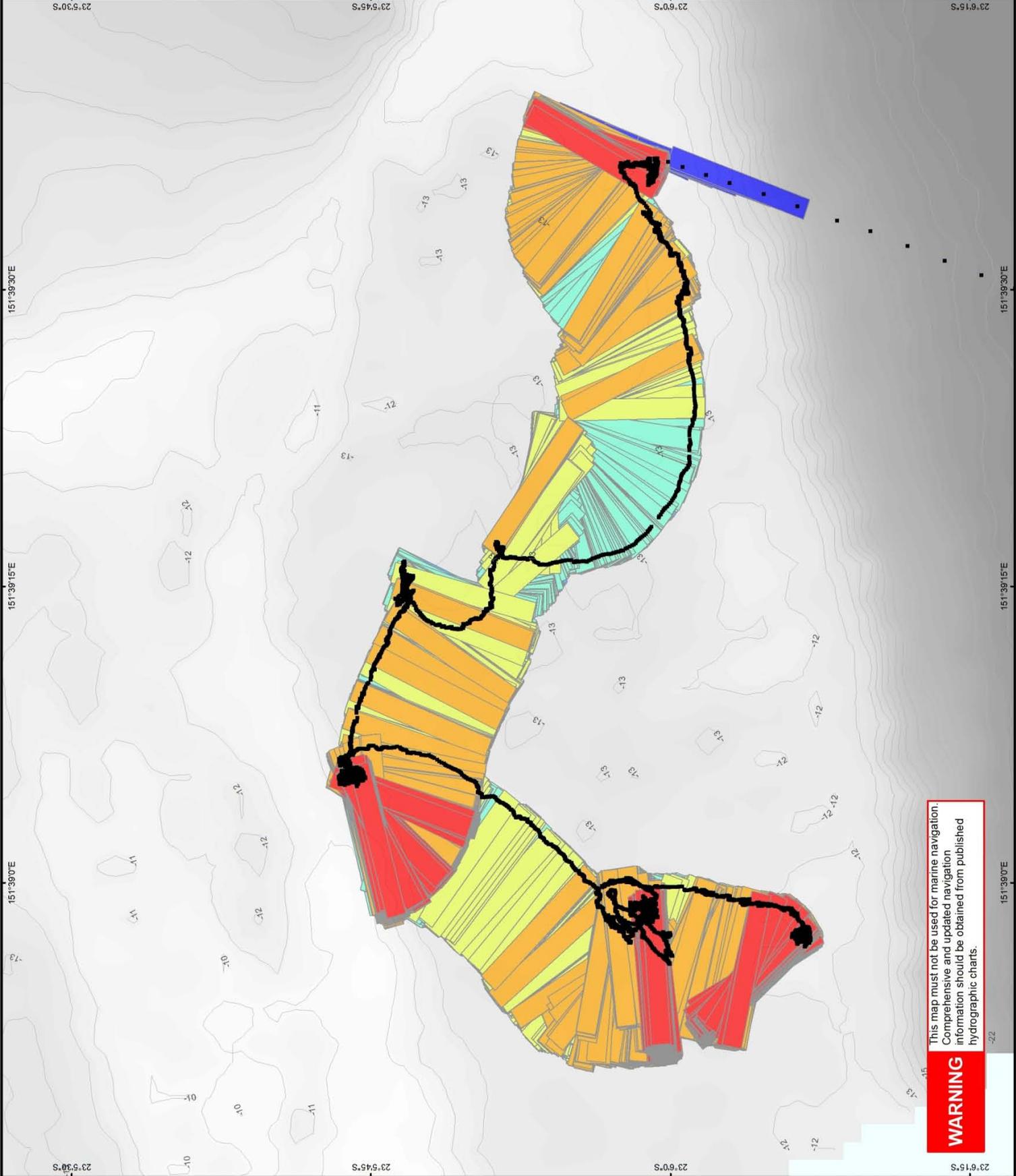
# Shen Neng 1 Grounding Douglas Shoal 23-044 3-12 April 2010

Figure 4  
Speed of Vessel

- LEGEND**
- AIS position of vessel (AMSA)
  - Depth contours (m) (JCU)
- Speed of vessel (kts)**
- 0
  - 0.01 - 0.1
  - 0.11 - 0.2
  - 0.21 - 0.5
  - 0.51 - 1.0
  - >1



Map Projection: Unprojected Geographics  
Horizontal Datum: World Geodetic System, 1984  
Raster Source: Dr. Robin Beaman, James Cook University  
and the Australian Hydrographic Service  
SDC 100405-3A2b 17 November 2010



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Sampling of paint directly from the hull of the *Shen Neng I* was undertaken by staff from the GBRMPA and QPWS, along with observations of the hull after the grounding (Monkivitch 2010). These samples were analysed for TBT, copper and zinc and the results of those analyses are included in a report provided at Appendix 4 (Monkivitch 2010). Critically, those analyses showed very clearly that high levels of TBT, as well as copper and zinc, were present in the antifoulant paints on the vessel's hull. Observations of the hull showed that very large areas of the hull had been scraped back to bare metal. The paint missing from the hull, and its toxic constituents, must have been deposited in the marine environment. According to the report (Monkivitch 2010), the grounding was estimated to have removed between 39 to 78 kg of copper oxide and 15 to 39 kg of zinc oxide from recently applied paint systems on the flats of the hull and an unknown mass of TBT and other biocides and metals from the historic antifouling paint systems.

The results of chemical analyses of sediments sampled from the shoal during the first and third site visits are included in this report.

Information on pollution by oil, and by oil dispersants is also included, drawn from an independent review (Miller 2010) and witness statements.

Finally, remote sensing using satellite imagery has been used to identify impacts on the shoal seafloor (substratum). That information is provided in the next section.

## **Remote Sensing**

### ***Objectives:***

- To obtain indications of the impacts of the ship grounding using satellite imagery, including comparisons of before-after images where possible.

### ***Personnel and Expertise:***

- Cherie Malone, A/Manager, Spatial Data Centre, GBRMPA, Bachelor of Science in Geography (GIS) and Botany from James Cook University (2002). Eight years experience in spatial data analysis including field data collection, data acquisition, management, analysis and mapping. Four years experience in tutoring GIS-related subjects to university students and professional staff. Training and experience in Oil Spill Response mapping.  
Role: Coordination and interpretation of spatial data, map production.
- Dr Laurence J. McCook. Manager, Ecosystem Health and Resilience, Science Coordination Group, GBRMPA; Adjunct Senior Principal Research Fellow, Australian Research Council Centre of Excellence for Coral Reef Studies. Detailed experience and qualifications given in Site Assessment 3 section.  
Role: Scientific interpretation and reporting.

### ***Methods:***

Imagery from two different satellites provided relevant information: the WorldView2 and Quickbird satellites.

The clearest imagery of the shoal seafloor is available from the WorldView2 satellite. However, images from this satellite are only available after the ship grounding: there are no comparison images available from prior to the grounding.

Images from the QuickBird satellite are not as clear in terms of the shoal seafloor, but are available for times before the grounding and during a later stage of the grounding.

Images from both satellites were supplied by GeoImage ([www.geoimage.com.au/geoimage/](http://www.geoimage.com.au/geoimage/)). Where necessary, images were "deglinted" by the supplier (GeoImage), to remove the distracting effects of sunlight glinting off the water surface at the time of the image ("deglinting" refers to the use of algorithms to filter the data in an image to remove areas of intense light due to reflection from the sea surface; in-house algorithms used by GeoImage).

### **Results:**

Examination of the WorldView 2 image of Douglas Shoal taken on 19 May 2010 (Fig. 5<sup>5</sup>), clearly indicates patterns of light coloured seafloor. (Light colour on a tropical shoal or coral reef indicates exposed calcium carbonate (limestone), either as sand or exposed reef substrate, often as a result of damage to the darker, pigmented reef organisms such as corals and algae. Calcium carbonate is white in colour). Comparisons of this image with Fig. 3 and Fig. 4 in particular show that there is a strong overlap between these light areas and the areas where the vessel remained stationary during the grounding.

Importantly, these light coloured areas were not present prior to the grounding. Comparisons of QuickBird satellite imagery on the 27 April 2008 (Fig. 6<sup>6</sup>), well before the grounding, with images captured at the end of the grounding period 7 April 2010 (Fig. 7<sup>7</sup>), clearly show that the light coloured areas were not a prior feature of the undisturbed shoal, but appeared between these dates.

The significance of these results is discussed further in the Overall Damage Assessment section.

---

<sup>5</sup> Fig. 5 (over): WorldView2 satellite image showing patterns of light colour in the shoal seafloor. Comparison with Figs. 3 and 4 indicates that these areas are consistent with damage caused by the ship grounding, especially during periods where the ship was stationary. Markings indicate the path of the stern of the vessel.

<sup>6</sup> Fig. 6 (over): QuickBird satellite image captured April 2008 showing absence of light coloured areas on shoal seafloor prior to the ship grounding (compare to Fig. 7). Markings indicate the path of the stern of the vessel.

<sup>7</sup> Fig. 7 (over): QuickBird satellite image captured 7 April 2010 showing presence of light coloured areas on shoal seafloor immediately after the ship grounding (compare to Fig. 6). Image processed to remove the effects of sunlight glinting off waves and sea surface and obscuring image (see text). Markings indicate the path of the stern of the vessel.



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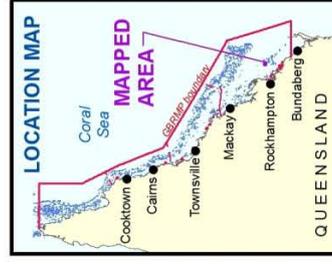
Shen Neng 1 Grounding  
Douglas Shoal 23-044  
3-12 April 2010

Figure 5

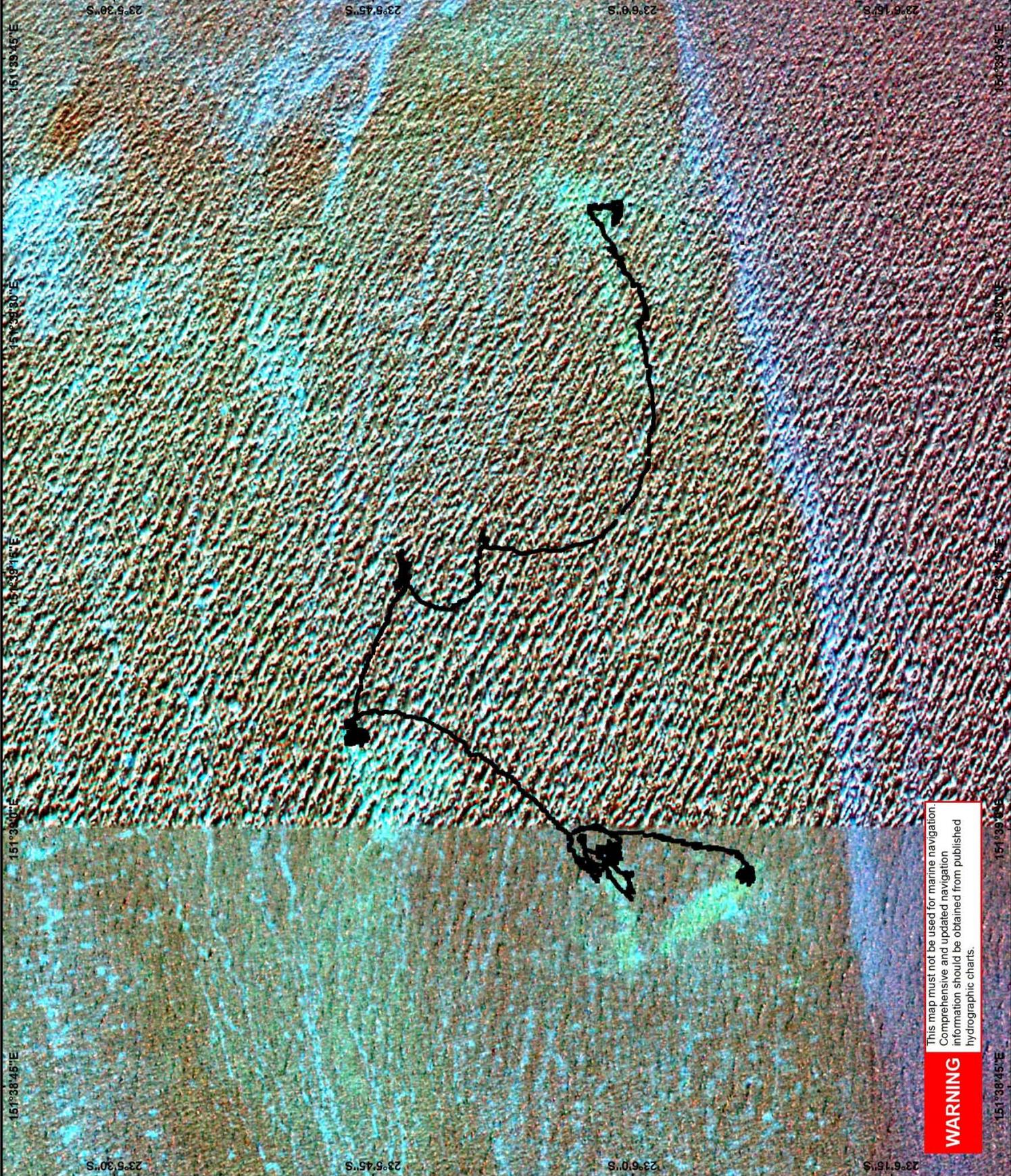
WorldView2 Image  
After Grounding  
(captured 19 May 2010)

LEGEND

- AIS position of vessel (AMSA)



Map Projection: Unprojected Geographics  
Horizontal: World Geodetic System 1984  
Raster Source: WorldView2 Image Digital Globe 2010  
SQC 100465-846 17 November 2010



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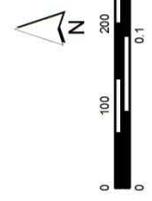
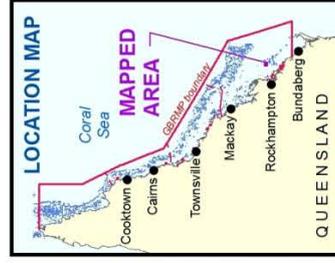


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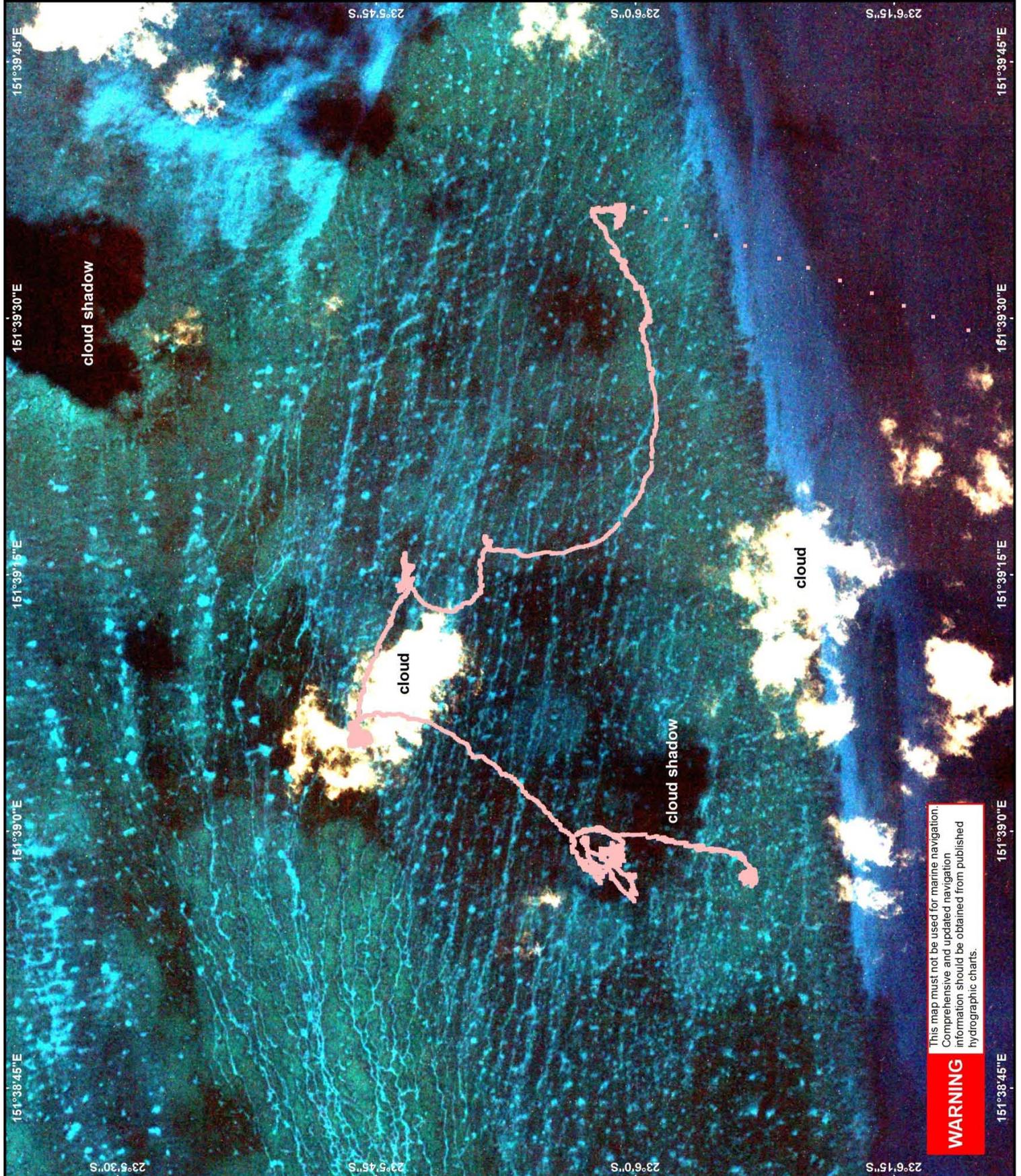
**Shen Neng 1 Grounding  
Douglas Shoal 23-044  
3-12 April 2010**

Figure 6  
**Quickbird Image  
Prior to Grounding  
(captured 27 April 2008)**

LEGEND  
■ AIS position of vessel (AMSA)



Map Projection: Unprojected Geographics  
Horizontal Datum: World Geodetic System, 1984  
Raster Source: Quickbird Image, Digital Globe 2010  
SOC-100405-8A7, 17 November 2010



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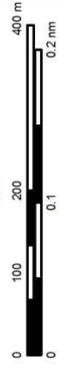
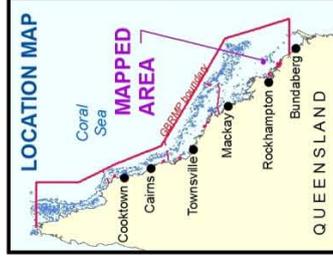


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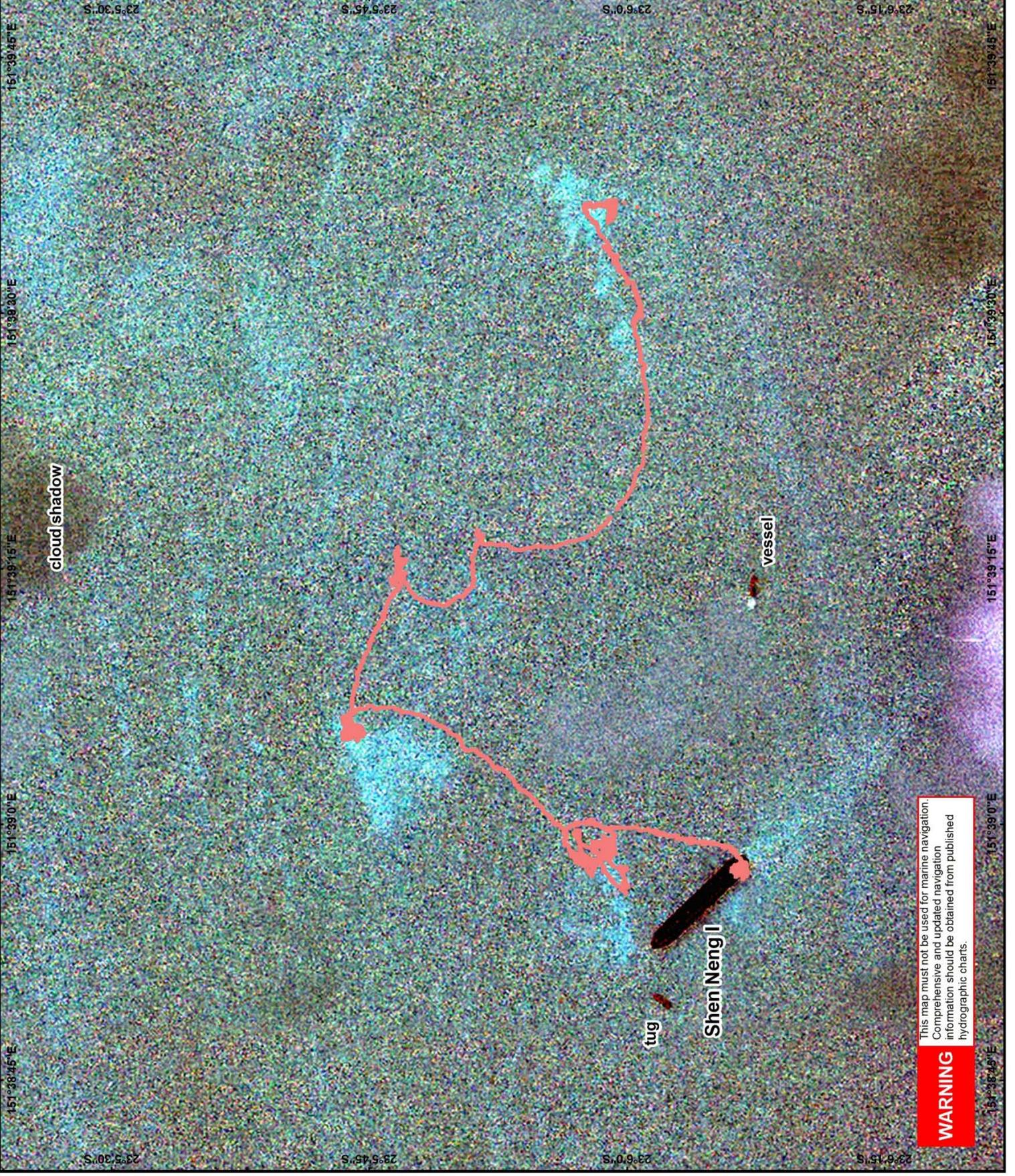
**Shen Neng 1 Grounding  
Douglas Shoal 23-044  
3-12 April 2010**

Figure 7  
**Quickbird Image  
During Grounding  
(captured 7 April 2010)**

**LEGEND**  
■ AIS position of vessel (AMSA)



Map Projection: Unprojected Geographics  
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## Site Assessment 3: 11 - 12 May 2010

### Objectives

- To obtain descriptions of the spatial distribution of physical damage and chemical pollution of the shoal habitats and benthos due to the grounding of the ship.

### Personnel and Expertise

- Dr Laurence J. McCook. Manager, Ecosystem Health and Resilience, Science Coordination Group, Great Barrier Reef Marine Park Authority (GBRMPA); Adjunct Senior Principal Research Fellow, ARC Centre of Excellence for Coral Reef Studies. Awarded international Pew Fellowship in Marine Conservation (2005). Ph.D. in Marine Ecology from Dalhousie University, Canada (1992); Bachelor of Science (Hons 1st Class) in Neurobiology, Australian National University (1984). 23 years experience in marine science, 18 years in coral reef ecology and conservation science on the Great Barrier Reef and a dozen countries in the Coral Triangle region, Pacific and Caribbean Oceans; more than 50 peer-reviewed, international scientific publications, > 25 consultancy reports, policy documents etc. Qualified Commercial Scuba Diver (Australian Diver Accreditation Scheme (ADAS) AS 2815.1), Mixed Gas Diver, Dive Master, Diving Biologist, Association of Canadian Underwater Clubs; Scientific Diver, Coldwater Diver, Dalhousie University, with estimated 1500+ logged dives including remote locations, diving under ice, mixed gas diving. Coxswains Certificate (Restricted) issued by Maritime Safety Queensland (MSQ), Speedboat License, MSQ; Restricted Operator's Certificate of Proficiency in Radiotelephony.  
Role: Survey and scientific leader.
- Malcolm Turner. Manager, Field Operations, Field Management Coordination Unit, GBRMPA. Bachelor of Science in Zoology and Botany, Monash University (1978). 32 years experience in natural resource and marine park management, including research and monitoring projects: National Parks Service, Victoria (1978 - 1991); 1991 to present at GBRMPA, including a secondment to the Queensland Parks and Wildlife Service (QPWS), in Marine Park and Island National Park Management. Since 1989 has been the Environment and Science Coordinator for shipping and pollution incidents in the Great Barrier Reef World Heritage Area under arrangements of The National Plan to Combat Pollution of the Sea by Oil and other Noxious and Hazardous Substances. Member of the Environment Working Group for the National Plan. Have undertaken and assisted several damage assessments of sites of grounded vessels including three ships, *Doric Chariot*, *Peacock* and *Sattha*. Coordinates a coral reef health assessment program and has trained field and technical staff in reef damage assessments and reef health. Qualified Commercial Diver (ADAS AS 2815.1).  
Role: Assisted with sample collection and interpretation of photographs.
- James Monkivitch: Manager, Ports and Shipping, Environmental Assessment and Management Group, GBRMPA. Bachelor of Science in Marine Biology, James Cook University (1994). Certified Environmental Practitioner (through the Environment Institute of Australia and New Zealand). GBRMPA Deputy Dive Officer. Qualified Commercial Scuba Diver (ADAS AS 2815.1) (1994). Advanced Open Water Diver (PADI), Wreck Diver and Ice Diver. Coxswains Certificate issued by MSQ. Sixteen years experience as a marine environmental impact assessor and manager. Experienced and trained in marine sediment sampling and analysis, coral reef visual and video

surveys and vessel impact site assessments in the Great Barrier Reef Marine Park and other marine environments, including: eight years experience as a marine science consultant including tropical coral reefs, seagrass and mangrove studies, assessing impacts of dredging and conducting sediment contamination sampling and interpretation studies; production of over 50 consultant reports and expert review reports for marine environmental projects across Australia and New Zealand; more than eight years with the GBRMPA in environmental impact assessment and management roles including current role of preparation and response to shipping incidents, including delivery of over 22 conference presentations, training sessions or published papers on risk assessment, impact management, coral transplantation and artificial reefs.

Role: Dive supervisor, dive leader, diver and photography.

- Ms Jessica Hoey. A/Manager, Permits, Environmental Assessment and Management Group, GBRMPA. Bachelor of Science in Marine Biology (Hons) from James Cook University (2001). Nine years experience in coral reef ecology and conservation science on the Great Barrier Reef and Papua New Guinea. One peer-reviewed international scientific publication and three publicly available management reports on coral bleaching, reef fish and crown-of-thorns starfish. Prior experience in the collection of evidence from a vessel grounding incident on the Great Barrier Reef. Development of rapid assessment monitoring programs (specifically "BleachWatch" and the "Rapid Assessment Monitoring Program") to identify and report on damage to coral reef ecosystems – and training of staff in these programs. Qualified Commercial Scuba Diver (ADAS AS 2815.1), Advanced Open Water Diver (PADI), Speedboat License, MSQ; and Certified Environmental Practitioner (through the Environment Institute of Australia and New Zealand). Role: Diver; sediment sample collection and some photography.
- Elise M. Godwin, Graduate Project Officer, Environmental Assessment and Management, GBRMPA. Bachelor of Science in Marine and Coastal Management and Marine Biology, University of Western Australia. Experienced in supporting the Environment and Science Coordinator in the Incident Control Centre in Gladstone in the second week of the grounding. Role: Monitoring, recording and storage of data and specimens/samples including chain of custody documentation; assisted with data analysis.
- Paul Groves, A/Project Manager, Coastal Ecosystems and Water Quality, Environment and Sustainability Group, GBRMPA. Bachelor of Science in Marine Science, Murdoch University Western Australia (2004). Five and a half years working with GBRMPA, 10 years experience in public aquariums including work with Reef HQ Townsville, Underwater World Perth, Manly Ocean World Sydney, Coral World Eilat, Israel and Maui Ocean Centre, Hawaii. Qualified Commercial Scuba Diver (ADAS AS 2815.1), PADI Rescue diver with approximately 1000 logged dives including dives in the Southern Ocean, Indian Ocean, Pacific Ocean and the Red Sea. Five years experience in the retail aquarium industry. Published cover story for Scientific American December 1998. Lifelong marine aquarium hobbyist, founder and former president of the Marine Aquarium Society of Western Australia. Role: Diver, sample handling and chain of custody to mother ship.
- Thomas E. S. Hatley. Project Officer, Reef Permits, Environmental Assessment and Management, GBRMPA. Bachelor of Applied Science (Aquaculture), James Cook University, (2000). 11 years experience in marine science, including 6 years animal husbandry of Great Barrier Reef coral reef

organisms (Marine and Aquaculture Research Facility, James Cook University & Reef HQ Aquarium, GBRMPA). Qualified Commercial Scuba Diver (ADAS AS 2815.1; Nitrox endorsement); Advanced Open Water Diver (PADI); estimated 800+ hours logged dives. Coxswains Certificate (Restricted) issued by MSQ (2005); Restricted Operator's Certificate of Proficiency in Radiotelephony.

Role: Diver, photographer.

- Laise E. Harris. GIS Officer, Spatial Data Centre, Spatial and Information Technologies, GBRMPA. Bachelor of Environmental Science (Honours) in Geographic Information Systems (GIS), Deakin University (2005). Bachelor of Science in Marine and Freshwater Science, Deakin University (2004). Committee member and education representative for Surveyors and Spatial Sciences Institute (SSSI) Queensland Young Professional; Far North GIS User Group (Fungis) Deputy Chair and executive committee member. ITIL Information Technology Service Management Foundations, International IT Service Support and Delivery accreditation, Information Technology Infrastructure Library (ITIL). Six years professional experience GIS, three years professional experience IT. Trained and experienced in supporting >50 software applications, with >25 spatial software applications, including all industry leaders to advanced levels. Trained and experienced in Field Data Capture, GPS<sup>8</sup> and surveying including development of customised applications. Trained and experienced in Remote Sensing, Spatial Analysis and project management. Trained in Australasian Inter-Agency Incident Management System (AIIMS), Emergency Response (mapping role). Trained in Fieldwork and Sampling protocols. Level 2 First Aid. Speedboat License, MSQ. Role: Spatial data coordination and management.
- Dr Andrew P. Negri. Senior Research Scientist, Water Quality and Ecosystem Health, Australian Institute of Marine Science (AIMS); Ph.D. in Chemistry from RMIT, Melbourne (1993); 17 years experience in aquatic ecotoxicology including 15 years in marine ecotoxicology ecology in Pacific, Indian and Antarctic waters; more than 70 peer-reviewed, international scientific publications. Qualified Commercial Scuba Diver (ADAS 2815.1) with extensive scientific diving experience in tropical and Antarctic waters. Speedboat License, MSQ; Restricted Operator's Certificate of Proficiency in Radiotelephony. Role: Diver and sample collection, scientific advisor (ecotoxicology).
- Mr Eric Matson. Technical Officer AIMS Climate Change team. Bachelor of Teaching (Adults), Qualified Commercial Scuba Diver (ADAS and AIMS Commercial Level 2 Diving Supervisor (SSBA)), Recreational Diving Instructor (NAUI, CMAS, FAUI), Diploma of Occupational Diving (AQF), Recompression Chamber Operator, Master Class V Certificate issued by MSQ. Extensive experience in scientific, underwater, outdoor and sporting photography, including credits in scientific and mainstream media, including prize-winning photograph in underwater photography competition. Role: Diver, photographer.
- Oliver Lanyon, Senior Ranger (Compliance), QPWS, Rosslyn Bay. Authorised Marine Park Inspector under the Commonwealth of Australia for the *Great Barrier Reef Marine Park Act 1975* and

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<sup>8</sup> GPS: Global Positioning System- satellite-based location and navigation system

*Environment Protection and Biodiversity Act 1999*. Advanced Diploma in Aquatic Resource Management, Central Queensland University (1996). Bachelor of Science Degree in Aquatic Resource Management with co-major in Industrial Chemistry (2003); Diploma of Government (Fraud Control). 13 years experience as a Ranger with QPWS. Previous experience as Investigator/Senior Investigator with the GBRMPA (2006 - 2007) Qualified Commercial Scuba Diver (ADAS AS 2815.1) (2003); Advanced Open Water Diver (PADI), 217+ dives; Coxswains Certificate (Open) issued by MSQ (2000). Training and experience in visual surveys, video surveys, coral surveys and vessel impact site assessments in the Great Barrier Reef Marine Park environment (Rapid Assessment Monitoring Program (RAMP); Reef Health & Impact Surveys (RHIS); Site Assessment of Damage (SAD), including production of damage assessment reports and Briefs of Evidence.

Role: Diver, photographer, GPS navigation.

- Mr Damon Shearer. Senior Technical Officer, QPWS, Central Marine Region. Bachelor of Technology in Biology, Central Queensland University (1998). Qualified Commercial Scuba Diver (ADAS AS 2815.1) (2000) 200+ commercial/scientific dives. Trained in Reef Health Impact Surveys and Site Assessment of Damage. Seven years experience as Research Technician and Dive Officer for the Centre of Environmental Management at Central Queensland University (1999 - 2006); Member of Coastal CRC, working in the Coastal Wetlands and Contaminant Risk Assessment teams in Port Curtis (2002-2006). Extensive experience in sampling marine sediments for contaminant testing. Role: Diver, sample collection.
- Mr Chris Maple, Senior Ranger (Marine Parks), QPWS. Bachelor of Applied Science in Wildlife & Park Management, (1988). 20 years experience as a Marine Park Ranger working between Bundaberg and the Whitsundays. Qualified Commercial Scuba Diver (ADAS AS 2815.1) (1991), 100+ dives and numerous snorkels primarily in coral reef habitats, most conducting surveys to assess coral morphology and general reef health. Open Coxswains Certificate issued by MSQ (1997), experience in navigating and operating many small commercial ships. Role: Diver, sample handling and chain of custody to mother ship.

## ***Sampling Approach and Methods***

### **Sampling approach**

Surveys were aimed to assess the nature and extent of damage to the shoal habitats, and to collect sediment samples to test for pollution derived from the antifoulant paints on the vessel. The overall sampling approach involved comparisons of the condition of habitats within the grounding site with nearby areas of the shoal outside the grounding area (Fig. 8<sup>9</sup>).

Surveys prioritized areas likely to have been damaged, based upon high resolution benthic bathymetry (Negri et al 2010), as well as a limited number of undamaged areas, removed from the ship's path, for comparison. As many areas as possible were sampled within the time available. The

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<sup>9</sup> Fig. 8(over): Map showing tracks of all survey scuba dives and manta tows for Site Assessment Trip 3. (Note that locations of sampling indicated by straight lines is less precise than other data due to technical difficulties; see Sampling Procedures for explanation).

sampling design was progressively adapted and updated as work progressed, using mapping software, to obtain the best possible coverage of the grounding site in the time available and under the diving conditions.

Sampling involved scuba-based transects<sup>10</sup>, collecting photographs and sediment samples at regular intervals. Transect locations were allocated based on the sampling approach, with a starting point (GPS location) and direction for each dive team determined before each dive. Overall, 18 scuba transects were surveyed, 14 of which included areas within the path of the ship during the grounding, and 4 transects covering areas removed from the ship path (several transects included areas within and without the path).

Two snorkeling, manta tow surveys were also conducted (Fig. 8), to complement the scuba-based coverage. Manta tow surveys involve a snorkel diver towed behind an outboard dive tender using a "manta board" to dive and observe the shoal bottom (Fig. 9). Manta surveys provide information over a broader area, but with less detail and less spatial precision. (Because they use snorkel, rather than scuba, they are also free of the constraints of decompression tables which limit bottom time on scuba equipment).



Fig. 9: Snorkel diver undertaking manta tow surveys. Diver is being towed behind a dive tender boat, and uses the board to dive down and make observations of the shoal habitats. Photograph taken during first site assessment trip.

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<sup>10</sup> "Transect" refers to a line or path of survey; divers used underwater compasses and water currents to follow the predetermined direction.

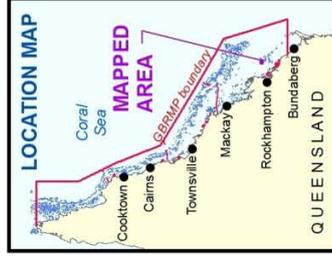


Figure 8

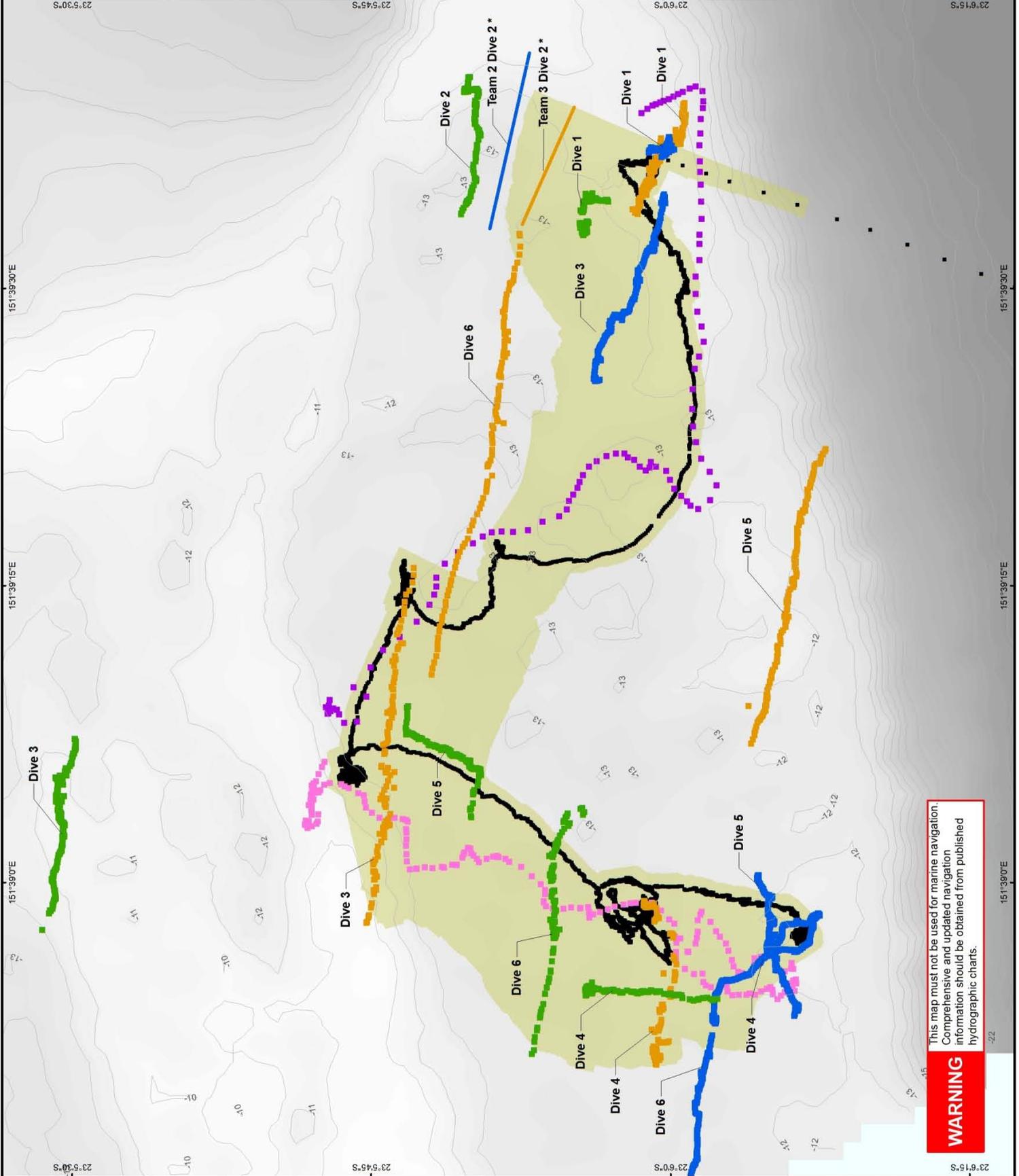
**Site Assessment 3**  
**Dives and Manta Tows**

- LEGEND**
- AIS position of vessel (AMSA)
  - Depth contours (m) (JCU)
  - Path of vessel
  - Team 1 (GBRMPA) dive location
  - Team 2 (QPWS) dive location
  - Team 3 (AIMS) dive location
  - Manta Tow 1
  - Manta Tow 2

\* Positions for Team 2 Dive 2 and Team 3 Dive 2 estimated from GPS start and end points



Map Projection: Unprojected Geographics  
 Horizontal Datum: World Geodetic System, 1984  
 Raster Source: Dr. Robin Beaman, James Cook University and the Australian Hydrographic Service  
 SDC 1004057A1 17 November 2010



**WARNING**  
 This map must not be used for marine navigation.  
 Comprehensive and updated navigation  
 information should be obtained from published  
 hydrographic charts.

All sampling/surveys were "georeferenced" using GPS units to precisely locate survey and sample locations (detailed methods below).

Field work for this Site Assessment involved a number of challenges, including limited preparation time prior to the fieldwork and severely limited time (2 days) for field work due to narrow window of manageable weather and sea conditions (strong winds and the resultant waves made it too difficult to manage diving operations, especially in such an exposed location, with no emergent reef or island for shelter). Further, very strong tidal currents at Douglas Shoal make diving work very difficult except at the turn of the tides, when a 1-2 hour period of minimal water movement provided easier conditions. The depth of the impact site (generally 12+ metres) is beyond snorkeling depth for all but very brief inspections, and limited scuba dive times due to limits for no-decompression diving. The remoteness of the shoal from safety facilities (~7-8 hours travel) increased the need for margins of error in safety procedures especially regarding diving practices. The variable nature of the substratum (shoal bottom), made it difficult to collect sufficient loose sediment in some areas.

The general consequence of these challenges was to limit the quantity of data and samples collected; through careful planning, organisation and adaptation, the survey team was able to ensure that these issues did not compromise the quality of the data and samples. Nonetheless, specific issues did arise during three survey dives; those issues are addressed in the Sampling Procedures section below.

## **Methods: Surveys of physical damage and sampling of sediment pollution**

The scuba based assessment combined:

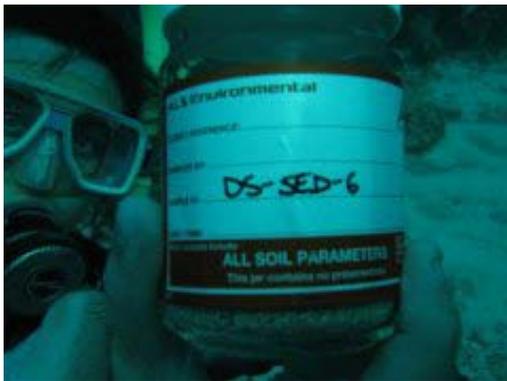
- i. Sampling of sediments and any paint or other human-derived materials on shoal surface (sea bottom);
- ii. Photographs taken to record sediment sampling, to allow time and hence location of sampling to be documented (see Georeferencing, below; Fig. 10);
- iii. Photographic documentation of the condition of shoal benthic habitats, for subsequent analysis of damage (Fig. 10).

These methods are based on standard marine ecological methods (e.g. Jonker et al. 2008), adapted to the purposes and circumstances of this assessment (i.e. collection of sediment; time constraints, etc).

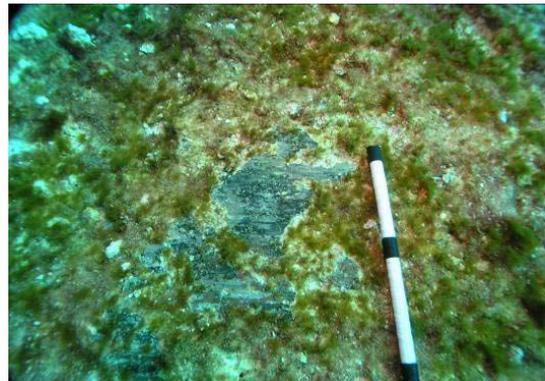
Manta tow surveys were used to complement the spatial coverage of the scuba surveys. Methods involved the snorkel diver (L. McCook) using the manta board to dive as deep as feasible, to observe the condition of and damage to the benthic habitats, and then reporting these observations to a scribe in the tender. The scribe recorded them, along with times and occasional depth measurements taken using a hand-held depth-gauge. Observations were limited to assessments of the extent of damage. These methods were an adaptation of standard procedures outlined in English et al (1997) and the AIMS Standard Operating Procedures (Miller et al. 2009), adapted to the purpose and circumstances of this damage assessment.



A.



B.



C.

Fig. 10. A. Photograph showing divers collecting sediment from an area which has been crushed to a smooth pavement. Note the smooth area which has considerable paint smears on the surface. B. Diver holding sediment sample jar recording sample identifier. Time records on the digital photograph electronic file allowed georeferencing by cross-referencing with time records in towed GPS units. C. Paint smear on the seafloor of the shoal. Scale bar intervals are 10 cm.

## Georeferencing

Scuba based surveys were geo-referenced with considerable precision by means of GPS units attached to surface floats (body surfing "boogie boards") towed by the dive team.

By downloading time referenced spatial coordinates from the GPS units, and matching them to times recorded on digital photographs, the precise location of each photograph could be recorded. Clocks in all GPS units, digital cameras and divers' watches were synchronised at the beginning of the trip.

Cross-referencing with the photographs of sample collection provides the exact time and hence accurate location of each sample collected.

Overall precision of the spatial locations is within 20-30 m. The GPS units used provide accuracy to within 10-15 m ([www8.garmin.com/aboutGPS/](http://www8.garmin.com/aboutGPS/); Garmin 2007). The towed GPS units generally floated within about 5 m, and less than 15 m, of the horizontal location of the divers (i.e. surface floats did not

float exactly vertically above the divers, but were pushed by wind and currents; this horizontal offset was observed to be consistently less than 15 m, based on the angle of the tow-cord and the depth of the water).

## Sampling Procedures: Scuba based surveys

Diving surveys involved three teams of three divers, each team with pre-designated transects determined according to the sampling approach (above). The exact dive procedures depended on the strength of the tidal currents, which were reduced during slack tides (i.e. high or low tide periods), but very strong at other times. For dives during low current periods (slack tides), divers swam on a pre-designated compass bearing, collecting sediment samples and photographs approximately every 10 metres. During high current periods, divers followed the direction of the current (drift dives), and sampled at greater intervals, as feasible (strong tidal currents make it much more difficult to work reliably and safely on the seafloor). In all cases, dive tenders followed the divers' progress from the surface.

Procedures outlined below provided a basic operational plan for each dive, but required modification and adaptation to circumstances for operational and safety reasons.

- a. Initial and final photograph at commencement and completion of each dive recorded start and finish times for the dives;
- b. Sample sites were photographed at approximately 1 m from the substratum, with a 50 cm scale bar;
- c. Photograph of empty jar or evidence bag to record sampling event and time (for cross reference with GPS location);
- d. Collect sediment sample from photographed area, over approximately 1 metre<sup>2</sup>;
- e. Rephotograph jar or evidence bag with sample inside;
- f. Human derived debris or artifacts, such as paint or metal flakes, were collected when found, using clip seal evidence bags. Photographs were taken of the item *in situ*, of collection and of the evidence bag containing the specimen.
- g. Photographs of the seafloor habitat were also collected as systematically as feasible under the dive conditions.

Consistent chain of custody measures were implemented during dives, return to vessel and storage for collected samples, cameras and GPS units, as documented in individual statements of assessment team personnel. Samples were kept refrigerated on board the vessel, during transport and transfer to the laboratory for analyses.

Note that the extent of pollution of shoal sediments by antifoulant paint would be very patchy, depending on the distribution of paint material deposited (e.g. Fig. 10). This means that pollution levels would be expected to vary considerably within a relatively small spatial area, between very high levels (where paint material was present in the sediments), and very low levels (where none happened to be; e.g. Fig. 10A). As the objective is to detect any pollution present, and it is the higher levels of pollution that indicate the greatest risks to the environment, sampling procedure aimed to target and measure the higher concentrations of pollution within a sampling location. For this reason, sampling deliberately included any identifiable paint material found within the sampling area, so that sediment sampling procedures maximised the likelihood that any pollution present was detected (e.g. in Fig. 10A, divers would deliberately collect sediment that included the paint). Thus concentrations in

samples measured represent upper levels, rather than average levels (for both impacted and undisturbed sites).

On one dive (first dive by GBRMPA team), the attachment to the GPS float was lost by the divers due to strong currents. Therefore data for this dive have not been used after that time (8:38:39am 11 May 2010). On two dives (second dives by both AIMS and QPWS teams), the GPS recording failed due to human error, although the start and finish positions were recorded for these dives. For this reason, the geolocation of sample and photograph sites is less precise, and these data are plotted differently on all maps. Since the dives were essentially linear transects (i.e. a relatively straight line in a single direction: see tracks of other dives in Fig. 8), these data are presented as straight lines but should be interpreted as approximate. It is safe to assume that they are within 20-30 metres of the true location. In neither case does this significantly affect the interpretation of the results, and this issue is noted in each caption.

### **Sampling Procedures: Manta Surveys**

The observer/snorkel diver was towed behind an outboard dive tender (small boat), with a boat driver and a scribe with a handheld GPS, handheld depth sounder and watch. At intervals, the observer/diver signaled the boat to stop and called out observations. The scribe noted the time and observations, and occasionally the depth. Georeferencing was intrinsically less precise due to the tow distance and insufficient precision in time recording (generally only recorded to nearest minute). These times were then matched to locations based on tracks stored in the GPS unit.

### **Benthic analyses**

Assessments of benthic cover and condition were based on analyses of photographs collected during the scuba surveys. These analyses were undertaken on Thursday 13 May 2010, the day immediately following the field work. Methods are an adaptation of standard photometric survey methods used in marine ecological monitoring (e.g. English et al. 1997; Jonker et al. 2008), adapted to focus on the assessment of damage and habitat condition.

Dive teams went through all photographs of shoal seafloor habitats and benthos taken by their team, and assessed composition (percent cover) of major categories of benthic organisms, and the extent of damage to reef substrate or benthos. Categories included: Ephemeral algae ("Slime"); Turf algae; Crustose algae; "Tree-like" Algae; Leafy/Fleshy Algae; Live Hard Coral; Live Soft Coral; Recent Dead Coral; Other invertebrates; Sand; Rubble; Coral Rock; Recent Rubble and Compacted Benthos. Descriptions are given in Table 1. Data were checked at the time of entry to ensure that overall estimate of cover within an area totalled 100 percent (excluding slime, turf and crustose, because they co-occur with other categories, often as understory or growth on disturbed substrate<sup>11</sup>).

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<sup>11</sup> Just as a grass and a canopy tree can occupy the same horizontal location in a terrestrial landscape, so can an understory alga and a tree-like or leafy alga. In such cases the total cover of all categories will be greater than 100 percent.

**Table 1: Categories of benthic organisms, substrate and damage used in the assessment of photographic surveys.**

Slime (ephemeral algae)	Filamentous slimy algae that form mats over the seafloor; typically indicates recent damage to substratum. Up to 30 mm in height. (e.g. Fig.s 11-13)
Turf Algae	Often filamentous algae that attain a canopy height of only 1 to 10 mm and resemble cropped grass (however usually shorter than slime).
Crustose Algae	Hard, crust-like algae, often usually pink to red in colour, attached to the substratum like a paint layer.
Tree-like Algae	Large macroalgae with distinct holdfast attachment to the substratum, with distinct branches and 'leaves' (or blades); on Douglas Shoal, up to 50 cm high (e.g. Fig. 11 A & B).
Leafy/fleshy Algae	Smaller macroalgae, still attached by a holdfast to the seafloor but smaller and bushy.
Live Hard Coral	Coral that contains a hard skeleton with live coral tissue over the surface of the skeleton.
Live Soft Coral	Coral that does not contain a hard skeleton, but has spicules inside live soft tissue.
Recent Dead Coral	Dead coral skeleton that has only recently died (e.g. within the last ~10 days) and the live tissue has sloughed away. The skeleton is usually still visibly white and may have very early stages of ephemeral algal growth over the skeleton. The skeleton does not show signs of boring nor long-term erosion of skeletal structure (e.g. polyps etc).
Other Invertebrates	Benthic invertebrates attached to the substratum other than hard or soft coral.
Sand	Small grains of sand, forams, and or coral grit.
Rubble	Substratum material larger than sand, often composed commonly of finger sized pieces of dead hard coral skeleton.
Coral Rock	Hard area of seafloor composed of calcium carbonate (limestone).
Recent Rubble	Similar to rubble, but recognizable by the whiter colour, the presence of ephemeral algae growing on it, the absence of established turf algae and boring organisms and the lack of erosion of coral skeletal structure.
Compacted Benthos	Crushed hard coral and benthos packed flat (with no vertical structure).

Assessments were standardised between teams by an initial training exercise (joint assessment of a range of photographs). Given the large number of photographs to be assessed, and that habitat damage was generally very clear, percent cover was estimated visually. Several studies have shown that such direct estimation provides similar results to methods such as line intercepts, with considerably greater efficiency (e.g. Wilson et al. 2007 and related references therein); in the present case, any possible observer bias would be very minor in comparison to the variability in habitat condition within the impacted areas, and so would have negligible effects on the interpretation of the

Results (i.e. because most sites had either considerable or relatively little damage (see Results), any variability between observers would be much smaller than those differences, and so would not change the fundamental patterns detected by the surveys; see also Ninio et al. 2003).

Recent Rubble and Compacted Benthos were clearly distinctive indications of large scale disturbance, indicated by the white colour of the substrate (calcium carbonate) and the bright green "slime" ephemeral algae which grows on newly disturbed reef substrate (see e.g. Fig.s 11D, 12B,C and 13; Diaz-Pulido & McCook 2002; Diaz-Pulido et al. 2007). Recent Dead Coral similarly indicates disturbance.

The "Extent of Damage" at a site was calculated as an aggregate percent based on addition of different types of damage within each photograph (i.e. sum of Recently Dead Coral + Recent Rubble + Compacted Benthos). This value was then summarized into 5 broad categories of damage (<5%; 5-25%; 25-50%; 50-75% and 75-100%) and colour coded (Blue, Green, Yellow, Orange and Red, respectively). These data were then plotted by the GBRMPA Spatial Data Unit to indicate spatial extent of physical damage to the shoal benthos and substrate.

## **Chemical analyses**

Chemical analyses of sediment and other samples were targeted at identifying and estimating levels of the toxic chemicals tributyltin (TBT), copper and zinc which are common constituents of antifoulant paints used on ships.

All analyses were handled by Queensland Health Forensic and Scientific Services<sup>12</sup>, with analyses of tributyltin subcontracted to ALS Laboratory Group<sup>13</sup>. Quality assurance and control information about the chemical analyses is available from those agencies.

All samples were initially thawed and then dried in an air oven at 40°C. The dried samples were subsequently ground to a fine powder in a TEMA iron-chrome swing mill. One gram portions (1.0000g) of the resultant fine powders were then digested to AS4479 (aqua regia digest) and made up to a volume of 100mL in a standard flask. The resultant digestates were then analysed for heavy metals by Inductively Coupled Plasma Atomic Emission Spectrometry (ICPAES) using a Varian Vista instrument. For TBT analyses (USEPA SW 846 - 8270D, prepared sample extracts were analysed by GC/MS coupled with high volume injection, and quantified against an established calibration curve (USEPA SW 846 - 8270D).

## **Results:**

This section only reports observations of levels of physical damage and pollution, and only for Site Assessment 3. The following section, Overall Damage Assessment, considers the relationship between these levels of damage or pollution and the ship's location during the grounding, and integrates information for all three Site Assessments.

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<sup>12</sup> Queensland Health Forensic and Scientific Services, PO Box 594, Archerfield, Queensland 4108, Ph: 61 7 3274 9071; [www.health.qld.gov.au/qhcss/qhss/](http://www.health.qld.gov.au/qhcss/qhss/)

<sup>13</sup> ALS Laboratory Group, Environmental Division Brisbane, 32 Shand Street Stafford QLD Australia 4053  
Tel. +61-7-3243 7222 [www.alsglobal.com](http://www.alsglobal.com).

## Physical Damage

Extensive areas of severe damage to the shoal benthos were observed (Figs. 10-13). The nature of this damage included areas where the seafloor had been scraped severely, resulting in either compacted bare substrate (Fig. 10A), with minimal original biota, or loose gravel or rubble material, again with minimal original living biota attached (Figs. 11D, 12B). Coral colonisation and recovery can be severely limited or delayed by unstable bottom material (e.g. Fox et al. 2003; Fox et al. 2005).

In many cases the substrate had become overgrown with a thin mat of bright green "slime"-like ephemeral algae (Figs. 11D, 12B, 13). Such algae are almost universally found growing on damaged substrates within coral reef habitats at periods of weeks to months (Diaz-Pulido & McCook 2002; Diaz-Pulido et al. 2007). Other damage included broken and overturned corals.

In contrast, undisturbed areas of the shoal (Figs. 11A-C, 12A) had abundant and diverse flora and fauna, including extensive beds of *Sargassum* and other large, perennial seaweeds, corals, and diverse invertebrates, and abundant benthic (bottom-dwelling) fishes. Shoal topography was complex, and included many features up to 30 cm high. Extensive unconsolidated rubble was not observed on this shoal outside the ship grounding area.

Figure 14 shows the extent of damage to the shoal assessed from photographs taken during scuba dives (square symbols), with large areas assessed as having more than 75% damage to the reef benthos (red shading). Figure 14 also shows damage categories assessed by manta tow.

Significantly, most sites were either undamaged or severely damaged (blue or red symbols respectively): intermediate levels of damage were uncommon (green, yellow and orange symbols). Of photographs recording damage, most (75%) recorded severe damage (>75% damaged area). One implication of this is that damage detection was relatively easy and reliable using the methods employed here.

The estimated total area of damage, and relationship to the ship's path are discussed in the Overall Damage Assessment section.

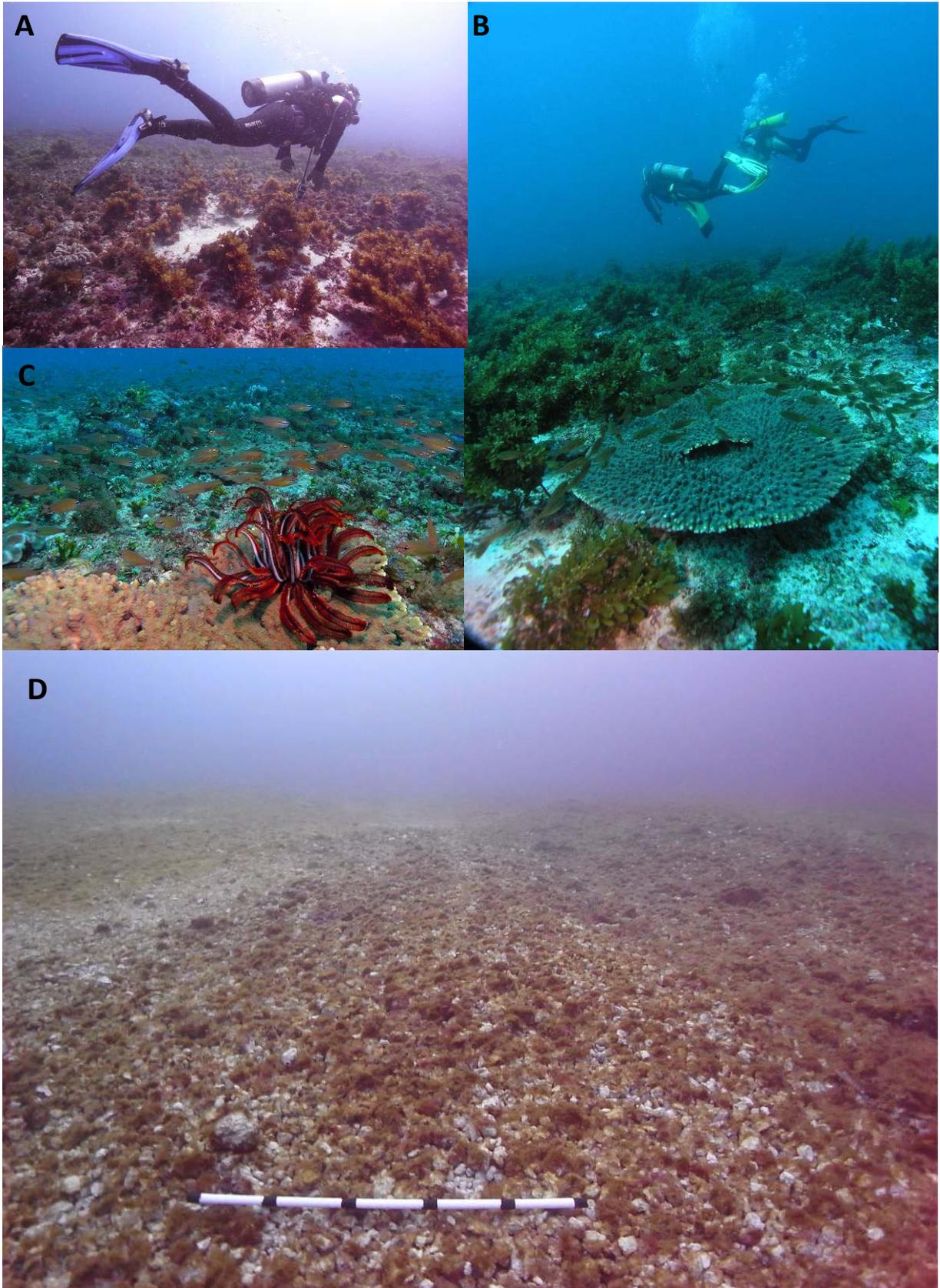


Fig. 11. A-C. Photographs showing undisturbed shoal habitats in areas remote from the vessel grounding. The shoal habitats included abundant seaweeds, such as *Sargassum* (A, B), corals (B) and diverse invertebrates such as the crinoid (feather star) in C. Shoal topography includes many features up to 30 cm high. D. Contrasting view of shoal in area affected by the vessel grounding. Substrate has been reduced to broken rubble with a developing growth of ephemeral (short-lived, slimy) algae typical of disturbed sites. Virtually all of the organisms previously present have been removed or broken, and the 3-dimensional topography reduced to a few cms. Scale bar intervals are 10 cm.

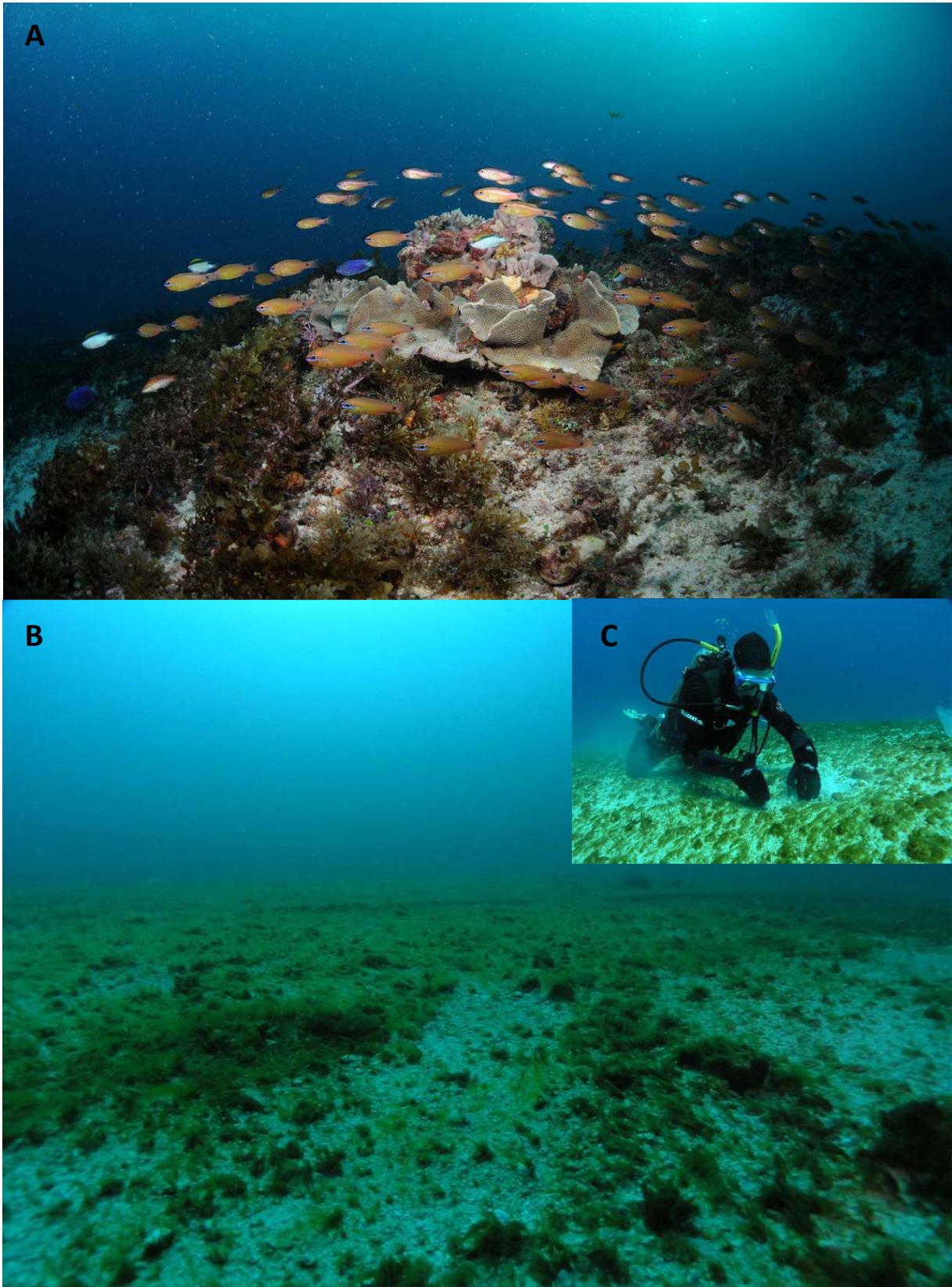


Fig. 12. A. Photographs showing diversity of seaweeds, corals and other invertebrates, and fishes in an undisturbed shoal habitat (remote from the vessel grounding). Note also the 3-dimensional topography. B. Shoal seafloor in the area of the vessel grounding, showing flattened topography, rubble and sand substratum, and thick growth of ephemeral (short-lived) algae typical of disturbed sites. C. Inset shows diver collecting sediment sample amidst ephemeral algal.



Fig. 13. Divers sampling sediments within a swathe of disturbed benthos on the shoal. Note the contrast between the larger, long-lived (perennial) seaweeds (predominantly *Sargassum*) and the new growth of ephemeral algae growing on the disturbed substratum. (A sea snake is just visible to the left of the lower diver).<sup>14</sup>

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<sup>14</sup> Fig. 14 (over). Map showing extent of damage to reef, based on assessments of photographs and manta tow observations. (Note that location of scuba sampling indicated by straight lines is less precise than other data; see Sampling Procedures for explanation). Note that most sites were either undamaged (blue symbols) or severely damaged (>75% of area damaged, red symbols); intermediate levels of damage were uncommon.



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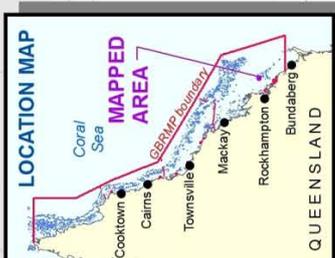
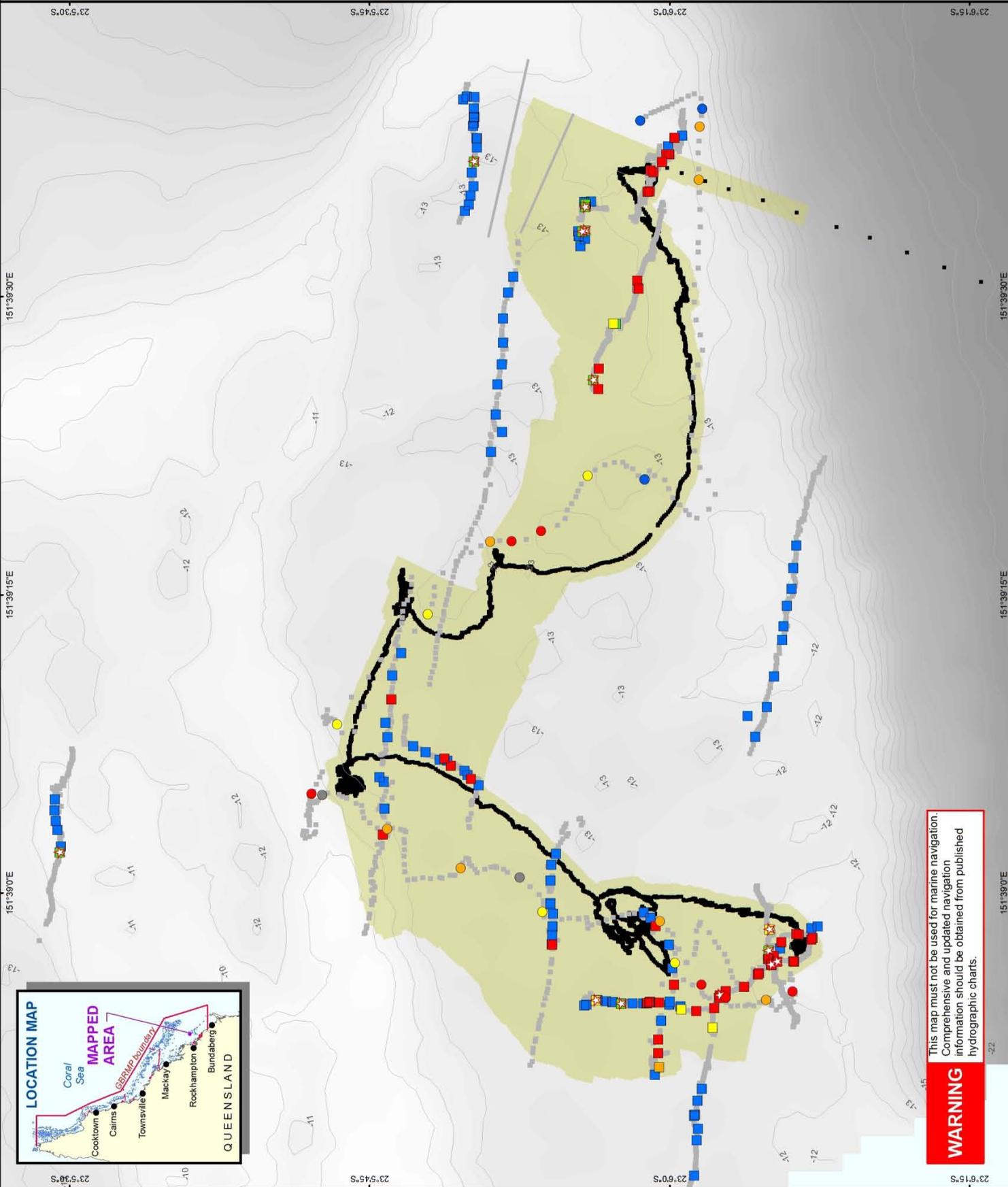
# Shen Neng 1 Grounding Douglas Shoal 23-044 3-12 April 2010

## Figure 14 Site Assessment 3 Physical Damage Observed

- LEGEND**
- Dives and Manta Tow locations
  - AIS position of vessel (AMSA)
  - Depth contours (m) (JCU)
  - Path of vessel
- Dives**
- 75 - 100%
  - 50 to <75%
  - 25 to <50%
  - 5 to <25%
  - <5%
- Broken coral**
- ☆
- Manta Tow**
- Severe
  - Moderate
  - Minor
  - Possible
  - Undamaged



Map Projection: Unprojected Geographics  
Horizontal Datum: World Geodetic System, 1984  
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## Pollution by antifoulant paint constituents

High levels of the toxic chemicals tributyltin (TBT), copper and zinc were found in samples taken both immediately after the grounding (site visit 1), and one month later (site visit 3), in several areas of the shoal. Note that sampling procedures differed slightly between site visits, so that levels may not be directly comparable between the two visits. On the first site visit, paint and sediment were sampled separately. Sampling for site visit 3 standardised the procedure to collect sediments in all cases, including any paint present. Summary statistics are given in Table 2.

Samples of paint collected from the seafloor during the first site visit had TBT concentrations as high as 35,000 µg Sn/kg dry weight (range 41.6 – 35,400 µg Sn/kg; 5 samples collected), copper concentrations ranging between 150 and 334,200 mg/kg and zinc concentrations of between 7,300 and 45,000 mg/kg. Sediment samples collected during the first site visit had TBT concentrations ranging from undetectable to as high as 52.8 µg Sn/kg, with copper up to 190 mg/kg and zinc up to 56 mg/kg (13 samples collected).

Sediments sampled on site visit 3 included some extremely high concentrations of TBT, as high as 545,000 µg Sn/kg dry weight (or 0.5 g Sn/kg) which is approximately 100,000 times the low trigger level for the ANZECC 2000 guidelines, and 7,700 times the high guideline. Of 166 sediment samples collected for TBT analysis, 35 samples showed levels above the low trigger level for ANZECC guidelines, 21 samples above the high trigger level and 9 samples more than 50 times the high trigger level. However, TBT was below detection limits in samples from many sites.

Concentrations of copper and zinc in sediments collected on site visit 3 also included some very high levels. Of the 167 samples collected for copper and zinc analysis, 23 contained more copper than the low trigger level for the ANZECC 2000 guidelines, 15 contained more than the high level, and 5 contained more than 50 times the high level (maximum value measured 152,300 mg/kg). For zinc, 14 contained more than the low trigger level, 12 contained more than the high level, and 2 contained more than 50 times the high level (maximum value measured 22,000 mg/kg).

The patterns of contamination in relation to the path of the vessel during the grounding, and the ecological effects of this contamination, are discussed in the Overall Damage Assessment section.

**Table 2: Summary of antifoulant paint chemical contamination results.**

	# of samples	Min.	Max.	# Samples < detection limits*	# Samples > detection limits	# Samples > Low (trigger)	# Samples > High	Extreme: # Samples > 50 x High	ANZECC Low (trigger)	ANZECC High Guideline
Site Assessment 1- Paint Samples:										
TBT	5	41.6 µg Sn/kg	35,400 µg Sn/kg	0	5	5	4	1	5 µg Sn/kg	70 µg Sn/kg
Copper	5	150 mg/kg	334,200 mg/kg	0	5	5	4	4	65 mg/kg	270 mg/kg
Zinc	5	7,300 mg/kg	45,000 mg/kg	0	5	5	5	3	200 mg/kg	410 mg/kg
Site Assessment 1- Sediment Samples:										
TBT	12	< Detection	52.8 µg Sn/kg	6	6	1	0	0	5 µg Sn/kg	70 µg Sn/kg
Copper	13	< Detection	190 mg/kg	11	2	1	0	0	65 mg/kg	270 mg/kg
Zinc	13	< Detection	56 mg/kg	4	9	0	0	0	200 mg/kg	410 mg/kg
Site Assessment 3- Sediment Samples:										
TBT	166	< Detection	545,000 µg Sn/kg	92	74	35	21	9	5 µg Sn/kg	70 µg Sn/kg
Copper	167	< Detection	152,300 mg/kg	137	30	23	15	5	65 mg/kg	270 mg/kg
Zinc	167	< Detection	22,000mg/kg	136	31	14	12	2	200 mg/kg	410 mg/kg

\* Includes samples collected outside the ship's path for Site Assessment 3.

## Overall Damage Assessment

This section combines information from all three site visits.

### ***Relationship between damage and ship position during grounding***

There is a strong correlation between the known position of the ship during the incident and the extent of damage to the shoal benthic communities, and no evidence of significant damage in locations that are not consistent with damage by the *Shen Neng I*. Figure 15<sup>15</sup> shows the extent of damage assessed during all site visits in comparison with the path of the vessel: almost all the damage observed is within, or extremely close to, the location of the vessel at some point. This is the case for scuba-based observations and photographs, for manta-towed observations, for video towed observations, and for assessments of fine-scale bathymetry using multibeam sonar (this report, Marshall et al 2010, Negri et a 2010).

Comparisons of damage severity within and outside the path of the vessel show dramatically more damage inside the ship's path than outside (Fig. 16). These differences were statistically highly significant (Table 3).

However, it is important to note that not all areas within the ship's path were damaged: some areas had little damage observed (Fig. 16B). It is concluded that the vessel was floating higher than the benthos at that location and time of the tidal cycle and so did not damage the shoal benthos.

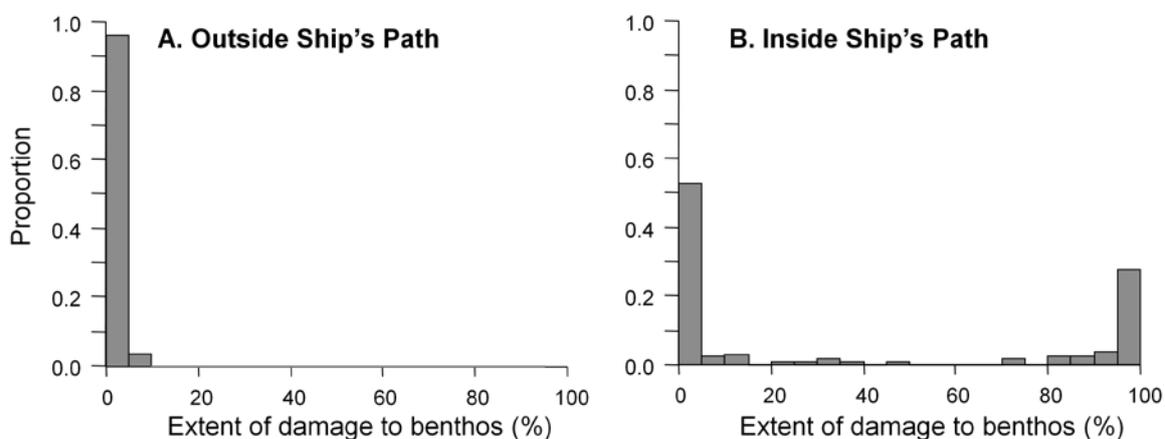


Fig. 16: Comparisons of estimated damage to the shoal benthos (A) outside the area of the ship's path and (B) inside that area\*. Frequency histograms of estimated damage to reef benthos: Graphs show the proportion of sites (vertical axis) with different degrees of damage (horizontal axis). The data show that (A) outside the ships path, almost all sites had no damage, whereas (B) inside the ships path many sites were assessed as having 80-100% damage. Note also that relatively few sites had intermediate damage (20-80%), showing that damage tended to be severe where it occurred. (\*Figure B area includes a 30m buffer zone around the plotted path, to allow for the precision of the georeferencing procedures: i.e. sites within 30m of the grounding path were included).

<sup>15</sup> Fig. 15 (over): Map showing relationships between the grounding path and damage assessments from all site visits. Note that almost all damaged observed during all three site visits is within, or extremely close to, the location of the vessel at some point. There were no observations of significant damage in locations that are not consistent with ship damage (Note that locations of sampling indicated by straight lines is less precise than other data; see Sampling Procedures for explanation; includes data from Marshall 2010, Negri et al 2010).



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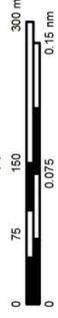
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Shen Neng 1 Grounding  
Douglas Shoal 23-044  
3-12 April 2010

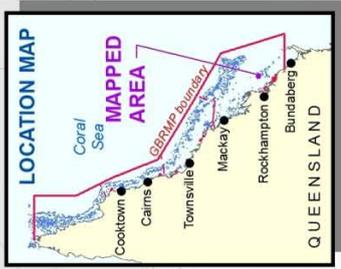
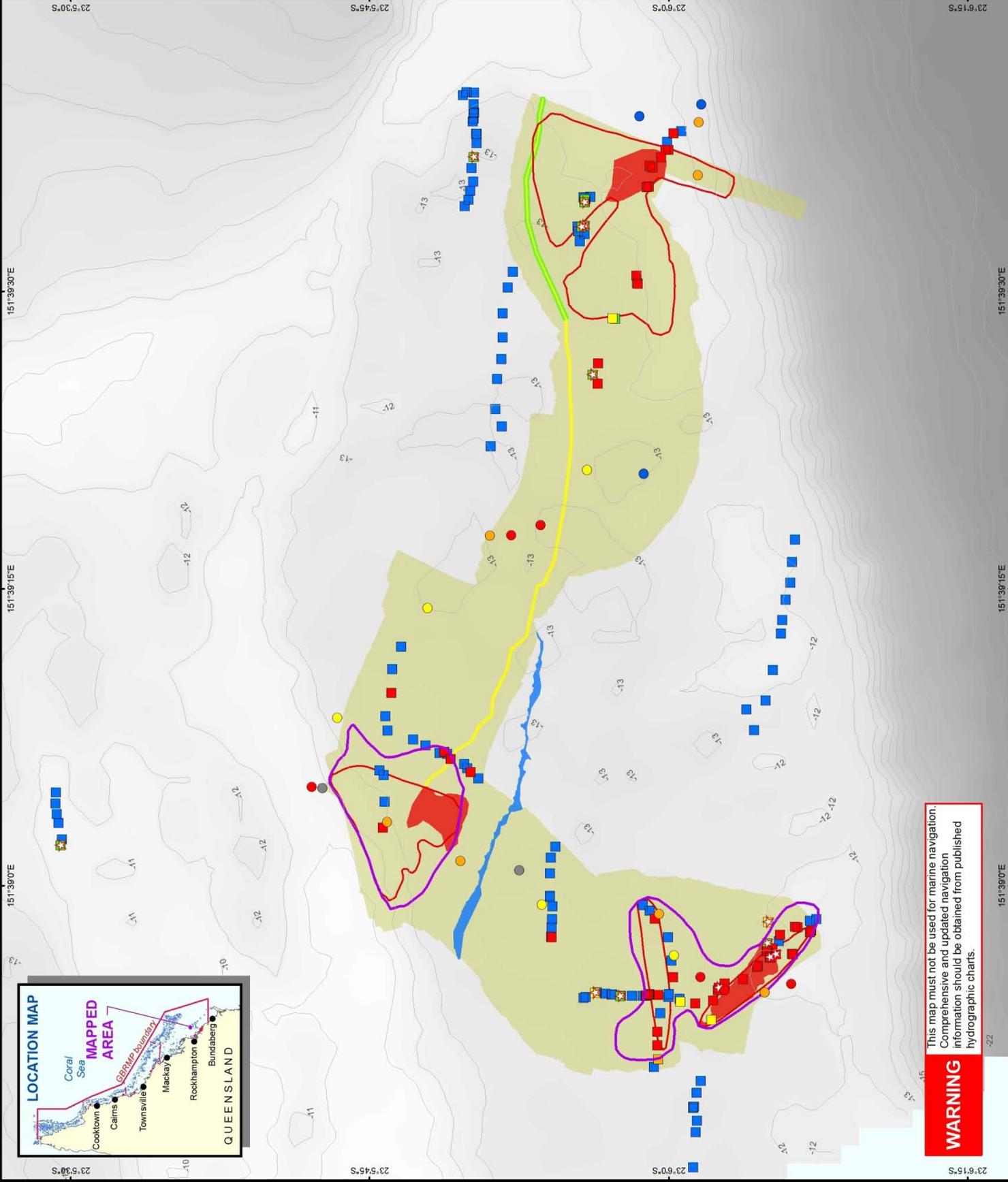
Figure 15

### Physical Damage Observed

- LEGEND**
- Depth contours (m) (JCU)
  - Path of vessel
  - Dive Teams (Site Assessment 1)
    - Severe
    - Moderate
    - Minor
    - Undamaged
  - Impact sites from sonar (Site Assessment 2)
  - Impact sites from video tow (Site Assessment 2)
  - Dive Teams (Site Assessment 3)
    - 75 - 100%
    - 50 to <75%
    - 25 to <50%
    - 5 to <25%
    - <5%
    - Broken coral
  - Manta Tow (Site Assessment 3)
    - Severe
    - Moderate
    - Minor
    - Possible
    - Undamaged



Map Projection: Unprojected Geographics  
 Horizontal Datum: World Geodetic System, 1984  
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**Table 3: Statistical Two Way Cross-tabulation of damage inside and outside the ship's path:**

	Damage Categories (as for Fig. 15)					Total	Pearson Chi Squared	df	P-value
	<5%	5-<25%	25 - <50%	50 -<75%	75-100%				
Outside Ship's Path	27.32	1.09	0	0	0	28.42	32.606	4	0.000
Inside Ship's Path	37.71	4.37	1.09	2.73	25.68	71.59			
<b>Total</b>	<b>65.03</b>	<b>5.46</b>	<b>1.09</b>	<b>2.73</b>	<b>25.68</b>	<b>100</b>			

Data are % of total counts (N=183); note that more sites were assessed within the grounding path than outside; also Inside ship's path includes a 30 m buffer zone to allow for precision of the georeferencing procedures. Note also that the very low counts for most Outside Ship's Path cells mean the estimated P value may not be exact.

Comparison of damage to the shoal benthos and the location of the vessel when stationary (Figure 17<sup>16</sup>) shows that much, but not all of the most severe damage was caused when the vessel was stationary, presumably because it was completely grounded, such as at low tide periods.

Patterns of damage observed directly during scuba-based surveys also match closely those indicated by the detailed bathymetric analyses (Fig. 18<sup>17</sup>). Taken together, these provide strong support for the interpretation of damage in the multibeam sonar analyses (Negri et al. 2010).

### ***Estimated extent of damage***

Based on integration of the information from direct observation (site visits 1 and 3) and the bathymetric and towed video assessments (site visit 2), the ship grounding appears to have caused severe damage in 3 main zones where it remained for significant periods (Fig. 19<sup>18</sup>; Table 4). The approximate areas of these damage zones are 49,633 m<sup>2</sup>, 32,670 m<sup>2</sup> and 34,060 m<sup>2</sup> in chronological order (east to west) with a total area of approximately 116,365 m<sup>2</sup> (areas calculated using geospatial software to overlay data from all three site visits). It is emphasised that this constitutes a *minimum estimate* of the area of *severely damaged* shoal habitat.

This estimate is larger than the interim estimates provided in either Marshall (2010) or Negri et al (2010) because it combines the survey areas of all three site visits to provide a more complete picture.

There was also considerable damage outside those three areas. Site visit 1 also documented a long narrow band of moderate damage (east-west path shown in Fig. 19) with an area of 4,293 m<sup>2</sup>.

Observations from site visit 3 elsewhere in the vessel path show that there was frequent but patchy,

<sup>16</sup> Fig. 17 (over): Map showing relationships between the severity of damage and the location of the vessel when stationary ("speed over ground" recorded by vessel GPS was zero). Much, but not all of the most severe damage is correlated with the location of the vessel when stationary.

<sup>17</sup> Fig 18: Map showing relationships between the detailed bathymetric analyses based on multibeam sonar (Negri et al 2010) and direct observations of damage from the first and third site visits.

<sup>18</sup> Figure 19: Map showing minimum estimates of area of severe damage integrated from all three site visits. Total estimated area of severe damage is 116,365 m<sup>2</sup>. Note also moderate to severe damage (indicated by yellow, orange and red markers) scattered throughout the rest of the ship's path. Total area of ship's path was estimated to be 407,348 m<sup>2</sup>.

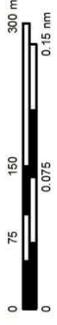


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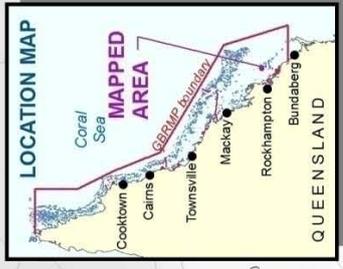
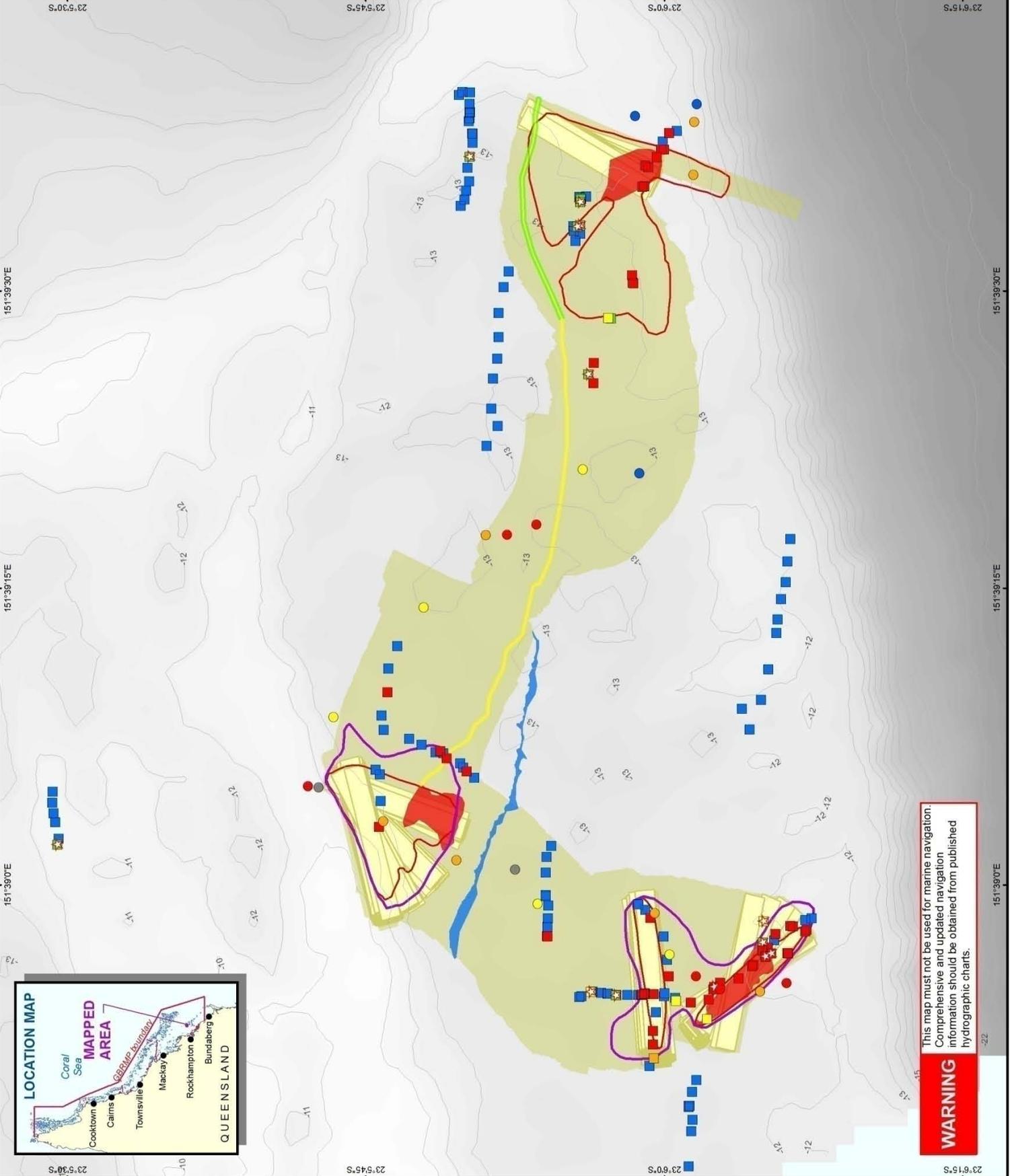
**Shen Neng 1 Grounding**  
**Douglas Shoal 23-044**  
**3-12 April 2010**

**Figure 17**  
**Location of**  
**Stationary Vessel**  
**with Damage Observed**

- LEGEND**
- Depth contours (m) (JCU)
  - Path of vessel
  - Vessel Location
  - Speed Over Ground = 0 knots
  - Dive Teams (Site Assessment 1)**
  - Severe
  - Moderate
  - Minor
  - Undamaged
  - Impact sites from sonar (Site Assessment 2)**
  - Impact sites from video tow (Site Assessment 2)**
  - Dive Teams (Site Assessment 3)**
  - 75 - 100%
  - 50 to <75%
  - 25 to <50%
  - 5 to <25%
  - <5%
  - Broken coral
  - Manta Tow (Site Assessment 3)**
  - Severe
  - Moderate
  - Minor
  - Possible



Map Projection: Unprojected Geographics  
 Horizontal Datum: World Geodetic System, 1984  
 Raster Source: Dr. Robin Beaman, James Cook University  
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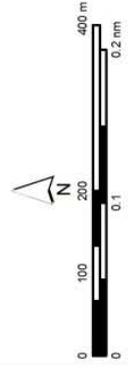
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Douglas Shoal 23-044  
3-12 April 2010

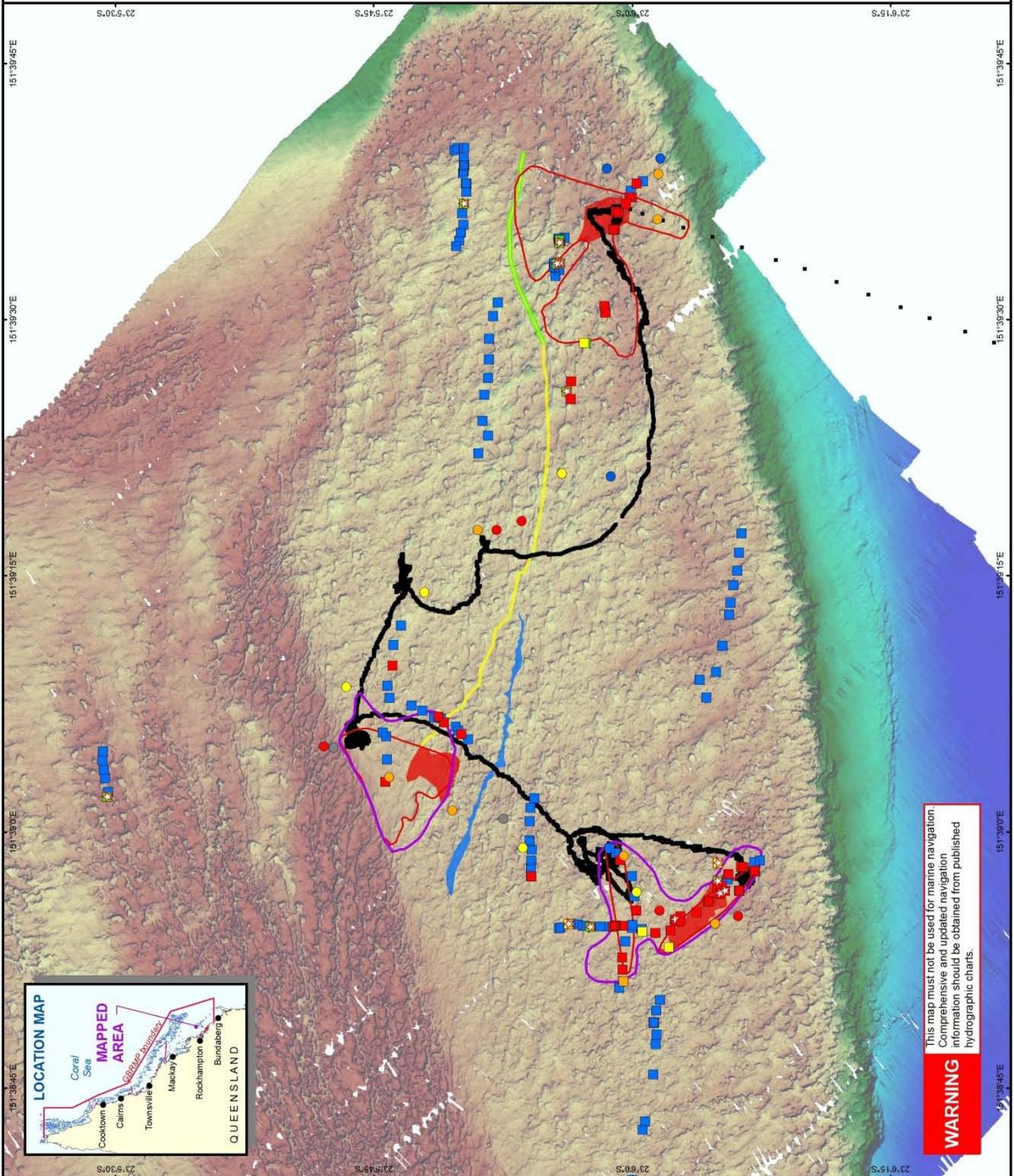
Figure 18

### Preliminary Bathymetric Survey with Damage Observed

- LEGEND**
- AIS position of vessel (AMSA)
  - Dive Teams (Site Assessment 1)**
    - Severe
    - Moderate
    - Minor
    - Undamaged
  - Impact sites from sonar (Site Assessment 2)**
  - Impact sites from video tow (Site Assessment 2)**
  - Dive Teams (Site Assessment 3)**
    - 75 - 100%
    - 50 to <75%
    - 25 to <50%
    - 5 to <25%
    - <5%
  - ☆ Broken coral
  - Manta Tow (Site Assessment 3)**
    - Severe
    - Moderate
    - Minor
    - Possible
    - Undamaged



Map Projection: Unprojected Geographics  
Horizontal Datum: World Geodetic System, 1984  
Raster Source: Bathymetric Survey, AMIS, 2010  
SDC 100405-8AS 17 November 2010



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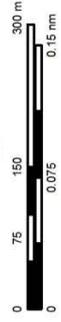
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Douglas Shoal 23-044  
3-12 April 2010

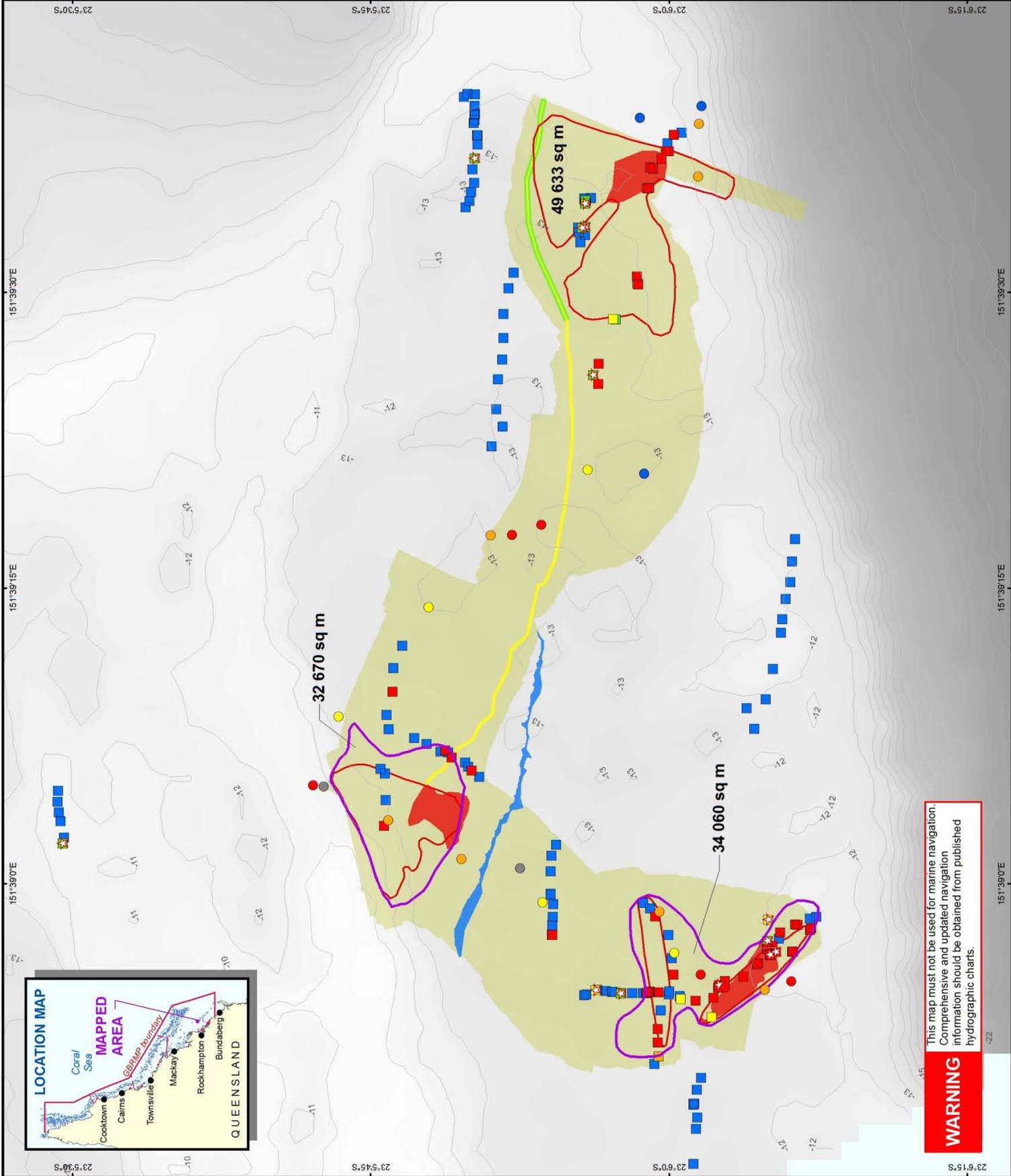
Figure 19

### Physical Damage Observed

- LEGEND**
- Depth contours (m) (JCU)
  - Path of vessel (407 350 sq m)
  - Dive Teams (Site Assessment 1)
  - Severe
  - Moderate
  - Minor
  - Undamaged
  - Impact sites from sonar (Site Assessment 2)
  - Impact sites from video tow (Site Assessment 2)
  - Dive Teams (Site Assessment 3)
  - 75 - 100%
  - 50 to <75%
  - 25 to <50%
  - 5 to <25%
  - <5%
  - Broken coral
  - Manta Tow (Site Assessment 3)
  - Severe
  - Moderate
  - Minor
  - Possible
  - Undamaged



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Observations from site visit 3 elsewhere in the vessel path show that there were numerous patches with moderate to severe damage (yellow, orange and red markers in Fig. 19) interspersed throughout much of the remaining area of the path of the vessel, an estimated area of 290,985 m<sup>2</sup> (note that there were also many sites with no damage observed within this path – blue markers in Fig. 19). It is not possible to provide greater certainty around this estimate without further field surveys, but these observations indicate an upper limit on the area of damage.

Thus, in summary, the vessel grounding caused severe physical damage to a minimum of 116,363 m<sup>2</sup>, and considerable physical damage to significant further areas, with the total area of physical damage likely to be less than 400,000 m<sup>2</sup> (the total area of the ship's path).

**Table 4: Summary of estimated area of damage**

	Area		
Severe damage:	1	49,633 sq m	5.0 hectares
	2	32,670 sq m	3.3 hectares
	3	34,060 sq m	3.4 hectares
	Total	116,363 sq m	11.6 hectares
Patchy, moderate to severe damage:	290,985 sq m	29.1 hectares	
Total area of ship's path	407,348 sq m	40.7 hectares	

### ***Distribution of chemical pollution within the shoal environment***

There is a strong correlation between the concentrations of antifoulant paint contaminants and the path of the ship during the grounding. Figures 20<sup>19</sup> and 21 shows that high concentrations of TBT in sediment samples from site visits 1 and 3 were consistently found within or very close to the ship's path (within 50 m), and levels further from the ship's path were generally below detection limits, or very low (below 5 µg Sn/kg, the trigger level for ANZECC 2000 Guidelines). These differences were statistically significant (Table 5).

Low levels of TBT were also found in areas within the ship's path, consistent with the expectation that concentrations would be highly variable, depending on the distribution of paint fragments and scrapes (See Sampling Procedures: Scuba based surveys).

<sup>19</sup> Figure 20 (over): Map showing concentrations of tributyltin (TBT), an antifoulant paint contaminant, compared to the path of the vessel during the grounding. Note that high concentrations of TBT (red and black symbols) were found exclusively within or very close to the ship's path, concentrations further from the ship's path were usually below detection limits, or very low. TBT levels are shown for samples collected during site visits 1 and 3. Levels are shown as: Below the detection limit (0.5 µg Sn/ kg sediment); Low = less than the ANZECC low trigger value (5 µg Sn/ kg); Medium = between the low and high ANZECC guideline levels (5 to 70 µg Sn/ kg); High = between one and 50 times the high ANZECC guideline level; and Extreme = more than 50 times the high guideline level. Note that sampling procedures differed slightly between site visits, so that levels may not be directly comparable between the two visits.



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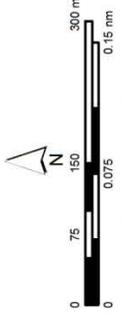
Shen Neng 1 Grounding  
Douglas Shoal 23-044  
3-12 April 2010

Figure 20

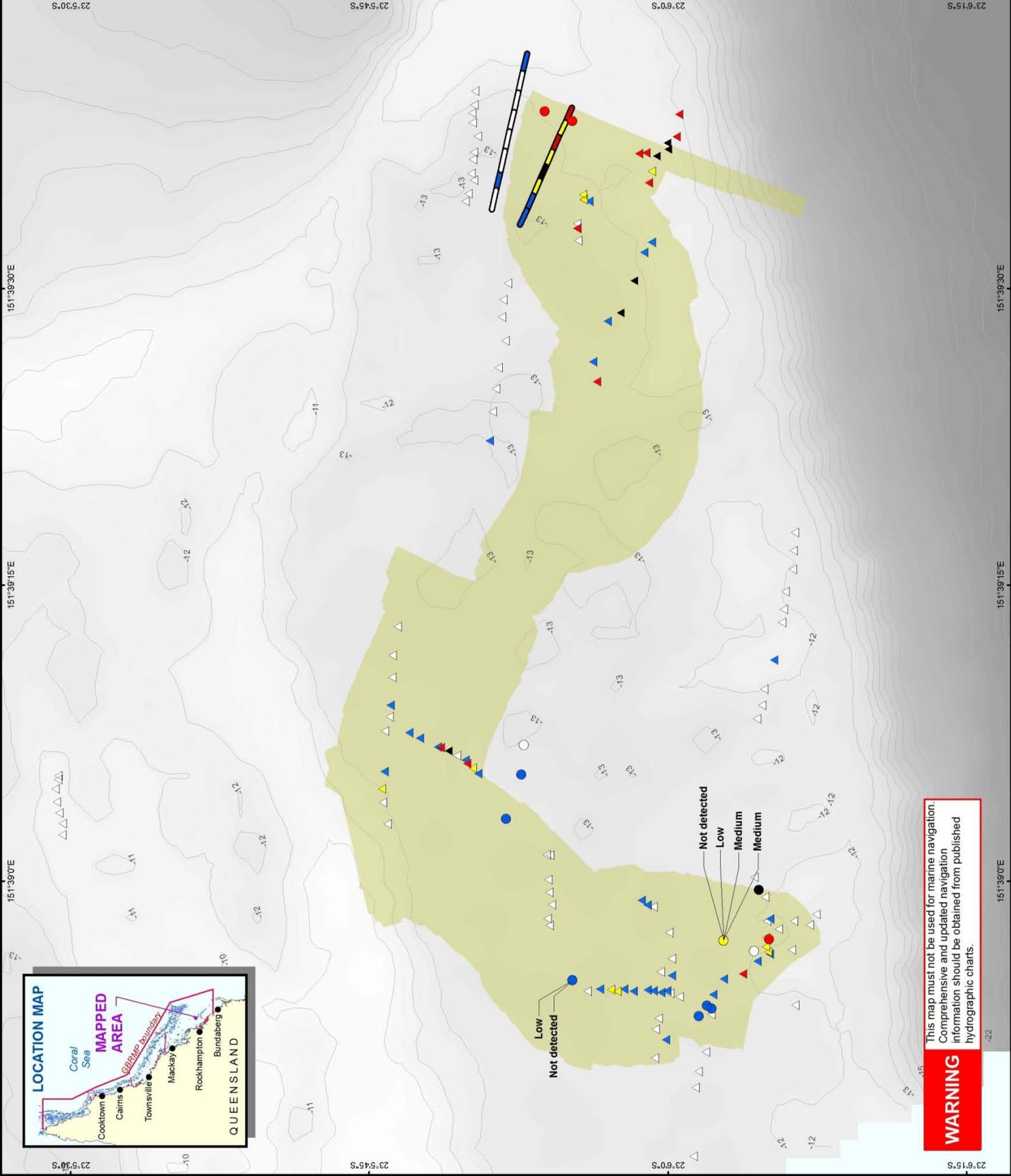
### Concentrations of Tributyltin (TBT) found in paint and sediment samples

- LEGEND**
- Depth contours (m) (JCU)
  - Path of vessel
  - Site Assessment 1**
  - TBT Concentration**
    - Extreme (> 3500 µg Sn/kg)
    - High (70 - 3500 µg Sn/kg)
    - Medium (5 - 69.9 µg Sn/kg)
    - Low (< 5 µg Sn/kg)
    - Not detected
  - Site Assessment 3**
  - TBT Concentration**
    - Extreme (> 3500 µg Sn/kg)
    - High (70 - 3500 µg Sn/kg)
    - Medium (5 - 69.9 µg Sn/kg)
    - Low (< 5 µg Sn/kg)
    - Not detected
  - Site Assessment 3 (approx. locations)\***
  - TBT Concentration**
    - Extreme (> 3500 µg Sn/kg)
    - High (70 - 3500 µg Sn/kg)
    - Medium (5 - 69.9 µg Sn/kg)
    - Low (< 5 µg Sn/kg)
    - Not detected

\* Sample locations derived by ordering photo times collected for each sample (total of 10 samples)



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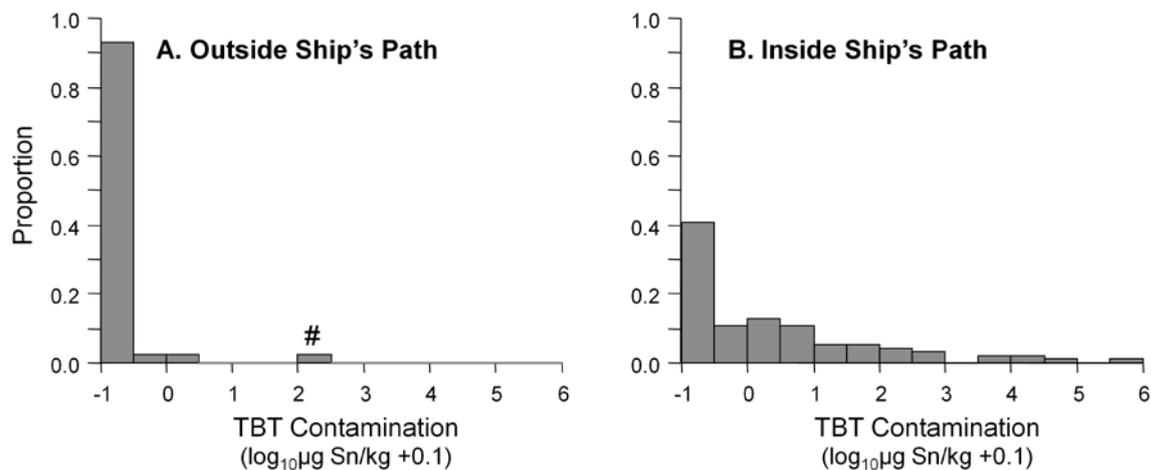


Fig. 21: Comparisons of TBT concentrations in samples collected (A) outside the area of the ship's path and (B) inside that area\*. Frequency histograms of concentrations on a log scale: Graphs show the proportion of samples (vertical axis) with different concentrations of TBT (horizontal axis). The data show that (A) outside the ships path, almost all samples had very low concentrations, whereas (B) inside the ships path many samples had much higher concentrations. The only sample with a high TBT concentration outside the ship's path, indicated with #, was <50m from the path, in the area of the initial grounding. (\*Figure B includes a 30m buffer zone around the plotted path, to allow for the precision of the georeferencing procedures: i.e. sites within 30m of the grounding path were included).

Patterns of distribution of copper (Figure 22<sup>20</sup>) and zinc (Figure 23<sup>21</sup>) contamination are very similar to those for TBT, with high concentrations consistently found within or very close to the ship's path, and levels further from the path generally below detection limits. Again, concentrations within the ship's path were highly variable.

It is critical to note that although sediment contamination by antifoulant paint chemicals appears limited to the area of the ship's path, any dissolution of those contaminants into the water column, or suspended fine particulate material, will be very widely dispersed across a large area of marine environment (Jones 2007), given the very strong tidal currents that would mix the contaminated water widely. Antifouling material deposited during ship groundings is suggested to continue to leach active constituents for some time (Jones 2007), and there was considerable mobilisation of sediments as a turbid plume during the grounding (see plume visible in Monkivitch 2010, Appendix D Figure 8).

<sup>20</sup> Fig. 22 (over): Map showing concentrations of copper, an antifoulant paint contaminant, and the path of the vessel during the grounding. Note that high concentrations of copper (red and black symbols) were found exclusively within or very close to the ship's path, concentrations further from the ship's path were usually below detection limits, or very low. Concentrations are shown for samples collected during site visits 1 and 3, as below the detection limits of 30 mg/kg sediment, Low = less than the ANZECC low trigger value (65 mg/ kg), Medium = between the low and high ANZECC guideline levels (65 to 270 mg/ kg), High = between one and 50 times the high ANZECC guideline level, and Extreme = more than 50 times the high guideline level.

<sup>21</sup> Fig. 23: Map showing concentrations of zinc, an antifoulant paint contaminant, and the path of the vessel during the grounding. Note that high concentrations of zinc (red and black symbols) were found exclusively within or very close to the ship's path, concentrations further from the ship's path were usually below detection limits, or very low. Concentrations are shown for samples collected during site visits 1 and 3, as below the detection limits of 4 mg/kg sediment, Low = less than the ANZECC low trigger value (200 mg/ kg), Medium = between the low and high ANZECC guideline levels (200 to 410 mg/ kg), High = between one and 50 times the high ANZECC guideline level, and Extreme = more than 50 times the high guideline level).

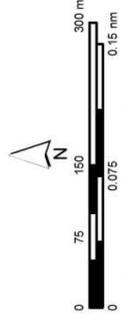


Figure 22

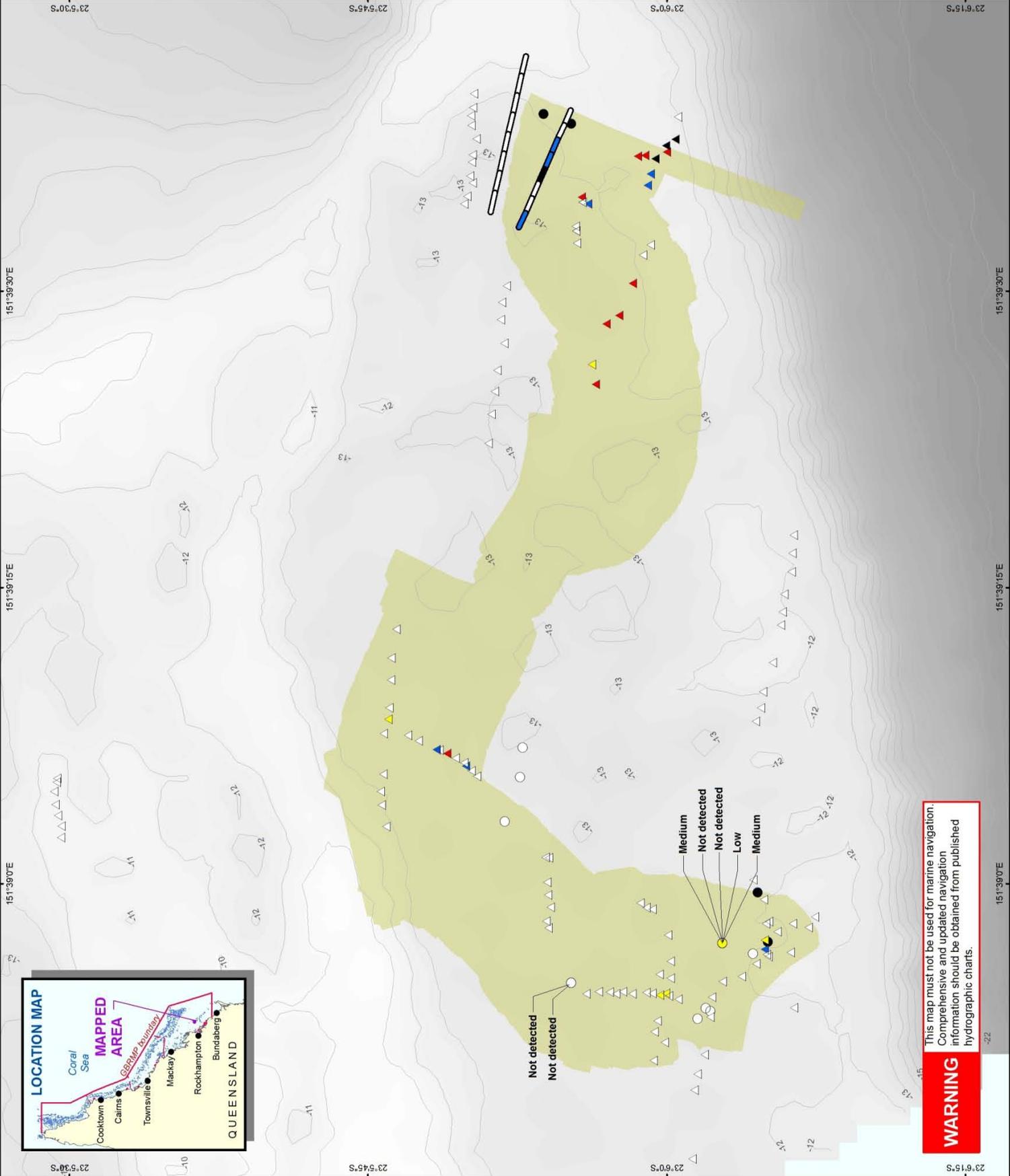
**Concentrations of Copper (Cu) found in paint and sediment samples**

- LEGEND**
- Depth contours (m) (ICU)
  - Path of vessel
  - Site Assessment 1**
  - Cu Concentration**
    - Extreme (> 13500 mg Cu/kg)
    - Medium (65 - 269 mg Cu/kg)
    - Low (< 65 mg Cu/kg)
    - Not detected
  - Site Assessment 3**
  - Cu Concentration**
    - ▲ Extreme (> 13500 mg Cu/kg)
    - ▲ High (270 - 13500 mg Cu/kg)
    - ▲ Medium (65 - 269 mg Cu/kg)
    - ▲ Low (< 65 mg Cu/kg)
    - △ Not detected
  - Site Assessment 3 (approx. locations)\***
  - Cu Concentration**
    - ▬ Extreme (> 13500 mg Cu/kg)
    - ▬ Low (< 65 mg Cu/kg)
    - ▬ Not detected

\* Sample locations derived by ordering photo times collected for each sample (total of 16 samples)



Map Projection: Unprojected Geographics  
 Horizontal Datum: World Geodetic System, 1984  
 Raster Source: Dr. Robin Beaman, James Cook University and the Australian Hydrographic Service  
 SDC 100/05-8A/10 17 November 2010



**WARNING**  
 This map must not be used for marine navigation. Comprehensive and updated navigation information should be obtained from published hydrographic charts.

23°53'00"S 151°39'00"E 23°54'55"S 151°39'15"E 23°56'00"S 151°39'30"E 23°57'00"S 151°39'45"E 23°58'00"S 151°40'00"E 23°59'00"S 151°40'15"E 23°59'55"S 151°40'30"E 23°59'00"S 151°40'45"E 23°58'00"S 151°40'00"E 23°57'00"S 151°39'45"E 23°56'00"S 151°39'30"E 23°55'00"S 151°39'15"E 23°54'00"S 151°39'00"E



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**Shen Neng 1 Grounding**  
**Douglas Shoal 23-044**  
**3-12 April 2010**

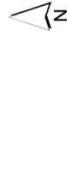
Figure 23

**Concentrations of Zinc (Zn) found in paint and sediment samples**

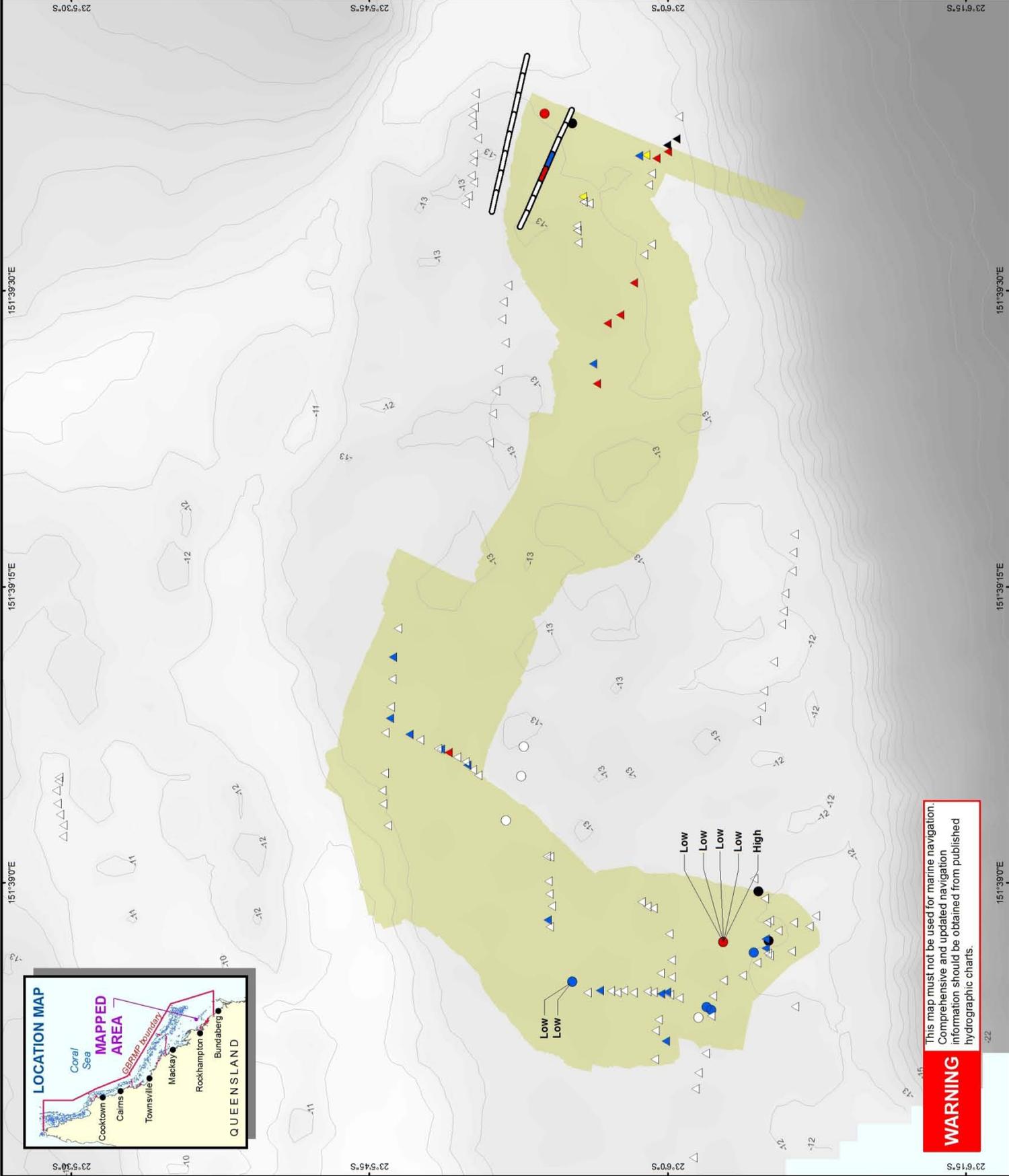
**LEGEND**

- Depth contours (m) (JCU)
- Path of vessel
- Site Assessment 1**
- Zn Concentration
  - Extreme (> 20500 mg Zn/kg)
  - High (410 - 20500 mg Zn/kg)
  - Low (< 200 mg Zn/kg)
  - Not detected
- Site Assessment 3**
- Zn Concentration
  - ▲ Extreme (> 20500 mg Zn/kg)
  - ▲ High (410 - 20500 mg Zn/kg)
  - ▲ Medium (200 - 409 mg Zn/kg)
  - ▲ Low (< 200 mg Zn/kg)
  - △ Not detected
- Site Assessment 3 (approx. locations)\***
- Zn Concentration
  - ▬ High (410 - 20500 mg Zn/kg)
  - ▬ Low (< 200 mg Zn/kg)
  - ▬ Not detected

\* Sample locations derived by ordering photo times collected for each sample (total of 16 samples)



Map Projection: Unprojected Geographics  
 Horizontal Datum: World Geodetic System, 1984  
 Raster Source: Dr. Robin Beaman, James Cook University  
 Vertical Datum: Australian Hydrographic Service  
 SDC 100-005-8A 11 17 November 2010



**WARNING**  
 This map must not be used for marine navigation. Comprehensive and updated navigation information should be obtained from published hydrographic charts.

**Table 5: Statistical Two Way Cross-tabulation of TBT contamination inside and outside the ship's path:**

	TBT Contamination					Total	Pearson Chi Squared	df	P-value
	Below Detection	Low	Medium	High	Extreme				
Outside Ship's Path	29.412	1.471	0	0.735	0	31.618	32.606	4	0.000
Inside Ship's Path	27.941	21.324	8.088	6.618	4.412	68.382			
<b>Total</b>	<b>57.353</b>	<b>22.794</b>	<b>8.088</b>	<b>7.353</b>	<b>4.412</b>	<b>100</b>			

Data are % of total counts (N=136); note that more samples were gathered within the grounding path than outside; also Inside Ship's Path includes a 30 m buffer zone to allow for precision of the georeferencing procedures. Note also that the very low counts for most Outside Ship's Path cells mean the estimated P value may not be exact.

Such extensive and high levels of contamination will have significant ecological impacts on the benthic communities of Douglas Shoal. A recent review of the effects of TBT on tropical marine organisms (Negri and Marshall 2009) found a wide range of detrimental effects on corals at low concentrations throughout the life history, including inhibition of fertilisation and recruitment, both critical to reef recovery. TBT is also detrimental to algae, a key component of the Shoal habitats, and bioaccumulates in higher trophic levels (i.e. the chemical may accumulate up the food chain, through consumption of contaminated plants and animal by herbivorous and predatory fish etc). Studies of other grounding sites within the GBR suggest that antifoulant pollution can harm otherwise undisturbed corals tens or hundreds of metres from the grounding site (Marshall et al 2002).

### ***Oil and dispersant pollution***

Approximately 3-4 tonnes of heavy fuel oil was reported to have been spilled into the sea as a result of the grounding of the *Shen Neng I* on Douglas Shoal (Miller 2010), and oil was found on reef islands in the Capricorn Bunker Group, 20-25 km to the south and south-east of the incident site (Statement by James Wallace McFarlane, QPWS, Cairns 5 May 2010). In response to the spill, a total of 3,000 litres of the oil dispersant Slickgone, and 2000 litres of the oil dispersant Corexit were applied to the ocean in the area of the *Shen Neng I* grounding between 4 and 5 April 2010 (Statement by Patricia Anne Oliver, Aerotech First Response Pty Ltd, Adelaide, 19 July 2010).

No monitoring or assessment was undertaken to establish the effects of this oil, the dispersants or dispersed oil, on either benthic (bottom) or pelagic (i.e. water column) habitats, but heavy fuel oil contains many toxic components which are harmful to such habitats (e.g. Levings et al 1994; Burns and Yelle-Simmons 1994; Burns et al 2000), and research indicates that the use of dispersants does not reduce this toxicity (Duke et al 1998; Burns et al 1999; Burns et al 2000).

In contrast to other areas, marine microbial communities on the southern Great Barrier Reef have been shown to take up to 2 months to degrade spilled oil (Burns et al 2000, 2010). Research has also shown that dispersants themselves, or dispersed oil can be harmful to marine organisms and habitats (Duke et al 1998; George-Ares and Clark 2000; Epstein et al 2000; Judson et al 2010).

The fact that the oil was largely mixed into the seawater, or subsequently chemically dispersed (Miller 2010), does not actually remove it from the ecosystem: at best it disperses the toxicity over a wider area of ecosystem.

Similarly, the fact that only relatively little of the spilt oil was found on island beaches does not mean that the damage was limited to those sites and that the rest disappeared: rather it suggests that the oil

either sank, affecting deeper reef, shoal and seafloor habitats, or it mixed into the water column, affecting pelagic ecosystems (e.g. Burns et al. 2010). Thus the spillage of oil into the sea at Douglas Shoal will have caused unquantified but real environmental harm to the marine habitats in the area.

## Conclusions

### Assessment against Criteria for Significant Impact Guidelines

The Australian Government's Department of Sustainability, Environment, Water, Population and Communities has outlined guidelines for significant impacts on the Great Barrier Reef Marine Park, as a Matter of National Environmental Significance under the *Environment Protection and Biodiversity Conservation Act 1999*. Under these guidelines, an action is likely to have a significant impact on the environment of the Great Barrier Reef Marine Park if there is a real chance or possibility that the action will meet any of the following significant impact criteria:

***"modify, destroy, fragment, isolate or disturb an important, substantial, sensitive or vulnerable area of habitat or ecosystem component such that an adverse impact on marine ecosystem health, functioning or integrity in the Great Barrier Reef Marine Park results"***

This criterion is relevant to the action (the ship grounding). The grounding of the *Shen Neng I* has clearly severely modified, disturbed or destroyed the habitats of Douglas Shoal, with over 116,000 m<sup>2</sup> severely damaged (destroyed) by physical destruction, and a further 291,000 m<sup>2</sup> of patchy damage throughout the vessel path during the grounding. The chemical environment of the habitats has also been seriously modified and damaged by the pollution by persistent, toxic chemical components in the antifoulant paint. The release of fuel oil and the subsequent application of dispersant chemicals has added to this pollution, potentially affecting a wider area because of its dissolved state. The nature of the shoal habitats, with strong tidal currents, limited 3 dimensional topography, and moderate coral abundance suggest that these are important representatives of habitat types, and are likely to be very sensitive and vulnerable in terms of slow recovery from this damage. These impacts will have adverse impacts on the health and functioning of the shoal ecosystem.

***"have a substantial adverse effect on a population of a species or cetacean including its life cycle (for example, breeding, feeding, migration behaviour, life expectancy) and spatial distribution"***

This criterion is likely to be relevant. The various species, especially the corals, which have been destroyed by the ship grounding are likely to be significantly affected in population recovery within the damaged areas for many years. This is due to i. the mortality of corals and other organisms directly due to the physical damage; ii. the toxic effects of the antifoulant paint on remaining corals and other organisms; iii. effects of anti-foulant paint in inhibiting settlement and growth of new corals etc; iv. the inhibition of settlement and growth of new corals on the unconsolidated rubble on the shoal seafloor, created by the grounding. It is known that coral colonisation and recovery is severely limited or delayed by unstable bottom material (e.g. Fox et al. 2003; Fox et al. 2005). Extensive unconsolidated rubble was not observed on this shoal outside the ship grounding area.

***"result in a substantial change in air quality or water quality (including temperature) which may adversely impact on biodiversity, ecological health or integrity or social amenity or human health"***

This criterion is relevant to the action (grounding). Large amounts of strongly biocidal chemicals (in the antifoulant paint) have been deposited onto the shoal seafloor, and are likely to continue to leach into the water column for some time. As these chemicals are specifically formulated to kill marine organisms, the effects on the biodiversity and ecosystem health and integrity will be considerable. This report does not assess the potential risks to human health and/or social amenity, such as fishers' perceptions of the health risk.

***"result in a known or potential pest species being introduced or becoming established in the Great Barrier Reef Marine Park"***

This criterion is unlikely to be relevant to the action (grounding), unless there was any release of ballast water during the grounding or salvage operations. If that were the case, this criterion may need to be further investigated.

***"result in persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, or social amenity or human health may be adversely affected"***

This criterion is relevant to the action (grounding). The results of the sediment sampling during site visits 1 and 3 clearly show very high levels of contamination by the highly toxic chemicals, tributyl tin, copper and zinc, apparently derived from the antifoulant paints. Without removal, these chemicals are likely to persist in the marine environment for years (e.g. Seligman et al. 1996). The persistence of these chemicals is likely to affect the shoal's recovery and ecological integrity via impacts on recruitment of newly settling corals and other organisms, as well as toxic effects on remnant shoal flora and fauna.

***"have a substantial adverse impact on heritage values of the Great Barrier Reef Marine Park, including damage or destruction of an historic shipwreck"***

This criterion will require careful assessment by experts in the heritage values of the Great Barrier Reef World Heritage Area / Marine Park.

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## Appendices

### Appendix A:

Map showing locations of photographs in Figures in this report.

### Appendix B:

Marshall, P. 2010, *Grounding of the Shen Neng I on Douglas Shoal: preliminary impact assessment report*, Great Barrier Reef Marine Park Authority, Townsville.

### Appendix C:

Negri, A., Speare, P., Stieglitz, T., Botting, T., Berkelmans, R. and Steinberg, C. 2010, *Grounding of the Shen Neng 1 on Douglas Shoal: multibeam sonar bathymetry and towed video assessments: final report - Douglas Shoal Ship Grounding Survey: RV Cape Ferguson: habitat damage monitoring using multibeam sonar and towed video assessments*, Australian Institute of Marine Science, Townsville.

### Appendix D:

Monkivitch, J.V. 2010, *Shen Neng I hull sampling: field report, 21 May 2010*, Great Barrier Reef Marine Park Authority, Townsville.



## Appendix A:

Map showing locations of photographs in Figures  
in this report.





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**Marine Park Authority**

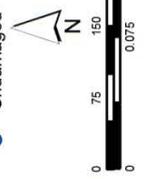
**Shen Neng 1 Grounding**  
**Douglas Shoal 23-044**  
**3-12 April 2010**

**Physical Damage**  
**Observed**  
**with photos**

- LEGEND**
- Dives and Manta Tow locations
  - Depth contours (m) (JCU)
  - Path of vessel

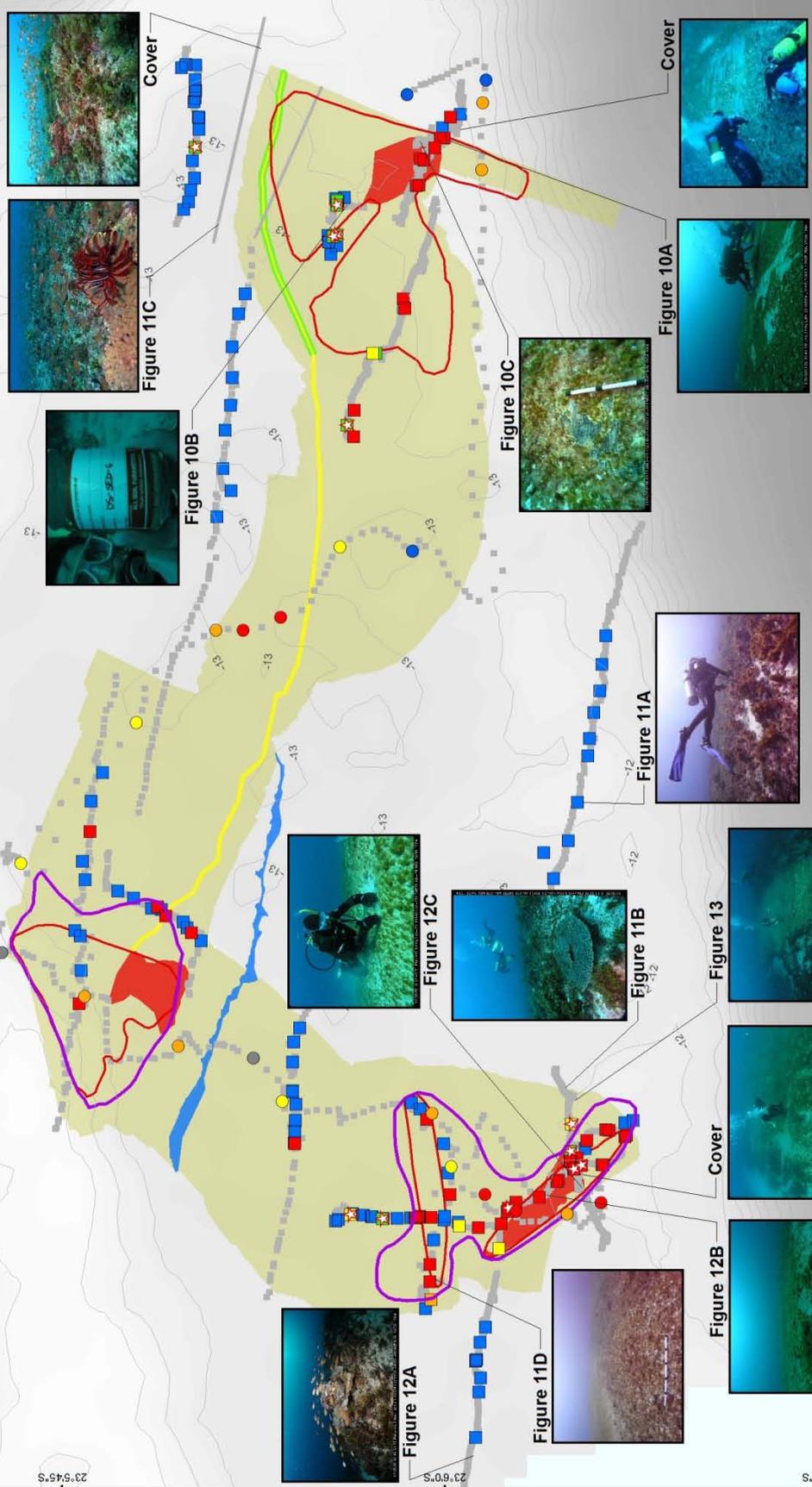
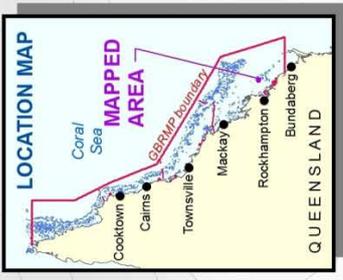
- Dive Teams (Site Assessment 1)**
- Severe
  - Moderate
  - Minor
  - Undamaged
- Impact sites from sonar (Site Assessment 2)**
- Impact sites from video tow (Site Assessment 2)

- Dive Teams (Site Assessment 3)**
- 75 - 100%
  - 50 to <75%
  - 25 to <50%
  - 5 to <25%
  - <5%
  - Broken coral
- Manta Tow (Site Assessment 3)**
- Severe
  - Moderate
  - Minor
  - Possible
  - Undamaged



Map Projection: Unprojected Geographics  
 Horizontal Datum: World Geodetic System, 1984  
 Raster Source: Dr. Robin Beaman, James Cook University  
 and the Australian Hydrographic Service  
 SDC 100405-8A3Photos 29 November 2010

**WARNING**  
 This map must not be used for marine navigation.  
 Comprehensive and updated navigation  
 information should be obtained from published  
 hydrographic charts.



151°39'30"E 23°6'15"S  
 151°39'15"E 23°6'0"S  
 151°39'0"E 23°5'45"S  
 151°38'45"E 23°5'30"S



## **Appendix B:**

### **Grounding of the *Shen Neng 1* on Douglas Shoal: preliminary impact assessment report.**

[Report based on site visit 1]





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PRELIMINARY IMPACT ASSESSMENT REPORT:

# Grounding of the *Shen Neng 1* on Douglas Shoal



*Dr Paul Marshall*

*30 July 2010*



PRELIMINARY IMPACT ASSESSMENT REPORT:

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# **Grounding of the *Shen Neng 1* on Douglas Shoal**

**Dr Paul Marshall**

30 July 2010



**Australian Government**

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**Great Barrier Reef  
Marine Park Authority**

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ISBN 978 1 921682 28 5 (pdf)

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## Executive summary

Staff of the Great Barrier Reef Marine Park Authority and Queensland Parks and Wildlife Service conducted a preliminary assessment of damage to Douglas Shoal in the area of the *Shen Neng 1* grounding incident on 12-13 April 2010.

The initial assessment found spatially extensive and severe damage to the reef community on Douglas Shoal. While this preliminary assessment only surveyed a small proportion of the seabed within the track of the *Shen Neng 1*, approximately 19,087 m<sup>2</sup> of reef area was found to be damaged. The 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. Particles of antifoulant paint were observed amongst the rubble and smeared onto the reef substrate in some of the severely damaged areas. Coral reef communities suffering this type of damage can take substantially longer to recover compared to recovery from natural disturbances. Remediation of damaged areas can facilitate natural recovery processes.

Additional, more detailed surveys will help ascertain the full extent of physical damage, the severity and distribution of contamination from antifoulant paints, and inform evaluation of remediation options.

## Contents

Executive summary .....	1
Contents .....	2
Introduction .....	3
Assessment objectives .....	3
Methods .....	4
<i>Impact assessment team</i> .....	4
<i>Chronology of preliminary assessment</i> .....	4
<i>Assessment methods</i> .....	6
<i>Categorisation of physical damage</i> .....	7
Results .....	8
<i>Habitats, species and community of Douglas Shoal</i> .....	9
<i>Extent and severity of damage</i> .....	10
Conclusions .....	12
References .....	14
Appendix 1: Schedule of events during the preliminary impact assessment at Douglas Shoal following grounding of the <i>Shen Neng 1</i> . .....	15
Appendix 2: Catalogue of images and video footage collected during the preliminary impact assessment.....	16

## Introduction

The cargo carrier *Shen Neng 1* ran aground on Douglas Shoal (Figure 1), around 92km north-east of Gladstone, on Saturday 3 April 2010. After transfer of some of the oil on board the *Shen Neng 1* to a bunker barge, salvage specialists assessed the ship as safe for refloating and transport. At approximately 8pm on Monday 12 April the *Shen Neng 1* was removed from its position on Douglas Shoal.

The initial focus of the grounding response was on minimising risks associated with an oil spill or sinking of the *Shen Neng 1*. In addition to these risks, there was also substantial concern about the environmental damage done to Douglas Shoal as a result of the vessel grounding and related salvage activities (hereafter referred to as the grounding incident).

A damage assessment team comprising experts from the Great Barrier Reef Marine Park Authority (GBRMPA) and the Queensland Parks and Wildlife Service (QPWS) was deployed to the site on 12-13 April 2010 to make a preliminary assessment of the nature and extent of environmental impacts and to provide information to inform further assessments and remediation options.

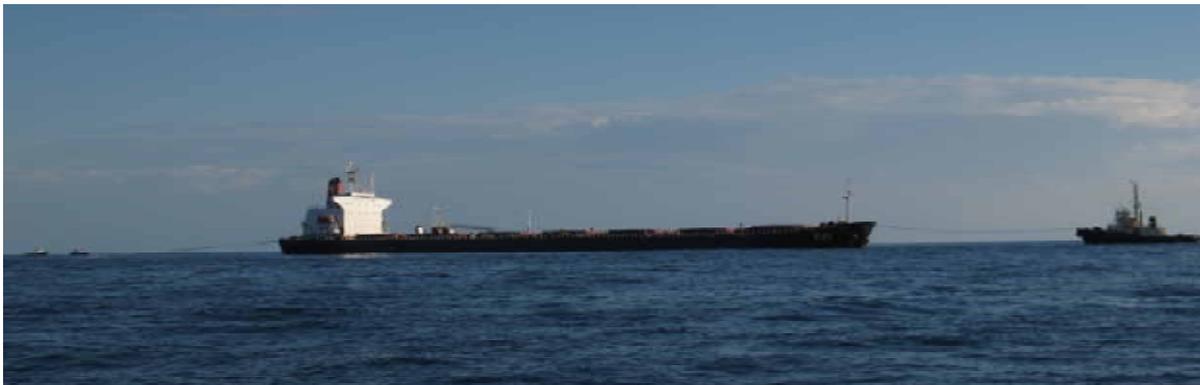


Figure 1. *Shen Neng 1* over Douglas Shoal on the southern Great Barrier Reef.

## Assessment objectives

This initial assessment aimed to characterise the nature and spatial extent of ecological damage at areas of Douglas Shoal potentially affected by the grounding of the *Shen Neng 1*. The results of this initial survey were used to inform subsequent, more detailed, surveys of ecological damage to the shoal and to provide advice on further assessments and remediation options. This preliminary assessment only inspected a small proportion of the total area of seabed within the track of the *Shen Neng 1*. Consequently, it did not aim to map all damaged areas on Douglas Shoal, or to provide a detailed quantitative analysis of the ecological impacts of the grounding incident.

The primary objectives of the preliminary impact assessment were to:

- 1) Inspect areas of Douglas Shoal in the vicinity of the known path of the grounded vessel (Figure 2) and identify areas that had suffered recent physical damage
- 2) Delineate areas of recent physical damage and characterise the type and severity of damage
- 3) Collect indicative samples of sediments, including samples of any reef material visibly affected by antifoulant paint
- 4) Collect water samples (if there was any indication of oil leakage or hydrocarbon contamination of discharged ballast water)
- 5) Collect photos and video footage representative of damaged and undamaged areas of Douglas Shoal.

## Methods

### *Impact assessment team*

The impact assessment team was lead by Dr Paul Marshall from the Great Barrier Reef Marine Park Authority. Dr Marshall has a PhD in coral reef ecology, with a focus on recovery of corals from physical damage. He has led marine ecology surveys and impact assessments throughout Australia and overseas for over 17 years, including assessment and restoration projects following vessel grounding incidents. These have included major grounding incidents caused by the *Bunga Teratai Satu* and *Doric Chariot* in the northern Great Barrier Reef and the *Jessica* in the Galapagos Islands, as well as a range of smaller grounding incidents. Dr Marshall has published over 40 scientific papers, including five publications in international journals relating to ship grounding incident responses.

Other members of the assessment team included Dr Tyrone Ridgway (GBRMPA; coral biologist), Laise Harris (GBRMPA; GIS specialist), Jesse Low (QPWS; dive supervisor), Oliver Lanyon (QPWS; compliance expert) and Darren Larcombe (QPWS; marine operations). Vessel support was provided by the Gladstone-based *MV Eastern Voyager*.

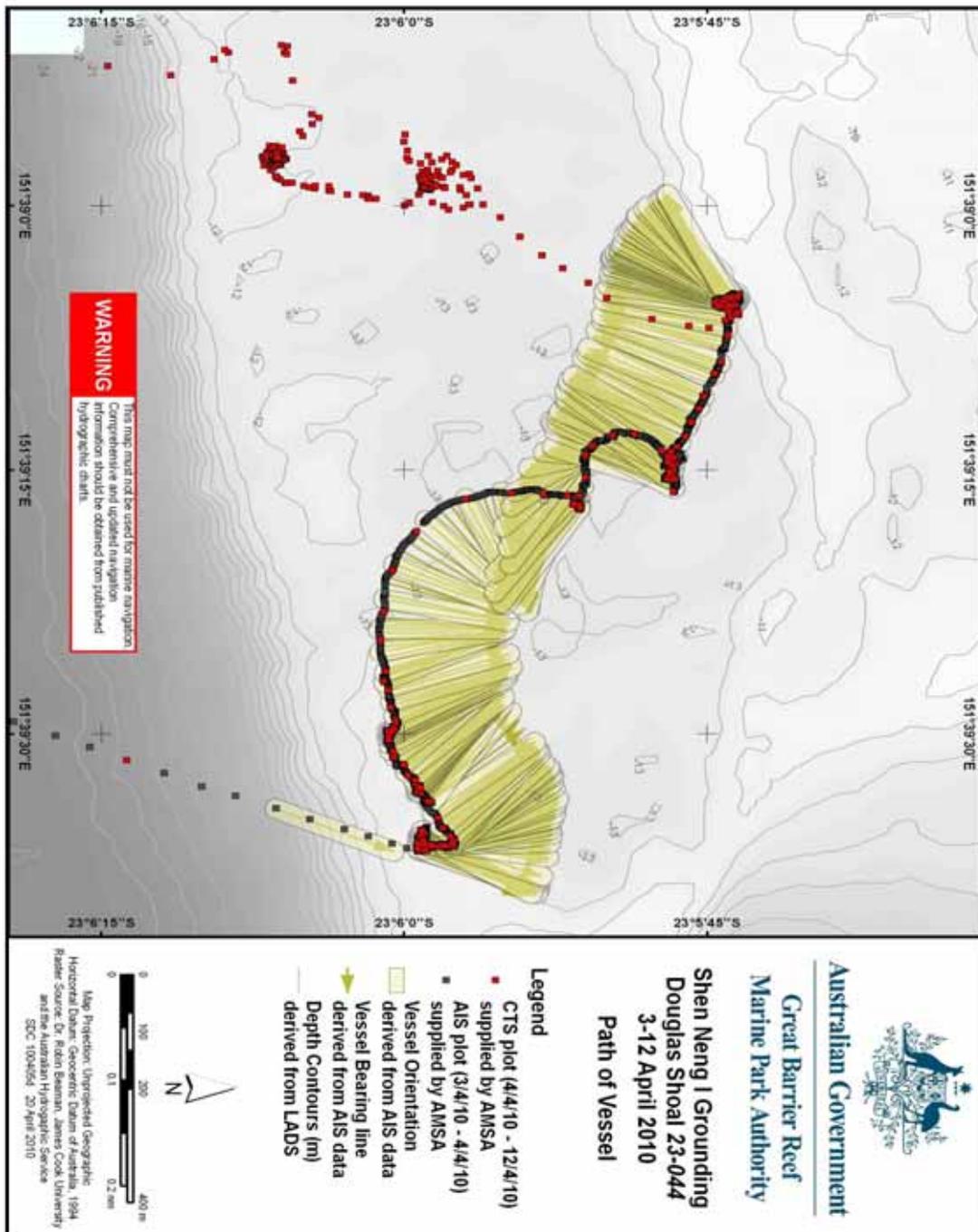
An environmental scientist, Andy Graham (Polaris Applied Sciences), advising the vessel insurer, joined the *MV Eastern Voyager* to work alongside the assessment team during the surveys. A selection of underwater photos showing the general nature and extent of the grounding impacts were shared with Mr Graham.

### *Chronology of preliminary assessment*

The assessment team arrived on site at approximately 06:00 h on Monday 12 April 2010. On arrival the *Shen Neng 1* was observed to be still aground at the centre of a 2 nm exclusion zone. The exclusion zone was declared by the Australian Maritime Safety Authority (AMSA) to prevent vessels and aircraft that were not directly assisting the salvage operation from approaching the area.

The assessment team sought and was granted special permission to enter the exclusion zone to enable commencement of the preliminary impact assessment. The survey vessel entered the zone at approx 09:30 h on Monday 12 April, allowing the preliminary impact assessment to begin at approx 10:30 h.

**Figure 2.** Map provided for preliminary assessment by GBRMPA's Spatial Data Centre. The map is plot of the location of the Shen Neng 1 over Douglas Shoal, based on information provided by the Australian Maritime Safety Authority.



The Incident Controller instructed the assessment team to leave the shoal by 17:00 h to clear the exclusion zone to allow for the efforts to refloat the grounded vessel.

The successful refloat of the *Shen Neng 1* on the evening of Monday 12 April enabled the assessment team to resume work on the shoal at 07:30 h on Tuesday 13 April. The preliminary impact assessment was concluded approximately midday on 13 April.

The schedule of events of the assessment is outlined in Appendix 1.

### *Assessment methods*

A range of standard observation methods were employed by the assessment team to meet the objectives of the assessment. Implementation of the assessment was coordinated and supervised by the assessment team leader.

Areas of Douglas Shoal where there was the greatest potential for damage from the grounding of the *Shen Neng 1* were identified from a map of the position of the vessel while over the shoal (Figure 2). This map was generated by the Great Barrier Reef Marine Park Authority's Spatial Data Centre using coordinates of the vessel's position supplied by the Australian Maritime Safety Authority (AMSA).

The initial focus of the assessment team was to visually locate signs of physical damage to the shoal in the area where the *Shen Neng 1* position data indicated the vessel had travelled over the shoal. Recent damage was discerned by clean, uncolonised surfaces on broken corals or on other calcium carbonate (reef substrate) materials.

The assessment team used snorkelling equipment to identify areas of shoal that had been recently damaged. Four areas of substantial damage were identified (Site A, B, C and D in Figure 5). Surface snorkelling and breath-hold diving were used to delineate two broad areas of physical damage (Sites A and C) and one linear strip of damage (Site B). SCUBA diving was used to delineate the largest area of damage (Site D).

SCUBA equipment was used to do more detailed inspections of the damage at two broad areas of the shoal confirmed to have suffered severe damage (Site B and D), and one area of the shoal that was undamaged (Site E). The area of undamaged shoal was inspected to provide an indication of the type of coral reef community that was likely to have characterised the shoal in areas that were severely damaged.

Still photographs and video footage were collected during snorkel and SCUBA inspections using digital compact cameras in underwater housings. A summary of the nature of the ecological damage in each area was compiled by the assessment team leader from a combination of in-situ observations and qualitative analysis of the still photos and video footage. A catalogue of images and video footage collected during the assessment is provided in Appendix 2.

Handheld global positioning system devices (GPS units) were used to obtain spatial coordinates of observations made by the assessment team. For the linear strip of damage (Site B) the location of the centreline of the damage was recorded. For broad areas of damage the perimeter was recorded. For damaged areas delineated on snorkel, GPS fixes were recorded by an assistant in the snorkelling tender vessel. This was done by navigating the tender over the point of interest indicated by the snorkel diver and taking a GPS fix directly above the point of interest. For damaged areas delineated on SCUBA, GPS fixes were recorded automatically at fixed intervals by the GPS unit that was being towed on a surface float by the dive team. The coordinates of the location of underwater photos were estimated by correlating the time at which the photo was taken with the position recorded by the GPS unit at that time. The approximate area of shoal damaged at the areas inspected (Site A, B, C and D) was estimated using GIS software from maps of the GPS fixes and additional observations made during snorkel and SCUBA inspections.

Samples of sediments and antifoulant paint and metal debris were collected during SCUBA dives at Sites B and D. Sediment samples were also collected during the SCUBA dive at Site E. A total of 14 samples of sediments were collected. Four samples of paint particles were also collected, as well as four samples of metal debris (large metal flakes; bolt; gasket) found on the sea floor in areas recently damaged. Contamination of samples was avoided through the use of gloves and specially-prepared sampling jars and spatulas. Samples were handled in accord with standard procedures for evidence collection and laboratory analysis.

### *Categorisation of physical damage*

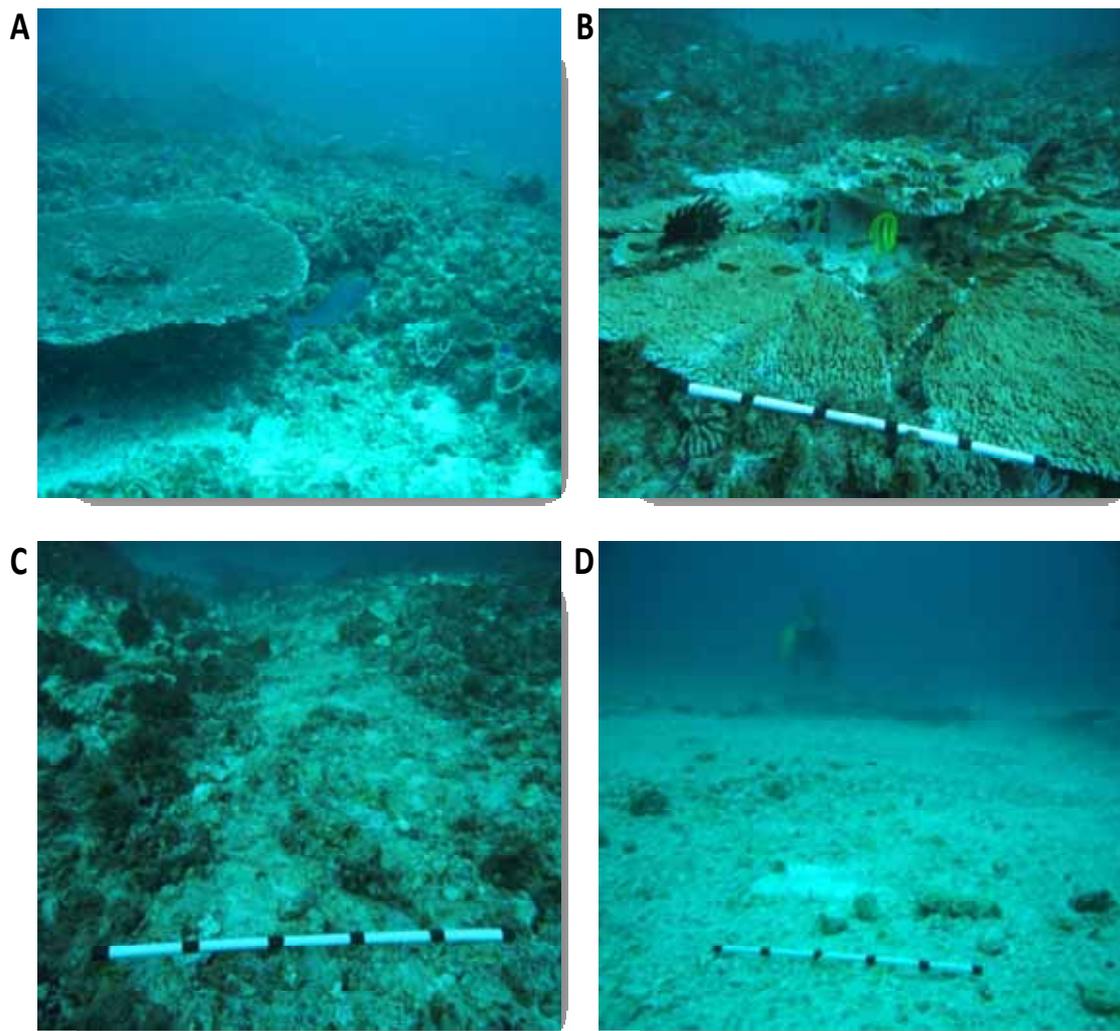
It was observed through initial snorkel surveys that the severity of physical damage varied among areas inspected. To assist the team to categorise and report on damage observations, three qualitative categories of damage were defined. These were chosen to broadly reflect the ecological severity of the damage using the experience of the team leader derived from previous research and ship grounding impact assessments.

The three categories of physical damage (Figure 3) defined for describing the severity of impacts to the shoal were:

- Severe damage : *all benthos<sup>1</sup> displaced, crushed or smothered and substrate scraped or covered in rubble*
- Moderate damage: *most benthos killed; patchy damage to substrate*
- Minor damage: *most benthos intact; some damaged*

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<sup>1</sup> Benthos refers to those organisms (plants and animals) attached to, or living on, in or near, the seabed.

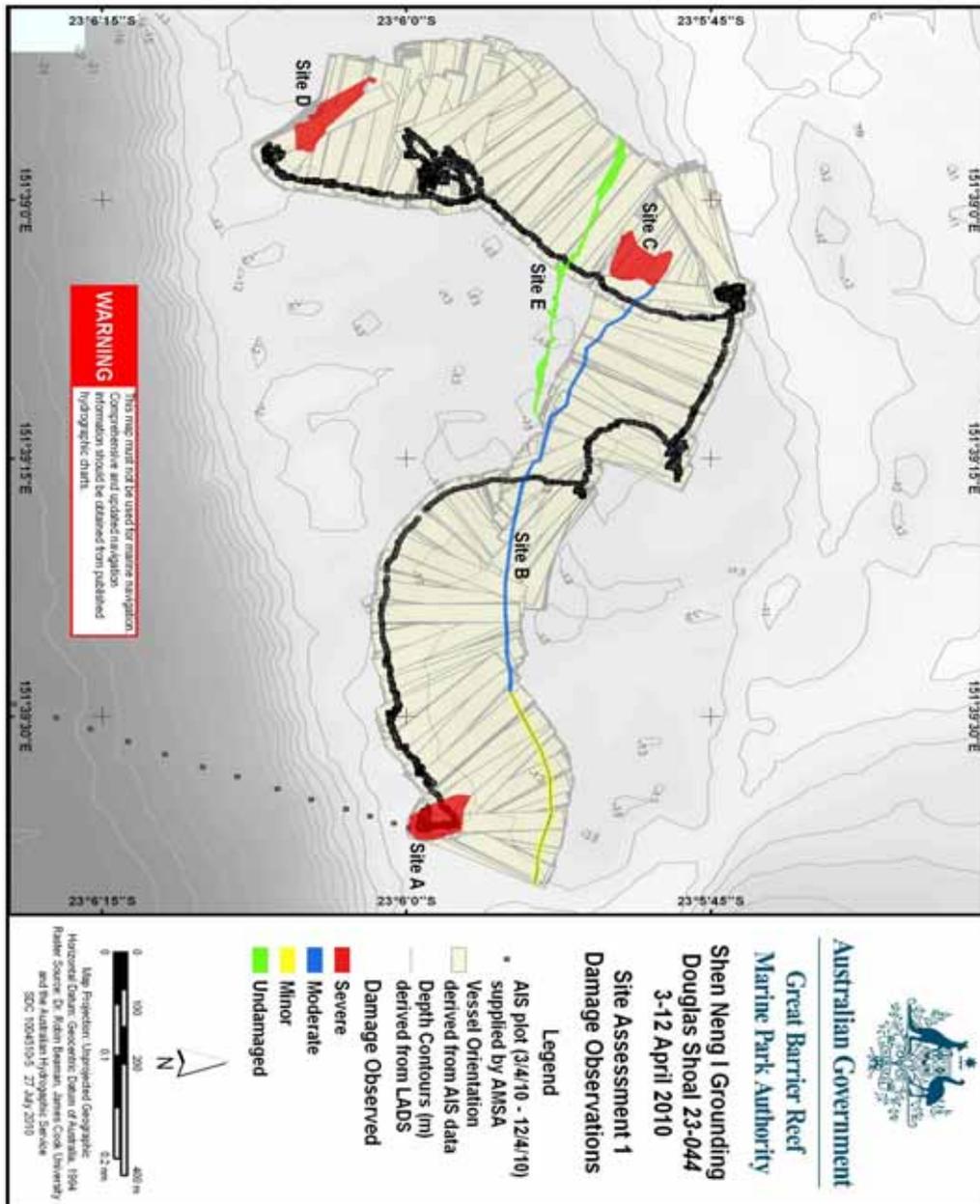


**Figure 3.** Images from Douglas Shoal after *Sheng Neng 1* grounding showing the different categories of damage. (A) Undamaged reef; (B) Minor damage (most benthos intact; some damaged); (C) Moderate damage (most benthos killed; patchy damage to substrate); (D) Severe damage (all benthos displaced, crushed or smothered and substrate scraped or covered in rubble). Scale bar = 50 cm.

## Results

This section presents the results of the preliminary assessment. The results are based on the in-situ observations of the assessment team leader and other members of the assessment team, photographs and video footage collected during in-water inspections, and from maps of the vessel position available at the time of the assessment. Observations were obtained from snorkel and SCUBA inspections of the five sites identified as priority areas for this initial assessment. The location of the priority sites and a summary of the severity of damage is provided in Figure 5.

**Figure 5.** Locations of the sites inspected during the Preliminary Impact Assessment at Douglas Shoal, showing categories of damage observed against backdrop of vessel positions.



### ***Habitats, species and community of Douglas Shoal***

Douglas Shoal is a large, isolated reef rising from approx 25-30 m depth to within 9-15 m of the surface. Inspections of the shoal indicated that the top of the shoal is very flat, with little topographical relief or structural complexity. Inspections of the benthic community adjacent to damaged areas and in other areas away from the track of the vessel (Site E in Figure 5) showed the shoal top to be visually dominated by macroalgae (seaweeds). The brown algae *Sargassum* was the most abundant genus, interspersed with coralline red algae and a range of other seaweeds.

The undamaged areas were also characterised by a diverse assemblage of benthic invertebrate animals inhabiting Douglas Shoal. This assemblage included sponges (up to 20 cm), ascidians, zooanthids, anemones, soft corals (particularly *Sarcophyton*, *Lobophytum*, and *Sinularia*), hard corals, echinoderms (Asteroidea and Crinoidea), and crustaceans (Palinuridae).

Hard corals represented approximately 10% of benthic cover, and included the genera, *Acropora*, *Stylophora*, *Pocillopora*, *Porites*, *Montipora*, *Goniastrea*, *Goniopora*, *Scolymia*, *Turbinaria* and various other faviid species. *Turbinaria* and plating *Acropora* were the most visually dominant hard corals and obtained the largest sizes (up to 100 cm for *Acropora* plate corals).

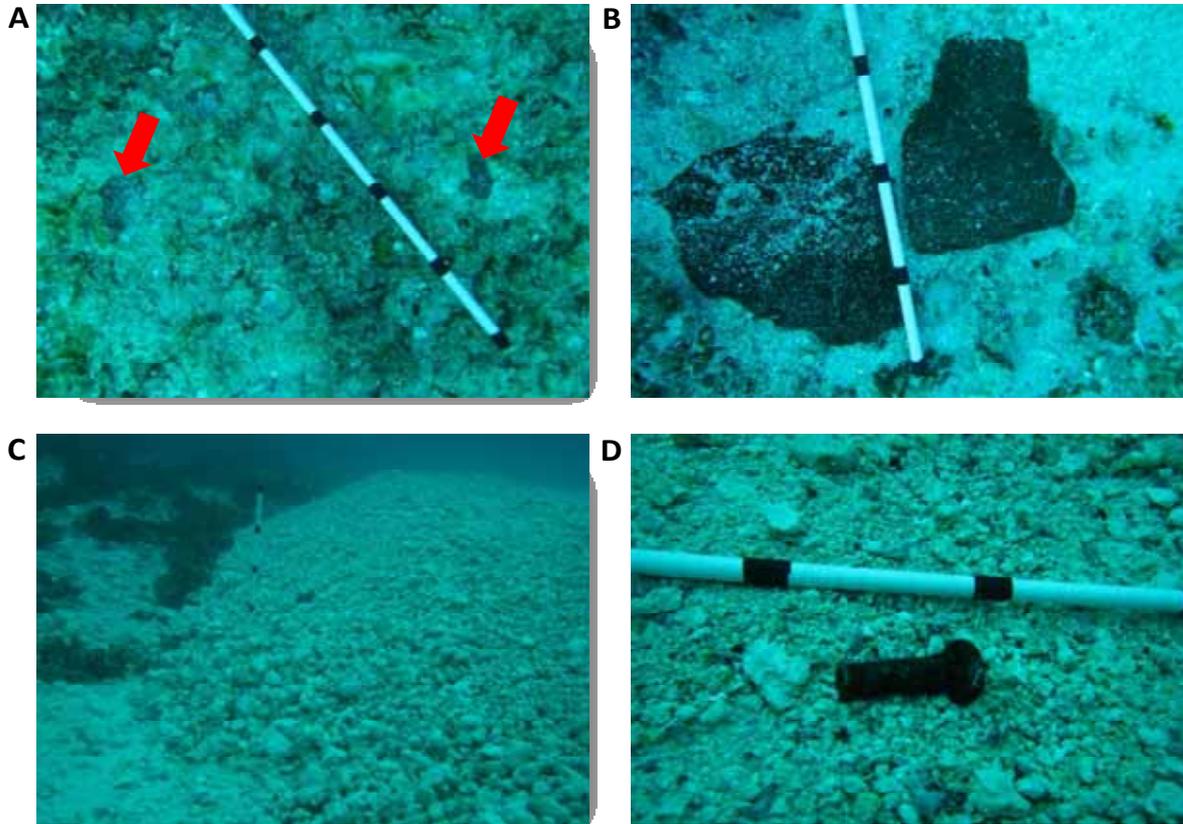
There was abundant fish life observed on undamaged areas of Douglas Shoal. Any small outcrops or patches of relief on the shoal were the focus of a diverse aggregation of fish. Species of emperor (Lethrinidae) and sweetlip (Haemulidae) were observed congregating around small outcrops amidst schools of fusiliers (Caesionidae), damselfishes (Pomacentridae) and other small fish. Coral trout (*Plectropomus sp.*) and other cods (Serranidae) were observed commonly over the shoal, as were breams (Sparidae), wrasses (Labridae), parrotfishes (Scaridae), and large schools of pelagic fish such as mackerels (Scombridae) and trevally (Carangidae). Coral-associated fish included butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae), blennies (Blennidae), and gobies (Gobiidae) as well as extremely large schools of cardinalfishes (Apogonidae), which blanketed large areas of the shoal (1000s of m<sup>2</sup>). Other vertebrate taxa observed included sea snakes, turtles and large stingrays.

### ***Extent and severity of damage***

The survey team identified areas of recent ecological damage at four locations on the shoal (marked as Sites A, B, C and D on Figure 5). Sites A, C and D were characterised by broad areas of severe damage. Site B was a long, narrow tract of moderate damage. The severity of damage can be seen in the photographs and video footage recorded during the survey and in representative photos presented in Figures 3 and 4. A more detailed description of observations at each site is provided below. Table 1 provides a summary of the estimated size of damaged areas at each site.

Inspections in Site A identified a large area of severe damage approximately 4492 m<sup>2</sup>. One part of this had all benthos and the top layers of reef substrate removed, leaving a flat section of solid reef matrix with large smears of antifoulant paint. In the other part all benthos had been crushed or displaced and the substrate ground into gravel-sized pieces. Severe damage was observed extending further along the shoal in the direction travelled by the grounded vessel, as indicated by the mapped vessel position data, although the full extent of this damage was not surveyed during this preliminary assessment. Adjacent to the severely damaged zones the assessment team observed numerous corals (most noticeably

*Acropora* plate corals) that were shattered or showing signs of recent partial mortality. Pieces of antifoulant paint were recovered from this area.



**Figure 4.** Photographs from damaged areas of Douglas Shoal. (A) Antifoulant paint smears (red arrows) on moderately damaged site (Site A); (B) Large metal flakes on moderately damaged reef site (Site B); (C) Recently created rubble bank on edge of severely damaged site (Site D); (D) Metal bolt on severely damaged seabed (Site D). White sections on scale bar = 8 cm.

A long, narrow tract of damage was observed in Site B, running in a general westerly direction for approximately 1.5 km. The reef was moderately damaged along the centre of this tract, with most benthos smashed or displaced, and some large (up to 3 x 3 m) chunks of reef substrate fractured and broken off the main reef. The area of moderate damage totalled approximately 4293 m<sup>2</sup>. A more detailed inspection of the eastern end of the tract revealed a band of minor damage either side of the centre of the tract. This totalled approximately 1346 m<sup>2</sup> in area. A few pieces of rusted metal plating were recovered from this area.

In Site C, another large area, approximately 4642 m<sup>2</sup> was found to have severe damage with all benthos removed and substrate reduced to gravel.

Site D was a large area of contiguous and particularly severe damage. The survey team recorded an area of at least 4314 m<sup>2</sup> in which the only observed intact benthic reef organisms were in small depressions. In the remainder of the area, there were no visible remnants of benthic reef organisms and the substrate had been crushed into gravel or scraped down to solid reef matrix. Along the outer edges of this area were linear ridges of coral rubble up to 1 m high. Observations of the colour and form of the rubble clearly indicated it had been recently created or mobilised.

The animals and plants growing on the seabed up to 20 m on either side of this the severely damaged area at Site D were smothered in a layer of rubble and sand, and small seaweeds (mostly *Sargassum*) were the only reef life that appeared to have survived the smothering. Pieces of antifoulant paint and other metal components (e.g. bolts) were found in this area.

Some areas of reef in Sites A and D were clearly exposed to contamination from antifoulant paint, as evident from visible flakes of paint amongst the rubble or smears of paint on the exposed reef substrate (Figure 4).

Site E was mostly undamaged, although a small patch of moderate damage was observed near the western end of the area inspected.

**Table 1.** Summary of estimated size of damaged areas at inspection sites.

<i>Damage Site</i>	<i>Damage</i>	<i>Area (m2)</i>
Site A	Severe	4492
Site B	Moderate	4293
Site B	Minor	1346
Site C	Severe	4642
Site D	Severe	4314
<b>Total</b>		<b>19087</b>

## Conclusions

This preliminary assessment found that the community of animals and plants growing on the seabed atop Douglas Shoal is similar to other mid-depth reefs exposed to strong currents and rough seas in the southern Great Barrier Reef that have previously been visited by members of the assessment team. It has many of the characteristics of a highly dynamic environment, with moderate diversity, heterogeneous distribution of species and few large sessile (attached) organisms. Like many coral reef habitats, the benthic community growing on Douglas Shoal is prone to damage from physical disturbances such as vessel anchoring or groundings. However, reef communities of the type observed at Douglas Shoal often have

the capacity to recover relatively quickly from natural physical disturbance due to high recruitment rates and short replacement times for much of the biota.

This preliminary assessment identified approximately 19,087 m<sup>2</sup> of the seabed atop Douglas Shoal to be recently damaged. Of this, approximately 13,448 m<sup>2</sup> was severely damaged (all benthos displaced, crushed or smothered and substrate scraped or covered in rubble). A further approximately 4,293 m<sup>2</sup> of seabed was moderately damaged and approximately 1,346 m<sup>2</sup> had minor damage. There were also signs that additional patches of the reef community had been smothered by freshly created coral gravel that appeared to have spilled out beyond the main damage area at Site D, although the size of the area was not measured.

Recovery times for areas of reef damaged by vessel groundings are likely to take much longer than recovery from natural disturbances (Negri and Marshall 2009). Large areas of stable reef substrate on Douglas Shoal were covered by coral rubble and crushed reef substrate that are prone to movement by currents and waves. Loose and mobile substrate is not suitable for colonisation by most sessile organisms and these damaged areas are likely to remain bare of reef growth as long as the substrate remains mobile (Marshall et al. 2002).

Signs of freshly deposited antifoulant paint were observed at three of the damage sites inspected. Visible flakes of paint were observed among the crushed coral substrate at Sites A, C and D, and antifoulant paint was seen smeared onto the exposed reef substrate at Site A. Antifoulant paints are designed to inhibit settlement by larvae of sessile marine organisms, including algae, ascidians, sponges, molluscs and corals. They are also known to be toxic to adult reef organisms, such as corals (Smith et al. 2003). The presence of antifoulant chemicals at a ship grounding site can prevent or slow recolonisation of damaged areas, and also has the potential to cause additional stress or mortality to corals not damaged by direct physical impacts (Haynes et al. 2002; Marshall et al. 2002).

In summary, this preliminary assessment identified extensive areas of Douglas Shoal that had been recently and severely damaged. These areas correlate with areas of the shoal traversed by the *Shen Neng 1* during the grounding incident, as indicated by plots of the vessel's location data. The presence of unstable substrate and antifoulant chemicals in damaged areas suggests that recovery of the damaged areas is likely to take substantially longer than would normally be expected for natural disturbances. More detailed ecological surveys and analyses of antifoulant contamination of sediments will be valuable for determining the full spatial extent of the damage and for informing analyses of the costs and benefits of remediation of the site.

## References

Haynes, D., Christie, C., Marshall, P. (2003). Antifoulant concentrations at the site of the Bunga Teratai Satu grounding, November 2000, Great Barrier Reef, Australia. *Marine Pollution Bulletin*. Vol. 44, no. 9, pp. 968-972. Sep 2002.

Marshall, P., Christie, C., Haynes, D., Michalek-Wagner, K., Smith, A. (2002) Grounded ship leaves TBT-based antifoulant on the Great Barrier Reef: an overview of the environmental response. *Spill Science and Technology Bulletin*. 7: 215-221.

Negri, A., Marshall, P. (2009) TBT contamination of remote marine environments: Ship groundings and ice-breakers as sources of organotins in the Great Barrier Reef and Antarctica. *Journal of Environmental Management*, 90 (SUPPL. 1)

Smith, L., Negri, A., Philipp, E., Webster, N., Heyward, A. (2003). The effects of antifoulant-paint-contaminated sediments on coral recruits and branchlets. *Marine Biology* 143: 651–657.

**Appendix 1: Schedule of events during the preliminary impact assessment at Douglas Shoal following grounding of the *Shen Neng 1*.**

<b>Date</b>	<b>Time</b>	<b>Activity</b>
11 April	21:00	Board MV Eastern Voyager in Gladstone Harbour; depart for overnight travel to Douglas Shoal
12 April	05:00	Arrived Johnson Patch and awaited confirmation of permission to access Douglas Shoal within exclusion zone; low winds, good surface conditions
	10:00 – 14:00	Snorkel swims and manta tows to locate damaged areas of reef; strong currents
	14:00 – 16:45	SCUBA dive in vicinity of initial impact site to collect photos, video and sediment samples; strong currents
	17:00	MV Eastern Voyager required to relocate outside exclusion zone due to planned attempted refloat; relocate to North Reef for overnight anchorage
13 April	07:30	MV Eastern Voyager returns to Douglas Shoal (vessel refloat successful); SCUBA dive in vicinity of final resting place of grounded vessel (timed at slack tide; no current) to collect photos, video and sediment samples; winds increasing, surface conditions deteriorating
	10:00	SCUBA dive east of final resting place to collect photos, video and sediment samples in undamaged area of shoal; strong current (drift dive); winds increasing, surface conditions rough
	13:00	MV Eastern Voyager returns to North Reef due to conditions becoming unsuitable for diving
	16:00	MV Eastern Voyager departs for Gladstone; PM, TR and JL transfer to Heron Island on MV Reef Heron to await arrival of RV <i>Cape Ferguson</i> .

## Appendix 2: Catalogue of images and video footage collected during the preliminary impact assessment

Shen Neng 1 Photo Catalogue				
Photo label	Description	Original ID	Date taken	Location
Photo 001	Shen Neng 1 on Douglas Shoal with tugs	IMG_3288	12-Apr-10	Close to initial grounding location
Photo 002	Charter vessel MV Eastern Voyager	IMG_3295	12-Apr-10	Close to initial grounding location
Photo 003	Metal fragments on reef substrate	IMG_1974	12-Apr-10	Close to initial grounding location
Photo 004	Damage from ground level	IMG_1975	12-Apr-10	Close to initial grounding location
Photo 005	Diver over damage	IMG_1977	12-Apr-10	Close to initial grounding location
Photo 006	Damage from ground level	IMG_1978	12-Apr-10	Close to initial grounding location
Photo 007	Broken rubble on reef substrate	IMG_1979	12-Apr-10	Close to initial grounding location
Photo 008	Broken rubble on reef substrate	IMG_1981	12-Apr-10	Close to initial grounding location
Photo 009	Close up of damaged substrate	IMG_1982	12-Apr-10	Close to initial grounding location
Photo 010	Broken <i>Acropora</i> plate coral	IMG_1986	12-Apr-10	Close to initial grounding location
Photo 011	Overturned <i>Acropora</i> plate coral	IMG_1989	12-Apr-10	Close to initial grounding location
Photo 012	Damage and diver	IMG_1992	12-Apr-10	Close to initial grounding location
Photo 013	Damage from above	IMG_1993	12-Apr-10	Close to initial grounding location
Photo 014	Manta towing with Shen Neng 1 in background	IMG_3188	12-Apr-10	Close to initial grounding location
Photo 015	Damaged reef substrate	IMG_3210	12-Apr-10	Close to initial grounding location
Photo 016	Damaged reef substrate	IMG_3211	12-Apr-10	Close to initial grounding location
Photo 017	Diver over damaged reef substrate	IMG_3214	12-Apr-10	Close to initial grounding location
Photo 018	Diver over damaged reef substrate	IMG_3217	12-Apr-10	Close to initial grounding location
Photo 019	Metal fragment and antifouling paint on reef	IMG_3218	12-Apr-10	Close to initial grounding location
Photo 020	Antifouling paint on the reef	IMG_3219	12-Apr-10	Close to initial grounding location
Photo 021	Broken coral	IMG_3224	12-Apr-10	Close to initial grounding location
Photo 022	Broken coral and rubble	IMG_3225	12-Apr-10	Close to initial grounding location
Photo 023	Broken coral and rubble	IMG_3228	12-Apr-10	Close to initial grounding location
Photo 024	Broken encrusting coral on reef	IMG_3229	12-Apr-10	Close to initial grounding location
Photo 025	Stressed <i>Acropora</i> plate coral	IMG_3237	12-Apr-10	Close to initial grounding location
Photo 026	Damage from above	IMG_3241	12-Apr-10	Close to initial grounding location
Photo 027	Overturned <i>Acropora</i> plate coral	IMG_3242	12-Apr-10	Close to initial grounding location
Photo 028	Stressed <i>Acropora</i> plate coral	IMG_3270	12-Apr-10	Close to initial grounding location
Photo 029	Metal fragments on reef	IMG_3271	12-Apr-10	Close to initial grounding location
Photo 030	Damage from above	IMG_3274	12-Apr-10	Close to initial grounding location
Photo 031	Diver on damaged substrate	IMG_2003	13-Apr-10	Final resting location
Photo 032	Broken rubble on reef	IMG_2004	13-Apr-10	Final resting location
Photo 033	Diver taking sediment samples	IMG_2011	13-Apr-10	Final resting location
Photo 034	Close up of damaged substrate	IMG_2017	13-Apr-10	Final resting location
Photo 035	Antifouling paint on the reef	IMG_2019	13-Apr-10	Final resting location
Photo 036	Diver on rubble bank	IMG_2030	13-Apr-10	Final resting location
Photo 037	Bolt on damaged substrate	IMG_2035	13-Apr-10	Final resting location
Photo 038	Large broken piece of reef	IMG_2036	13-Apr-10	Final resting location
Photo 039	Overview of damaged substrate	IMG_2049	13-Apr-10	Final resting location
Photo 040	Material debris on substrate	IMG_2056	13-Apr-10	Final resting location
Photo 041	Diver taking sediment samples	IMG_2058	13-Apr-10	Final resting location
Photo 042	Rubble bank at edge of damaged substrate	IMG_2068	13-Apr-10	Final resting location
Photo 043	Sediment on <i>Acropora</i> plate coral	IMG_2076	13-Apr-10	Final resting location
Photo 044	Divers on damaged substrate	IMG_3304	13-Apr-10	Final resting location
Photo 045	Diver taking sediment samples	IMG_3313	13-Apr-10	Final resting location
Photo 046	Diver on damaged substrate	IMG_3330	13-Apr-10	Final resting location
Photo 047	Diver on damaged substrate	IMG_3335	13-Apr-10	Final resting location
Photo 048	Overview of damaged substrate	IMG_3351	13-Apr-10	Final resting location
Photo 049	Diver on damaged substrate	IMG_3359	13-Apr-10	Final resting location
Photo 050	Dead <i>Acropora</i> plate coral	IMG_3364	13-Apr-10	Final resting location
Photo 051	Close up of damaged substrate	IMG_3365	13-Apr-10	Final resting location
Photo 052	Rubble bank at edge of damaged substrate	IMG_3368	13-Apr-10	Final resting location
Photo 053	Rubble bank at edge of damaged substrate	IMG_3369	13-Apr-10	Final resting location
Photo 054	Potential dislodged massive coral scar	IMG_3406	13-Apr-10	Final resting location
Photo 055	Dive float with GPS attached	IMG_3421	13-Apr-10	Final resting location
Photo 056	Natural sand channel in undamaged reef	IMG_2084	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 057	Undamaged reef substrate	IMG_2094	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 058	Cardinalfish blanketing substrate	IMG_2109	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 059	Diver taking sediment samples	IMG_2111	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 060	Undamaged coral and algae	IMG_2124	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 061	Undamaged <i>Stylophora</i> coral	IMG_2129	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 062	<i>Tridacna</i> clam on undamaged reef	IMG_2135	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 063	Undamaged reef substrate	IMG_2136	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 064	Undamaged <i>Acropora</i> plate coral	IMG_2148	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 065	Sponge on undamaged reef	IMG_2152	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 066	Diver on damaged substrate	IMG_3423	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 067	Cardinalfish blanketing substrate	IMG_3429	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 068	Undamaged <i>Acropora</i> coral	IMG_3436	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 069	Undamaged reef substrate	IMG_3459	13-Apr-10	Undamaged reef adjacent to final resting location
Photo 070	Diver over undamaged reef	IMG_3484	13-Apr-10	Undamaged reef adjacent to final resting location
Video label	Description	Original Video	Date taken	Location
Video 001	Diver sampling antifouling paint from reef substrate	MVI_3222	12-Apr-10	Close to initial grounding location
Video 002	Pan over area of moderate damage	MVI_3267	12-Apr-10	Close to initial grounding location
Video 003	Diver sampling metal fragments from reef substrate	MVI_3272	12-Apr-10	Close to initial grounding location
Video 004	Pan from adjacent reef over final resting location	MVI_3349	13-Apr-10	Final resting location
Video 005	Pan over final resting location	MVI_3354	13-Apr-10	Final resting location
Video 006	Diver taking sediment sample	MVI_3355	13-Apr-10	Final resting location
Video 007	Pan from adjacent reef over final resting location	MVI_3378	13-Apr-10	Final resting location
Video 008	Pan from severely damaged area over adjacent undamaged reef	MVI_3424	13-Apr-10	Undamaged reef adjacent to final resting location

## Appendix C:

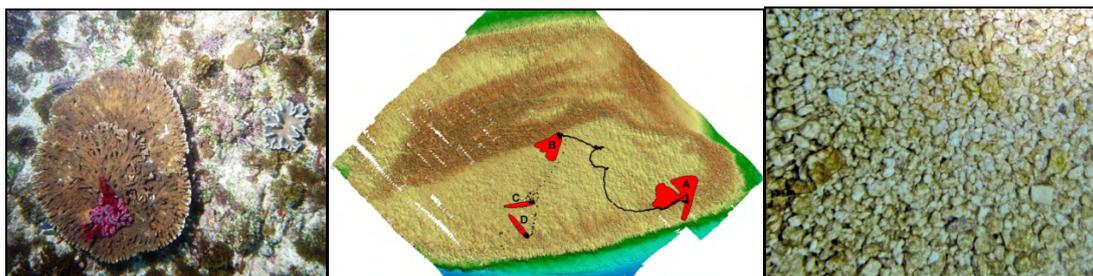
**Grounding of the *Shen Neng 1* on Douglas Shoal:**  
multibeam sonar bathymetry and towed video  
assessments.

[Report based on site visit 2]



Douglas Shoal  
Ship Grounding Survey: RV Cape Ferguson

Habitat Damage Monitoring using  
Multibeam Sonar and Towed Video Assessments



## FINAL REPORT

# Grounding of the *Shen Neng 1* on Douglas Shoal: Multibeam Sonar Bathymetry and Towed Video Assessments

---

**Andrew Negri, Peter Speare, Thomas Stieglitz, Ralph Botting,  
Ray Berkelmans and Craig Steinberg**

PRODUCED FOR  
**Great Barrier Reef Marine Park Authority (GBRMPA)**



Townsville  
October 2010

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## CONTENTS

<b>LIST OF FIGURES .....</b>	<b>II</b>
<b>LIST OF TABLES .....</b>	<b>III</b>
<b>EXECUTIVE SUMMARY .....</b>	<b>I</b>
<b>1. INTRODUCTION .....</b>	<b>2</b>
<b>2. METHODS AND EQUIPMENT .....</b>	<b>3</b>
2.1 Impact Assessment Team .....	3
2.2 Approach .....	4
2.3 Grounding site.....	5
2.4 Multibeam Bathymetry and Backscatter Strength .....	6
2.5 Towed Underwater Video .....	7
<b>3. RESULTS.....</b>	<b>9</b>
3.1 Multibeam Bathymetry and Backscatter Strength.....	9
3.2 Towed Underwater Video .....	13
<b>4. DISCUSSION .....</b>	<b>20</b>
<b>5. CONCLUSIONS .....</b>	<b>21</b>
<b>7. REFERENCES .....</b>	<b>22</b>
<b>8. APPENDIX .....</b>	<b>24</b>
8.1 Additional Multibeam Images .....	24
8.2 Physical Oceanographic Observations.....	26

## LIST OF FIGURES

Figure 1. The path of the <i>Shen Neng 1</i> over the course of its grounding (sites overlaid on map provided by the Spatial Data Centre, Great Barrier Reef Marine Park Authority 2010).....	5
Figure 2. Towed underwater video equipment on the rear deck of the <i>RV Cape Ferguson</i> .....	8
Figure 3. Multibeam Bathymetry Overview. Colour-coded, sunshaded multibeam bathymetry of Douglas Shoal.....	9
Figure 4. Time series of bathymetry (bottom), tidal water level (centre) and water depth at the keel (top) at the location of the <i>Shen Neng 1</i> 's stern (GPS) in 10 minute time steps. The water depth under the keel is the sum of depth and tidal water level (note axis convention = positive down). The grey shading marks the periods when the vessel remained stationary or near stationary. Locations are marked above the figure. The figure illustrates the grounding at ca 13.5 m depth under keel (Site 1), subsequent refloating at greater depth under keel (Sites 2 and 3) and repeated grounding at Sites 4, 5 and 6. Note, only the first 6 hours of data is included at Site 6 for scale reasons.....	10
Figure 5. Colour-coded, sunshaded multibeam bathymetry of the impact sites of Douglas Shoal with track of <i>Shen Neng 1</i> and impact sites as determined from sonar data analysis.....	11
Figure 6. Aerial view of multibeam bathymetry of Site 6 at Douglas Shoal. The imprint of <i>Shen Neng 1</i> 's hull on the reef matrix is clearly visible in the foreground.....	12
Figure 7. Towed underwater video tracks and the movement of the <i>Shen Neng 1</i> (pink – grounding, orange – recovery of ship by tug boat) across Douglas Shoal. Black markers denote areas where damage was evident.....	13
Figure 8. Relative contributions of the major substrate classes recorded from towed video footage on Douglas Shoal. ....	14
Figure 9. The relative contributions of the predominant benthos classes to the undisturbed shoal (A) and areas affected by the grounding of the <i>Shen Neng 1</i> (B).....	15
Figure 10. Representative images of the undisturbed benthos on Douglas Shoal (left) and areas affected by the grounding of the <i>Shen Neng 1</i> (right). The top right image gives a clear indication of how the reef was ground down leaving only benthos on the sides. Further images representative of each of the specific damaged sites can be found in Fig. 15. ....	16
Figure 11. Acoustic image of Douglas Shoal where the <i>Shen Neng 1</i> encountered further shoaling which arrested its westerly drift (Site 4). Alterations to the topography are clearly evident as an area of disturbance (encompassed by black line) and visual assessment by towed camera validated and characterized these marks.....	17
Figure 12. Acoustic image of Douglas Shoal where the <i>Shen Neng 1</i> rested for 1 week prior to being refloated (Site 6). The impression of the hull is clearly evident and visual assessment by towed camera validated and characterized these marks and adjacent marks to the north and northwest. In this image, the ship lay east – west and then the stern was brought directly south with the ship rotating on its bow section.....	18

Figure I3. Photographs representative of damage Sites 1, 4, 5 and 6. ....	19
Figure A1. Multibeam backscatter strength of impact region. ....	24
Figure A2. Multibeam backscatter strength of impact region with vessel track, bearing line and impact sites. ....	24
Figure A3. Seabed slope of impact region. ....	25
Figure A4. Seabed slope of impact region with vessel track, bearing line and impact sites (site names see text).....	25
Figure A5. Southern GBROOS Moorings locations.....	27
Figure A6. Release of the satellite tracked drifter from the stern of the <i>RV Cape Ferguson</i> .....	27
Figure A7. Track of drifter between April 17 and July 2, 2010. ....	28

## LIST OF TABLES

Table 1. Site locations and designations, including damage sites identified by multibeam bathymetry.....	6
Table 2. Operational details for the 8 towed video transects undertaken on Douglas Shoal. ....	8

## Douglas Shoal Ship Grounding Survey: *RV Cape Ferguson*

# Grounding of the *Shen Neng 1* on Douglas Shoal: Multibeam Sonar Bathymetry and Towed Video Assessments

## EXECUTIVE SUMMARY

This report provides results from a high-resolution multibeam sonar bathymetry and backscatter strength survey of Douglas Shoal, quantifying physical damage caused by the grounding of the *Shen Neng 1*. The native and damaged habitats were further assessed by towed underwater video, providing geo-referenced imagery over 16.7 km of shoal habitat. Together, these surveys enabled quantitative estimates to be made of the extent and severity of damage to the structure of Douglas Shoal and its biota. A satellite tracked drifter was also released at the final site of the grounding and monitored over a period of 53 days to assess local circulation and current drift away from Douglas Shoal.

Adverse weather conditions reduced the sensitivity and resolution of both sonar and towed video surveys. Despite these limitations, acoustic analysis was able to identify structural impact on the shoal at 4 locations, corresponding to the initial and final grounding sites and two transit sites also consistent with the known grounding track of the *Shen Neng 1*. The damaged area, estimated from sonar bathymetry and backscatter strength, was approximately 80,000 m<sup>2</sup>. Towed video surveys 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%). Areas impacted by the hull of the *Shen Neng 1* were either sheared flat or pulverised into rubble (5 – 50 mm diameter). The impacted zones identified by towed video camera corresponded with the known grounding track of the *Shen Neng 1* and to damaged zones identified by multibeam bathymetry techniques. These rubble-beds were virtually lifeless, with less than 1% macroalgal cover identified by towed video camera. The satellite-tracked drifter released at the final grounding site indicated that persistent oil slicks originating in the Douglas Shoal region have the potential to travel towards the coast of the mainland and also towards sensitive coral reefs.

The combination of multibeam bathymetry and towed underwater video revealed the large scale of physical damage to the shoal and almost complete elimination of sessile invertebrates and algae where the ship contacted the reef. While some areas of shoal were razed flat to bare, compacted substratum, other areas, particularly the final grounding site, now resemble a coarse gravel road. If antifoulant contamination is low, the hard compacted areas should recover relatively quickly; however, areas ground into rubble are unconsolidated making recruitment of macroalgae and invertebrates difficult over the short and medium terms.

## 1. INTRODUCTION

On Easter Saturday, 3 April 2010, the 225 m bulk carrier *Shen Neng I* ran aground on Douglas Shoal in the southern section of the Great Barrier Reef, fully laden with approximately 65,000 tonnes of bulk coal and 977 tonnes of fuel oil (ATSB 2010, MSQ 2010). Douglas Shoal is a large, flat reef reaching between 9 and 15 m of the surface and hosts a diversity of invertebrate and fish species (Marshall 2010). The vessel was underway at a speed of approximately 8 knots when the grounding occurred and she sustained severe damage to her hull, and to the propeller and rudder. The grounding coincided with the afternoon low tide and the last of the spring tides. By half tide the ship had moved further onto the shoal and with the continuing tidal rise undertook a further westward drift of ~ 1.3 km before coming to rest on the falling tide (Fig. 1). By the afternoon of the 2<sup>nd</sup> day, the ship moved ~ 1 km south towards the edge of the shoal where it remained for a week. During spring tides on 12 April she was re-floated with the aid of tugs following removal of approximately half of the fuel oil. A minor oil spill (~ 2 tonnes) that occurred earlier in the grounding was treated with chemical dispersants (ATSB 2010, MSQ 2010). During this 9 day event, the ship ground its way across the top of the shoal, rotating as alternate fore and aft sections of the hull resisted the drift (Fig. 1). Physical damage to the reef and its biota by the movement and grinding of the hull on the substratum was highly likely.

As major oil and coal spills did not occur, the most important impacts to Douglas Shoal were considered to be physical damage to the reef structure and its biota as well as potential contamination by antifouling paint which can affect invertebrate recruitment and reef recovery (Haynes et al. 2002, Negri & Marshall 2009). Previous ship groundings on the GBR have caused structural destabilisation and widespread contamination of reefs with antifouling paint (Haynes et al. 2002, Haynes & Loong 2002) prompting significant mitigation responses from the Great Barrier Reef Marine Park Authority (GBRMPA) (Marshall et al. 2002). Similar measures may be required at Douglas Shoal. As the lead agency, the GBRMPA initiated an environmental assessment response which included divers (GBRMPA and QPWS) and remote tools for acoustic and visual surveys (Australian Institute of Marine Science, AIMS). The initial surveys by SCUBA identified large areas of severe damage to the reef structure and biota as well as evidence of antifouling paint contamination [for more details see Marshall (2010)]. The remote techniques, more suited to a broader shoal-wide assessment, were undertaken from the AIMS RV *Cape Ferguson* between 16 and 20 April 2010 following the successful salvage of the *Shen Neng I*. The present report details the approach and methods adopted, describes the results from the RV *Cape Ferguson* voyage and discusses the scale and severity of damage to Douglas Shoal identified by these remote techniques.

The priority objectives of the impact assessment for determining physical impact on Douglas Shoal were:

- Map Douglas Shoal using high resolution multibeam bathymetry techniques to assess the extent of damage caused by the grounding of the *Shen Neng I*.
- Assess the benthic habitat and biota in undamaged and damaged areas of Douglas Shoal using towed underwater video (TUV).

Additional objectives included:

- Deploy a satellite tracked drifter at Douglas Shoal to assess local circulation and current drift away from Douglas Shoal. The results of this objective are outlined in the Appendix Section 8.2 under the heading "Physical Oceanographic Observations".
- The deployment of passive samplers and the collection of water to assess potential water contamination at Douglas Shoal. The analysis of these samples is currently underway at the National Research Centre for Environmental Toxicology (ENTOX) and will form the basis of a later report.

- Collect sediment samples to assess possible contamination by antifouling paint by SCUBA. This was not attempted due to poor weather conditions.

## 2. METHODS AND EQUIPMENT

### 2.1 Impact Assessment Team

The impact assessment team was led by *Dr Andrew Negri*, Senior Research Scientist, Water Quality and Ecosystem Health at AIMS. Andrew has: a Ph.D. from RMIT, Melbourne in 1993; 17 years experience in aquatic ecotoxicology including 15 years in marine ecotoxicology and ecology in Pacific, Indian and Antarctic waters; more than 70 peer-reviewed, international scientific publications. Andrew is a qualified Commercial (Level 1) Scuba Diver with extensive scientific diving experience in tropical and Antarctic waters. *His role was Cruise Leader, co-author and senior editor of this report.*

*Mr Peter Speare* graduated from James Cook University in 1982 with a Bachelor of Science degree. Peter has used towed underwater video (TUV) equipment as a habitat classification and mapping tool since 2004 and has operated this equipment in over 600 deployments in various marine habitats. Peter designed both the software that supports real time classification and geo-referencing of the imagery and the database to house the data records. These techniques, including the software and database, have been used to successfully deliver analysis and representation of TUV information in a large number of reports to various clients. *His role was to acquire geo-referenced imagery, both stills and video, of the damage caused by the grounding. The imagery was geo-referenced by applying measured and estimated positional offsets from the ship's GPS to the towed equipment trailing over its stern. Peter analysed and interpreted all TUV data for this report.*

*Dr Thomas Stieglitz* is a Research Fellow at the School of Engineering & Physical Sciences, James Cook University. Thomas has: an MSc Physics (1998); PhD Biogeography (2002); 8 years post-PhD experience in marine geophysics; > 30 peer-review publications and book chapters: substantial expertise with multibeam bathymetry data collection, processing and interpretation for scientific research, environmental monitoring and commercial survey. *His role was processing and interpretation of all multibeam bathymetry data presented in this report.*

*Mr Ralph Botting* is the Manager of the Research Vessel James Kirby, for the School of Earth & Environmental Science, James Cook University. As part of this role he provides technical support on voyages and is responsible for operating the vessel's Reson 8101 Multibeam Sonar and Geophysical equipment, collecting Bathymetry data, when fitted to the James Kirby, or providing consultancy services on the equipment when fitted to other vessels. His expertise with the use of this equipment has been obtained over the past 5 years as result of carrying out surveys along the GBR, Torres Strait and PNG waters. This experience is backed by over 2 years marine and environmental science support in Antarctica and over 25 years electronics experience in the RAAF. *His role was to acquire all multibeam bathymetry data presented in this report.*

*Dr Ray Berkelmans* is a Research Scientist in the Responding to Climate Change team at AIMS. Ray has: a Ph.D. in Marine Biology from James Cook University, Townsville in 2002; over 10 years experience in coral ecology in tropical and subtropical Australian waters; more than 50 peer-reviewed, international scientific publications. Ray is a qualified Commercial (Level 1) Scuba Diver with extensive scientific diving experience. *His role was Dive supervisor, sample collection, photography.*

Mr Craig Steinberg is a Senior Experimental Scientist in the Responding to Climate Change team at AIMS. Craig has: a BSc (Hons.) in Meteorology and Oceanography from Flinders University 1984; 23 years experience as a Physical Oceanographer undertaking research in multi-disciplinary studies across Northern Australian waters and in the Pacific. He has authored or co-authored peer reviewed 6 book chapters, 35 journal articles and 34 consulting reports. Craig is the sub-facility manager of the Integrated Marine Observing System Great Barrier Reef Ocean Observing System's Satellite Remote Sensing and Australian National Mooring Network. *His role was scientific advisor and author of the Physical Oceanography section in Appendix 8.2 of this report.*

Other members of the assessment team included Mr Shaun Smith and Mr Marcus Stowar (AIMS: field support), Mr Dave Williams (AIMS, HSE manager), Dr. Paul Marshall and Dr Tyrone Ridgeway (GBRMPA; coral ecologists/biologists) and Mr Jesse Low (QPWS; dive supervisor).

## 2.2 Approach

At the request of the GBRMPA, the AIMS research vessel *Cape Ferguson* redeployed to the site of the grounding of the *Shen Neng 1* on 16 April 2010. The overall aims of the voyage were to assess the scale of the physical damage to the reef and the severity of damage to the native biota. The key methods employed were high-resolution multibeam sonar bathymetry coupled with towed underwater video (TUV) surveys. In combination, these methods provide high quality data to assess damage over the very broad area of reef impacted by the ship grounding.

Multibeam bathymetry is a form of echo sounding which uses pulses directed from the surface to the seafloor to measure the distance to the bottom by means of sound waves. The echo sounder used here has 101 beams with a beam angle of 1.5° for each beam. These signals are reflected from the ocean floor at different angles and at different times, depending on the topography and depth of the sea floor. The precision of this technique can be within 10 cm under ideal conditions but the pitch and roll of a vessel due to poor weather conditions can reduce the sensitivity of this technique, despite compensation measures to account for vessel roll, pitch and yaw. Multibeam bathymetry and backscatter techniques are well suited to estimate areas of physical damage on coral reefs as they can detect flattening and gouging of the substratum as well as compacting of substratum expected following the grounding of large ships. Multibeam and backscatter techniques are best suited to detect physical damage on reefs with a relatively high degree of topographic complexity as this would provide the greatest contrast to reef flattened and/or gouged by a grounded vessel.

TUV surveys of benthic habitats are well suited to conditions where diving is impractical or where large areas require survey. A strengthened underwater housing containing a digital video camera mounted on a sled is tethered to and towed behind the ship with electromechanical cable controlled by a winch. The imagery is automatically geo-referenced with GPS data and both are simultaneously recorded on miniDV tapes aboard the vessel. TUV became the primary method for benthic biota assessment on the *RV Cape Ferguson* voyage as diving surveys were ruled out due to poor weather conditions. While poor sea conditions are more favourable for TUV than diving, the increased pitch and roll of the vessel along with strong currents can reduce the quality of captured imagery. TUV is effective in detecting gross physical damage to habitat and /or widespread mortality at a broad taxonomic level. It is also well suited to estimating physical habitat types but again within broad classifications. More detailed taxonomy and habitat descriptions require detailed surveys by divers [this was carried out as part of a related report (McCook 2010)].

Currents in the vicinity of Douglas Shoal were assessed using a satellite tracked drifter. The deployment of a satellite tracked drifter from the site of the grounding was to demonstrate the potential path of water-borne sediment plumes and oil spill contamination from shipping accidents at

Douglas Shoal. Results from this oceanographic study are reported in Appendix Section 8.2 under the heading "Physical Oceanographic Observations".

## 2.3 Grounding site

The track and bearing of the *Shen Neng 1* during the period of the grounding was provided the Spatial Data Centre, Great Barrier Reef Marine Park Authority 2010 (Fig. 1). Several sites were prioritised for sampling towed video survey, including the initial grounding site (Site 1) on the South East edge of the Shoal, the final grounding site (Site 6), a randomly selected unimpacted site on the same shoal but a minimum of 1050 m from the ship's path (Site 7), and several intermediate sites (Fig. 1, Table 1).

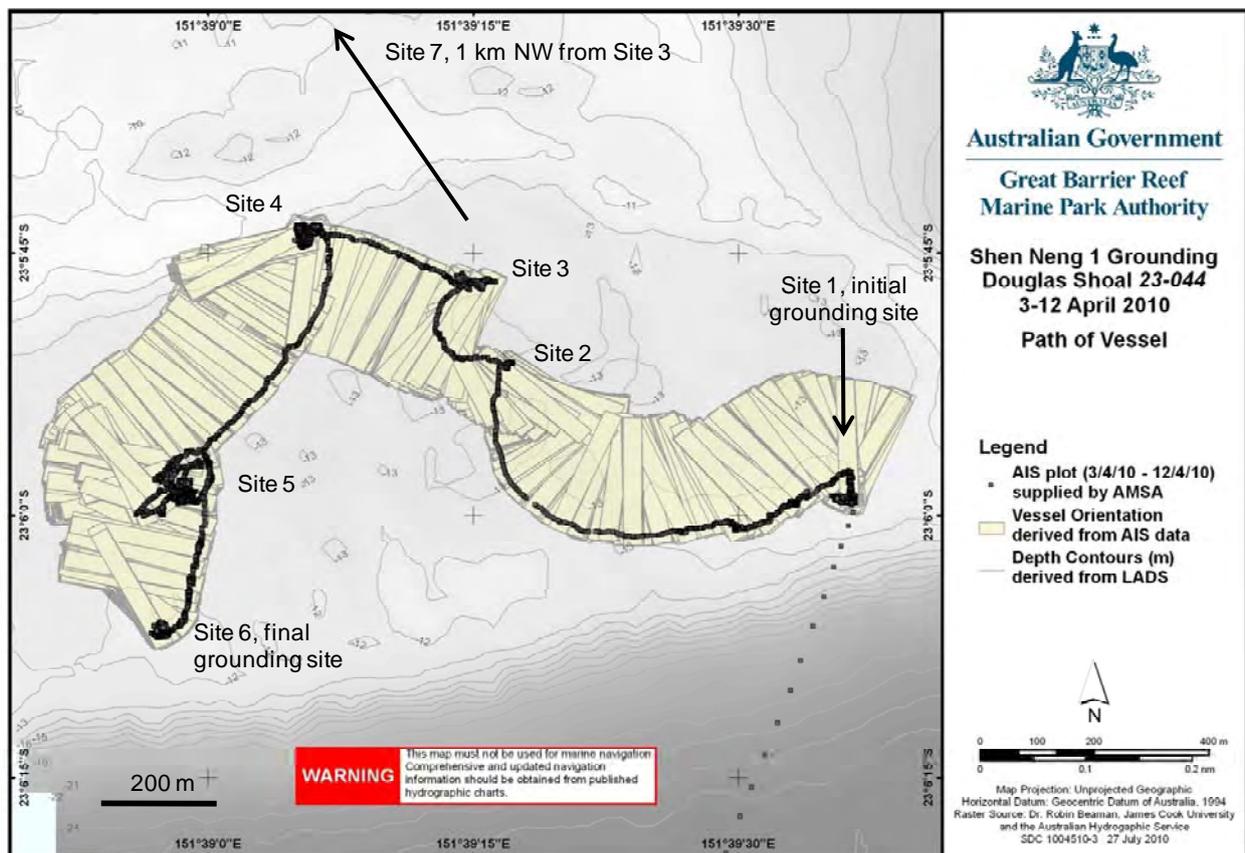


Figure 1. The path of the *Shen Neng 1* over the course of its grounding (sites overlaid on map provided by the Spatial Data Centre, Great Barrier Reef Marine Park Authority 2010).

Table 1. Site locations and designations, including damage sites identified by multibeam bathymetry.

Site	Latitude	Longitude
Site 1, Initial scar	23°05.986'	151°39.598'
Site 2	23°05.857'	151°39.282'
Site 3	23°05.779'	151°39.248'
Site 4	23°05.792'	151°39.089'
Site 5	23°05.982'	151°38.978'
Site 6, Final scar	23°06.107'	151°38.953'
Site 7, Unimpacted site	23°05.316'	151°38.664'

## 2.4 Multibeam Bathymetry and Backscatter Strength

### *Multibeam bathymetry*

Multibeam bathymetry of Douglas Shoal was recorded with a hull-mounted multibeam echosounder RESON Seabat 8101 on *RV Cape Ferguson* between 15 and 17 April 2010. Reson 8101 Multibeam Bathymetry and associated technical support provided by the School of Earth & Environmental Science, James Cook University, Townsville. The echosounder has 101 beams with a beam angle of 1.5° for each beam. Concurrently, vessel track and heading were recorded with DGPS and gyrocompass, and the motion of the vessel was recorded with a motion sensor mounted at the centre of gravity of the vessel. Approximate static offsets were calculated from feature comparison in the multibeam data along with dynamic offsets.

Data were processed with the software SWATHED of the Ocean Mapping Group of the University of New Brunswick, Canada, and visualised with IVS Fledermaus. This data processing and reporting was carried out by the School of Engineering & Physical Sciences, James Cook University. Sonar ranges measured with the echosounder were converted to depth by integrating the range, GPS, heading and motion data whereby the acoustic data was corrected for refraction using a sound velocity profile representative for the region at the time of data collection. Tidal water level variation was corrected by using high-resolution AHO tidal predictions at Tyron Island, which is the tidal prediction station nearest to Douglas Shoal. Multibeam data collected along a total of 51 parallel survey tracks is reported here. In the planning phase, a survey grid consisting of tracks with a distance of 40 m was chosen, and these tracks were followed. Deviations in the order of 10 m from the planned track occurred at times due to vessel drift because of sea conditions. This results in incomplete coverage at some locations (data gaps). These data gaps were not removed by interpolation to retain data accuracy. The processed data were converted into a digital terrain model (DTM) with a spatial resolution of 0.5 m by weighted gridding, whereby data recorded with the outer ten beams on both port and starboard side was disregarded. Subsequently, seabed slope was calculated for each 0.5 m grid cell (Appendix Figs. A3 and A4).

### *Backscatter strength*

Together with multibeam bathymetry, the RESON Seabat 8101 records uncalibrated (relative) backscatter strength (sidescan option). Unfiltered backscatter data were compiled into a mosaic, whereby data outside an angular range of 0 to 60 degrees were excluded (unacceptable data quality beyond 60 degrees). Data were variable-gain corrected with a window size of 100 pings assuming a flat bottom. No corrections for bathymetry were made.

All geographic data is reported in WGS84; UTM projection zone 56S. Bathymetry is reported to prediction datum at Tyron Island (datum Lowest Astronomical Tide (LAT); 1.63 m below mean sea level (MSL))

### *Data quality and limitations*

Adverse weather conditions resulted in significantly reduced data quality, some data gaps and vessel motion residuals. In particular the backscatter data is of compromised quality and associated with large artefacts. Notwithstanding these limitations, the data is well suited to assess structural damage to the shoal by the vessel grounding. Note there is an offset of approximately 0.5 m between the multibeam bathymetry data reported here and LADS bathymetry data of Douglas Shoal available at AIMS and GBRMPA. The reason for this offset is unclear, but it is likely related to the lack of accurate survey vessel configuration (sensor offset) data. The offset is a constant value added to or subtracted from each data point of the multibeam grid. Thus structural information (e.g. depth difference between a bommie and the substrate) is not affected by this offset (similar to looking at the seafloor at low and high tide – the structure remains the same).

### *Analysis of structural damage to shoal matrix*

In order to assess and delineate structural damage of the shoal matrix by the grounding of the vessel, multibeam bathymetry, seabed slope and backscatter strength were visually inspected, and locations with acoustic signatures different to the surrounding seafloor were manually delineated to the nearest pixel (a commonly applied method in multibeam analysis for seafloor habitat delineation). Structural damage is here defined on the scale of the bathymetry observations, i.e. with a horizontal and vertical extent of 0.5 m and 0.1 m respectively. This damage expresses itself in the data as a loss of small-scale bathymetric variability and flattening of the seafloor, i.e. reduction of slope, and/or increased backscatter strength from flat seafloor as a result of the grounding. However, it is suggested that the multibeam data may serve as a tool to assign a priority ranking for affected areas in the further assessment of the damage. Damaged areas were estimated to the nearest 500 m<sup>2</sup>.

## 2.5 Towed Underwater Video

A towed camera system incorporating a standard definition video camera and digital stills camera was deployed to recover imagery of the benthos (Fig. 2). The visual imagery of the benthic habitat was captured using a 1/3 inch single CCD colour video camera mounted on a tow frame and controlled by a winch with 320 m of electromechanical cable (Speare et al. 2004). The video signal was recorded on a shipboard miniDV tape recorder. In addition to the visual imagery, the miniDV tape recorder received GPS and sounder data (latitude and longitude, ground speed, true heading, date, depth and time), which was recorded on the audio track. A computer-based application (TowVid), developed by AIMS (for details see Speare et al (2008)), allowed for real-time classification of substrata, benthos and individual organisms. Data points were recorded at 2-second intervals or on demand when a new substrate, benthos or organism was observed. A Sea & Sea 12MP digital stills camera, illuminated by a fibre-optically triggered strobe, was set to record at a nominal 5 second interval throughout the tows. All still images were geo-referenced by matching image time with the logged tow position. No analysis was undertaken on the still images which may provide a higher resolution taxonomic profile of the benthic communities on Douglas Shoal.



Figure 2. Towed underwater video equipment on the rear deck of the *RV Cape Ferguson*

Initially it was envisioned that the acoustic survey of an area encompassing all known positions of the coal freighter would generate real time high resolution topographical imagery to guide the TUV survey. Rough conditions on the voyage meant that a great deal of post-survey analysis was required to reduce signal noise; therefore the path of the stern of the *Shen Neng 1*, together with the lay of the ship (courtesy GBRMPA), was used to guide the TUV survey course between April 17 – 18, 2010. Rough weather and strong currents also precluded data collection in replicated transects. Instead the tows were planned to intercept and traverse areas where damage was likely to have occurred from contact of the ship's hull on the shoal along with areas of shoal not affected by the grounded ship.

A total of 16.7 kms of towed underwater video generated 5097 data records at a nominal 2 second interval and an average horizontal resolution of 3.3m. In addition, approximately 1800 high resolution still images were recorded (Table 2).

Table 2. Operational details for the 8 towed video transects undertaken on Douglas Shoal.

Site name	Start time	Average Depth	No. Records	No. Stills
DouglasShoal1	17/04/2010 4:46:55 PM	-11.2	1401	258
DouglasShoal2	18/04/2010 12:05:24 PM	-12.3	710	278
DouglasShoal3	18/04/2010 12:45:35 PM	-12.7	996	393
DouglasShoal4	18/04/2010 2:22:32 PM	-14.9	224	195
DouglasShoal5	18/04/2010 2:54:30 PM	-12.9	1015	367
DouglasShoal6	18/04/2010 4:00:59 PM	-11.7	107	48
DouglasShoal7	18/04/2010 4:16:09 PM	-12.1	440	169
DouglasShoal8	18/04/2010 4:41:37 PM	-11.9	204	90

### 3. RESULTS

#### 3.1 Multibeam Bathymetry and Backscatter Strength

Multibeam sonar bathymetry of Douglas Shoal revealed a typical reef topography and geomorphology (Hopley et al. 2007) (Fig. 3).

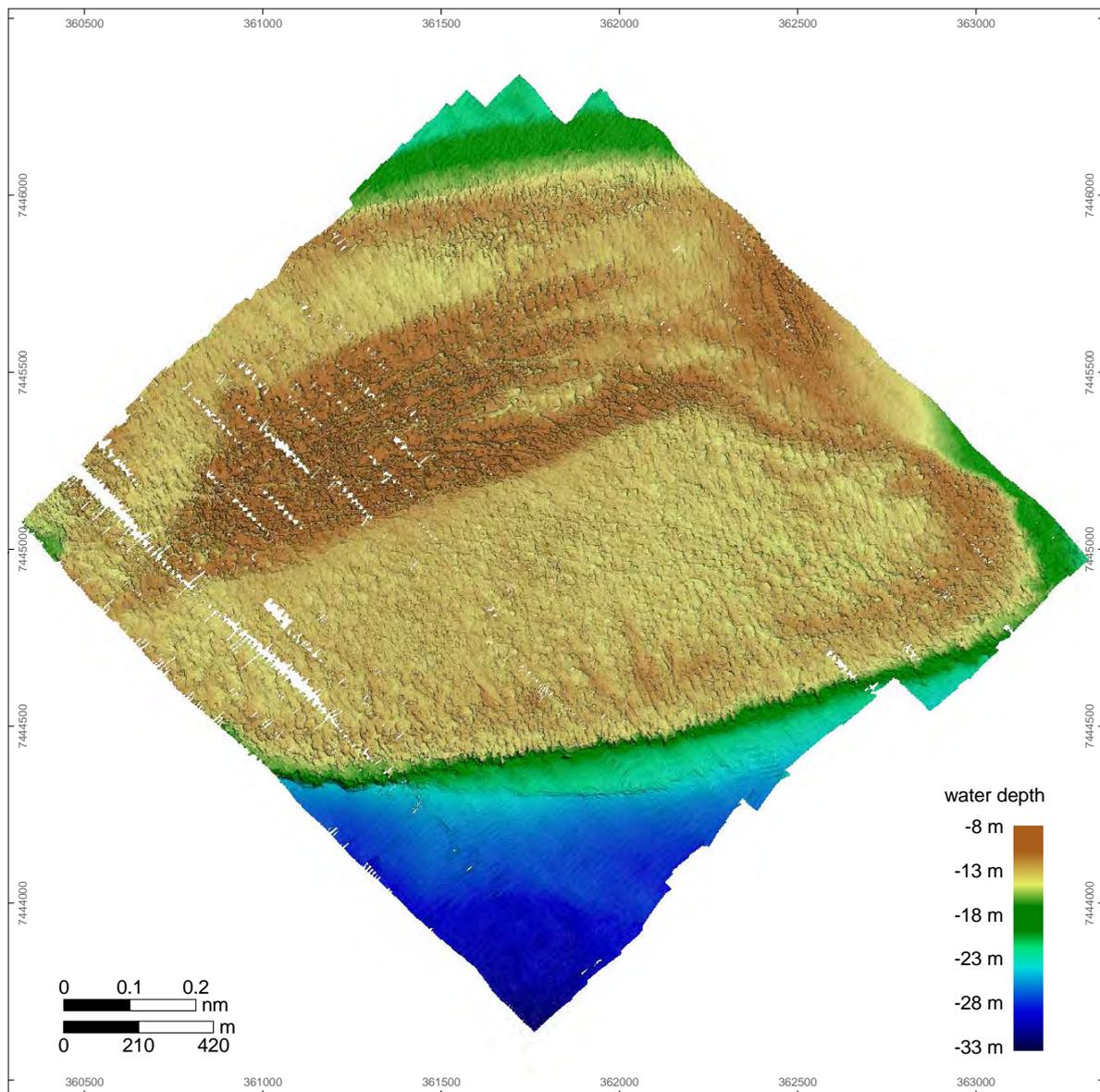
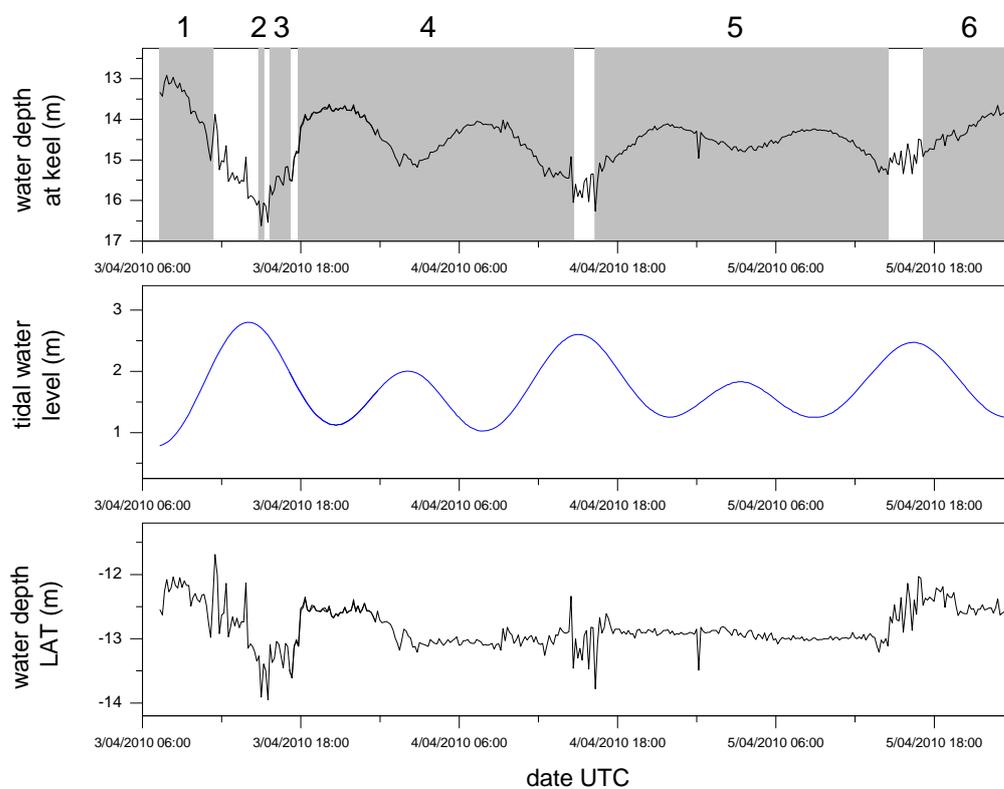


Figure 3. Multibeam Bathymetry Overview. Colour-coded, sunshaded multibeam bathymetry of Douglas Shoal.

Between initial grounding and removal from the shoal, the reported track of the *Shen Neng I* shows six locations where the vessel's stern (where the *Shen Neng I*'s GPS was located) remained stationary or approximately stationary for some duration [Sites 1, 2, 3, 4, 5 and 6 (Fig. 4); see Table 1]. Impact sites were assumed to most likely be located in the vicinity of these locations. The sonar data shows structural impact in the vicinity of four out of those six locations [Sites 1, 4, 5 and 6 (Fig. 5)]. These four impact sites are consistent with estimated locations of not only the stern but also the

bow of the ship (as derived from projecting the length of the vessel onto its heading as measured onboard, see Fig. 1). At the other two locations (Sites 2 and 3), no feature in the sonar data is detectable that could be associated with structural damage. At these two locations, the vessel remained only for comparatively short periods of time, which coincided with greater depth of water under the keel of the vessel (Fig 4, top panel). Damage at these two locations is likely to be less significant than at the other locations.

Between these six locations, the vessel was moving comparatively quickly during periods of greater water depth under the keel (Fig. 4). Again, no feature in the sonar data is detectable that could be associated with structural damage during these 'transit' periods. A brief description of each of the damage sites follows:



**Figure 4.** Time series of bathymetry (bottom), tidal water level (centre) and water depth at the keel (top) at the location of the Shen Neng 1's stern (GPS) in 10 minute time steps. The water depth under the keel is the sum of depth and tidal water level (note axis convention = positive down). The grey shading marks the periods when the vessel remained stationary or near stationary. Locations are marked above the figure. The figure illustrates the grounding at ca 13.5 m depth under keel (Site 1), subsequent refloating at greater depth under keel (Sites 2 and 3) and repeated grounding at Sites 4, 5 and 6. Note, only the first 6 hours of data is included at Site 6 for scale reasons.

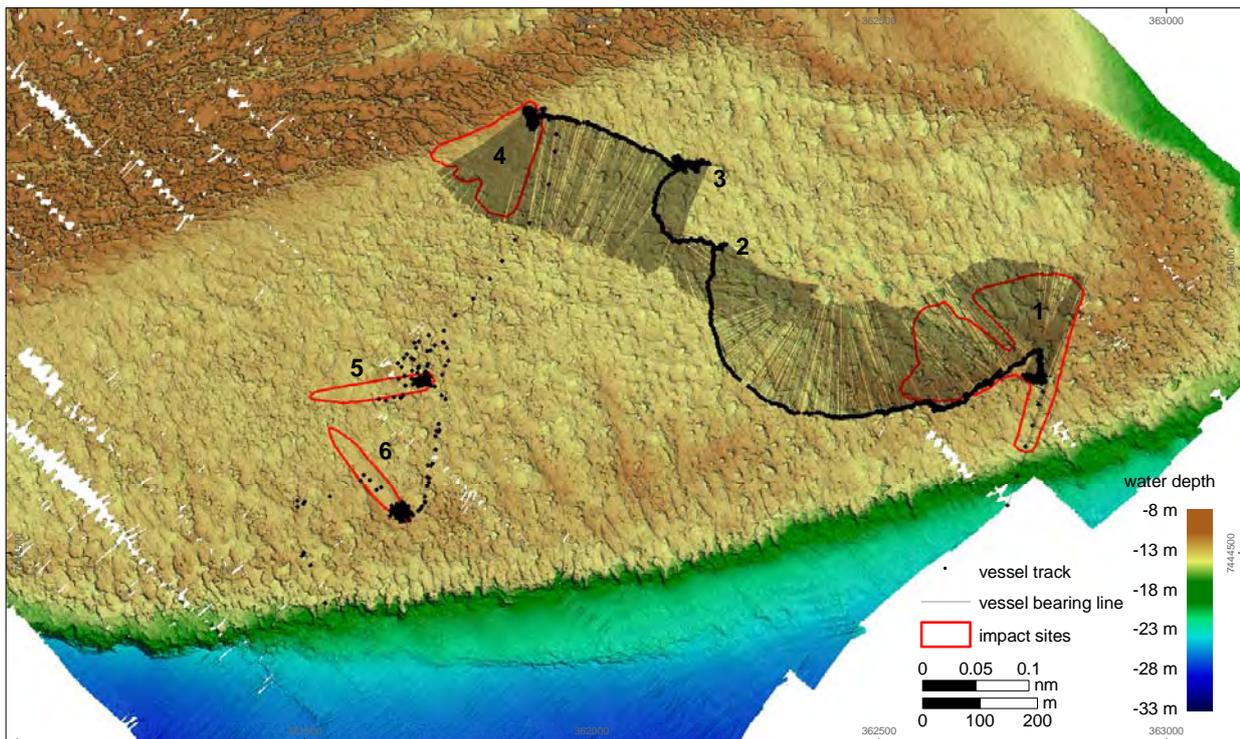


Figure 5. Colour-coded, sunshaded multibeam bathymetry of the impact sites of Douglas Shoal with track of *Shen Neng I* and impact sites as determined from sonar data analysis.

#### *Site 1 (initial grounding site)*

The bathymetry and slope maps of the site of initial grounding (Site 1) show little to no structural difference to the adjacent reef matrix. However, a systematic increase in backscatter strength is associated with this site (see Appendix Figs. A1 and A2). This is likely caused by an abrasion and flattening of the reef top, without destruction of the reef matrix itself and covers an area of approximately 49,500 m<sup>2</sup>. This site includes the ‘approach’ of the grounding site to the south, and a section less well defined to the west of the initial grounding site. The outlines of Site 1 were estimated based on backscatter data only, and should be regarded as a ‘guideline’ only. Note that the backscatter signature observed at Site 1 is similar to the signature of the flat seafloor immediately adjacent to the southern reef edge, an area that has not been impacted by the vessel due to its greater depth.

#### *Site 4*

The northward drifting *Shen Neng I* was likely stopped at Site 4 as the reef became shallower (Fig. 4). The *Shen Neng I*’s GPS and heading data shows that the stern remained in about the same location, whereas the bow was swaying in an approximately 45 degree arc, restricted to the North by the shallower reef. This caused significant wearing-down of the seafloor, clearly discernable in both bathymetry and backscatter data, which resulted in substantial destruction of the reef matrix (approximately 20,000 m<sup>2</sup>); little reef structure remains at this site.

#### *Site 5*

At Site 5, structural damage is comparatively small in both surface area and impact (approximately 6000 m<sup>2</sup>). The imprint of the bow of the vessel is clearly visible in the bathymetry data, and

elsewhere the systematically reduced slope together with a weak backscatter signal suggests abrasion of the top of the coral reef matrix with moderate destruction of the reef matrix.

*Site 6 (final grounding site)*

The imprint of the *Shen Neng 1*'s hull is clearly visible in the bathymetry data at Site 6 (Fig. 6). Here, the vessel likely remained for seven days in one location with little swaying. This resulted in a distinct scour, with increased seabed elevation at the eastern and western sides, likely as a result of accumulation of coral debris from the destruction of the reef matrix under the hull (approximately 6000 m<sup>2</sup> damaged reef). The backscatter signal is weak, likely as a result of compromised data quality at this site.

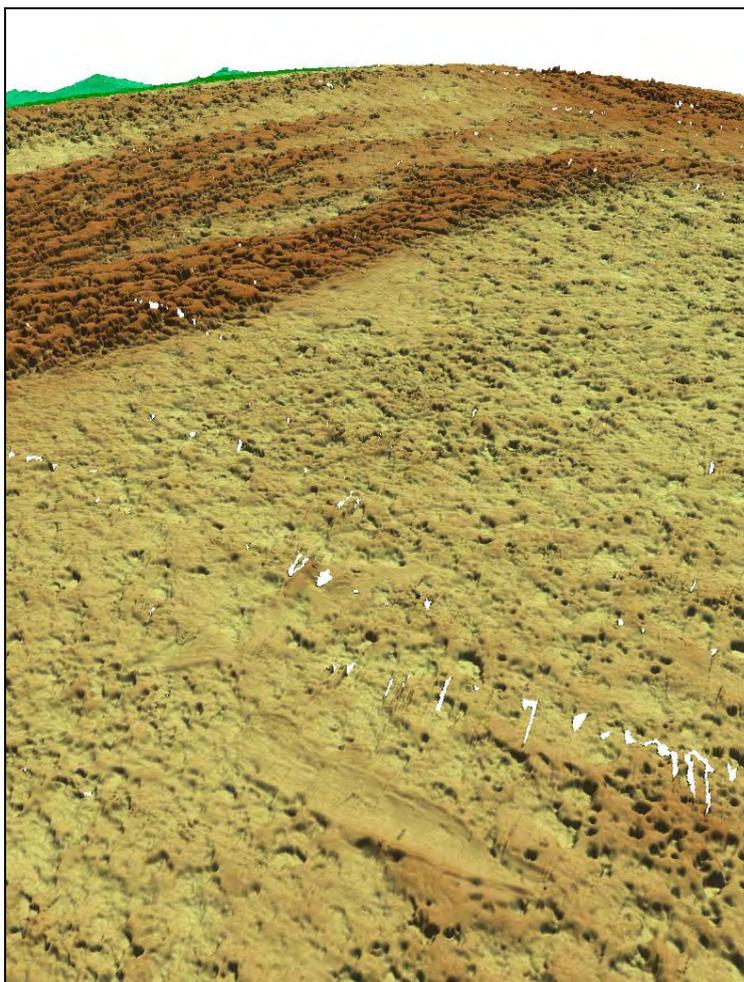


Figure 6. Aerial view of multibeam bathymetry of Site 6 at Douglas Shoal. The imprint of *Shen Neng 1*'s hull on the reef matrix is clearly visible in the foreground.

### 3.2 Towed Underwater Video

Visual survey was severely limited by sea surface conditions and strong currents due to spring tides. Difficulties in maintaining a course in the prevailing sea conditions resulted in a meandering track intersecting the known positions of the *Shen Neng I* (Fig. 7).

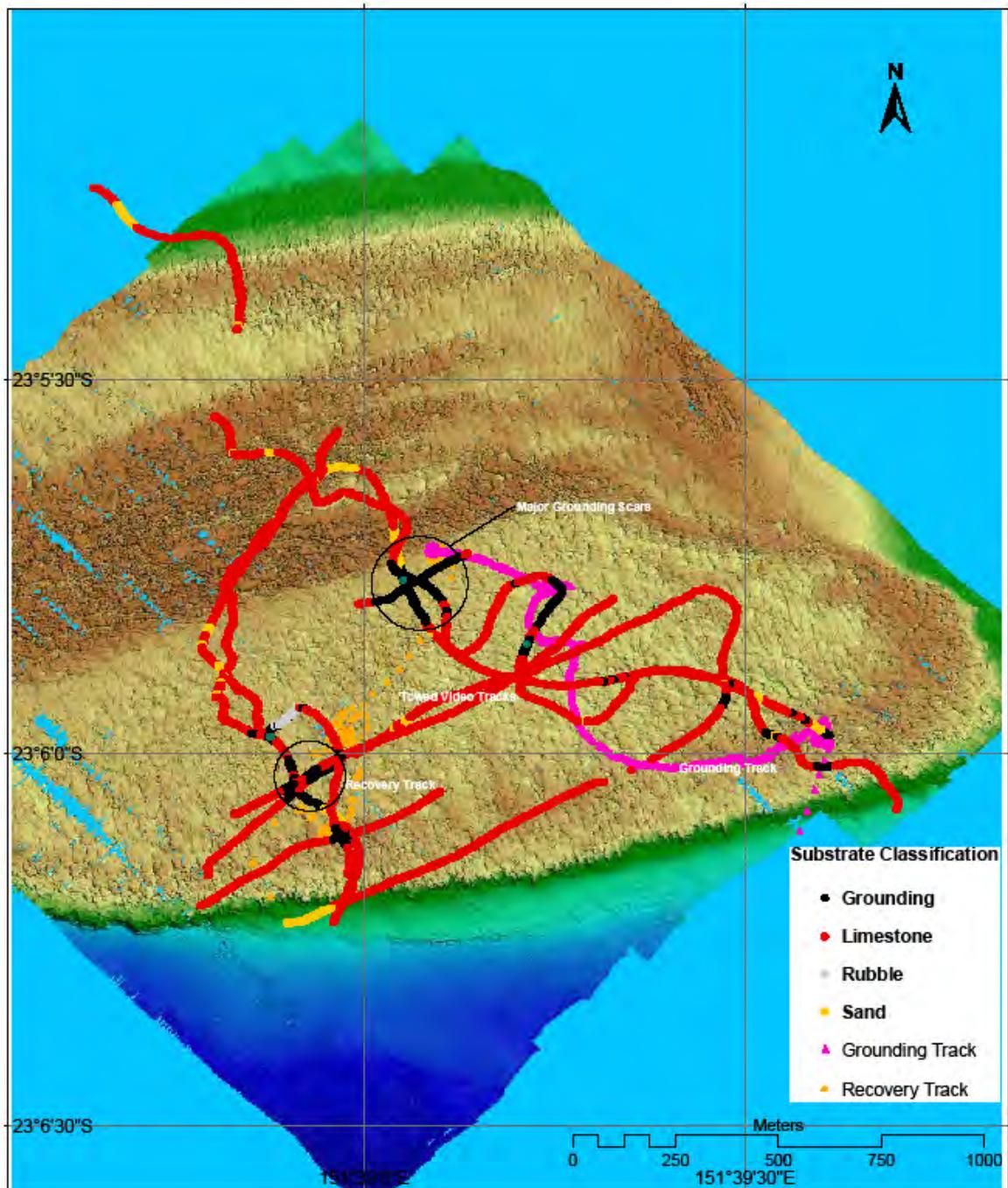


Figure 7. Towed underwater video tracks and the movement of the *Shen Neng I* (pink – grounding, orange – recovery of ship by tug boat) across Douglas Shoal. Black markers denote areas where damage was evident.

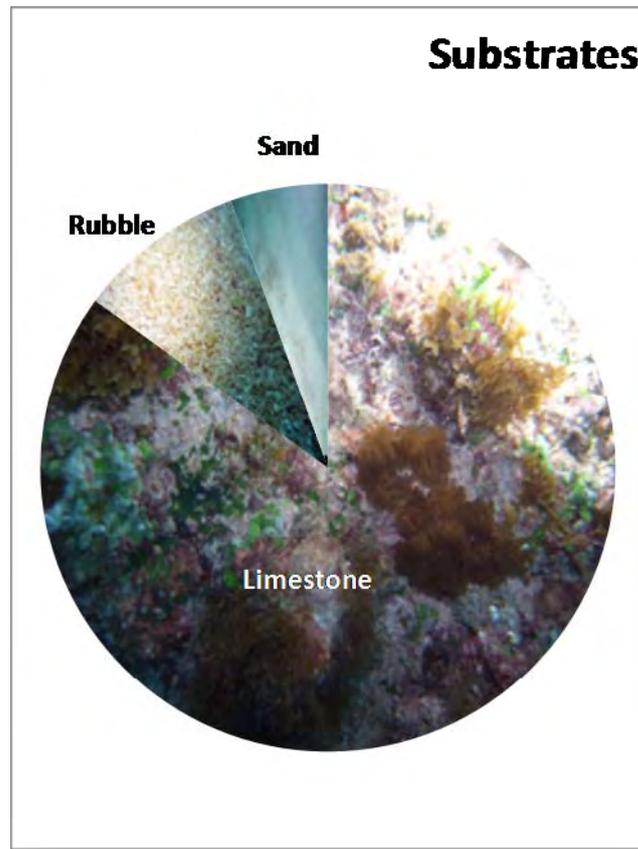


Figure 8. Relative contributions of the major substrate classes recorded from towed video footage on Douglas Shoal.

### *Native Reef*

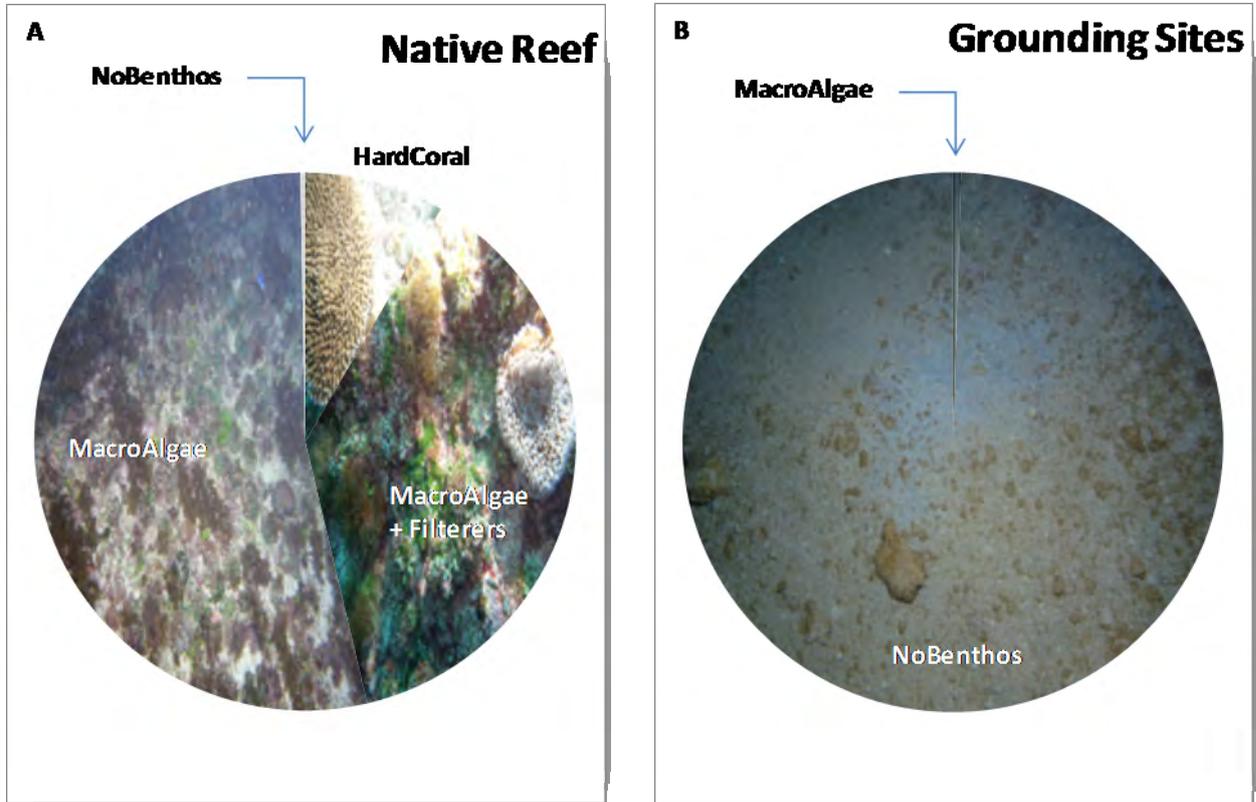
The shoal was limestone (85%) with gutters and holes where rubble (10%) and sand (5%) accumulated (Fig. 8). TUV revealed low profile benthic habitats, caused by relatively strong tidal currents. The lack of structural complexity was consistent with results obtained from the multibeam bathymetry. Macroalgae, visually dominated by *Sargassum*, was abundant over 53% of the surveyed tracks (Fig. 9A). A further 38% was classified as macro algae and filter feeder dominated communities. This included various algal species and, hard and soft corals. Approximately 8% of the surveyed shoal was dominated by small hard reef building coral colonies and the remaining 1% uncolonised.

### *Disturbed Reef*

There were extensive areas of destruction associated with contact of the hull on the shoal. Due to the size of the vessel, damage was observed some distance from the position recorded by the Automatic Identification System (AIS) onboard the *Shen Neng I* (data provided to AIMS by GBRMPA) but this was consistent with the lay of the ship as it initially drifted across the shoal in a WNW direction and then hauled south (Fig. 1).

Areas affected by the ship's grounding and subsequent passage across the shoal were clearly pulverized (Fig. 9B and Fig. 10). The resultant substrate was classed as unconsolidated rubble (5 – 50

mm fragments). Damage due to the ship's anchor (distinctive drag marks) and hull (rubble areas or dislodged corals/reef) were also identified. Broad areas were levelled where the ship lifted and rotated with the tide and wind pressure.



**Figure 9.** The relative contributions of the predominant benthos classes to the undisturbed shoal (A) and areas affected by the grounding of the *Shen Neng 1* (B).

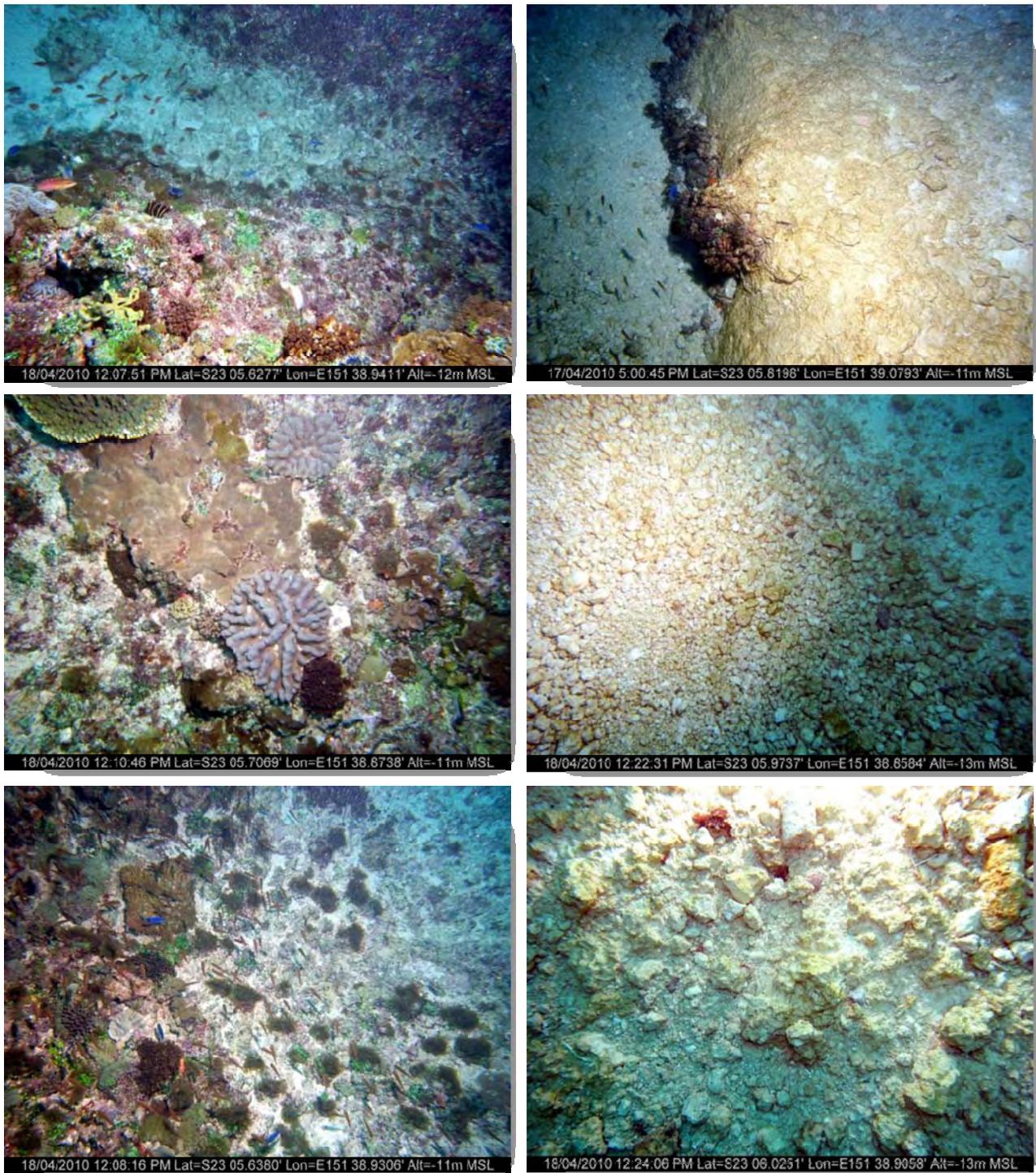


Figure 10. Representative images of the undisturbed benthos on Douglas Shoal (left) and areas affected by the grounding of the *Shen Neng 1* (right). The top right image gives a clear indication of how the reef was ground down leaving only benthos on the sides. Further images representative of each of the specific damaged sites can be found in Fig. 13.

Due to the influence of the prevailing weather conditions over the management of the survey vessel's low speed course and the absence of realtime acoustic imagery, not all impact sites were characterized. Regardless, sufficient ground was traversed (16.7 km) to indicate that the ship's hull effected considerable grinding of the reef structure. Figure 11 shows the temporary resting site of the *Shen Neng 1* (Site 4) following its initial westerly drift on the rising evening tide immediately following collision with Douglas Shoal. Three towed camera passes were made through the area and the distribution of pulverized substrate identified (black dots). The vessel arrived from the east (stern - pink track) with its head to the SW. The marks evident in the acoustic image were well matched by the classified camera imagery and show a vessel arriving broadside with much of the hull making contact with the seafloor. It was also evident from the video footage that very little of the seafloor in this area escaped being damaged.

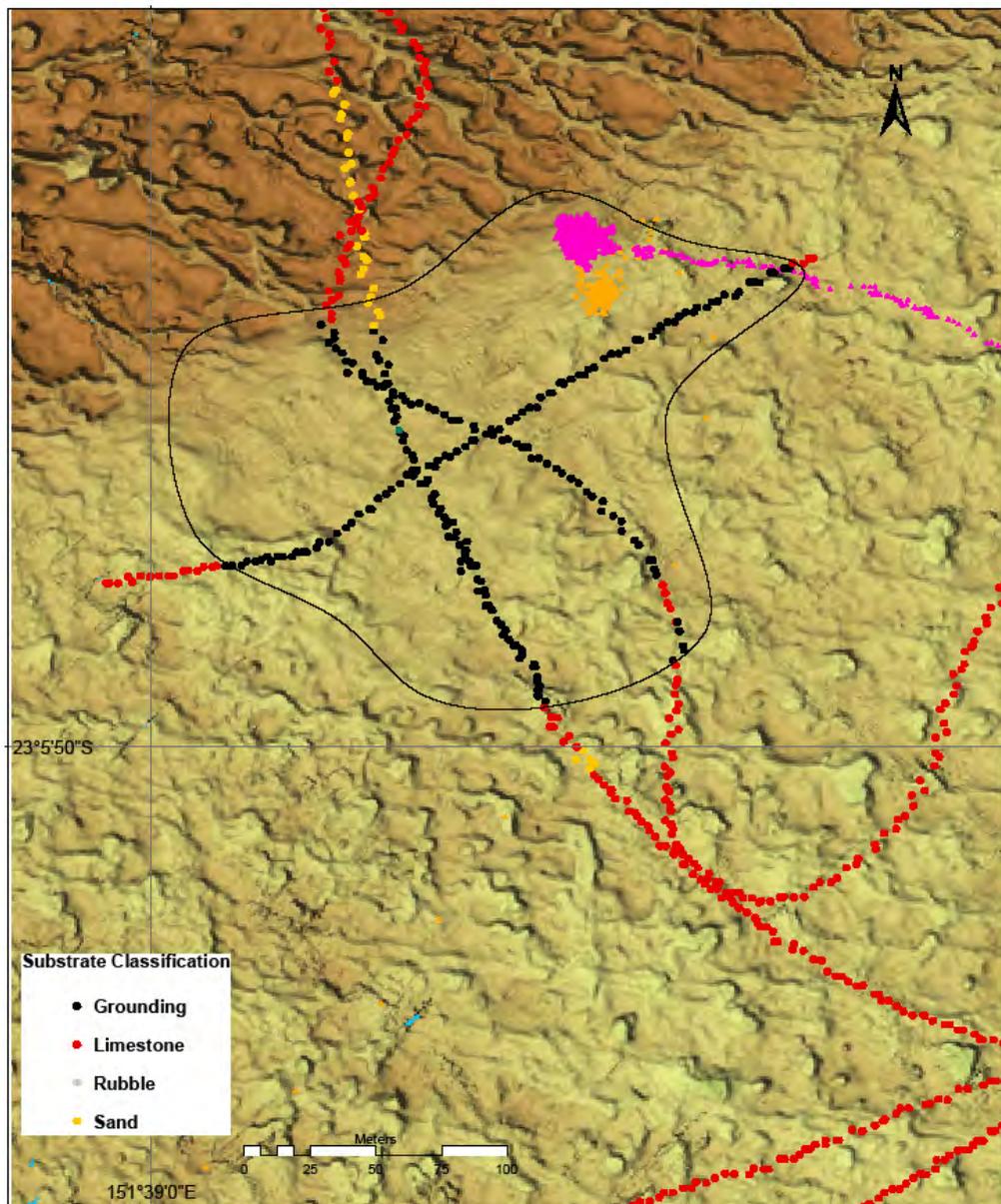
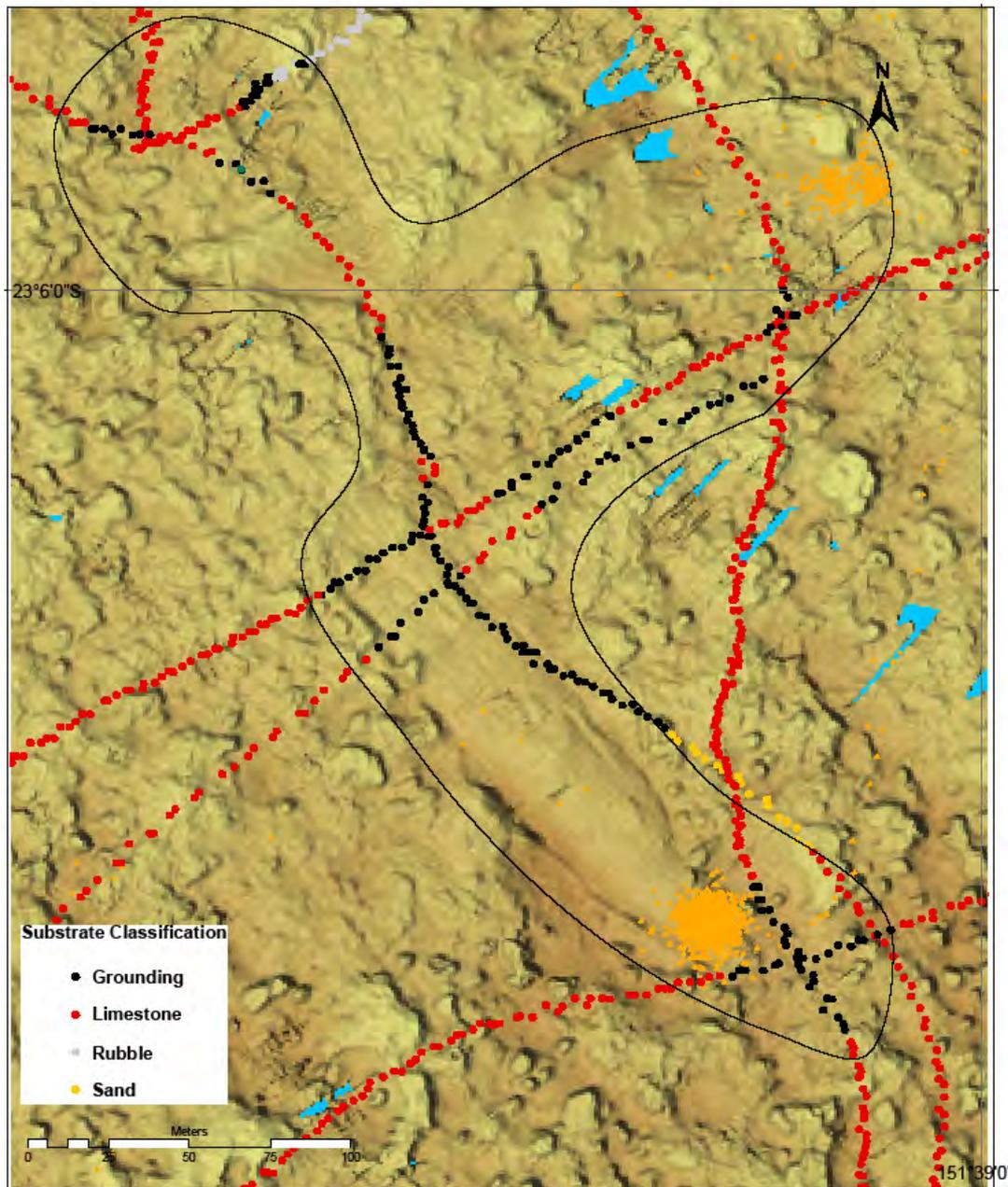


Figure 11. Acoustic image of Douglas Shoal where the *Shen Neng 1* encountered further shoaling which arrested its westerly drift (Site 4). Alterations to the topography are clearly evident as an area of disturbance (encompassed by black line) and visual assessment by towed camera validated and characterized these marks. Pink dots represent the grounding track and the orange dots the recovery track of the *Shen Neng 1* (see Figs. 1 and 7).

Similarly, the position of the vessel where it rested for one week prior to being refloated (Site 6) showed a very clear outline of the hull laying to the NW and the towed camera imagery captured some extent of the damage which was essentially a thorough pulverizing to rubble of the limestone reef matrix (Fig. 12). Immediately to the north of this resting site the vessel was also stationary for a period in an east – west orientation prior to the stern being brought south. Undamaged reef was encountered through an area between here and the resting depression to the south as the hull moved clear of the bottom.



**Figure 12.** Acoustic image of Douglas Shoal where the *Shen Neng 1* rested for 1 week prior to being refloated (Site 6). The impression of the hull is clearly evident and visual assessment by towed camera validated and characterized these marks and adjacent marks to the north and northwest. In this image, the ship lay east – west and then the stern was brought directly south with the ship rotating on its bow section. Orange dots represent the recovery track of the *Shen Neng 1* (see Figs. 1 and 7).

Extensive damage was also observed over the initial drift where the vessel put additional weight on the bottom prior to coming to rest in the early hours of the April 4<sup>th</sup> (Sites 2 and 3). Little damage was seen elsewhere on this passage - there was some dislodgement of hard corals and sections of reef matrix which is consistent with a relatively rapid drift (0.5 kts) and the hull largely clear of the sea floor. Images representative of each of the specific damaged sites can be found in Fig. 13.

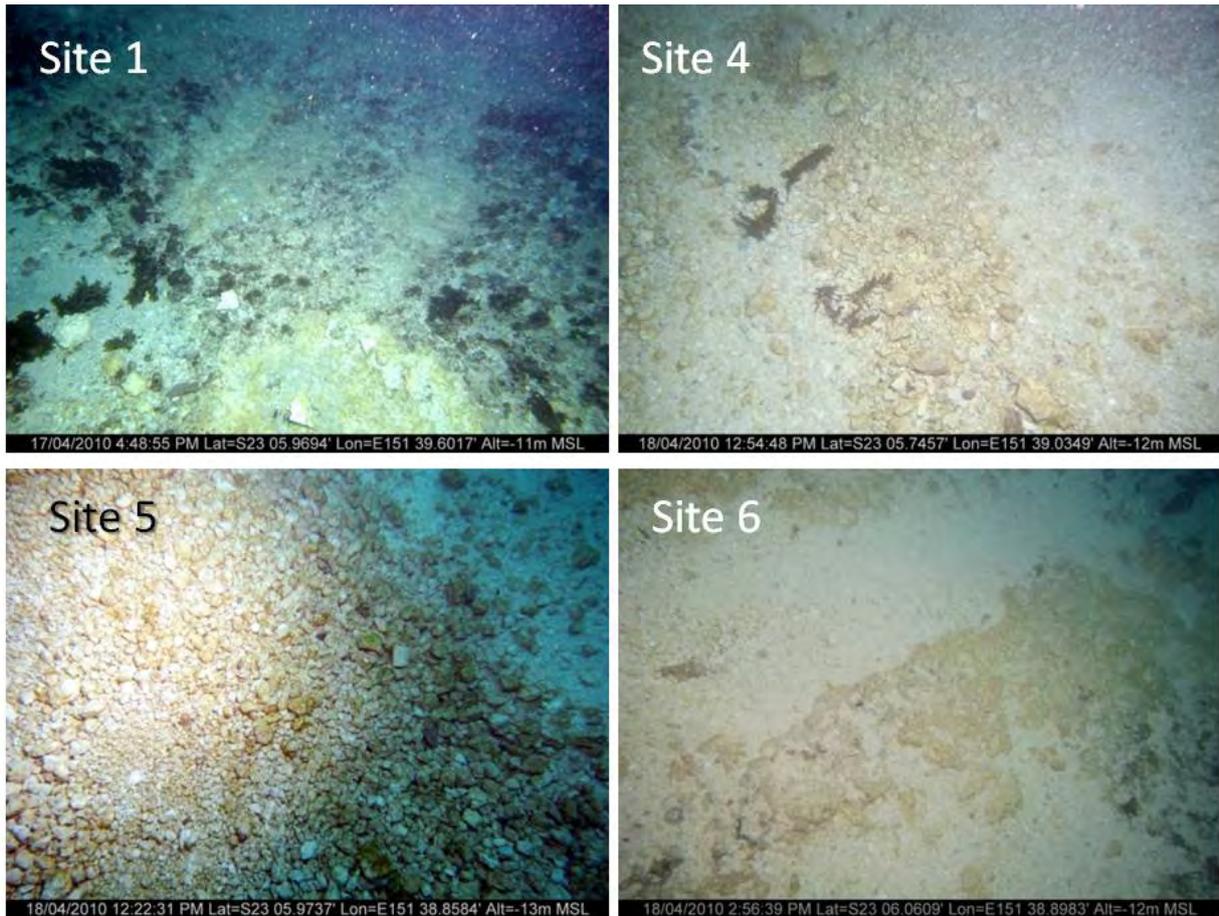


Figure 13. Photographs representative of damage Sites 1, 4, 5 and 6.

## 4. DISCUSSION

This report outlines a unique study into the physical and ecological damage caused by a large ship grounding using remote techniques. Multibeam bathymetry was used to map the topography of Douglas Shoal and, despite reduced sensitivity due to poor weather conditions, identified four large areas of physical damage caused by the grounding of the *Shen Neng I*. Towed underwater video (TUV) was then used to record the habitat types and broadly classify biota over 16 km of reef. Physical damage to the reef identified by multibeam bathymetry coincided with visual observations (geo-referenced) made by TUV. Multibeam bathymetry indicated physical damage to approximately 80,000 m<sup>2</sup> of Douglas Shoal, a much greater area than recorded for previous ship groundings on the GBR (Marshall et al. 2002). TUV revealed that the ship either sheared away the reef where it was in contact for periods of hours (e.g. Site 1) or ground the substratum into unconsolidated rubble when the ship was aground for periods of days (e.g. Site 6) (representative photographs in Fig. 13). While native reef exhibited 99% cover by algae, corals and other sessile organisms, disturbed reef was bare, supporting less than 1% algal cover. The combination of these remote techniques clearly demonstrated severe damage to reef and biota over a very large area of coral shoal.

The estimated area of reef damaged by the grounding of the *Shen Neng I* is far greater than the previous grounding of the *Bunga Teratai Satu* on Sudbury Reef (GBR) in 2000 (Marshall et al. 2002). While the *Bunga Teratai Satu* remained relatively stationary in a deep impact gouge, the stern of the *Shen Neng I* travelled approximately 2.4 km before the vessel was refloated. The extensive damage identified by multibeam bathymetry is consistent with the path and bearing of the ship recorded during the grounding (Fig. 5). This revealed broadside movement of the hull and a swinging motion over the course of the grounding, increasing the area of impact. Damage to the substratum was most severe where the ship remained stationary for at least hours (Fig. 4, Sites 1, 4, 5 and 6). Although multibeam bathymetry proved useful in identifying damaged reef structure, the estimated areas of damage should be considered approximate only since (i) weather-related motion of the *RV Cape Ferguson* reduced the sensitivity of this method and (ii) the relatively flat and featureless nature of the shoal reduced the contrast between native and damaged reef.

The physical structure and benthic communities visualized by TUV on the top of Douglas Shoal were similar to those recorded at Karamea and Barcoo Banks to the north or the Warregoes to the south (Stowar et al. 2008). All of these weather and tide-exposed banks exhibit complex fine-scale topography along with a relatively low structured benthos. The survey and characterization of Douglas Shoal with TUV equipment identified relatively large areas, consistent with the size of the *Shen Neng I*, which had been completely denuded and reduced to rubble. There was no evidence that the benthos survived contact with the ship's hull where sufficient deadweight of the boat was involved. Elsewhere, over the course of the vessel's drift, intermittent damage was evident as bumps from the hull rather than scrapes.

The initial grounding at the bottom of the tide pulverized and ground the reef flat (Site 1), but the subsequent westerly drift on the rising tide caused substantially less damage than the size of the vessel and its predicament might otherwise imply (between Sites 1 and 2). The recovery track (between Sites 4 and 5) was not very well covered by TUV survey apart from areas to the south where the vessel remained for a week prior to being refloated (around Site 6). The waypoints for the vessel indicate that it was largely free of the bottom between Sites 4 and 5 and it might be expected that there would be minimal damage over this course. At Site 6, damage to the reef was severe, with a large area of reef pulverised into unconsolidated rubble.

The grounding of the vessel caused two major classes of physical impact on Douglas Shoal. Where reef was scraped by horizontal motion of the hull, the substratum became very flat and compacted. Recruitment of corals onto this type of habitat may be reduced as larvae usually prefer to settle on

vertical surfaces or on the undersides of small platforms (Babcock & Mundy 1996). Mortality of juvenile corals on sedimented upper surfaces is also high. These flat, compacted habitats may also be contaminated by antifouling paint as reported at Site 1 (Marshall 2010). Antifouling paints typically contain biocides including copper, zinc, herbicides and (until a recent ban) tributyltin. At high enough levels these biocides have the potential to inhibit and reduce coral settlement and recruitment (Reichelt-Brushett & Harrison 2000, Negri & Heyward 2001, Smith et al. 2003, Reichelt-Brushett & Michalek-Wagner 2005), further slowing reef recovery. Analysis of approximately 160 sediment samples taken from Douglas Shoal by divers (McCook 2010) following the *RV Cape Ferguson* Voyage will reveal the extent of this contamination threat. Sediment analysis will be augmented by the assessment of water column contamination following analysis of passive samplers and water samples taken during the *RV Cape Ferguson* voyage. The *Shen Neng I* also pulverised large sections of hard limestone reef into unconsolidated rubble (Site 6). Corals and many other invertebrates require solid substrata for juvenile survival (Rinkevich 2005). The rubble identified with TUV was in the size class 5 – 50 mm and is much less suitable for coral recruitment than solid substratum. Reef recovery in these areas is likely to take much longer than areas compacted by the ship grounding.

## 5. CONCLUSIONS

The structure and biota of Douglas Shoal were successfully assessed using the dual remote techniques of multibeam bathymetry and towed underwater video. In combination, these techniques revealed the large scale of physical damage to the shoal (estimated to be in the order of 80,000 m<sup>2</sup>) and almost complete elimination of sessile invertebrates and algae where the ship contacted the reef.

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## 8. APPENDIX

### 8.1 Additional Multibeam Images

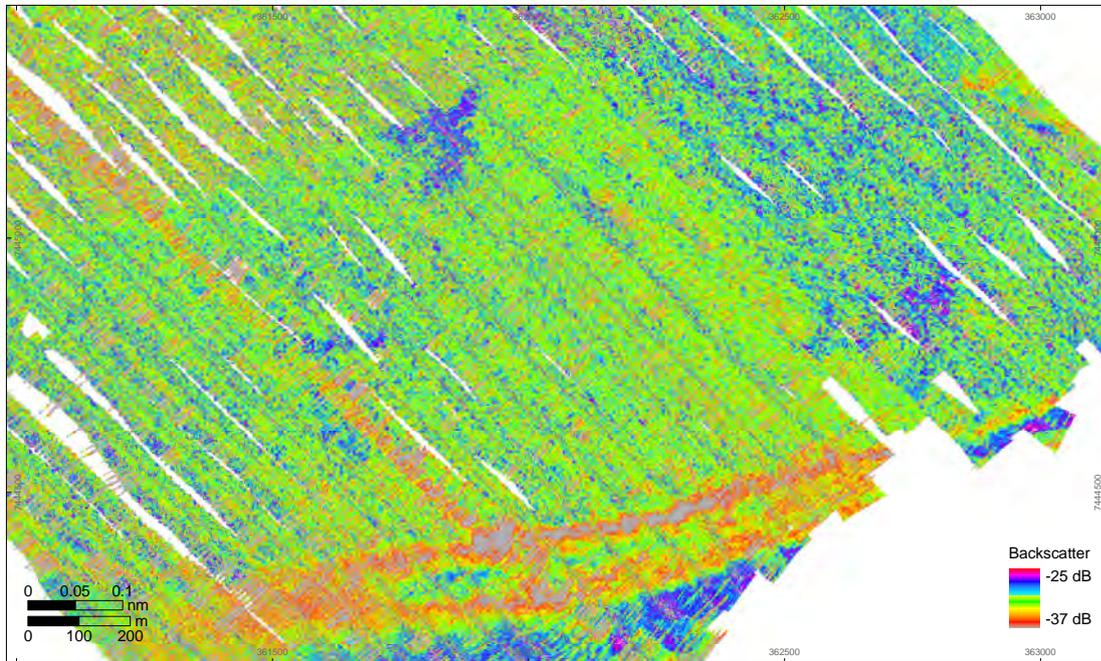


Figure A1. Multibeam backscatter strength of impact region.

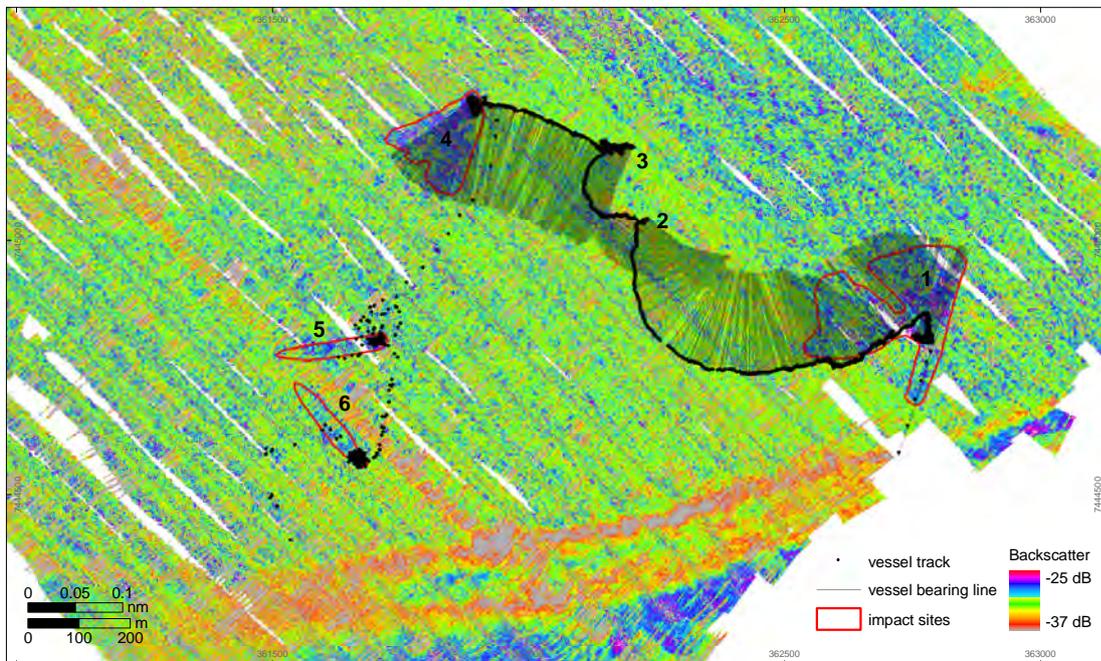


Figure A2. Multibeam backscatter strength of impact region with vessel track, bearing line and impact sites.

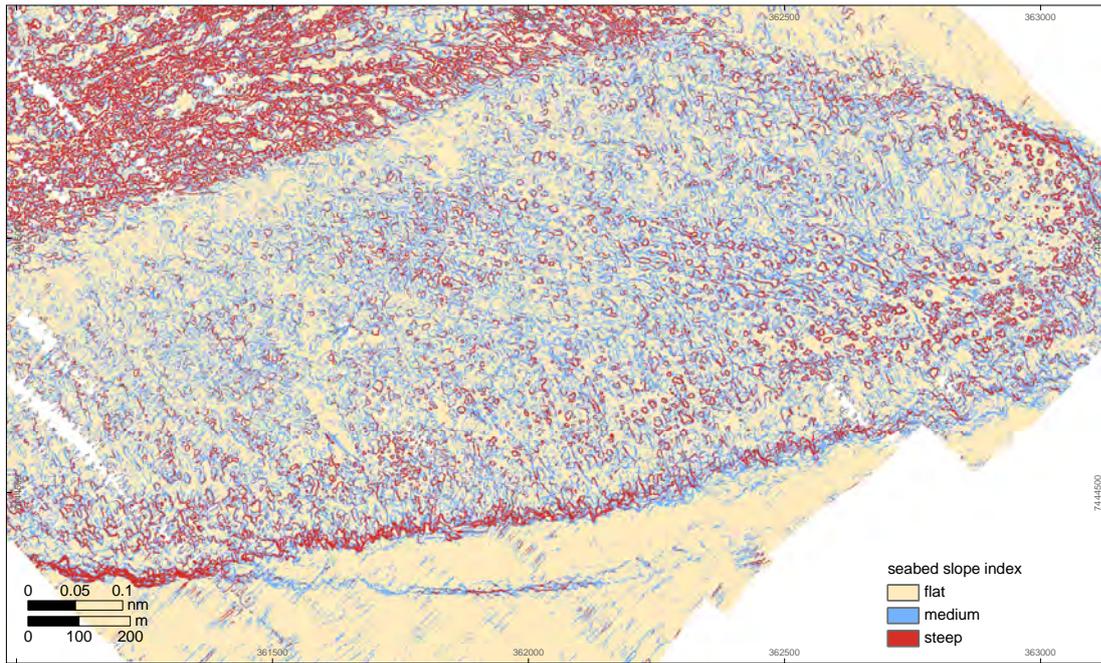


Figure A3. Seabed slope of impact region.

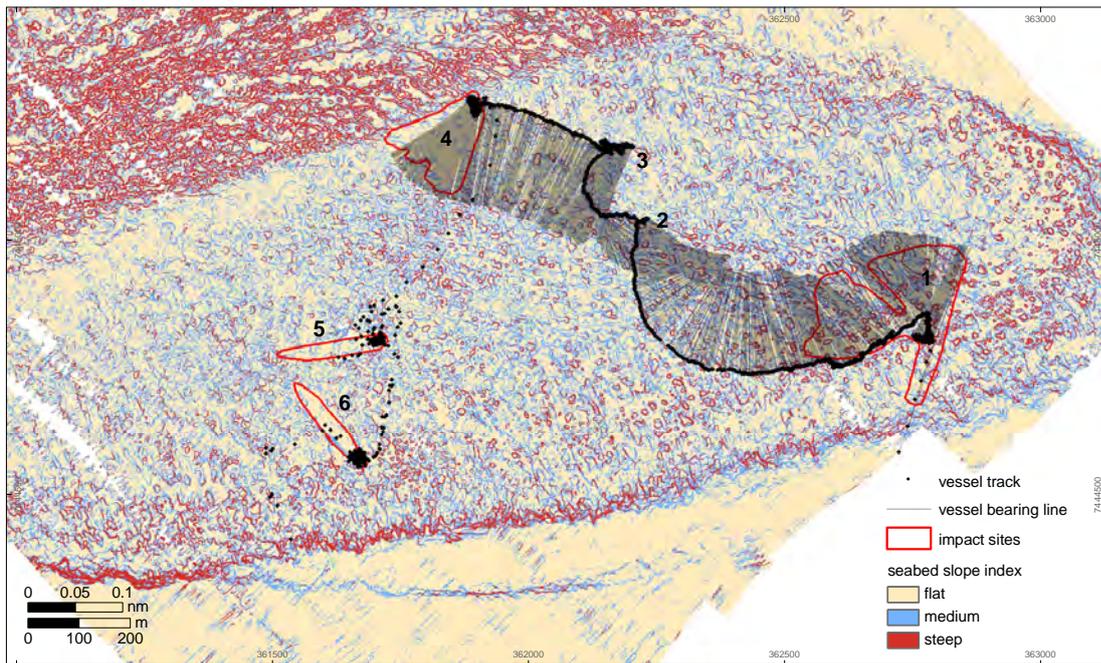


Figure A4. Seabed slope of impact region with vessel track, bearing line and impact sites (site names see text).

## 8.2 Physical Oceanographic Observations

### *Oceanographic Background*

The southern section of the Great Barrier Reef in the vicinity of Douglas Shoal, the Capricorn Group of Islands and the Capricorn channel is a region of rich oceanographic complexity. Tides in the area are semi-diurnal, with a maximum range of > 3.5 m. It would be expected that away from the steering influence of shoals and islands, the general tidal flows are towards the north-west during the flooding phase of the tide and towards the southeast during ebb.

Prevailing currents on the inner and mid shelf are driven by the tides and wind forcing, with the contribution from wind forcing being proportional to the wind strength. During periods of SSE winds, flow on the inner- and mid-shelf is predominantly north-north-west with tidal motion superimposed on the wind driven circulation. Currents in the mid- to outer-shelf experience a greater influence from the shelf expression of the East Australian Current in the Capricorn Channel. The boundary between the inshore northwards flow and the more southerly mid-shelf flow is spatially and temporally variable and depends on atmospheric and larger scale oceanic forcing. Douglas Shoal appears to lie within the transition zone of these inner- and outer-shelf current regimes. An oceanographic feature of the region which adds to the complexity is the Capricorn Eddy (Woodhead 1970, Weeks et al. 2010) which is a semi-permanent clockwise circulation feature at the mouth of the Capricorn Channel. This eddy can drive a recirculation of material originating from the Capricorn Channel along a trajectory that is characterized by a northwards flow along the shelf edge east of the Capricorn Group of Islands.

### *Existing Current Observations*

As part of the Great Barrier Reef Ocean Observing System (GBROOS) and array of oceanographic moorings equipped with Acoustic Doppler Current Profilers (ADCP) and water quality instruments are deployed in the southern section of the GBR, including current monitoring around Heron and One Tree Islands, about 50 km to the south-east of Douglas Shoal and in the Capricorn Channel to the north-north-east. The location GBROOS moorings are shown in Fig. A5. The GBROOS mooring array was recovered during April 13 - 30, 2010 as part of a regular bi-annual service schedule.

### *Satellite Tracked Drifter Release*

Satellite tracked drifters recently developed at AIMS provide accurate, high frequency and low cost mapping of surface currents via satellite communications. Following the successful removal of the *Shen Neng 1*, a satellite tracked drifter was deployed at Douglas Shoal from the AIMS RV *Cape Ferguson* to assess local circulation and current drift away the shoal (Fig. A6). The drifter used a sea anchor drogued to a depth of 7 m and was released at the final grounding site of the *Shen Neng 1* (Site 6) at 17:49 on 17 April 2010 [23°06.03' (S); 151°38.86' (E)].

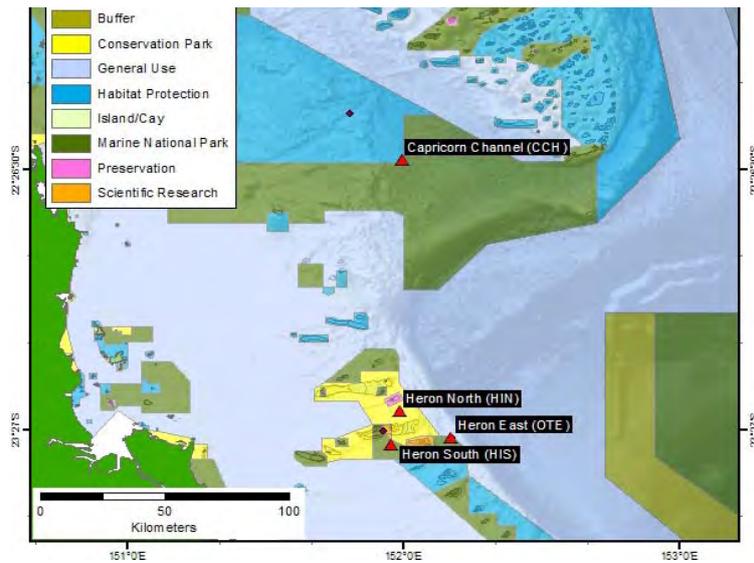


Figure A5. Southern GBROOS Moorings locations



Figure A6. Release of the satellite tracked drifter from the stern of the *RV Cape Ferguson*.

#### *Path taken by the satellite tracked drifter*

During the first 36 hours after release from Douglas Shoal, under light wind conditions, the drifter travelled in a predominantly WNW / ESE trajectory, under the influence of flooding / ebbing tidal currents (Fig. A7). The SE trade winds subsequently move it to the NW.

Under strong SE winds, the drifter moved towards and then past Cape Clinton, and then gradually travelled off-shore and into a SE lagoonal branch of the East Australian Current (Fig. A7) (Brinkman et al. 2002) and towards the Swains Reef Complex (Fig. A7). The transition of the drifter trajectory from within a coastal current to an offshore path corresponds to the “Cape Clinton Front” first described by Burrage et al (1996) from satellite imagery; it is hypothesised that the macro-tides near

Broad Sound effectively create a frictional barrier to coastal low frequency flow and steer the coastal current offshore.

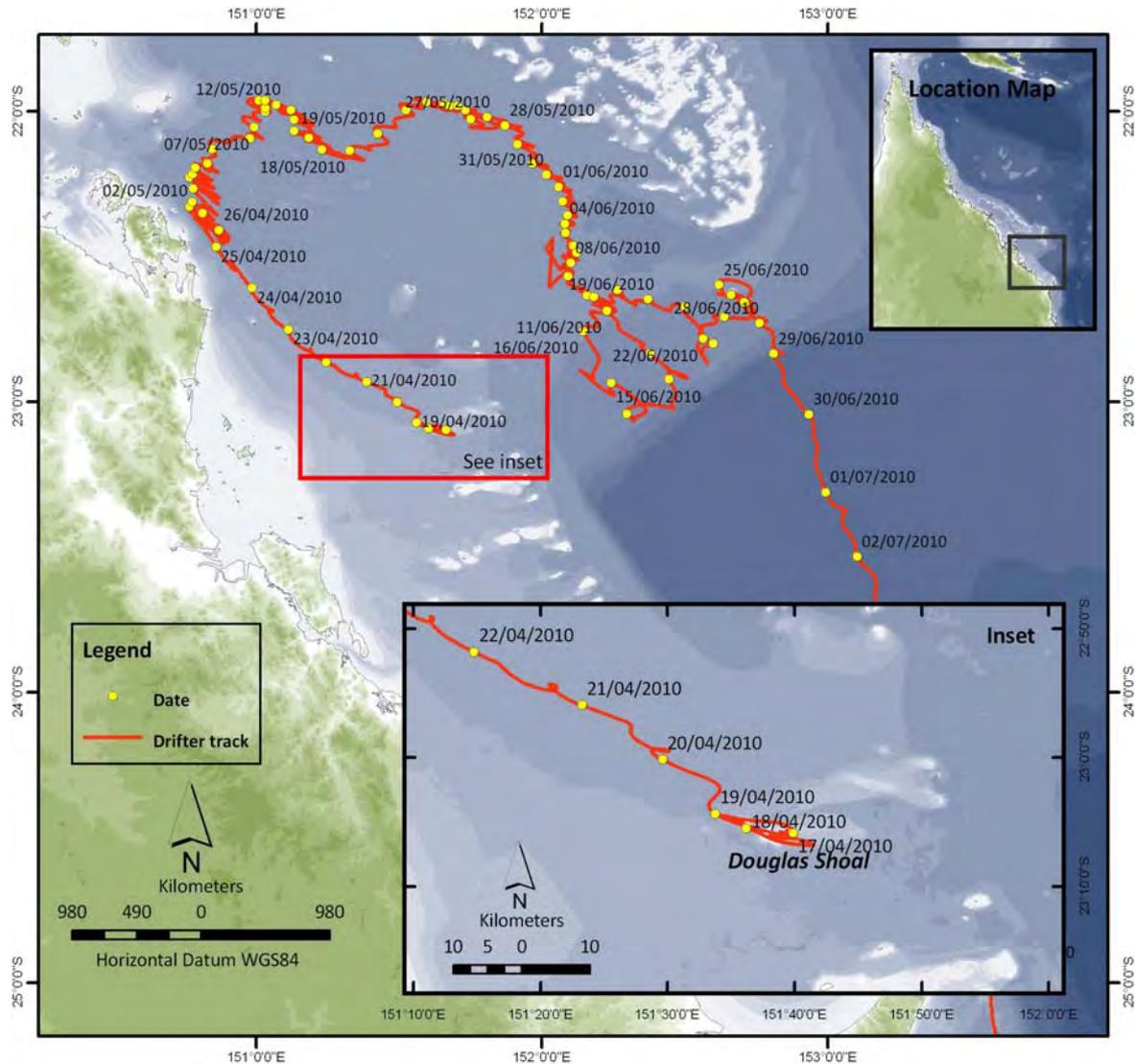


Figure A7. Track of drifter between April 17 and July 2, 2010.

### *The potential influence of currents and winds on spills at Douglas Shoal*

Although geographically isolated, Douglas Shoal represents a potential shipping hazard for vessels leaving the busy Port of Gladstone and exiting the GBR via the passage north of North West Island. Calm weather over the course of the *Shen Neng 1*'s eight day grounding was extremely fortunate as Maritime Safety Queensland was initially concerned that the working of the vessel on the hard reef top might cause major structural damage, permitting the release of fuel and cargo (MSQ 2010). During the period of the grounding, winds from the SE persisted locally until April 09, 2010. Between April 09 and April 12, winds were from the NW, before reverting back to SE on April 13, 2010 (GBROOS 2010). A major oil spill at Douglas Shoal is likely to follow a complex course as demonstrated by the path of the drifter deployed at the grounding site. The initial drifter release at Douglas Shoal had a tidal excursion of 13.8 km oriented WNW on the flood and east-south-east on the ebb. The drifter returned to almost the same location, demonstrating that under benign wind

conditions the tide would likely have moved an oil slick away from, then back towards the shoal along a WNW / ESE trajectory on each changing tide. However, the trade winds in this region are generally from the SE, creating wind-driven currents towards the NW, in the direction of Cape Clinton. Under SE winds, an oil spill is likely to be transported NW towards the coast, as was observed for the drifter after 19/4/2010 as SE winds increased. A persistent slick may then be carried off-shore by the Cape Clinton Front, an oceanographic feature that steers northward flowing currents towards the pristine and sensitive Swains Reef Complex, approximately 140 km offshore. Other drifters released at Heron Is. around the time of the grounding followed similar paths (Steinberg, unpublished). However, strong winds from the NW or relaxation of NW-ward currents could transport oil from spills towards islands and reefs SE of Douglas Shoal. These oceanographic observations indicate that persistent oil slicks originating in the Douglas Shoal region have the potential travel towards the coast of the mainland and towards sensitive coral reefs.

**Appendix D:**

***Shen Neng 1* Hull Sampling, 21 May 2010:  
field report**

[Report of hull sampling for anti foulant paint constituents]





Australian Government

Great Barrier Reef  
Marine Park Authority

FIELD REPORT:  
***Shen Neng 1*** Hull Sampling:  
**21 May 2010**



*Great Barrier Reef Marine Park Authority*

***James Monkivitch***

*13 December 2010*



## Executive Summary

Observations, scraping samples and photographs were taken of the hull of the *Shen Neng 1* whilst it was at anchor in Platypus Bay, Queensland on 21 May 2010.

Analysis of the samples and records confirms that the entire underside of the *Shen Neng 1* had experienced significant abrasion and damage, consistent with the reported grounding event at Douglas Shoal in the Great Barrier Reef Marine Park on 3 April 2010 and the next nine days before being refloated.

Damage was recorded for all underside (flats) areas of the ship observed. The entire underside (flats) of the hull is highly likely to have been in contact with the shoal during the grounding. Paint loss from the hull varied from significantly damaged areas of bare exposed metal with corrosion (that is total loss of all paint systems - for example, from the underside of the hull at holds 1, 2, 3, 4 & 5) to no noticeable impact in elevated areas such as the stern areas adjacent the propeller shaft.

Antifouling paint is highly likely to have been lost from most of the underside of the *Shen Neng 1*.

Chemical analysis confirmed that for all areas sampled the antifouling paint contained environmentally significant concentrations of *tributyltin* (TBT), zinc, copper and other metals.

Observations confirmed that the damage to the hull was sufficient to expose and abrade the underlying TBT containing paints from the hull and therefore contamination of the sediments of Douglas Shoal with antifouling paints including TBT is certain to have occurred as a result of the grounding.

The grounding was estimated to have removed between 39-78 kg of copper oxide and 15 to 39 kg of zinc oxide from recently applied paint systems on the flats of the hull and an unknown mass of TBT and other biocides and metals from the historic antifouling paint systems.

The concentrations of TBT and other metals including copper and zinc recorded for the paint system of the *Shen Neng 1* pose a significant risk for corals and other organisms if they contaminate the sediments of Douglas Shoal as a result of the grounding.

Contamination of the substrate of Douglas Shoal with antifouling paints is likely one of the most significant ecological impacts of the grounding of the *Shen Neng 1*.

The impact of the antifouling paint contamination is not likely to be limited to the immediate grounding site and may persist for some years if not removed or remediated.

## Contents

Executive Summary.....	1
Background .....	3
Objective.....	3
Methods.....	3
Grounding Incident.....	3
Hull Sampling.....	3
Scraping Sample Collection.....	6
Chemical Analysis .....	7
Laboratory Methods.....	8
Paint System Information.....	8
Results.....	8
Grounding Incident.....	8
Hull Sampling.....	9
Personnel and Expertise.....	9
On Board Briefing .....	11
Sample Collection.....	12
Chemical Analysis.....	12
Hull Observations .....	17
Antifouling Paint Regulation .....	22
Paint System Records for <i>Shen Neng 1</i> .....	23
Presence of TBT.....	23
Previously Known Condition of Paint System .....	23
Paint System Product Information. ....	24
Discussion .....	25
Potential for Contamination from Antifouling Paints .....	25
Previous Groundings in the Reef and TBT Contamination .....	26
Implications of Contamination from Grounding of Shen Neng 1 .....	26
References .....	28
Annexure A: Observations and Analytical Results from Hull Scrapings.....	29
Annexure B: Shen Neng 1 Hull Sampling 21 May 2010 Photographic Log. ....	31

## Background

At approximately 11 am on Saturday 3 April 2010 the 230m long bulk coal carrier *Shen Neng 1* left its berth in Gladstone Harbour bound for China. She was loaded with 68,052 tonnes of coal and had a forward draft of 13.29m and an aft draft of 13.38 m (Commonwealth of Australia 2010a).

At approximately 5.10pm on that day, the *Shen Neng 1* ran aground on Douglas Shoal, approximately 92km north-east of Gladstone, within the Great Barrier Reef Marine Park (refer **Figure 1**).

Initial grounding site assessment reports confirmed significant physical impacts to the shoal and the presence of antifouling paint in the area of the grounding (Marshall 2010).

## Objective

The objective of this report is to:

- confirm the amount of damage to the hull
- inform assessment of amount of paint lost from the vessel during grounding
- confirm the chemical composition of hull coatings; and
- assess the nature of the grounding event at Douglas Shoal.

## Methods

### Grounding Incident

A range of reports and information were reviewed to extract relevant information around the events of the grounding of the *Shen Neng 1*. The principal purpose of that review was to confirm the nature of the grounding to assist in interpretation of the condition of the hull and analysis of the results.

### Hull Sampling

The sample plan included SCUBA dive survey and sample collection to be undertaken at pre determined locations on the vessel hull (refer **Figure 2**). Position of samples was determined by physical locations on the ship, for example mid points of hatch covers, and use of an in-water shot line to provide a point for divers at the bilge keel (refer **Figure 3**).

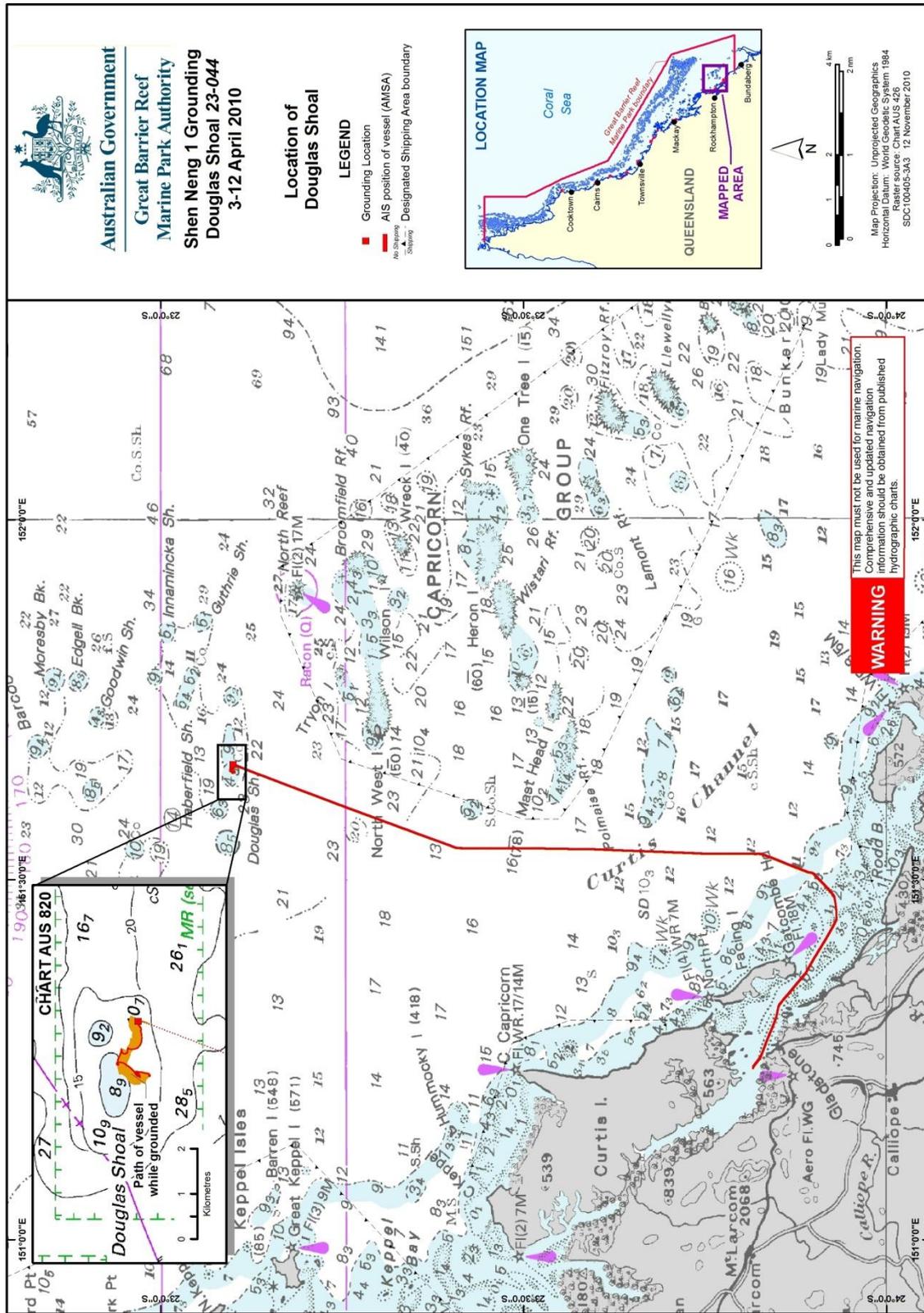


Figure 1. Location of Shen Neng 1 grounding

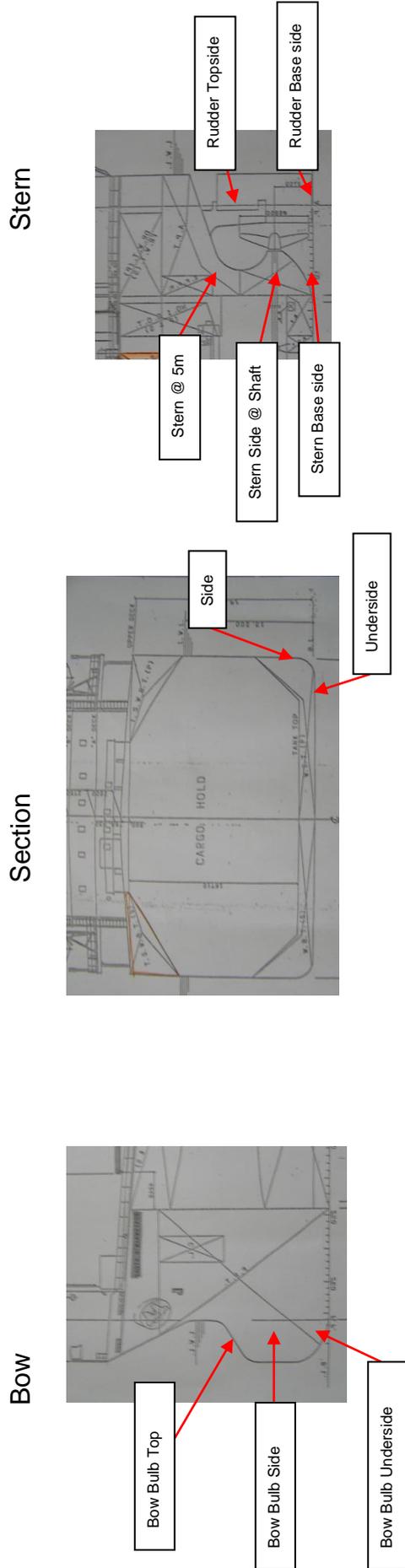
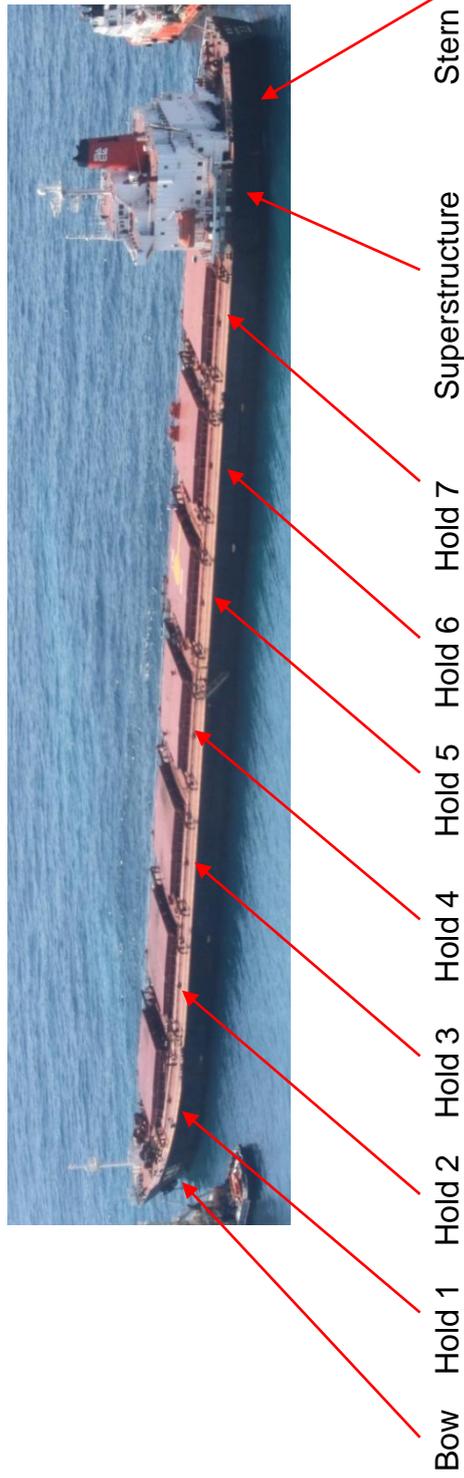


Figure 2. Indicative Hull Sample locations:

At other locations (such as on the bow bulb and stern areas) divers confirmed their positions through visual orientation using ship's features.

For safety purposes, access to the underside of the vessel was deliberately limited to areas visible and in reach from a position less than 2 m from the outer margin of the bilge keel/turn providing appropriate unrestricted access to the surface by SCUBA divers.



Figure 3. Shot line to confirm in-water sample location

### Scraping Sample Collection

Sample containers were unpreserved, pre-prepared (washed) sample jars (refer **Figure 4**) provided by Queensland Health Forensic and Scientific Services (Queensland Health Forensic and Scientific Services, PO Box 594, Archerfield, Queensland 4108, Ph: 61 7 3274 9071; [www.health.qld.gov.au/qhcss/qhss/](http://www.health.qld.gov.au/qhcss/qhss/)).



Figure 4. Laboratory pre-prepared sample containers

Sample jars were labelled and pre-filled with sea water collected on site and recapped before collection dives.

At each pre determined site the following actions took place in order:

- photograph hull surface area of an approximate minimum of 30 cm x 30 cm
- lightly clean hull surface of fouling to improve visibility of paint systems through rubbing with scourers or glove
- rephotograph cleaned area
- observations recorded in-water included: hull surface colour, condition and similarity to adjacent areas visible to the divers but not included in the photograph.
- hull scraping samples were obtained by the deliberate targeting of an area within or adjacent to the photographed area that included visible paint
- scraping of paint directly from the ship's hull using a stainless steel dive knife
- hull scrapings were collected directly into the sample container
- samples were sealed immediately, a record made of the sample number and samples were photographed and placed in the diver's carry bag
- the diver provided a description of the condition of the photographed hull area in context with larger adjacent areas within visibility range
- after each dive sample containers were refrigerated on the *Mirrigimpa*; and
- samples were maintained chilled until delivered to the Queensland Health Forensic and Scientific Services and stored.

Collection of hull scraping samples and observations from a range of locations on the vessel aimed to provide the best possible indication of the general condition of the hull within the limited dive times available. The number of samples collected was limited by available time and dive profiles.

### Chemical Analysis

On 22 June 2010 at the Queensland Health Forensic and Scientific Services laboratory, the samples were ground to a fine powder in a TEMA Fe/Cr swing mill. Each powdered sample was then split three ways:

- one split provided to the ship owner's insurance representative on-site;
- one split dispatched on 23 June 2010 to the ALS Laboratory Group (ALS Laboratory Group, Environmental Division Brisbane, 32 Shand Street Stafford QLD Australia 4053, Tel. +61-7-3243 7222 [www.alsglobal.com](http://www.alsglobal.com)) for tributyltin (TBT) determinations; and
- one split retained at the Queensland Health Forensic and Scientific Services laboratory for the metals analysis.

Of the 29 samples, seven were not large enough to be split, consequently for these samples, the entire sample was sent to the ALS Laboratory Group for TBT determinations.

## Laboratory Methods

### *Organotin (TBT) Analysis:*

All samples were analysed for TBT by the ALS Laboratory Group according to the following brief statement of methods:

**Sample preparation:** (in-house process (ORG35)) the sample is spiked with surrogate and leached in a methanol:acetic acid:UHP water mix and vacuum filtered. Reagents and solvents are added to the sample and the mixture tumbled. The butyltin compounds are simultaneously derivatised and extracted. The extract is further extracted with petroleum ether. The resultant extracts are combined and concentrated for analysis.

**Organotin Analysis:** (Process EP090, per USEPA SW 846 - 8270D) Prepared sample extracts are analysed by GC/MS coupled with high volume injection, and quantified against an established calibration curve.

### *Metal Analyses:*

A known weight of each of the finely ground samples was taken and digested in acid to Australian Standard AS4479. The digestates were diluted to volume with high purity water and elements were then determined by Inductively Coupled Plasma Atomic Emission Spectrometry (ICPAES).

## Paint System Information

Information about the paint systems on the hull of the *Shen Neng 1* was sought from the ship owner's insurance representatives and paint system providers. Information included the recent ship maintenance records, International Maritime Organisation (IMO) compliance certificates, hull coating product description and materials safety and handling information.

## Results

### Grounding Incident

A range of reports and information were accessed to extract relevant information around the events of the grounding of the *Shen Neng 1*. The principal purpose of this information is to confirm the nature of the grounding to assist in interpretation of the condition of the hull and analytical results for the purpose of environmental impact assessment.

At approximately 5.10pm on Saturday 3 April 2010, the *Shen Neng 1* ran aground on Douglas Shoal, approximately 92km north-east of Gladstone, within the Great Barrier Reef Marine Park. Reports of investigation into the incident (Commonwealth of Australia 2010a) included that the ship "came to a shuddering stop" at GPS position 23°06.0'S 151°39.6'E. The charted depth on Douglas Shoal at that position is approximately 10 m (refer **Figure 1**). The tidal predictions for Gladstone on that

day indicated a falling tide to 1.25m at 1534 hours (Commonwealth of Australia, 2010b). On departure from Gladstone the *Shen Neng 1* was loaded with 68,052 tonnes of coal and had a forward draft of 13.29 m and an aft draft of 13.38 m.

The combined charted depth and a conservative allowance for tide indicate that the depth of water at that location and time would be greater than two metres less than the stated draft of the *Shen Neng 1*. It is clear that the vessel hull would have contacted the seabed in that location at that time.

Reports of soundings around the vessel by the crew at the time of grounding confirmed minimum water depths of 11-12 m around the ship, with the minimum depth of 11 m sounded approximately midlength on the port side (Commonwealth of Australia 2010a).

Similarly the reported positions of the vessel over the period 3 April 2010 until refloated on 12 April 2010 (refer **Figure 1**) indicate that the vessel hull is likely to have contacted Douglas Shoal in multiple places in that time. This would have been as a result of its draft exceeding the charted water depth plus tide.

### Hull Sampling

The *Shen Neng 1* was at anchor in Platypus Bay on 21 May 2010. The joint Great Barrier Reef Marine Park Authority and Queensland Parks and Wildlife Service (QPWS) hull sample team was comprised of: Oliver Lanyon (OL); Damon Shearer (DS); Daniel Clifton (DC); and James Monkivitch (JM).

### Personnel and Expertise

- James MONKIVITCH: Manager, Ports and Shipping, Environmental Assessment and Management Group, GBRMPA. Bachelor of Science in Marine Biology, James Cook University (1994). Certified Environmental Practitioner (through the Environment Institute of Australia and New Zealand). GBRMPA Deputy Dive Officer. Qualified Commercial Scuba Diver (ADAS AS 2815.1) (1994). Advanced Open Water Diver (PADI), Wreck Diver and Ice Diver (PADI). Coxswains Certificate issued by MSQ. Sixteen years experience as a marine environmental impact assessor and manager. Experienced and trained in marine sediment sampling and analysis, coral reef visual and video surveys and vessel impact site assessments in the Great Barrier Reef Marine Park and other marine environments, including: eight years experience as a marine science consultant including tropical coral reefs, seagrass and mangrove studies, assessing impacts of dredging and conducting sediment contamination sampling and interpretation studies; production of over 50 consultant reports and expert review reports for marine environmental projects across Australia and New Zealand; more than eight years with the GBRMPA in environmental impact assessment and management roles including current role of preparation and response to shipping incidents, including delivery of over 22 conference presentations, training sessions or published papers on

risk assessment, impact management, coral transplantation and artificial reefs.

Role: Diver, hull scraping sample collection and photography.

- Oliver LANYON, Senior Ranger (Compliance), QPWS, Rosslyn Bay. Authorised Marine Park Inspector under the Commonwealth of Australia for the Great Barrier Reef Marine Park Act 1975 and Environment Protection and Biodiversity Act 1999. Advanced Diploma in Aquatic Resource Management, Central Queensland University (1996). Bachelor of Science Degree in Aquatic Resource Management with co-major in Industrial Chemistry (2003); Diploma of Government (Fraud Control). 13 years experience as a Ranger with QPWS. Previous experience as Investigator/Senior Investigator with the GBRMPA (2006 - 2007) Qualified Commercial Scuba Diver (ADAS AS 2815.1) (2003); Advanced Open Water Diver (PADI), 217+ dives; Coxswains Certificate (Open) issued by MSQ (2000). Training and experience in visual surveys, video surveys, coral surveys and vessel impact site assessments in the Great Barrier Reef Marine Park (Rapid Assessment Monitoring Program (RAMP); Reef Health & Impact Surveys (RHIS); Site Assessment of Damage (SAD), including production of damage assessment reports and Briefs of Evidence.  
Role: Dive Supervisor, Diver, photographer, GPS navigation.
- Mr Damon SHEARER. Senior Technical Officer, QPWS, Central Marine Region. Bachelor of Technology in Biology, Central Queensland University (1998). Qualified Commercial Scuba Diver (ADAS AS 2815.1) (2000) 200+ commercial/scientific dives. Trained in Reef Health Impact Surveys and Site Assessment of Damage. 7 years experience as Research Technician and Dive Officer for the Centre of Environmental Management at Central Queensland University (1999 - 2006); Member of Coastal CRC, working in the Coastal Wetlands and Contaminant Risk Assessment teams in Port Curtis (2002-2006). Extensive experience in sampling marine sediments for contaminant testing.  
Role: Dive Supervisor, Diver, hull scraping sample collection.
- Mr Daniel CLIFTON. Senior Ranger Great Sandy Marine Park, QPWS, Hervey Bay. Bachelor of Applied Science (Honours) Southern Cross University (2001). Certificate IV in Statutory Compliance (2007). Marine Parks Inspector under the Marine Parks Act 2004 (Qld) with 3 years experience in conducting compliance and investigations in this role. PADI Divemaster and appointed as a QPWS Dive Supervisor with 90+ dives. Coxswains Certificate (Open) issued by NSW waterways in 2000 and later transferred to MSQ in 2010. Three years experience as a ranger with QPWS. Training and experience in visual surveys, video surveys, coral surveys, Rapid Assessment Monitoring Program (RAMP) and Reef Health & Impact

Surveys (RHIS).

Role: Diver, hull scraping sample collection.

The team operated from the QPWS vessel *Mirrigimpa* and tenders including from the QPWS vessel *Kerra Lyn*, also on site. Support crew including for boat operations, included the crews of both *Mirrigimpa* and *Kerra Lyn*.

### On Board Briefing

The team arrived alongside *Shen Neng 1* at approximately 0900 hours on 21 May 2010. The *Shen Neng 1* appeared stable and was at anchor on starboard anchor with no immediate signs of damage (refer **Figure 5**).



Figure 5. Shen Neng 1 on site in Platypus Bay 21 May 2010

From the water the draft of the *Shen Neng 1* was observed as: 12.6 m at bow, 12.6 m at mid ships and 14.4 m at stern using the hull draft marks in each case.

The boarding of the ship and the taking of samples from it by the team was done with the consent of the ship's owner and through the exercise of certain powers in accordance with ss 405 and 406 of the *Environment Protection and Biodiversity Conservation Act 1999*.

Permission was granted by Mr Jan Polderman (Salvage Master) via radio, for the team to board the *Shen Neng 1*. We met Mr Polderman in his cabin along with Mr Darron Simmonds (ship owner's insurer representative) and others. We provided Messrs Polderman and Simmonds and others a verbal brief of our dive safety requirements. Messrs Polderman and Simmonds requested that we also collect hull scraping samples in duplicate for them as we worked. We advised that it was not possible with the time constraints of the day. During our departure from the *Shen Neng 1*, we accepted four sample containers (for example of type refer **Figure 6**) by hand from Mr Simmonds and we agreed that if time permitted we would provide him some samples of hull scrapings. At approximately 0940 on 21 May 2010 we disembarked *Shen Neng 1*.

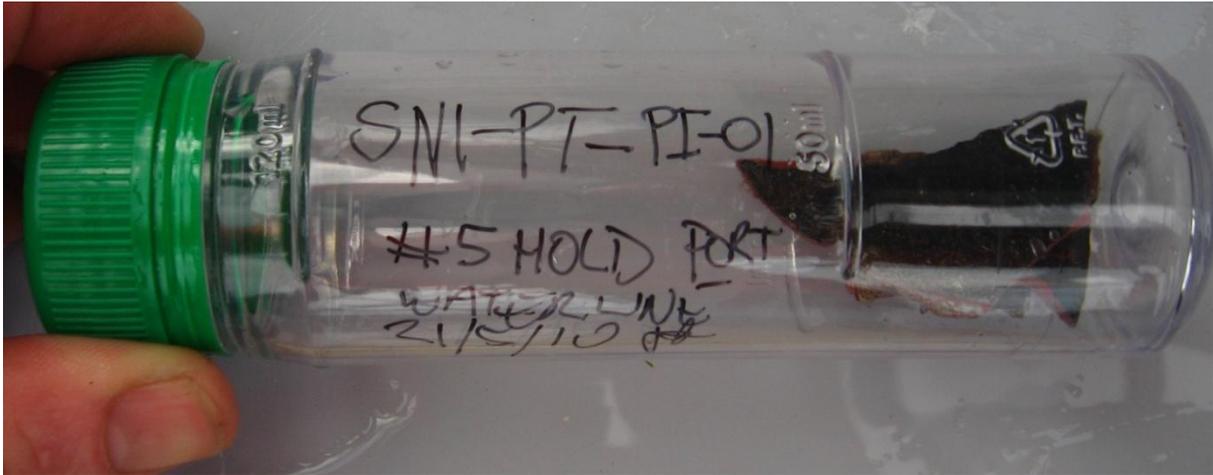


Figure 6. Example of sample container provided by insurance representative.

### Sample Collection

Dives commenced at approximately 1020 hours 21 May 2010 and were completed at approximately 1500 hours that day.

33 hull scraping samples were collected and 146 photographs relevant to this report were taken.

Locations of hull scrapings and photographs on the hull of the *Shen Neng 1* were generally as follows:

- Bow and bulb: one each from top and bottom and both sides of bulb.
- Along length of vessel at approximate mid point of each cargo hold and approximate mid point of superstructure. For each segment two samples were taken, one from the vertical side above the bilge keel or turn and one from the horizontal underside within 2 m of the bilge keel or turn.
- Stern of vessel and rudder, samples from the rudder being one each side at approximately bottom and top; samples from the stern being at the base, approximately midline and at approximately 5 m depth of water.

These locations are approximately indicated in **Figure 2**. Details of sample identifiers and collection points for each dive are presented in **Table 1**.

### Chemical Analysis

Four samples numbered SN1-PT-PI-01 to SN1-PT-PI-04 were handed to the ship owner's insurance representative, Mr Simmonds, on board *Mirrigimpa* prior to arrival in Urangan, they were not analysed further for this report.

The remaining 29 samples were ground and split at the Queensland Health Forensic and Scientific Services laboratory for distribution to the appropriate laboratories and to the owner's insurance representative where volumes allowed.

All 29 samples were analysed for tributyltin (TBT). Splits from 22 samples were also analysed for a range of metals. Splits from 22 of the samples were provided to the

owner's insurance representative. Results of the chemical analyses, including the minimum limit of reporting (LOR) designated by the laboratory are attached in **Annexure A**.

<b>Dive 1: JM and DS</b>	
Bulb port side - mid level	sample number – SN1-PT-06
Bulb starboard side - mid level	sample number – SN1-PT-08
bulb top –mid line	sample number – SN1-PT-05
Bulb underside – mid line	sample number – SN1-PT-02
Hold #1 port side -side at base	sample number – SN1-PT-07
Hold #1 port side- underside	sample number – SN1-PT-09
Hold #4 port side- waterline	sample number –SN1-pt-bag-01
<b>Dive 2: OL and DC</b>	
Hold #2 Port side – side at base	sample number – SN1-PT-04
Hold #2 Port side - underside	sample number – SN1-PT-11
Hold #3 Port side – side at base	sample number – SN1-PT-13
Hold #3 Port side - underside	sample number – SN1-PT-03
Hold #4 Port side – side at base	sample number – SN1-PT-12
Hold #4 Port side - underside	sample number – SN1-PT-14
<b>Dive 3: JM and DS</b>	
Hold #5 Port side – side water line - 5 m	sample number –SN1-PT-PI-01
Hold #5 Port side – side at base	sample number – SN1-PT-20
Hold #5 Port side - underside	sample number – SN1-PT-18
Hold #6 Port side – side at base	sample number – SN1-PT-17
Hold #6 Port side - underside	sample number – SN1-PT-16
Hold #7 Port side – side at base	sample number – SN1-PT-19
Hold #7 Port side - underside	sample number – SN1-PT-01
Segment #8 – superstructure Port side – side at base	sample number – SN1-PT-10
Segment #8 – superstructure Port side - underside	sample number – SN1-PT-15
Segment #8 – superstructure Port side - underside	sample number – SN1-PT-PI-02
<b>Dive 4: OL and DC</b>	
Rudder - Port side –base side	sample number – SN1-PT-28
Rudder - Port side –base side	sample number – SN1-PT-PI-03
Rudder - Starboard side –base side	sample number – SN1-PT-24
Rudder - Starboard side –Top side	sample number – SN1-PT-22
Rudder - Port side –Top side	sample number – SN1-PT-26
Rudder - Port side –Top side	sample number – SN1-PT-PI-04
Stern – starboard side @ shaft	sample number – SN1-PT-25
Stern – port side -@ shaft	sample number – SN1-PT-23
Stern – port side base side	sample number – SN1-PT-21
Stern – port side -@ ~ 5m	sample number – SN1-PT-27

Table 1. Hull Position and Label Number for Sampling of *Shen Neng 1* hull

### **Tributyltin and Tin**

All 29 samples analysed contained TBT. Concentrations ranged from the minimum of 2.9 mg Sn/kg from a sample taken from under hold 3 to the maximum concentration of 14700 mg Sn/kg from a sample taken from the underside of hold 1 (Refer **Annexure A** and **Graph 1**).

There is considerable variation in the concentration of TBT in samples from along the hull (refer **Graph 1**). The variation is likely a result of a combination of factors including variable historic painting and preparation of the hull paint systems and variability of losses from the grounding. For example, of the flats, the two lowest TBT concentrations are associated with the significant damage under holds 3 and 4 (refer **Graph 1**). The concentrations of TBT from all samples are significantly (at least three orders of magnitude) higher than environmentally relevant levels such as the ANZECC Screening and High levels of 9 µgm/kg and 70 µgm/kg respectively (for example in the Commonwealth of Australia 2009).

Tin was detected above the LOR of 400 mg/kg in 17 of the 22 samples analysed. Concentrations of tin ranged from the minimum of less than the LOR from samples taken from the rudder top on starboard side, water level of hold 4, under holds 3 and 4 and from the top of the bow bulb to the maximum concentration of 3400 mg/kg from the sample taken from the side at hold 7 (Refer **Annexure A**). There is no applicable ANZECC level for assessment of the environmental relevance of the concentrations of tin recorded.

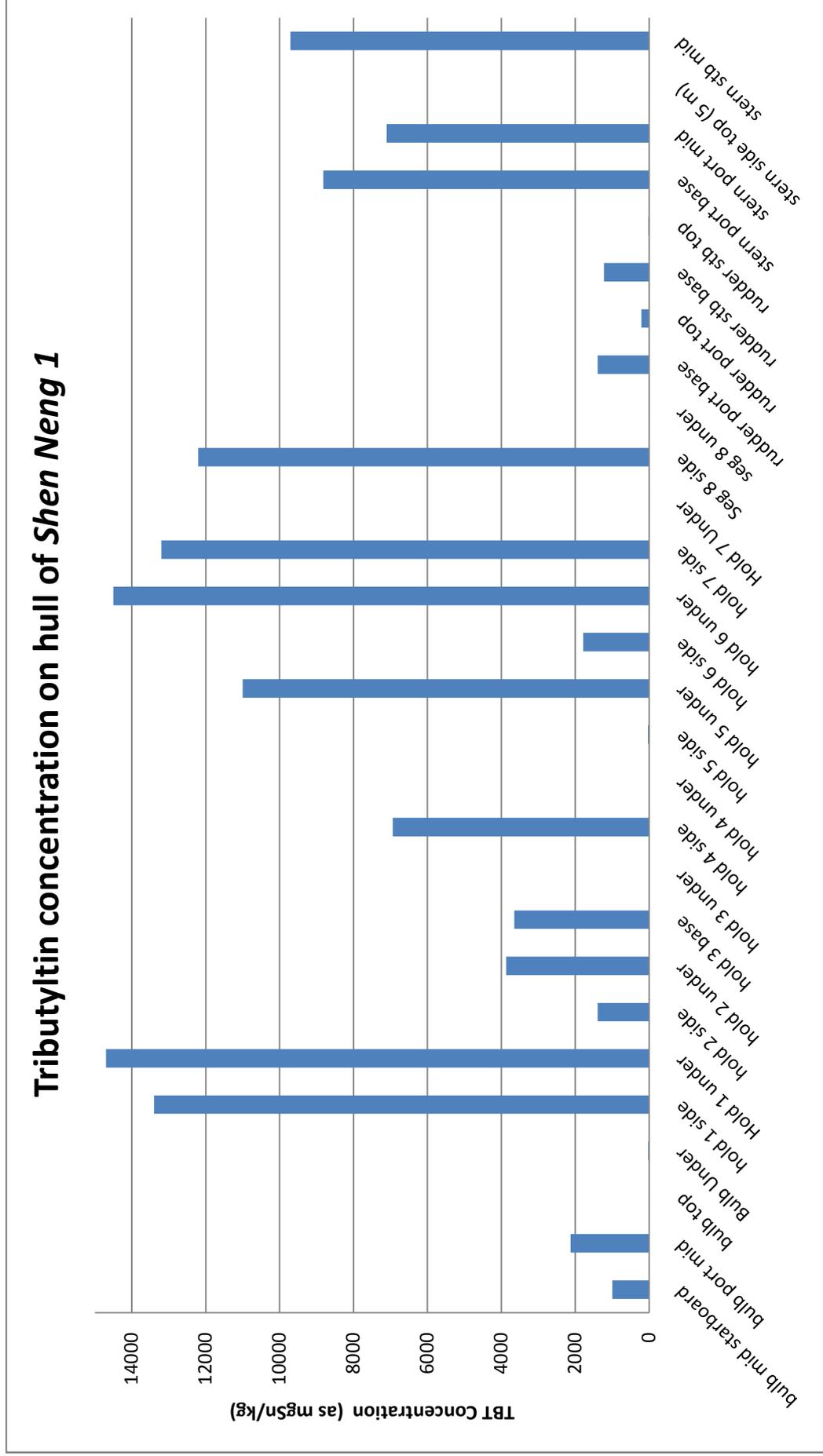
### **Other Metals**

Arsenic (LOR 800 mg/kg), antimony (LOR 1400 mg/kg), beryllium (LOR 4 mg/kg), cadmium (LOR 80 mg/kg), cobalt (LOR 100 mg/kg) and selenium (LOR 800 mg/kg) were not detected above their LOR in any of the 22 samples analysed (refer **Annexure A**).

For arsenic and antimony, the LOR were one and two orders of magnitude higher than the appropriate ANZECC sediment quality high guideline (SQHG) respectively (refer Commonwealth of Australia 2009). The LOR for Cadmium was significantly higher than the SQHG of 10 mg/kg. It was therefore not possible to apply ANZECC guidelines to determine if these metals were present in environmentally significant concentrations.

Barium, chromium, copper, iron, manganese, molybdenum, nickel, lead, tin, sulphur, vanadium and zinc were detected above their respective LOR in some or all of the samples (refer **Annexure A**).

Barium was detected above the LOR of 20 mg/kg in 20 samples ranging from the minimum concentration of less than the LOR from samples taken under holds 3 and 4 to the maximum concentration of 4600 mg/kg from the sample taken from the top of the bow bulb. There is no applicable ANZECC level for barium to assess the environmental relevance of the concentrations recorded.



Graph 1: Tributyltin concentrations on hull of Shen Neng 1. Note TBT was detected in all samples (refer Annexure A), resolution of display in this graph limits visibility of results in some locations.

Chromium was detected above the LOR of 80 mg/kg in 19 samples ranging from the minimum concentration of less than the LOR from samples taken under holds 3 and 4 and from the side at segment 8 (engine and superstructure) to the maximum concentration of 330 mg/kg from the sample taken from the stern midline on the starboard side. All detections of chromium were above the ANZECC screening level of 80 mg/kg.

Copper was detected above the LOR of 600 mg/kg in 21 samples ranging from the minimum concentration of less than the LOR from samples taken under hold 3 to the maximum concentration of 382 200 mg/kg from the sample taken from the side of hold 5. All detections of copper were significantly higher than environmentally relevant levels indicated by the ANZECC SQHG of 270 mg/kg. Of the 21 detections of copper, all but three were at least three orders of magnitude higher than the SQHG.

Iron was detected in all 22 samples ranging from the minimum concentration of 8 200 mg/kg from the sample taken from the rudder top on the starboard side to the maximum concentration of 600 000 mg/kg from the sample taken from under hold 4.

Manganese was detected in all 22 samples ranging from the minimum concentration of 23 mg/kg from a sample taken from the side at hold 2 to the maximum concentration of 460 mg/kg from the sample taken from under hold 4.

Molybdenum was detected above the LOR of 100 mg/kg in 1 sample being 110 mg/kg from the sample taken from under hold 3.

There are no applicable ANZECC levels for iron, manganese or molybdenum to assess the environmental relevance of the concentrations recorded.

Nickel was detected in five samples above the LOR of 100 mg/kg ranging from the minimum concentration of less than the LOR to the maximum concentration of 160 mg/kg from the sample taken from the side of hold 5. Of the 5 detections of nickel, all were higher than the SQHG.

Lead was detected above the LOR of 200 mg/kg in four samples ranging from the minimum concentration of less than the LOR to the maximum concentration of 290 mg/kg from the sample taken from the base of the rudder on the port side. All four of the detections of lead were higher than the SQHG.

Sulphur was detected above the LOR of 2000 mg/kg in eight samples ranging from the minimum concentration of less than the LOR to the maximum concentration of 7400 mg/kg from the sample taken from under hold 4. There are no applicable ANZECC levels for sulphur to assess the environmental relevance of the concentrations recorded.

Vanadium was detected above the LOR of 60 mg/kg in 2 samples from under holds 3 and 4. There are no applicable ANZECC levels for vanadium to assess the environmental relevance of the concentrations recorded.

Zinc was detected in all 22 samples ranging from the minimum concentration of 720 mg/kg from a sample taken under hold three to the maximum concentration of 72 000 mg/kg from the sample taken from the base of the stern on the port side. The concentrations of zinc from all samples are significantly higher than environmentally relevant levels such as the ANZECC Screening and High levels of 200mg/kg and 410mg /kg respectively; 18 of the samples were two orders of magnitude higher than the SQHG.

Plots of the concentrations of selected metals indicate that the areas of significant damage (specifically abrasion and deformation, for example, in undersides of holds 3 and 4) are characterised by peaks in concentration of manganese, iron and vanadium and decreased concentration of tin, barium, chromium, copper and zinc (refer **Annexure A** and **Graphs 2, 3 and 4**). Similar responses in manganese, tin, copper, zinc and iron were recorded for the top of the bow bulb presumably through the observed anchor chain abrasion (refer **Annexure A**).

### **Hull Observations**

Observations were recorded and a photograph was taken of the ship's hull at each sample location for the purpose of recording the condition of the hull and paint systems. The photograph lit by flash, where used, was used to indicate the various colours of the paint system present. Observations recorded in-water included colour, condition and similarity to adjacent areas visible to the divers but not included in the photograph.

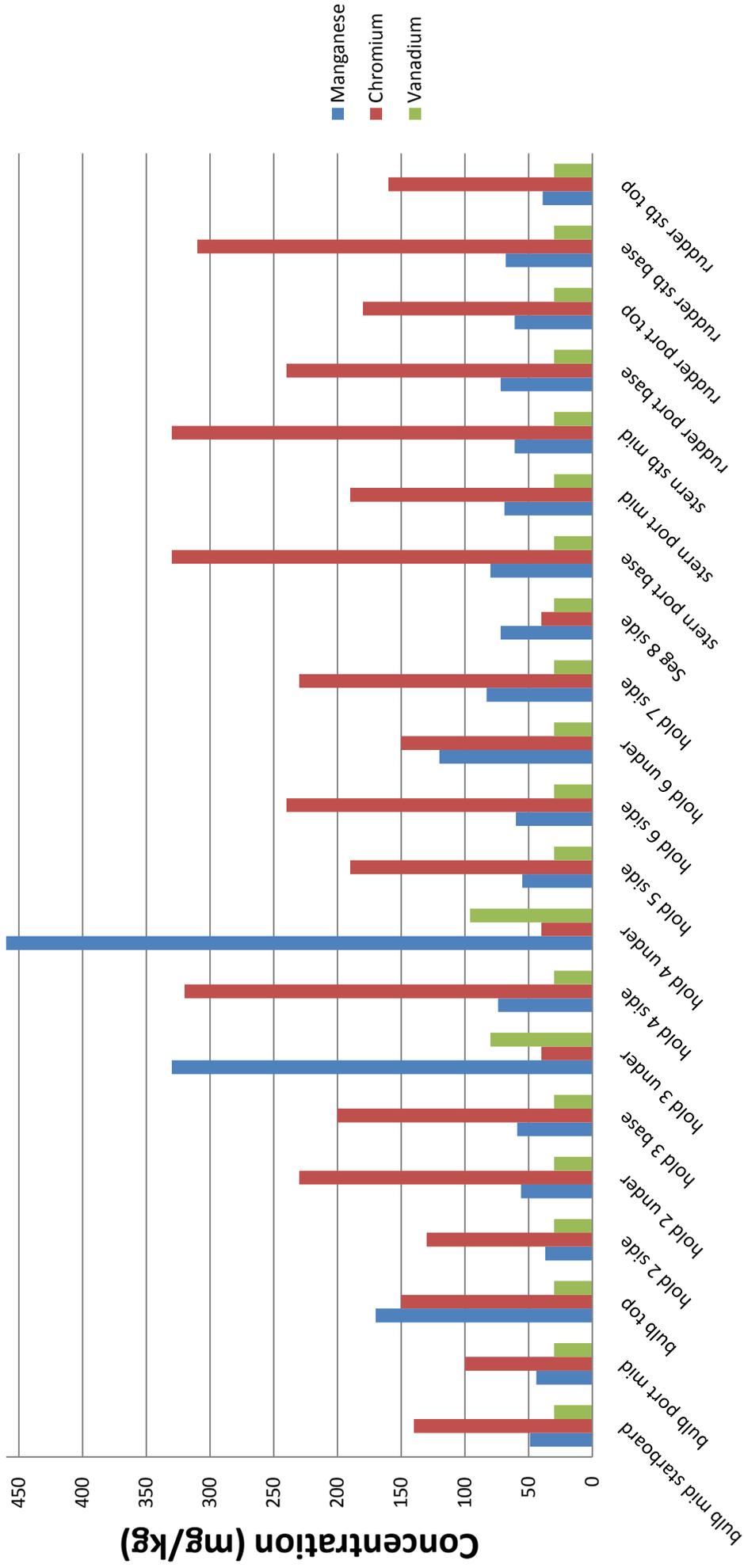
### ***Colour of Paint Systems on Immersion in Water***

On immersion the colour of the paint system top coats reportedly changes from: Dark Red to Light Red or Brown; and from Brown to Dark Brown or Black (refer Interswift 455FB and Interswift 655 Product Description Sheets- copy included in "Shen Neng 1 Hull Paint System Documents and Certificates" available on request from GBRMPA).

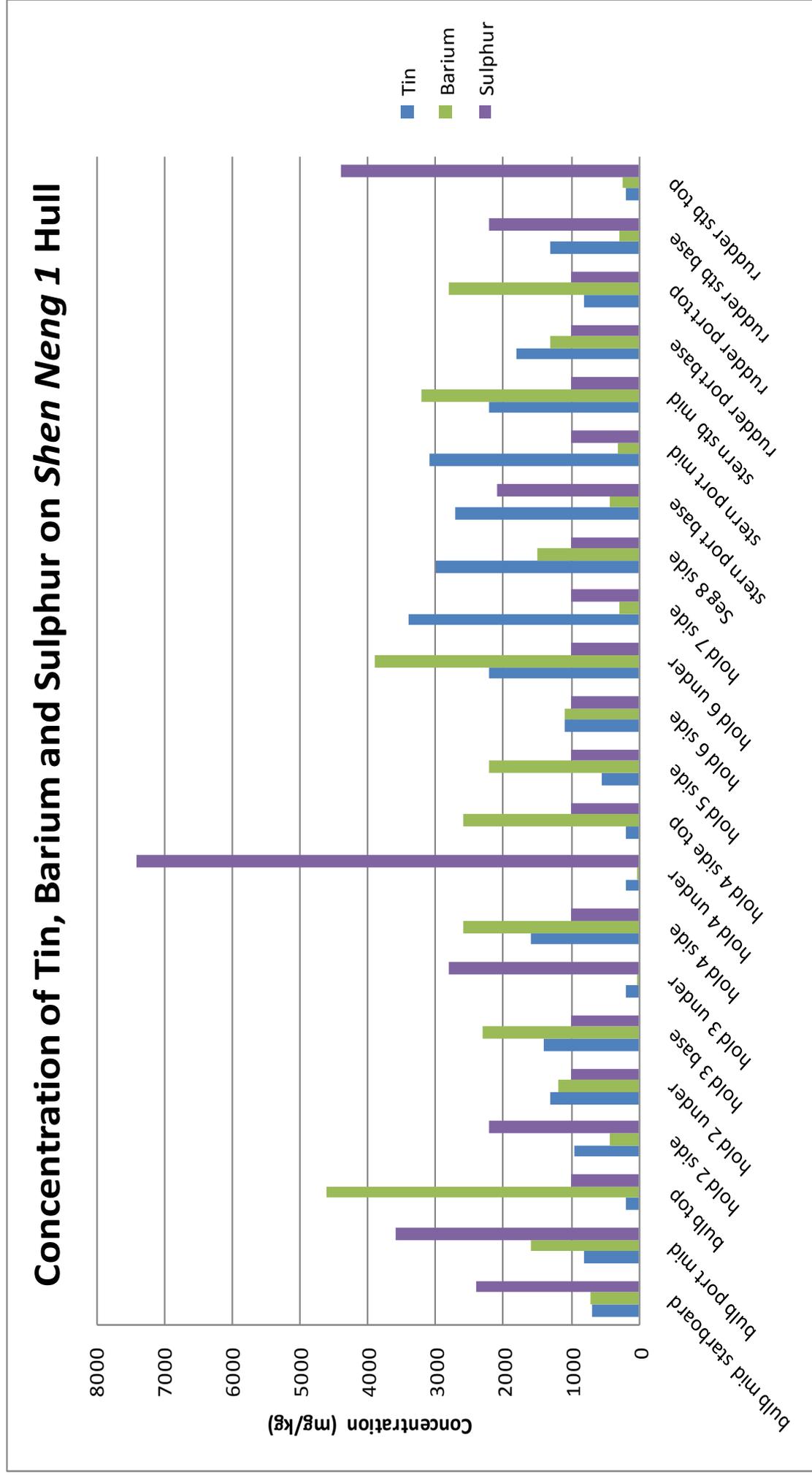
Therefore in-water observations with artificial light identified the recent antifouling paints as either: light red, brown or black. The barrier system was a light grey colour (for example see images for underside of bow bulb and side of hold 1 in **Annexure B**).

**Annexure A** contains the results of the hull observations. Photographic images of each sample location and sample, where recorded, are presented in **Annexure B**.

## Concentration of Manganese, Chromium and Vanadium on Shen Neng 1 Hull

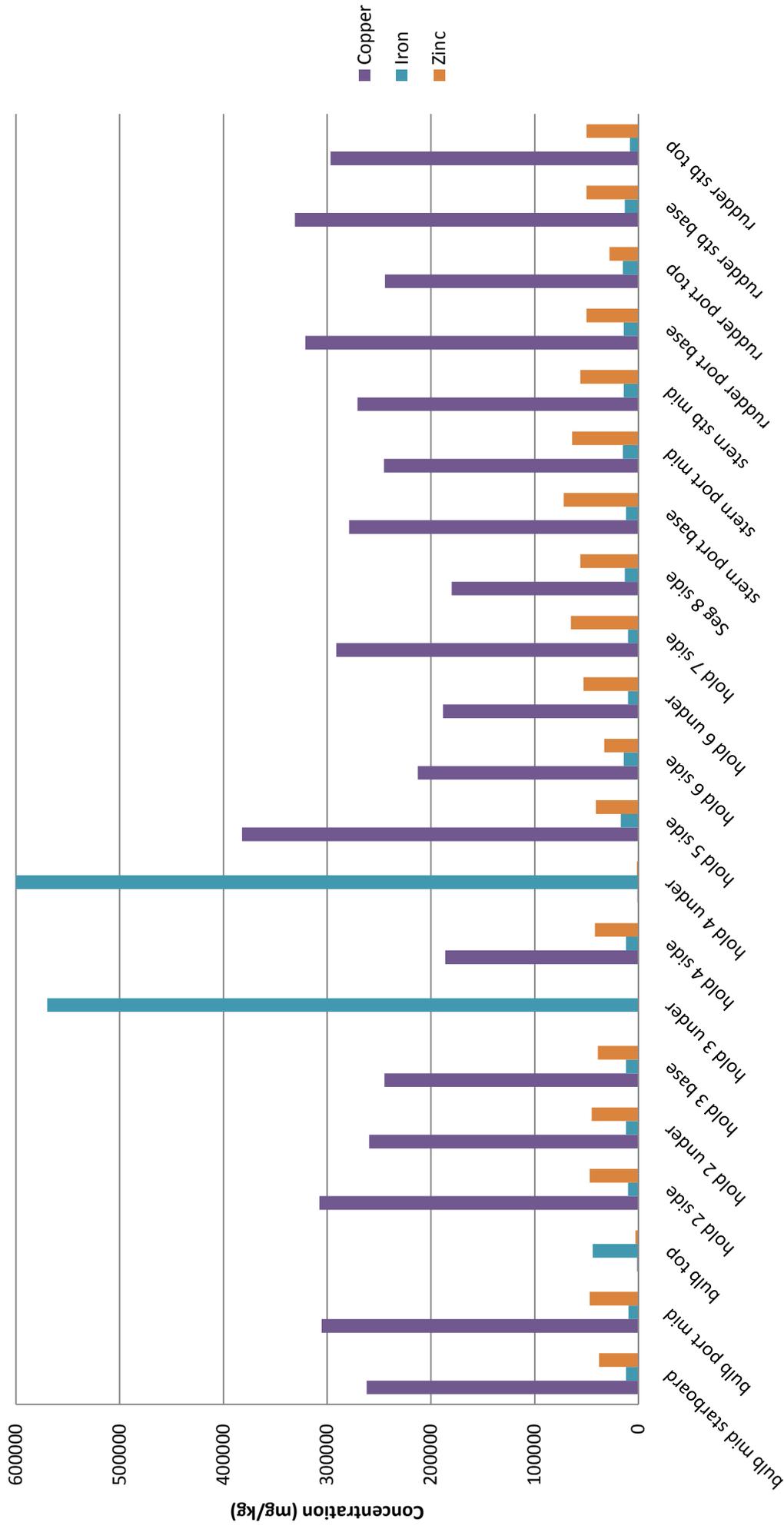


Graph 2: Manganese, Chromium and Vanadium concentrations on hull of Shen Neng 1.



Graph 3: Tin, Barium and Sulphur concentrations on hull of Shen Neng 1.

### Concentration of Copper, Iron and Zinc on Shen Neng 1 Hull



Graph 4: Copper, Iron and Zinc concentrations on hull of Shen Neng 1.

Based on the in-water observations and photographs it was clear that the hull of the *Shen Neng 1* had recently experienced significant damage to the majority of the flat bottom and abrasion and some damage to the sides. Areas observed with no appreciable damage were restricted to the elevated areas of the bow bulb, stern and rudder.

Paint loss from the hull varied from significantly damaged areas of bare exposed metal with corrosion, for example the underside of the hull at holds 1, 2, 3, 4 & 5 to elevated areas with no noticeable impact and with full paint coverage such as the stern areas adjacent the propeller shaft.

Observations of the ships sides, where only minor abrasion/damage occurred, indicate that loss of the top coats of paint was sufficient to expose the grey barrier coat (for example refer image for side of hold 1 in **Annexure B**). Areas receiving more abrasion such as the underside of holds clearly resulted in loss of topcoats, exposure of historic paints and loss of historic paints to the extent of exposing bare metal (for example refer image for underside of holds 1 and 5 in **Annexure B**).

Observations of existing hull coatings recorded in the field provide a good estimate of the extent of loss of the recent paint system including the barrier coating. However, given the unknown types and volumes of paint on the hull prior to the most recent coatings, the observations recorded here will not allow an accurate determination of the *total* paint loss from the hull during the grounding.

During the sampling, horizontal in-water visibility was a minimum of five metres (for example, refer to **Figure 7**). Consequently, diver observations and records included hull condition of at least the five metres radius around each sample location and either side along the path swum between each sample location. Damage was recorded for all underside (flats) areas of the ship that were observed here. Diver observations and records included that the damage was uniform across the wider area surrounding and visible from each sample location and for all areas along the swum path between sample locations.

Based on the relatively shallow gradients across the grounding area of Douglas Shoal (refer **Figure 1**) and the observed shape of the *Shen Neng 1* hull, the entire underside (flats) of the hull is highly likely to have been in contact with the shoal at some time during the grounding. Consequently whilst only target areas of the hull were inspected here, during the grounding antifouling paint is highly likely to have been lost from most of the underside of the *Shen Neng 1* to similar extents to that observed here.

It should be noted that the paint barrier system is applied as a seal over the TBT paints to prevent chemical leaching into the water column; the barrier coat is not designed as a physical barrier to protect underlying paints against the forces of grounding. Based on the observed physical damage to the hull including the noticeable abrasion and paint loss, it is clear that the grounding was sufficient to

penetrate the paint systems, including past the paint barrier system and that underlying TBT containing paints were also abraded from the hull.

Therefore, it is reasonable to conclude that contamination of the sediments of Douglas Shoal with antifouling paints that contain TBT is certain to have occurred as a result of the grounding.



Figure 7: Indicative in-water visibility during sampling

### Antifouling Paint Regulation

Australia developed specific legislation, the *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006*, which commenced on 27 September 2006 to address the issue of harmful antifouling paint systems. This was in support of international efforts led by the International Maritime Organisation (IMO). The IMO, through adoption of the International Convention on the Control of Harmful Anti-fouling Systems on Ships (the Convention), called for a global prohibition on the application of organotin (commonly referred to as TBT) compounds which act as biocides in antifouling systems on ships. Therefore under the Convention and under Australian law those compounds were completely prohibited by 1 January 2008.

Consequently, ships such as the *Shen Neng 1* either:

- (a) shall not bear such compounds on their hulls or external parts or surfaces; or
- (b) shall bear a coating that forms a barrier to such compounds leaching from the underlying non-compliant antifouling systems.

## Paint System Records for *Shen Neng 1*

### Presence of TBT

The coating and inspection report for the *Shen Neng 1* dated 7 April 2008 (copy included in "Shen Neng 1 Hull Paint System Documents and Certificates" available on request from GBRMPA) indicates that the hull was coated with an IMO approved barrier coat over the existing antifouling system in April 2008. That barrier coat was considered sufficient to make the vessel compliant with the Convention (refer to the Statement of Compliance issued under the International Convention on the Control of Harmful Anti-Fouling Systems on Ships by the China Classification Society for the *Shen Neng 1* dated 5 April 2008- copy included in "Shen Neng 1 Hull Paint System Documents and Certificates" available on request from GBRMPA).

On that basis it is apparent that the *Shen Neng 1* is likely to have an historic application of TBT containing antifouling paint on at least some areas of the hull at the time of grounding on Douglas Shoal. Analytical results confirm TBT in all samples recovered. This reasonably leads to a conclusion that TBT containing antifouling paints were likely present on all surfaces that came in contact with Douglas Shoal during the grounding.

According to the coating and inspection report the flats (underside hull area) of the *Shen Neng 1* had a stated "flats" surface area of 7000 m<sup>2</sup> and underwater sides surface area of 3819 m<sup>2</sup>. According to the report each surface had received a full coating of dark red antifouling paint variously Interswift 655 or Interswift 455FB (for Flat Bottom areas). The underwater sides also received a full coat of brown antifouling paint (Interswift 655). The volume of the top coat of antifouling paint used was reported as 1560 litres for the flats and 1480 litres for the underwater sides.

### Previously Known Condition of Paint System

According to the *Shen Neng 1* Coating and Inspection Report dated April 2008 (copy included in "Shen Neng 1 Hull Paint System Documents and Certificates" available on request from GBRMPA) the hull and paint system was in clean condition with low fouling and low levels of corrosion and cracking and no paint detachment at the time of inspection, prior to the preparation and application of the new coatings at that time. The vessel was due for dry docking again in October 2010. The occurrence of any grounding of the *Shen Neng 1* prior to the Douglas Shoal grounding has not been assessed. In the absence of any evidence about other major damage to the vessel's hull since April 2008, it is reasonable to conclude that the vessel at the time

immediately prior to its grounding on Douglas Shoal was in similar good condition to when leaving the Guangzhou Wenchong dry dock in 2008. As such, it is also reasonable to conclude that all significant damage and paint loss observed here occurred as a result of the April 2010 grounding on Douglas Shoal.

### Paint System Product Information.

The following information is based on the Coating and Inspection Report and the relevant Product Descriptions and Safety Data Sheets for each product applied to the hull of the *Shen Neng 1* at the last hull maintenance (copy included in "Shen Neng 1 Hull Paint System Documents and Certificates" available on request from GBRMPA).

**Table 2** contains a list of the applied products, their volumes as reportedly applied, a description of their key active ingredients and indication of environmental risk as provided by the manufacturer (International Marine Coatings

<http://www.international-marine.com/Pages/MarineHome.aspx> ) in the form of Safety Data Sheets and Product Description Sheets.

Area	Surface area	Paint type	Paint volume	Active ingredient	Concentration (mg/l)	Potential Mass (Kg)
Underwater sides	3819	Interswift 655 Brown	740	Zinc oxide	10 - < 25	7.4 -18.5
				Copper (I) oxide	25 - < 50	18.5 - 37
Underwater sides	3819	Interswift 655 Dark Red	740	Zinc oxide	10 - < 25	7.4 -18.5
				Copper (I) oxide	25 - < 50	18.5 - 37
Flats	7000	Interswift 455FB Dark Red	1560	Copper (I) oxide	25 - < 50	39 - 78
				Zinc oxide	10 - < 25	15.6 - 39

Table 2. *Shen Neng 1* Paint System Information

**Environmental Risk.** All of the applied products are described in their Safety Data Sheets as being "Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment".

For example ecotoxicity information provided in the SDS for Zinc oxide states:

Toxicity to fish - *Oncorhynchus mykiss* LC50 96 hours 1 mg/l

Toxicity to daphnia - *Daphnia magna* EC50 48 hours 10-50 mg/l

Toxicity to algae - *Desmodesmus subspicatus* EC50 72 hours 10-20 mg/l

Therefore in the concentrations as applied the paint would be toxic to those organisms tested.

Based on the flats areas of the *Shen Neng 1* there was likely around 39-78 kg of copper oxide and 15 to 39 kg of zinc oxide in the recent top coats alone; that is not

including the contents of the barrier coat and the underlying historic paint systems. Based on the reported damage and paint loss from the hull it is likely that much of that top coat paint was lost from the entire flats of the hull during the grounding.

Critically the paint system includes a range of other chemicals (refer analytical results **Annexure A**) and there is an unknown quantity of previously applied TBT abraded from the flats and deposited on the shoal.

## Discussion

Analytical results from this sampling confirm that the hull of the *Shen Neng 1* contained antifouling paints including environmentally significant concentrations of tributyltin, zinc, copper and a range of other metals on the majority of hull surfaces sampled. Damage to the flats of the hull and loss of antifouling paint was ubiquitous and significant paint loss from the entire observed flats area during the grounding is confirmed.

Observations of existing hull coatings provided a good estimate of the extent of loss of the recent paint system and including the barrier coating. However, given the unknown types and volumes of paint on the hull prior to the most recent coatings, the observations recorded here will not allow an accurate determination of the *total* volume of paint loss from the hull during the grounding.

Based on the observed physical damage to the hull and the noticeable paint loss it is confirmed that the paint barrier system was insufficient to prevent loss of the TBT containing paints from the hull and therefore contamination of the sediments of Douglas Shoal with antifouling paints including TBT is certain to have occurred as a result of the grounding.

## Potential for Contamination from Antifouling Paints

Grounding of a ship is likely to result in the contamination of the contacted substrates with the hull paint system through abrasion of the paint surface during contact with the sea bed. Personal observations (11-13 May 2010) and other surveys (Marshall 2010, Negri *et al.* 2010) conducted over the *Shen Neng 1* grounding area on Douglas Shoal indicate significant physical impacts to the shoal and the presence of smears and flakes of paint over the reef and on the sediments within the area.

Antifouling paints are designed to include biocides for the purpose of retarding or preventing the growth of marine organisms on the ships hull. Biocides historically have included TBT and other metals such as copper and zinc. Some of the antifouling material lost during the grounding of a ship may not be visible as it includes a range of fine particles (Jones 2007). Once released during a grounding the antifouling residue may continue to leach its active ingredients over time (Jones 2007).

In the initial phase of the grounding of the *Shen Neng 1*, the ship's main engine and propeller may have continued to run for over five minutes after the grounding (Commonwealth of Australia 2010a). Tidal flows observed across the site during the response to the *Shen Neng 1* grounding clearly indicated mobilisation of disturbed reef sediments as a turbid plume (**Figure 8**). Those plumes are likely to also contain particles of liberated antifouling paint from the hull. Consequently sediments remote from the direct grounding site may also include antifouling paint abraded from the *Shen Neng 1* hull.



Figure 8. Turbid plume associated with grounded Shen Neng 1 on 4 April 2010.

### Previous Groundings in the Reef and TBT Contamination

The first report of TBT contamination of the Great Barrier Reef Marine Park from a ship grounding was from the grounding of the vessel *New Reach* on Heath Reef in May 1999 (Haynes and Loong 2002). Sampling at that grounding site confirmed sediments in the immediate grounding scar were significantly contaminated by antifouling paint including butyltin (this may therefore also include mono- and di-butyltin, the compounds of degradation of tributyltin) concentrations of up to 340 mg Sn/kg. (Haynes and Loong 2002).

In the grounding of the *Bunga Teratai Satu* on Sudbury Reef off Cairns in November 2000, sampling at that grounding site found sediment TBT concentrations within the grounding scar of up to 160,000 mg Sn/ kg. The antifouling contamination had also dispersed over 250 m from the grounding scar (Marshall *et al.* 2002).

### Implications of Contamination from Grounding of Shen Neng 1

Whilst there are no studies examining TBT contamination of marine organisms within the GBRWHA, Negri and Marshall's (2009) review of the effects of TBT on tropical marine organisms indicates that contamination by TBT such as from antifouling paints is likely to have a significant and persistent ecological impact on biota at a ship grounding site and potentially the surrounding physically non-impacted areas.

In summary:

- There is persistent leaching of chemicals from paint flakes, smears and fines;
- Corals are sensitive to low concentrations of TBT throughout their life history;
- TBT reduces fertilisation of gametes therefore reduces the reproductive output of non-directly impacted reefs as well;
- TBT inhibits the normal recruitment of species such as algae and corals, at low concentrations for example, slowing natural settlement and attachment of coral larvae onto surfaces therefore slowing recovery of the grounded areas;
- TBT has a toxic effect on adjacent established organisms such as hard and soft corals, spreading damage if clean up is not implemented;
- TBT can reduce the photosynthetic output of a coral reducing the productivity of adjacent reefs;
- TBT results in bleaching of adult corals and mortality of juvenile and adult corals in adjacent areas; and
- The bioaccumulation of TBT occurs in higher trophic levels via consumption of contaminated animals and plants.

Most of the observable effects of TBT on corals are stated to occur within a narrow concentration range of 0.36 – 1.8 µg Sn/kg (Negri and Marshall 2009).

Observations from other GBR grounding sites include that otherwise physically non-impacted hard and soft corals can be subsequently killed by antifouling contamination over tens of metres from a grounding scar and partially killed hundreds of metres from the grounding site (for example, Marshall *et al* 2002). The concentrations of TBT recorded for the paint system of the *Shen Neng 1* confirm that there is therefore a significant risk for corals and other organisms if antifouling paint from the *Shen Neng 1* contaminates the sediments of Douglas Shoal as a result of the grounding.

Situation reports of the response to the grounding of the *Shen Neng 1* (Maritime Safety Queensland and Australian Maritime Safety Authority) indicated that a total maximum of approximately less than 10 tonnes of fuel oil was spilled in two separate events during the grounding but no major ecological impacts of that oil loss were assessed or reported.

Consequently, the contamination of the substrate of Douglas Shoal with antifouling paints is likely to be one of the most significant ecological impacts of the grounding of the *Shen Neng 1*. Given the sediment plumes and currents at the grounding site and evidence from other groundings, the impacts of the antifouling paint contamination is not likely not be limited to the immediate grounding site and may persist for some years if not removed or remediated.

## References

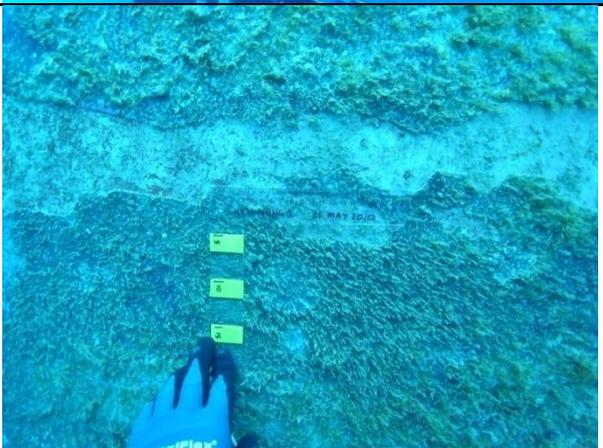
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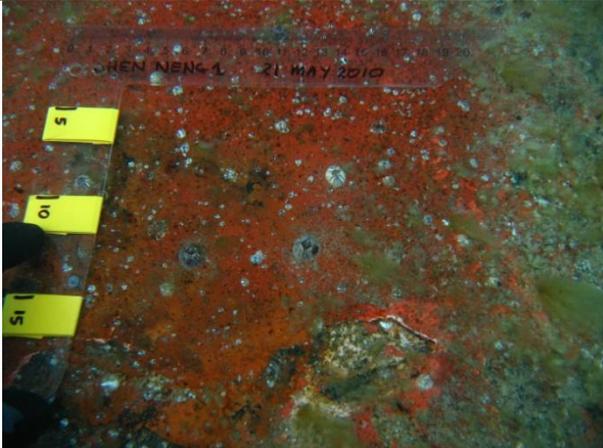


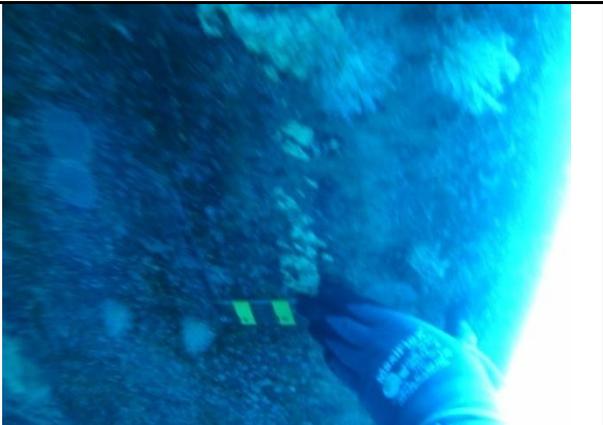
# Shen Neng 1 Hull Sampling: Field Report 21 May 2010.

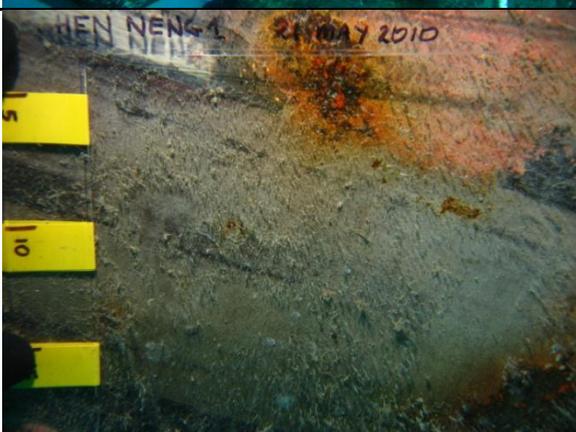
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3	3	3	3	3	4	4	4	4	4	4	4	4	1
hold 6 under K214FFE831_1000057.JPG (Poor quality strobe falling)	hold 6 side K214FFE831_1000055.JPG	hold 5 side K214FFE831_1000049.JPG, K214FFE831_1000050.JPG (colour)	hold 7 side No photo available	hold 5 side K214FFE831_1000049.JPG, K214FFE831_1000050.JPG (colour)	stern port base M0011425.JPG	rudder stb top M0011395.JPG	stern port mid M0011413.JPG	rudder stb base M0011392.JPG	stern stb mid M0011407.JPG	rudder port top M0011399.JPG	stern side top (5 m) M0011428.JPG	rudder port base M0011382.JPG	hold 4 side top K214FFE831_1000043.JPG
grey	black, red, grey	black, brown	red, grey, brown	black/red, grey	red	red, grey	red	red, black	red	red, grey	red	white, grey, red	red
5	10	30	n/a	30	100	75	100	70	100	95	100	20	100
abraded	abrasion	significant longitudinal hull infolds/dents	uniform	abraded, big flakes gone	minor abrasion	paint flaking	minimal, minor paint flaking	abrasion, flakes	nil	minimal, minor paint flaking	nil	rudder base bent	nil
uniform	uniform	uniform	uniform	uniform	uniform	uniform	uniform	variable	uniform	uniform	uniform	variable	uniform
Camera Batteries failing	surface fouled with weed and barnacles	K214FFE831_100051.JPG (dents) fouling and patchy corrosion.	Camera Batteries failed	fouling but not on grey surfaces	minor fouling	minor fouling	no fouling	minor fouling	no fouling	minor fouling	some fouling	fouling	some corrosion variable thickness paint flakes
400	400	400	400	400	400	400	400	400	400	400	400	400	400
3900	1100	2200	420	230	310	3200	3200	2800	2800	2800	1300	2600	2600
2	2	2	2	2	2	2	2	2	2	2	2	2	2
40	40	40	40	40	40	40	40	40	40	40	40	40	40
50	50	50	50	50	50	50	50	50	50	50	50	50	50
150	240	150	160	150	190	310	330	180	180	180	240	140	140
188400	212600	362200	279000	296800	249200	331200	278900	244400	244400	244400	921200	880	880
10000	14000	17000	12000	8200	15000	13000	14000	15000	14000	14000	14000	58000	58000
120	60	55	80	39	69	68	61	61	61	61	72	130	130
50	50	50	50	50	50	50	50	50	50	50	50	50	50
50	50	160	50	50	50	100	130	50	50	50	50	100	100
100	100	230	240	100	280	100	100	100	100	100	290	100	100
700	700	700	700	700	700	700	700	700	700	700	700	700	700
400	400	400	400	400	400	400	400	400	400	400	400	400	400
2200	1100	3400	2700	2000	3100	1300	2200	810	2200	1800	1800	200	1000
1000	1000	1000	1000	4400	1000	1000	1000	1000	1000	1000	1000	1000	1000
30	30	30	30	30	30	30	30	30	30	30	30	30	30
53000	33000	41000	72000	50000	64000	50000	56000	28000	28000	50000	50000	780	780
14500000	17800000	30000	8820000	16100	7100000	1220000	9710000	205000	205000	6740	1390000	27300	27300

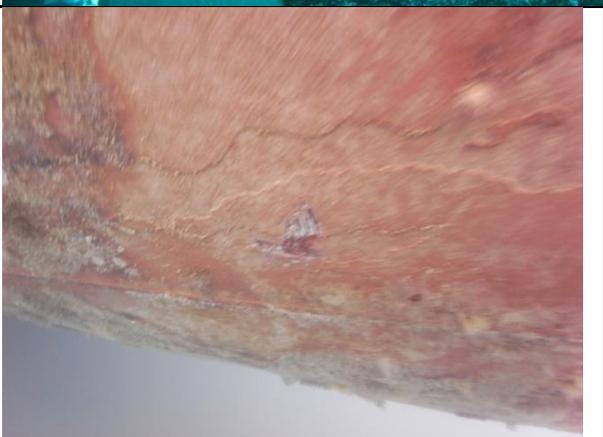
## Annexure B: Shen Neng 1 Hull Sampling 21 May 2010 Photographic Log

Sample ID	Location	Photo id	
SN1-PT-01	Hold 7 Under	No Photo available	
SN1-PT-02	Bulb Under	K214FFE831 _1000030.JP G	
SN1-PT-03	hold 3 under	M0011363.J PG	
SN1-PT-04	hold 2 side	M0011344.J PG	

<p><b>SN1-PT-05</b></p>	<p>bulb top</p>	<p>K214FFE831 _1000026.JP G</p>	
<p><b>SN1-PT-06</b></p>	<p>bulb port mid</p>	<p>K214FFE831 _1000015.JP G</p>	
<p><b>SN1-PT-07</b></p>	<p>hold 1 side</p>	<p>K214FFE831 _1000036.JP G</p>	
<p><b>SN1-PT-08</b></p>	<p>bulb mid starboard</p>	<p>K214FFE831 _1000023.JP G</p>	

<p><b>SN1-PT-09</b></p>	<p>Hold 1 under</p>	<p>K214FFE831 _1000039.JP G</p>	
<p><b>SN1-PT-10</b></p>	<p>Seg 8 side</p>	<p>No Photo available</p>	
<p><b>SN1-PT-11</b></p>	<p>hold 2 under</p>	<p>M0011350.J PG</p>	
<p><b>SN1-PT-12</b></p>	<p>hold 4 side</p>	<p>M0011366.J PG</p>	
<p><b>SN1-PT-13</b></p>	<p>hold 3 base</p>	<p>M0011358.J PG</p>	

<p><b>SN1-PT-14</b></p>	<p>hold 4 under</p>	<p>M0011375.J PG</p>	
<p><b>SN1-PT-15</b></p>	<p>seg 8 under</p>	<p>No Photo available</p>	
<p><b>SN1-PT-16</b></p>	<p>hold 6 under</p>	<p>K214FFE831 _1000057.JP G</p>	
<p><b>SN1-PT-17</b></p>	<p>hold 6 side</p>	<p>K214FFE831 _1000055.JP G</p>	
<p><b>SN1-PT-18</b></p>	<p>hold 5 under</p>	<p>K214FFE831 _1000052.JP G</p>	

<b>SN1-PT-19</b>	hold 7 side	No photo available	
<b>SN1-PT-20</b>	hold 5 side	K214FFE831 _1000049.JP G, K214FFE831 _1000050.JP G (colour)	
<b>SN1-PT-21</b>	stern port base	M0011425.J PG	
<b>SN1-PT-22</b>	rudder stb top	M0011395.J PG	
<b>SN1-PT-23</b>	stern port mid	M0011413.J PG	

<p><b>SN1-PT-24</b></p>	<p>rudder stb base</p>	<p>M0011392.J PG</p>	
<p><b>SN1-PT-25</b></p>	<p>stern stb mid</p>	<p>M0011407.J PG</p>	
<p><b>SN1-PT-26</b></p>	<p>rudder port top</p>	<p>M0011399.J PG</p>	
<p><b>SN1-PT-27</b></p>	<p>stern side top (5 m)</p>	<p>M0011428.J PG</p>	

<b>SN1-PT-28</b>	rudder port base	M0011382.J PG	
<b>SN1-PT-BAG-01</b>	hold 4 side top	K214FFE831 _1000043.JP G	