Port of Mackay

Appendix E

Dredge Plume Modelling

Port of Mackay: Sustainable Sediment Management Assessment

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Report No. P033_R02v02

Technical Report
October 2021

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North Queensland Bulk Ports Corporation Ltd

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Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to undertake a series of studies as part of NQBP's long-term Sustainable Sediment Management (SSM) assessments at the Port of Mackay. The aim of this assessment was to undertake natural sediment transport and dredge plume modelling specific to the Port of Mackay SSM project to better understand potential impacts from maintenance dredging.

The modelling approach adopted for this assessment was developed to ensure that it met the relevant Great Barrier Reef Marine Park Authority (GBRMPA) Hydrodynamic Modelling Guidelines (GBRMPA, 2012). The modelling included an extensive model calibration and validation process to demonstrate that the model could accurately represent the natural hydrodynamic, wave and sediment transport processes within the study area. Numerical modelling was undertaken for 20 different scenarios which included four different metocean conditions and five different dredge volumes. Therefore, the modelling has considered a range of possible metocean conditions which occur during future maintenance dredging as well as a range of different dredge volumes.

Results from the numerical modelling have shown that:

- the nearshore natural SSC was predicted to generally be much higher than the SSC resulting from maintenance dredging. The plume resulting from the maintenance dredging activity in Mackay Harbour was shown to predominantly remain within the Harbour with the harbour breakwaters preventing the majority of the suspended sediment from being transported out of the Harbour. The only area outside of the Harbour where increases in SSC from maintenance dredging were predicted to result in a clear increase in total SSC (natural plus dredging) was within and adjacent to the Mackay DMPA where the natural SSC is typically low;
- due to the location of the Mackay DMPA and the local tidal currents, the elevated SSC which results from the placement of dredged sediment at the DMPA was predicted to be advected to the north and south with limited dispersion to the east and west. There are no sensitive receptors located within the areas to the north and south of the DMPA where an elevated SSC of more than 2 mg/l was predicted to occur for 5 percent of the time due to the placement of dredged sediment;
- the known coral and seagrass sensitive receptors in the region were not predicted to be impacted by maintenance dredging at the Port of Mackay;
- the modelling predicted that the increase in 95th percentile SSC (exceeded for 5% of the time) at the sensitive receptors at Slade Islet and Round Top Island were less than 3 mg/l and 1 mg/l, respectively. These relatively low increases in SSC due to dredging meant that the combined natural plus dredging SSC was predicted to remain within natural conditions for the sensitive receptors for all dredge scenarios considered;
- the deposition resulting from maintenance dredging showed a similar pattern to the SSC, with the majority of the sedimentation associated with the dredge activity contained within Mackay Harbour and sedimentation occurring within and to the north and south of Mackay DMPA. It was therefore only within Mackay Harbour and to the north and south of Mackay DMPA where it was possible to clearly distinguish between the natural and natural plus dredging deposition;
- although the SSC from maintenance dredging at the sensitive receptors was predicted to increase as the maintenance dredging volume increased (from 125,000 to 1,000,000 m^3), the increases were not predicted to result in impacts to the sensitive receptors;
- the long-term resuspension modelling predicted that sediment placed within the DMPA was only resuspended and transported outside of the DMPA during relatively short, discrete events coinciding with large wave events. The modelling was also used to

estimate that in the order of 75% of the sediment dredged from the Port of Mackay would still be present at the DMPA one year after placement; and

- the long-term resuspension modelling predicted that the sediment resuspended from the Mackay DMPA would be deposited as a very thin layer of sediment and was not predicted to result in increased deposition at any nearby sensitive receptor or within the dredged areas of the Port of Mackay.

Overall, the results have predicted that maintenance dredging at the Port of Mackay would result in elevated SSC within Mackay Harbour and Mackay DMPA throughout the duration of the dredging. Mackay Harbour acts to retain the majority of the SSC resulting from the dredge activity, with limited suspended sediment predicted to be transported outside of the Harbour. The SSC resulting from the placement of sediment at Mackay DMPA was predicted to result in short-duration plumes which could be advected to the north or south of the DMPA by the prevailing tidal and wind driven currents. Due to the location of Mackay DMPA relative to the sensitive receptors, the local tidal currents and the short-duration of the plumes any increases in SSC at the sensitive receptors were considered to be small in relation to the natural conditions.

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to undertake a series of studies as part of NQBP's long-term Sustainable Sediment Management (SSM) assessments at the Port of Mackay. The scope of work for the studies being undertaken by PCS are as follows:

- Environmental Thresholds Analysis: the turbidity, deposition and benthic photosynthetically active radiation (PAR) data collected as part of the ambient water quality monitoring at the Port of Mackay and adjacent Port of Hay Point will be analysed to understand the natural variability of these parameters in the environment. Based on this and information available from the literature, relevant thresholds (using an intensity, duration and frequency approach) will be defined for the long-term monitoring sites closest to the Port of Mackay;
- Avoid and Reduce Assessment Update: the aim of this component of the work is to update the necessary sections of the previous Avoid and Reduce assessment so that it is up to date and corresponds with the other information supporting the Long Term Dredge Management Plan;
- Sediment transport and dredge plume modelling: the aim of this study is to undertake natural sediment transport and dredge plume modelling specific to the Port of Mackay SSM project to better understand potential impacts from maintenance dredging; and
- Resuspension Assessment: the aim of this study is to estimate the mass of sediment naturally resuspended in the Port of Mackay region and to develop a relationship between the natural SSC and the wind speed and compare this to the SSC resulting from maintenance dredging.

This report details the sediment transport and dredge plume modelling for the Port of Mackay.

1.1. Project Background

Regular but infrequent maintenance dredging has been required at the Port of Mackay to ensure there is sufficient depth for vessels to safely travel to and from the berths. Since 2010 maintenance dredging within the Port has been undertaken twice, with approximately 100,000 m^3 of sediment dredging in 2013 and approximately 120,000 m^3 of sediment dredged in 2020. The dredged sediment has been relocated to the approved dredge material placement area (DMPA) located approximately 3.5 km offshore and to the east north-east of Mackay Harbour (Figure 1).

In 2016, a Maintenance Dredging Strategy (MDS) was developed for the ports that are situated within the Great Barrier Reef World Heritage Area (GBRWHA) (DTMR, 2016). This MDS (which supports the wider Reef 2050 Plan) provides a framework for the sustainable, leading practise management of maintenance dredging in the GBR (Figure 2). It is a requirement of the MDS that each Port within the GBRWHA develops Long-term Maintenance Dredging Management Plans (LMDMPs). Such LMDMPs are aimed at creating a framework for continual improvement in environmental performance. DTMR have provided guidelines to assist in the development of the LMDMPs (DTMR, 2018). The guidelines note that they should include, among other aspects, the following:

- an understanding of port-specific sedimentation conditions and processes;
- management approaches (including dredge avoidance and reduction); and
- long-term dredging requirements based on sedimentation rates, port safety and port efficiency needs.

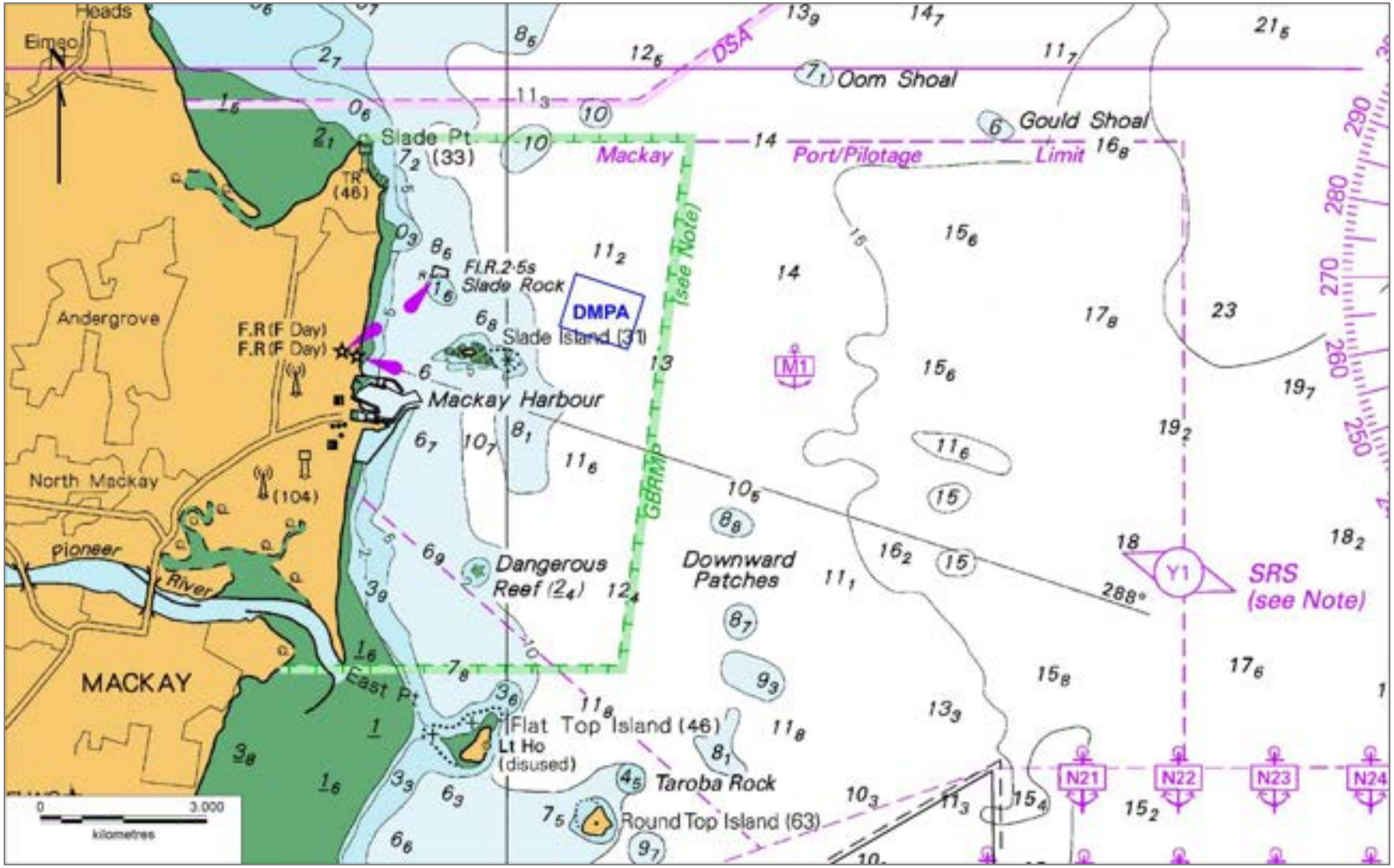

Figure 1. Location of Mackay Harbour and the Mackay DMPA.

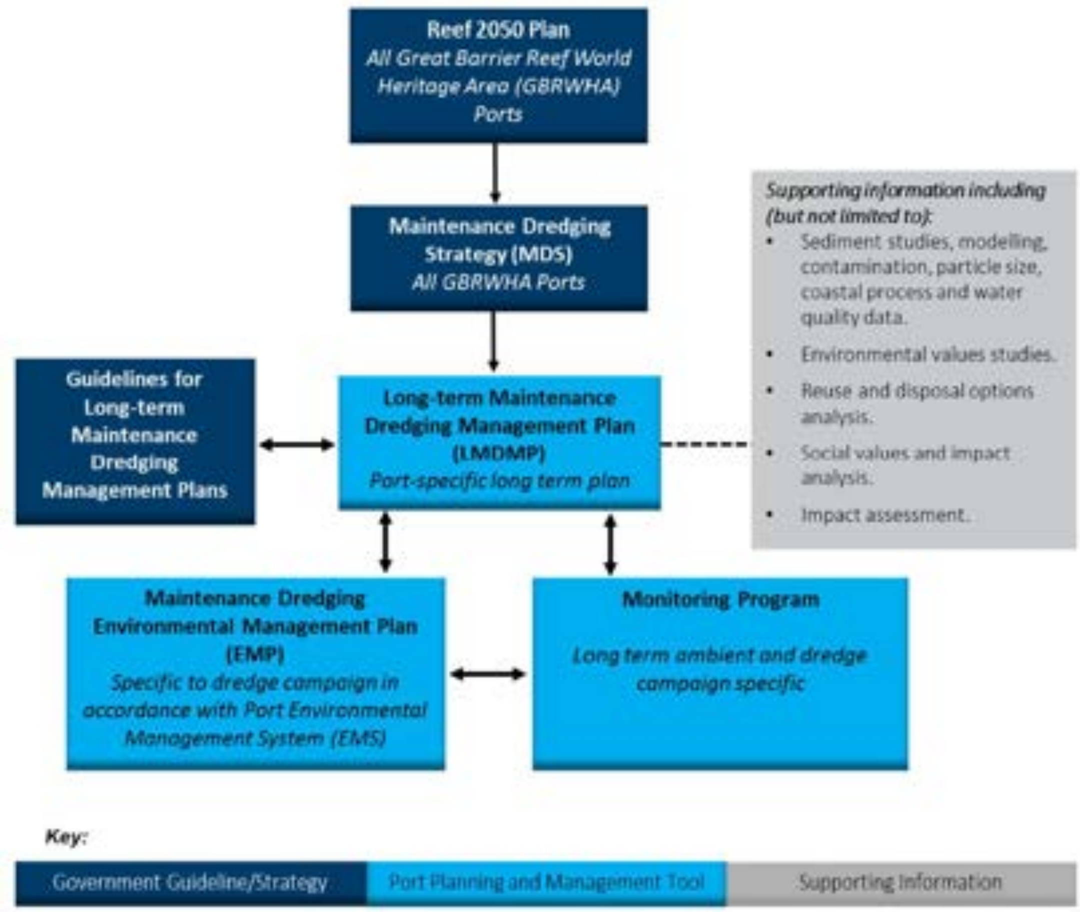

Figure 2. Planning and implementation mechanisms for maintenance dredging of Queensland Ports (DTMR, 2018).

The requirement to investigate whether sedimentation at ports can be managed to avoid or reduce the need for maintenance dredging is derived from the London Protocol, which forms the basis for Australia's Sea Dumping Act 1981. Based on this, the environmental regulators are particularly focused on the following questions:

1. Can sedimentation be managed at the Port to avoid or reduce the need for maintenance dredging?
   – Where do sediments accumulate in the Port and at what volumes and rates?
   – What causes sedimentation in the Port?
   – Does sedimentation at the Port pose a risk to port operations and safety?
   – Why does the Port need to undertake maintenance dredging?
2. If maintenance dredging must occur, has there been a comprehensive assessment of whether the material can be beneficially reused?
3. If no beneficial reuse options are available, what would be the most suitable and feasible disposal or placement options?
4. Has a comparative analysis of options been undertaken, that considers human health, social values, environmental impacts and disproportionate costs?

To answer these questions, NQBP developed a framework as part of the SSM assessment at the Port of Hay Point. This framework was subsequently used to inform the framework that has been adopted at the Port of Mackay as well as the framework developed for the MDS, demonstrating that NQBP have been proactive at developing sound long-term maintenance dredging strategies. The findings from all the SSM studies being undertaken will feed into the development of a new LMDMP at the Port of Mackay.

1.2. Port of Mackay

NQBP manages the Port of Mackay which is located on the central Queensland coast near the city of Mackay. The Port is located within Mackay Harbour which is positioned on Harbour Beach, approximately 4 km to the north of the mouth of the Pioneer River. The Harbour is enclosed by rock breakwaters with a 180 m wide entrance channel (Figure 3).

The key export trade through the Port is sugar (raw and refined). Fuel for agriculture and the mining industry is the dominant import, although the Port also provides for the import of a diverse range of other products. In the 2019-20 financial year the Port had a total throughput of approximately 3.2 million tonnes.

The Port of Mackay consists of a swing basin, a siltation trench and four berths (Figure 3) with varying design depths as follows:

- Swing Basin: area = 352,500 m^2, design depth = -8.6 m relative to Lowest Astronomical Tide (LAT);
- Siltation Trench: area = 29,700 m^2, design depth = -10.0 m LAT;
- Berth 1: area = 7,560 m^2, design depth = -10.6 m LAT;
- Berth 3: area = 9,720 m^2, design depth = -13.5 m LAT;
- Berth 4: area = 5,400 m^2, design depth = -10.6 m LAT; and
- Berth 5: area = 10,800 m^2, design depth = -12.5 m LAT.

Since 2004 the Trailing Suction Hopper Dredge (TSHD) *Brisbane* has undertaken the majority of the maintenance dredging at the Port of Mackay. Between 2004 and 2021 the dredge has undertaken four programs, in 2004, 2007, 2013 and 2020. Prior to 2004 the Port's grab bucket dredge *James Pearce* undertook the maintenance dredging, with an average annual volume of 40,000 m^3 dredged. Between 2004 and 2012 the *James Pearce* continued to undertake infrequent dredging of sedimentation in the berth pockets and the removal of high spots within the swing basin. The *James Pearce* was decommissioned in 2013 and the only maintenance dredging undertaken since then has been by the *TSHD Brisbane*. Details of the historical maintenance dredging undertaken at the Port since 2000 is detailed in Table 1.

In addition to maintenance dredging, bed levelling and drag barring has been undertaken at the Port to help manage the sedimentation in the berths and swing basin and maintain design depths. Historical drag barring was undertaken in 2010, 2011, 2016, 2017 and 2018 while bed levelling was undertaken along with the maintenance dredging in 2013 and 2020. Typically, drag barring programs have been up to a week in duration and have focused on the berths. Drag barring of the berths has been found to be most effective for short duration programs (e.g. 1 day), after this the loosely consolidated surface sediment in the berth fluidises and cannot be dragged up the batter slopes or resuspended.

Table 1. Historic in-situ dredging volumes at the Port of Mackay (PCS, 2021a).

Year	Grab *James Pearce* (m^3)	TSHD *Brisbane* (m^3)	Drag Barring
2000	47,872	-	
2001	44,200	-	
2002	44,098	-	
2003	46,736	-	
2004	4,760	118,000	
2005	-	-	
2006	520	-	
2007	-	106,000	
2008	3,406	-	
2009	-	-	
2010	-	-	✓
2011	-	-	✓
2012	-	-	
2013	-	98,381	
2014	-	-	
2015	-	-	
2016	-	-	✓
2017	-	-	✓
2018	-	-	✓
2019	-	-	
2020	-	122,338	

Previous investigations by PCS (2021a) found that the majority of the sedimentation which occurs within the Port of Mackay is due to fine-grained sediment being suspended by wave action offshore of the Harbour and then being imported into the Harbour in suspension during the flood stage of the tide. Tropical Cyclones were found to have the potential to result in increased sedimentation in the Port due to their potential to result in increased wave activity and therefore increased resuspension of sediment offshore of the Harbour.

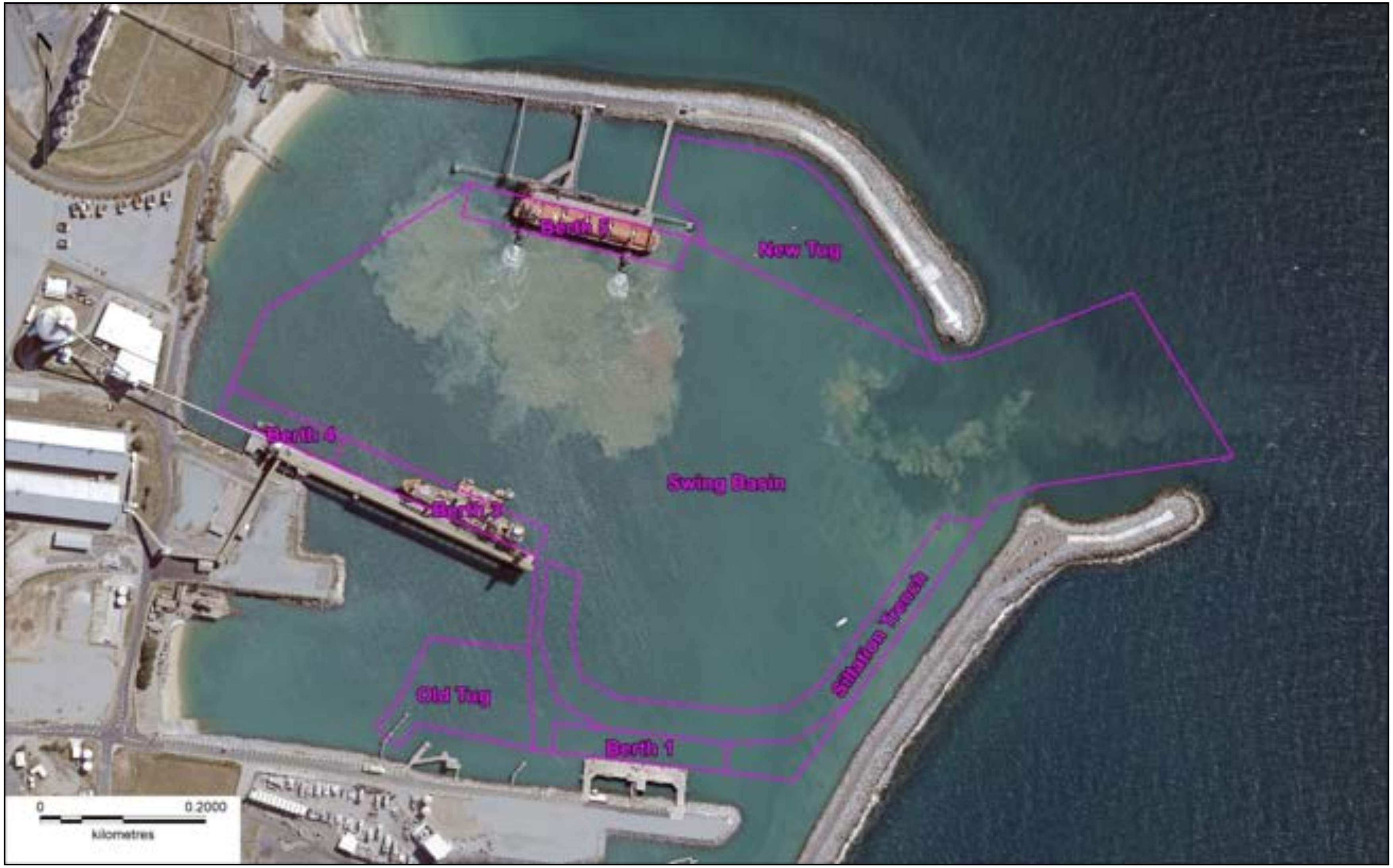

Figure 3. Dredged areas within the Port of Mackay.

1.3. Report Structure

The report herein is set out as follows:

- an introduction to the study is provided in **Section 1**;
- site conditions are defined in **Section 2**;
- the modelling approach is defined in **Section 3;**
- the model performance is assessed in **Section 4**;
- descriptions of the dredging programs simulated by the model are provided in **Section 5**;
- details of how the dredge plume modelling approach adheres to the Great Barrier Reef Marine Park Authority (GBRMPA) guidelines is provided in **Section 6**;
- the results of the numerical modelling are provided in **Section 7**; and
- the conclusions from the study are presented in **Section 8**.

The following conventions have been adopted throughout:

- volumes are *in-situ* cubic metres;
- depths are provided relative to Australian Height Datum (AHD) unless stated otherwise;
- current directions are quoted as directions to; and
- wave and wind directions are quoted as directions from.

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2. Site Conditions

Analysis and interpretation of available hydrodynamic, wave, meteorological, water quality and sedimentological data was undertaken as part of the Port of Mackay SSM Avoid and Reduce assessment to provide an understanding of the local conditions (PCS, 2021). This section provides a summary of the site conditions based on the analysis and interpretation undertaken as part of the previous SSM study. In addition, this section also provides an overview of the known sensitive receptors present in the region based on the latest available information.

2.1. Hydrodynamics

The Port of Mackay is located in a macrotidal environment with mixed semi-diurnal tides. The area has a peak tidal range of 6.58 m and mean spring tidal range of 4.55 m. The tidal planes for Mackay Harbour are provided in Table 2. Storm surges can also occur in the Mackay region with the largest typically associated with cyclonic events. When the surges coincide with high water during spring tides there is the potential for the combined tidal level and storm surge to exceed the Highest Astronomical Tide (HAT) level.

Table 2. Mackay Harbour tidal planes (MSQ, 2021).

Tidal Level	Height (m LAT)	Height (m AHD)
HAT	6.58	3.64
MHWS	5.29	2.35
MHWN	4.07	1.13
MSL	3.02	0.08
AHD	2.94	0
MLWN	1.96	-0.98
MLWS	0.74	-2.20

Current data were collected from January to April 2017 at a site located approximately 1 km to the east of the entrance to Mackay Harbour (RHDHV, 2017a). The current data showed that tidal currents close to the entrance to Mackay Harbour were as follows:

- peak tidal current speeds range from 0.3 to 0.8 m/s, with stronger currents occurring during the spring tides and weaker currents during neap tides; and
- the peak flood current direction is to the south-east and the peak ebb current direction is to the north. The reason that the flood current is to the south-east rather than the south (which would be expected given the general alignment of the shoreline) is because of the flow being deflected by Slade Islet and Mackay Harbour.

Results from previous numerical modelling presented by RHDHV (2017b) showed that northerly ebb currents are generally stronger in most locations in the Mackay region and as such a net northerly residual transport direction is expected. The currents increase around Slade Islet and adjacent to the Mackay Harbour breakwaters, with the strongest currents typically occurring between the Harbour breakwaters and Slade Islet. Within the Harbour the numerical model predicted that the peak flood current speed was significantly higher than the peak ebb speed, with peak ebb speeds within the Harbour typically remaining below 0.1 m/s. This suggests that the Harbour will act as a net importer of sediment, with the low ebb current speeds being unlikely to resuspend any sediment which is deposited in the Harbour over the high water slack period.

Winds can also influence the currents which occur in the Mackay region, with the dominant south-easterly trade winds acting to further strengthen the northerly ebb currents. Very strong winds during Tropical cyclones (TC) can also result in increased current speeds and changes in current direction due to the associated strong winds, this is further discussed in Section 2.5.

As well as tide and wind induced currents, regional scale circulation currents can occur in the Great Barrier Reef (GBR) Lagoon. These regional scale currents are dynamic and intermittent as they are primarily driven by a complex interaction between oceanic inflows caused by the North Vanuatu Jet and local wind driven circulation (Andutta *et al.*, 2013). Although these regional scale ocean circulation processes have the potential to intermittently influence current regimes at the Port of Mackay, their impacts are considered minor relative to tidal and wind induced currents.

2.2. Wind and Waves

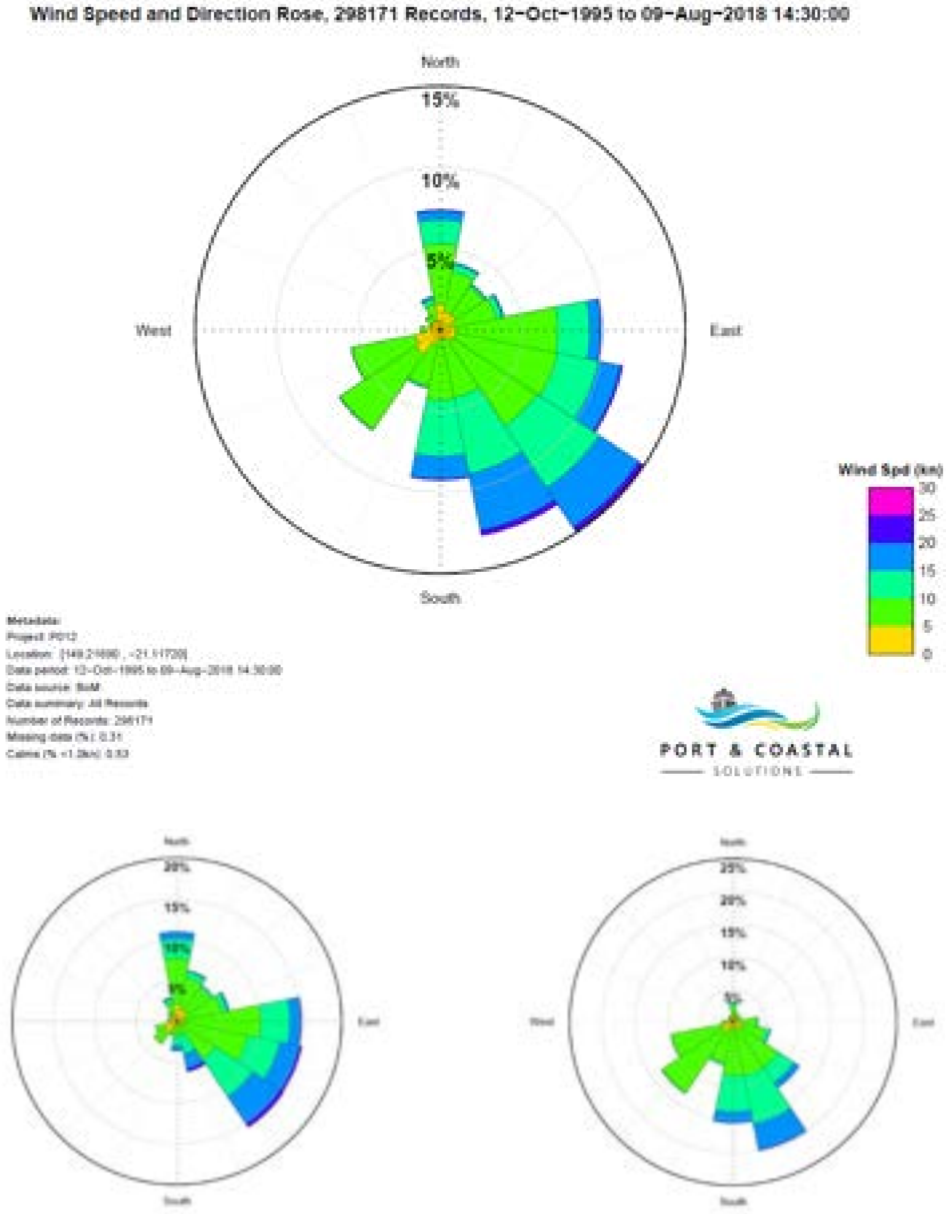
Mackay experiences trade winds from a south-easterly direction for most of the year (Figure 4). There is some seasonal variability in the wind conditions. During the summer months the winds tend to be stronger and more variable with winds frequently from the north and east to south-east. During the winter months the wind speed tends to be lower and the direction less variable, with wind directions from the south-east to south-west dominating. Local wind conditions are an important driver for both locally generated waves in the Mackay region as well as wind-generated currents.

The highest wind speeds which occur in the Mackay region are a result of tropical cyclones which can influence the area. The associated speed and direction of these winds are a direct result of the intensity and location of the cyclones, this is discussed further in Section 2.5.

Wave data have been collected for over 40 years at the Mackay waverider buoy (WRB) (located 33 km to the east of Mackay Harbour) and the Hay Point WRB (located 20 km to the south south-east of Mackay Harbour). The measured data can be used to provide an understanding of the offshore (Mackay WRB) and nearshore (Hay Point WRB) wave conditions in the Mackay region:

- Offshore wave conditions: for the majority of the time the wave direction is from the east-south-east and the significant wave height (H_s) is less than 2.5 m. The largest H_s measured was over 5.5 m and for the larger wave events (e.g. $H_s > 4$ m) the wave direction is typically from the east to east-south-east. The peak wave period for these larger wave events have been between 8 and 11 seconds (s); and
- Nearshore wave conditions: the nearshore wave direction is more variable (Figure 5) than the offshore direction, with waves typically from the east but also regularly occurring from the east-north-east and east-south-east. The H_s is less than 1.5 m for the majority of the time, with the largest H_s measured being just below 4 m. For larger wave events (e.g. $H_s > 3$ m) the wave direction has varied between the east and north-east and the peak wave period has been between 7 and 11 s.

The largest wave conditions measured at both sites were due to TCs, with TC Ului resulting in the largest wave heights at both WRBs in March 2010. Concurrent wave measurements were collected at a site 1 km to the east of Mackay Harbour (MK1) and at the Hay Point WRB during TC Debbie in March 2017 and comparison of the data showed that the wave conditions were very similar at the two nearshore locations, with a slightly higher peak in H_s at the site to the east of Mackay Harbour. Therefore, the wave conditions at the Hay Point WRB can be considered to be approximately representative of the nearshore conditions directly offshore of Mackay Harbour. As a result, the relationship between wind speed and H_s developed for the Hay Point WRB can be adopted to provide an indication of nearshore wave conditions at Mackay for varying wind speeds (Figure 6).



Summer Months *Winter Months*

Figure 4. Wind roses from the measured wind data from Mackay MO (1995 – 2018).

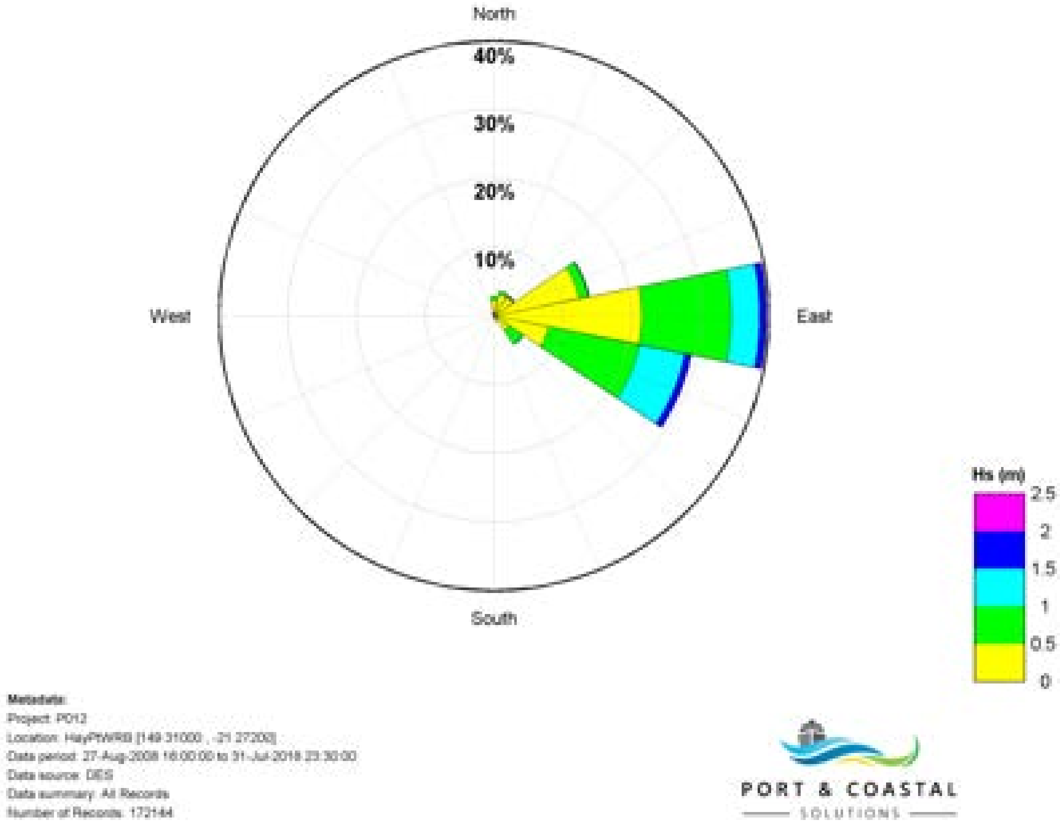


Figure 5. Wave rose showing the measured wave conditions at the Hay Point WRB.

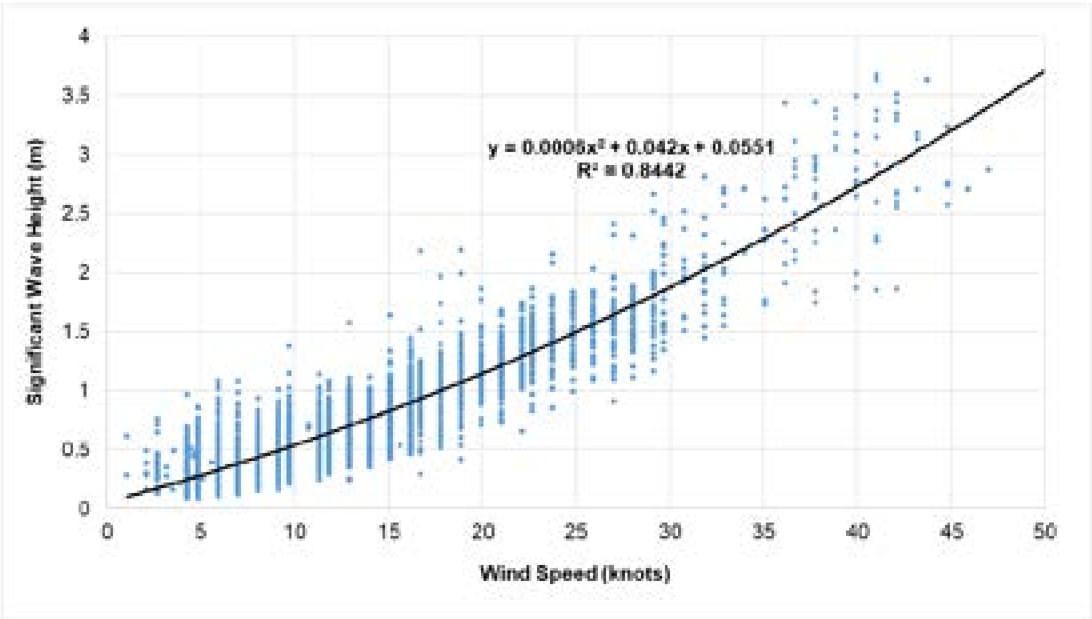


Figure 6. Relationship between H_s and wind speed at the Port of Hay Point (RHDHV, 2017c).

2.3. Rainfall and River Discharge

Mackay experiences a tropical climate with a distinct monsoonal rainfall trend with on average 1,595 mm of rainfall each year. Average monthly rainfall measurements, based on data recorded at the Bureau of Meteorology (BoM) weather station Mackay MO from 1959 to 2015, are shown in Figure 7. The monthly rainfall data show that:

- the wet season occurs between January and March and a significant proportion of the annual rainfall occurs over this period (approximately 60%);
- the dry season occurs between June and October with very little rainfall occurring (approximately 10%); and
- the months of April to May and November to December are the transition periods between the wet and dry seasons with monthly rainfall totals between the wet and dry seasons.

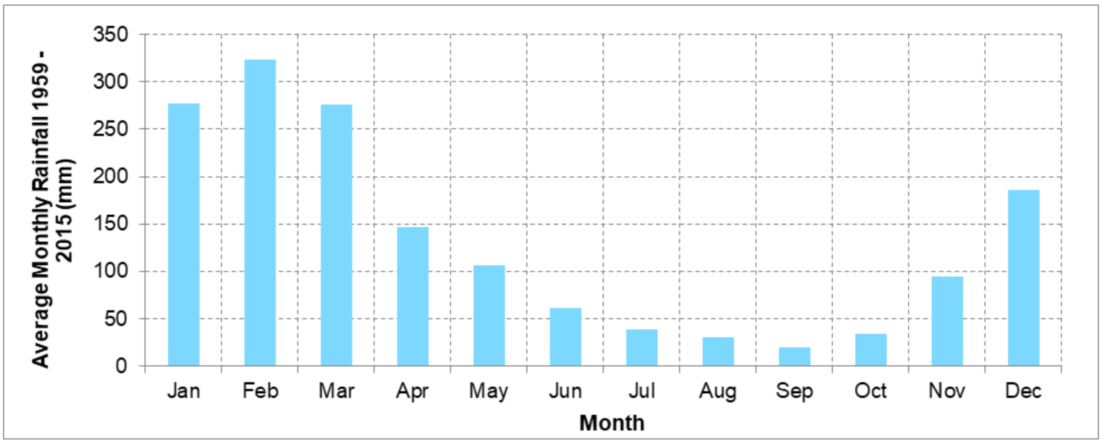


Figure 7. Mackay average monthly rainfall.

Rainfall can result in catchment runoff which in turn has the potential to cause soil erosion from the catchment which can be discharged into the GBR through the rivers. This is one of the key drivers responsible for the input of new terrigenous sediment to the inner shelf of the GBR. During the wet season, cyclones and periods of high rainfall can result in large volumes of sediment being input into the waters of the Great Barrier Reef (GBR) through local river systems and their associated catchment areas.

Based on the sediment budget developed for the Hay Point and Mackay region it was found that direct deposition during wet season flood events from local catchments accounted for less than 1% of the observed sedimentation at the Port of Hay Point (AECOM, 2016). In addition, it has been estimated that the sediment load from rivers within 20 km of the Port of Mackay is approximately 140,000 tonnes/yr (BMT WBM, 2018). When this is compared to the estimated resuspension of existing seabed sediment of 6.7 million tonnes/yr for the same region (BMT WBM, 2018) it is clear that the input of sediment from the rivers represents a small amount (2%) of the total sediment transport which is occurring in the region. Based on this, the direct input of sediment from rivers in the Mackay region can be considered negligible in terms of ongoing sedimentation at the Port of Mackay. However, water quality monitoring has shown that the discharge from the Pioneer River (the mouth is located 4.5 km south of Mackay Harbour) has the potential to result in elevated turbidity in the Mackay region. During the 2019 Port of Hay Point maintenance dredging program the benthic turbidity remained above 25 NTU (peak of 120 NTU) for a 5 day period at Slade Islet due to more than 150 mm of rainfall occurring over 3 days which resulted in a discharge from the Pioneer River of just over 30,000 ML/day (PCS, 2019a). Elevated turbidity due to the Pioneer River discharge only influenced the monitoring at the Slade Islet site as the event coincided with south-easterly winds which resulted in the turbid water discharged from the river being transported to the north of the river mouth and Slade Islet is the only nearshore monitoring site located to the north of the river.

2.4. Sediment Transport

Sediment sampling was undertaken in 2018 to assess the properties of the sediment in the Port of Mackay, results from the analysis were summarised by Adaptive Strategies (2018) and showed some spatial variability in sediment type:

- Berths: made up of approximately 95% silt and clay and 5% sand;
- Swing Basin and Channel: made up of approximately 65% silt and clay, just over 30% sand and a small amount of gravel;
- Old Tug Berths: just under 90% silt and clay with the remainder made up of sand; and
- New Tug Berths: just over 60% silt and clay with the remainder made up of predominantly sand with a trace of gravel.

It is likely that the spatial variability in the sediment composition is a result of some of the sampling in the Swing Basin, Channel and New Tug Berths not being representative of recently deposited sediment as widespread deposition does not occur in these areas (PCS, 2021a). In contrast, the sediment deposited in the Berths and Old Tug Berths is more likely to be representation of recently deposited sediment as these areas are naturally deeper than the surrounding areas and are prone to regular ongoing sedimentation. Therefore, as the majority of the sediment which will be removed by maintenance dredging will have been recently deposited it is the properties of the sediment in the Berths and Old Tug Berths which are likely to be most representative of the typical properties for future maintenance dredging sediment. It was also noted by Adaptive Strategies (2018) that the sediment sampling showed that the sediment accumulating in the dredged areas of the Port of Mackay was predominantly fine clay and silt sized sediment.

An ambient water quality monitoring program was initiated for the Mackay and Hay Point region by NQBP in 2014. James Cook University (JCU) has collected water quality and deposition data at seven sites in the Mackay and Hay Point region since 2014. Analysis of these data as part of previous investigations found that suspended sediment concentrations (SSC) in waters adjacent to Mackay are predominantly the result of existing bed sediments being resuspended by current and wave action (AECOM, 2016; RHDHV, 2016).

The closest ambient water quality monitoring site to the Port of Mackay is located at Slade Islet, approximately 1.5 km to the north-east of the entrance to Mackay Harbour. Measured SSC data at Slade Islet from 2014 to 2021 has been statistically analysed to better understand the natural water quality environment: median = 3 mg/l; 80th percentile = 16 mg/l; 90th percentile = 35 mg/l; and the 99th percentile = 140 mg/l (PCS, 2021b). The statistics show that the SSC can be considered to typically be relatively low (less than 20 mg/l), but with the potential of becoming very high during infrequent events. There is seasonal variability in the SSC at Slade Islet, with higher SSC occurring during the wet season relative to the dry season. For example, analysis of the measured data showed that the 90th percentile SSC during the wet season was 50 mg/l, while during the dry season it was 16 mg/l. The higher SSC which occurs is primarily due to increased wind and wave energy during the wet season resulting in increased resuspension of bed sediment compared to the dry season.

It was shown by PCS (2021c) that there was a strong relationship between wind speed and wave height in the Mackay region which allowed a relationship between wind speed and SSC at Slade Islet to also be developed (Figure 8). The plot shows that when the wind speed increases above 15 knots the resultant increase in SSC is approximately exponential showing that there is a significant increase in resuspension.

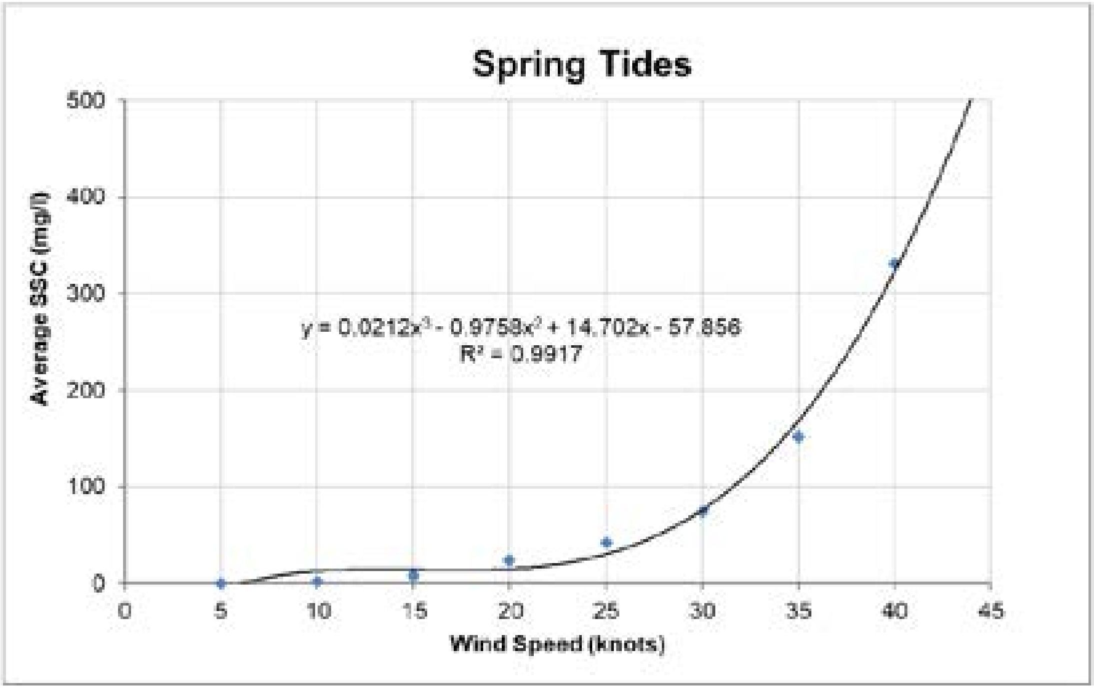


Figure 8. Relationship between wind speed and average peak in SSC (averaged between Slade Islet and Round Top Island) during spring tides (PCS, 2021c).

2.5. Tropical Cyclones

Mackay is located in an area where severe Tropical Cyclones (TCs) can occur during the wet season. Since 1969 a total of 29 TCs have passed within 200 km of Mackay and a number of TCs have affected the Port of Mackay since 2010, notably TC Ului (March 2010), TC Dylan (January 2014) and TC Debbie (2017). Wind and nearshore wave data collected during the passing of these cyclones are summarised in Table 3.

Table 3. Recent measured cyclonic wind (Mackay MO) and nearshore wave (Hay Pt WRB) conditions (from PCS, 2021a).

Cyclone	Peak 10 minute averaged wind speed (kn)	Peak H_s (m)	Peak H_{max} (m)
TC Ului (March 2010)	43	3.95	6.35
TC Dylan (January 2014)	37	3.74	7.05
TC Debbie (March 2017)	36	3.63	6.65

Tropical cyclones have the potential to generate large waves, strong currents and increased river discharge causing significant resuspension of sediment from the seabed, increased transport of suspended sediment and subsequent sedimentation. Due to the typical east to west projection of cyclones making landfall along the GBR coastline, passing cyclones generally result in the development of strong north-westerly longshore currents as well as large waves from the south-east to north-east. These higher energy wave and current events have the potential to mobilise bed sediment in deep water areas which would not normally be subject to bed sediment mobilisation under ambient conditions. Research conducted by Carter *et al.* (2009) showed that wave generated bed shear stresses from an intense cyclone can suspend sediments at water depths of up to 30 to 60 m. Cyclone induced waves and currents are also considered to be important in the supply of new fine-grained sediment to the inner-shelf of the GBR through the erosion and advection of seabed sediment from the deeper mid-shelf of the GBR (Gagan *et al.*, 1990; and Orpin and Ridd, 2012).

2.6. Sensitive Receptors

Previous surveys have identified that coral reefs and seagrass meadows are present in the Mackay region and these marine habitats are also sensitive receptors (NQBP, 2011). Both the seagrass and coral have been monitored for NQBP, with a broad-scale monitoring of the seagrass meadows occurring since 2014 (monitoring commenced in 2001 but was more localised) and ambient coral monitoring occurring since 2015 (monitoring commenced in 2006 but was focused on impacts from dredging as opposed to ambient conditions and metocean drivers).

The key areas with coral communities in the vicinity of the Port of Mackay are Slade Islet and Round Top Island (Ayling *et al.*, 2020). A summary of the behaviour of coral at these two sites since 2006 is provided below:

- the Mackay region reefs were experiencing a mass bleaching event due to elevated sea surface temperature (and not related to turbidity) at the time of the April 2020 survey, with on average 56% of the hard coral cover bleached and 20% of the soft coral cover;
- the hard coral cover reduced significantly due to TC Debbie in 2017, with coral cover reduced by approximately 40% relative to the initial 2006 survey resulting in hard coral cover post TC Debbie of between 33% and 20%;
- since TC Debbie there has been no sustained recovery evident in hard or soft coral at either of the sites; and
- the major driver of change to the coral in this region is thought to be sporadic cyclone events with all other impacts having been slight and non-significant, although the 2020 mass bleaching event due to elevated sea surface temperatures may have a significant future impact.

Extensive seagrass surveys in the Port of Hay Point region have shown that historically seagrass has been present in most of the region (Figure 9). The plot also shows that the surveys have focused on a much smaller region adjacent to the Port of Mackay, with a 4.8 km by 4.8 km square located approximately 1 km to the east of the Mackay DMPA. It is unknown whether any seagrass meadows are located between the monitoring square and the Port of Mackay. Previous monitoring at the Port of Hay Point found that the deep-water seagrass meadows present in the offshore areas are typically of low density and cover and that they are extremely variable with annual cycles of absence and occurrence. Results from the recent monitoring by York and Rasheed (2020) has shown:

- the deep-water seagrass in the Mackay offshore monitoring area is in very good condition and has more than doubled in biomass and increased in area more than four times compared to the previous year;
- the improved seagrass condition was likely due to two consecutive years with an absence of major storm and cyclone events following a series of almost yearly cyclones and floods which culminated in TC Debbie in 2017; and
- the maintenance dredging undertaken at the Port of Hay Point in 2019 did not appear to have an impact on the seagrass condition. Monitoring results since the Port of Mackay 2020 maintenance dredging are not yet available.

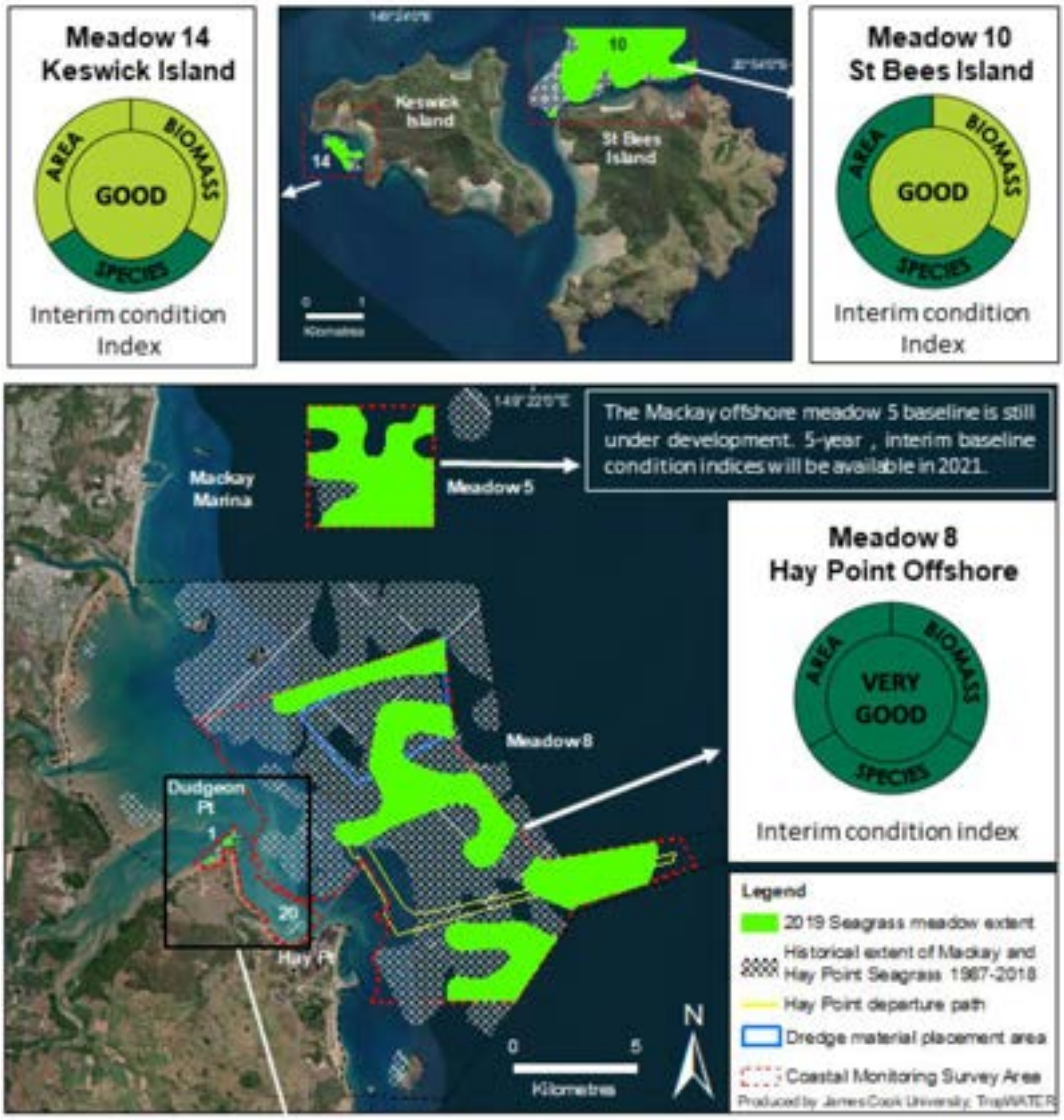


Figure 9. Seagrass meadow conditions for the Mackay region based on the 2019 survey (York and Rasheed, 2020).

2.7. Summary

The dominant processes which result in the resuspension of sediment in the Mackay region are wave action (locally generated due to wind conditions) and tidal currents. The waves have the potential to resuspend a much larger mass of bed sediment, while the tidal currents (and wind-generated currents) will transport the sediment when it is suspended. The currents at the entrance to Mackay Harbour are flood dominant, which indicates that the Harbour will act as a net importer of sediment and the low ebb current speed suggests that limited export of sediment from the Harbour occurs. The tidal currents in the area directly offshore of Mackay Harbour are relatively high and as a result there is expected to be limited ongoing deposition in the area. In contrast, the tidal currents within Mackay Harbour are relatively low indicating that any fine-grained sediment which is transported into the Harbour in suspension is likely to be deposited within the Harbour.

3. Modelling Approach

The approach adopted for the modelling has been developed to ensure that it complies with the guidelines provided by the GBRMPA (GBRMPA, 2012). The GBRMPA modelling guidelines were designed to ensure that all numerical modelling undertaken within the GBRWHA meets the highest international standards of best practise and therefore gives confidence in the results. Further details as to how the modelling has been undertaken in line with the GBRMPA modelling guidelines is provided in Section 6.

This section provides details of the numerical modelling software utilised, the models adopted and the approaches used for the various simulations.

3.1. Software

The MIKE software suite has been adopted for the assessment. The MIKE software has been developed by the Danish Hydraulics Institute (DHI) and is internationally recognised as state-of-the-art and has been previously adopted for dredge plume modelling at the Port of Hay Point (RHDHV, 2018), elsewhere in Australia and internationally for similar projects. The MIKE suite includes hydrodynamic (HD), spectral wave (SW) and mud transport (MT) modules which allow all the necessary processes required for this assessment to be represented in the model.

The MIKE modules can adopt a flexible mesh (FM) which allows the spatial resolution of the model mesh to be varied throughout the model domain. This allows suitable model resolutions to be adopted throughout ensuring the model accuracy and efficiency can be balanced. This means that areas of interest can have a higher mesh resolution (e.g. Mackay Harbour) while a lower mesh resolution can be adopted in offshore areas and areas away from any areas of interest.

3.2. Model Setup

The HD, SW and MT models which were adopted for the Port of Hay Point dredge plume modelling (see RHDHV (2018) for further details) were used as the basis for the models in this assessment. However, to ensure that the models adopted were suitable for undertaking dredge plume modelling at the Port of Mackay, further updates and refinements were made and a Mackay specific model calibration and validation exercise has been undertaken (see Section 4). Details of the model mesh, bathymetry and boundary conditions are provided in the following sections.

3.2.1. Mesh

The model mesh extent was selected with consideration to:

- the model needing to be able to accurately represent the hydrodynamics and waves in the Mackay region;
- ensuring that the majority of the sediment suspended by the maintenance dredging remaining within the model domain, with limited sediment reaching the model boundaries; and
- managing the domain so that it isn't overly large which would act to unnecessarily increase the model simulation times.

The final model domain extent and model mesh are shown in Figure 10. The model extends approximately 150 km along the central Queensland coast (north to south) and 60 km from the coast (east to west). The mesh extends approximately 90 km to the north of the Port of Mackay (just north of Lindeman Island) and 60 km to the south of the Port (down to Cape Palmerston). The same model mesh has been used for the HD, SW and MT modelling and as a result the mesh has been designed to ensure higher resolution in the area where the dredging is undertaken (Mackay Harbour), where the sediment is placed (Mackay DMPA) and where any resultant plumes are likely to be transported (the areas adjacent to the Harbour and DMPA). The model mesh and bathymetry are shown for the Mackay region in Figure 11. The arc lengths of the triangular mesh elements are approximately 40 m in Mackay Harbour, 200 m at Mackay DMPA and 2 km in the offshore areas.

The GBRMPA modelling guidelines note that the use of 3-Dimensional (3D) hydrodynamic and sediment plume modelling is considered international best practise (GBRMPA, 2012). The hydrodynamic and sediment plume modelling presented in this report was undertaken in 3D, with five equally spaced layers included in the model with each layer representing 20% of the water column.

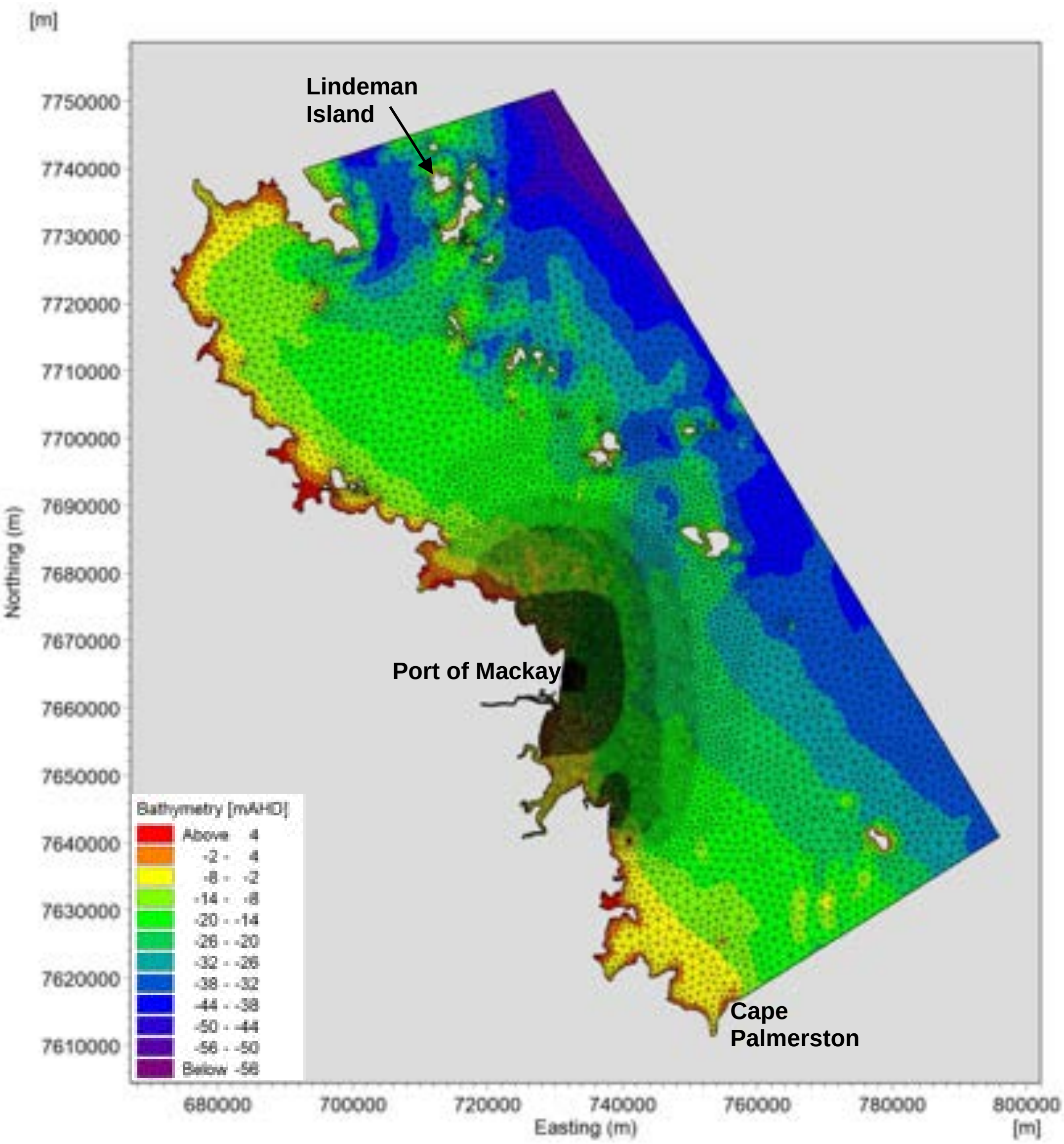


Figure 10. Extent of the Mackay numerical model including the model mesh and bathymetry.

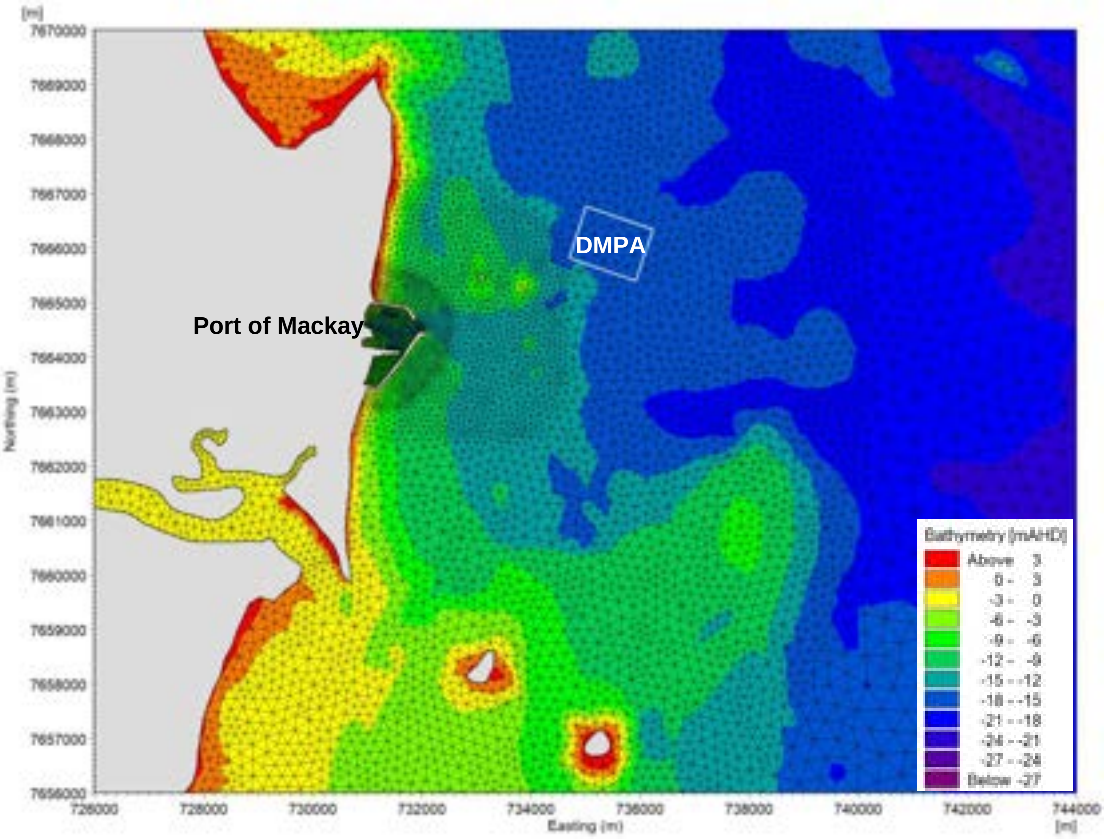


Figure 11. Close up of the model mesh resolution for the Mackay region.

3.2.2. Bathymetry

The model bathymetry has been based on the following sources:

- recent hydrographic survey: the most recent available hydrographic survey from the Port of Mackay and the Port of Hay Point have been adopted to represent the dredged areas of the Ports and the two DMPAs; and
- Geoscience Australia (GA) Great Barrier Reef (GBR) 30 m dataset: the remaining areas of the model domain were represented using bathymetric data from the GA GBR 30 m dataset which is based on a combination of historical and recent measurements (Beaman, 2018).

Data from the two sources were converted to AHD and then interpolated onto the model mesh. An overview of the interpolated model bathymetry covering the full extent of the model domain is shown in Figure 12 and for the Port of Mackay region in Figure 13.

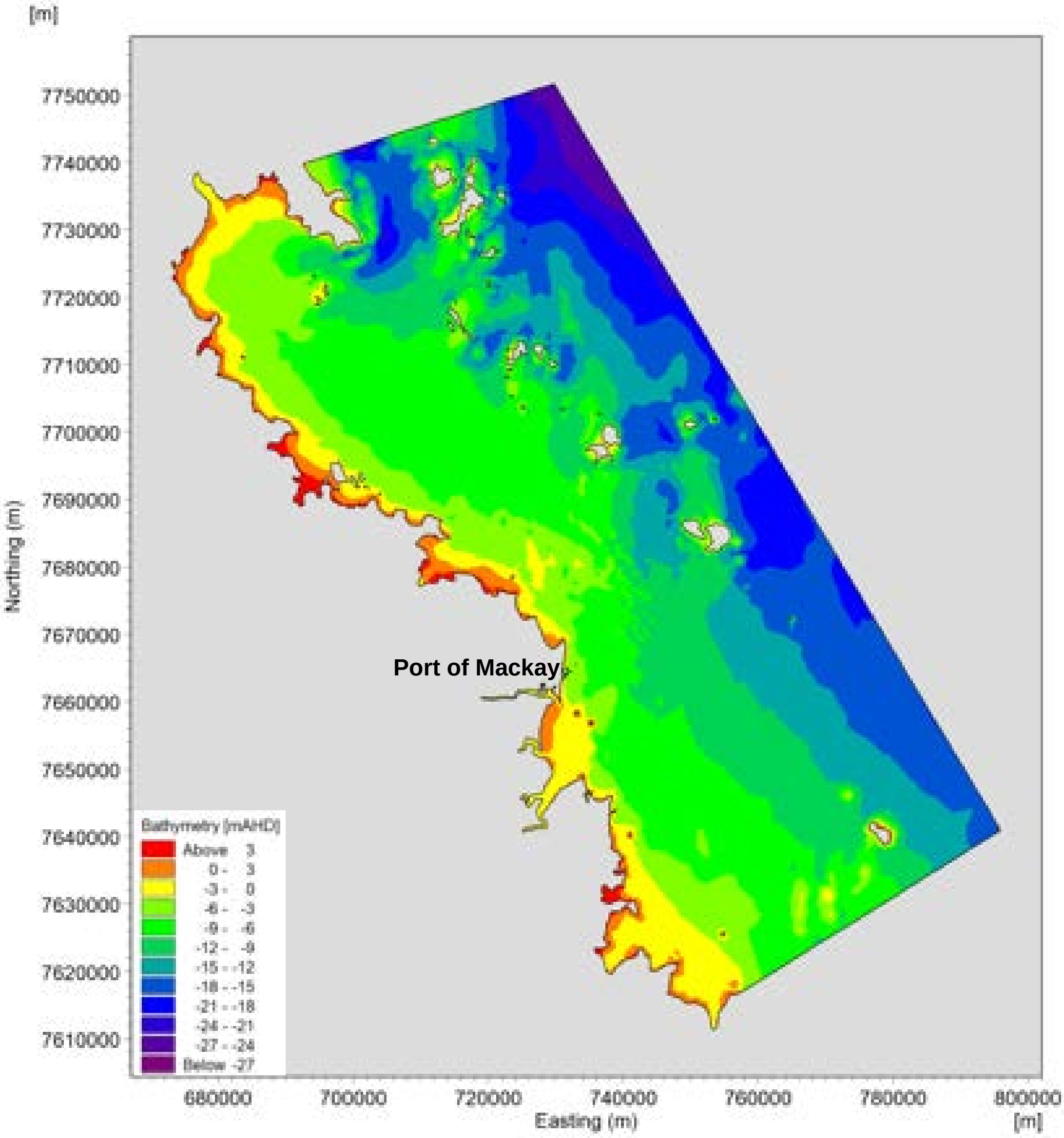


Figure 12. Bathymetry of the Mackay numerical model.

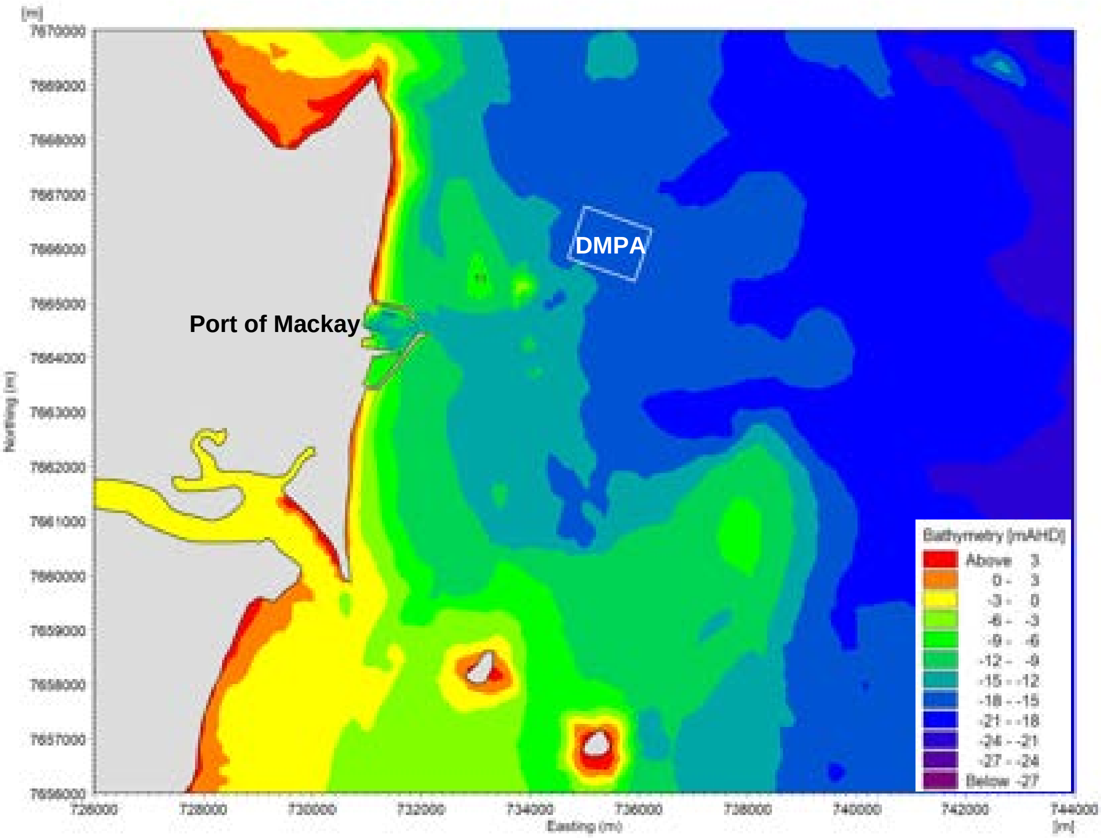


Figure 13. Close up of the model bathymetry for the Mackay region.

3.2.3. Boundary Conditions

Details of the boundary conditions adopted to drive the HD and SW models are provided in the following sections. The approaches used to generate the model boundaries was consistent with the approaches adopted for the previous Port of Hay Point modelling (RHDHV, 2018).

3.2.3.1. Hydrodynamic Model

The Mackay region is a challenging area to reliably define hydrodynamic model boundary conditions as global tidal models do not have sufficient resolution to resolve all the complex processes which occur such as the tidal amplification in Broad Sound (a large embayment approximately 150 km to the south south-east of Mackay). The best approach to provide a realistic representation of the astronomical tide for the Hay Point and Mackay region was found by RHDHV (2018) to be extracting boundary conditions from a larger regional model. Based on this, our Queensland hydrodynamic model has been used to provide water level boundaries along the three Mackay model boundaries (north, east and south) to drive the hydrodynamic model.

The hydrodynamic model also included local wind conditions as they can result in local wind induced currents. It was found by RHDHV (2018) that adopting a spatially uniform wind from the BoM weather station at Hay Point provided the most realistic representation of wind over water for the region. Therefore, the same spatially uniform wind condition based on the Hay Point weather station data was applied.

3.2.3.2. Spectral Wave Model

The boundary conditions for the SW model were derived from the measured offshore Mackay WRB data. The boundary conditions were applied to the east and south model boundaries.

In addition to the wave boundary conditions, local winds were also included in the model to ensure local wave generation processes were also represented in the model. The wind was represented in the same way as in the HD model.

3.3. Natural Sediment Transport

The MIKE MT model was setup to represent the natural sediment transport which occurs in the Mackay region. The only sediment present in the model at the start of the simulation was on the seabed, allowing the model to naturally resuspend sediment based on the metocean conditions. There was no additional input of suspended sediment applied at the model boundaries, meaning that the only sediment in the numerical model was the sediment on the seabed at the start of the simulation. The initial map of bed sediment adopted for the model simulations was defined by running the model multiple times to redistribute the bed sediment towards a dynamic equilibrium state representative of the natural environment.

The model includes the following three sediment types to represent the natural sediment which is regularly resuspended:

- clay;
- very fine to medium silt; and
- medium to coarse silt.

The model includes the process of flocculation, whereby the cohesive properties of the clay and silt allows grains to join together to create larger flocs. The flocs have higher settling velocities than individual particles and thereby promote higher rates of settling. The amount of flocculation which occurs for cohesive sediment is dependent on the SSC, with larger flocs and higher settling velocities occurring as the SSC increases.

As part of the model calibration process a range of critical erosion thresholds, which control when resuspension of the bed sediment occurs, were tested. Following the calibration process, a critical erosion threshold of 0.5 N/m^2 was adopted.

3.4. Dredge Simulations

The GBRMPA Modelling Guidelines specify that the modelling represents the ambient conditions at the time of year in which dredging occurs (GBRMPA, 2012). Future maintenance dredging at the Port of Mackay could occur anytime throughout the year, although it is more likely that dredging would occur during the dry season as there is a risk of TCs occurring during the wet season. However, the 2020 maintenance dredging at the Port of Mackay was undertaken in December, which is the transition period between the dry and wet season. Therefore, it is possible that future maintenance dredging could either occur during the wet or dry seasons.

Analysis of the wave conditions measured at the Hay Point WRB (which is approximately equivalent to the wave conditions offshore of Mackay Harbour) shows that there has been more variability in wave energy during the wet season than there has during the dry season (Figure 14). The monthly average wave energy was ranked for the whole year, the wet season and the dry season to identify lower and higher energy years to represent the range of possible metocean conditions in the modelling. Based on this analysis the following years were selected:

- lower energy year (ambient conditions): 2016 was selected as consistently low wave energy occurred in both the wet (ranked 14^{th} out of 20) and the dry (ranked 15^{th} out of 20) seasons, resulting in an overall annual wave energy which was ranked 17^{th} out of 20; and
- higher energy year (energetic conditions): 2019 was selected as relatively high wave energy occurred in both the wet (ranked 3^{rd} out of 20) and the dry (ranked 8^{th} out of 20) seasons, resulting in an overall annual wave energy which was ranked 2^{nd} out of 20.

To ensure that the modelling represents the range of possible metocean conditions that dredging could occur in, the dredge plume modelling was undertaken during the wet and dry seasons for both the ambient (lower) and energetic (higher) wave energy years. The models were setup so that the dredging commenced at the start of February for the wet season simulations and in the middle of July for the dry season simulations.

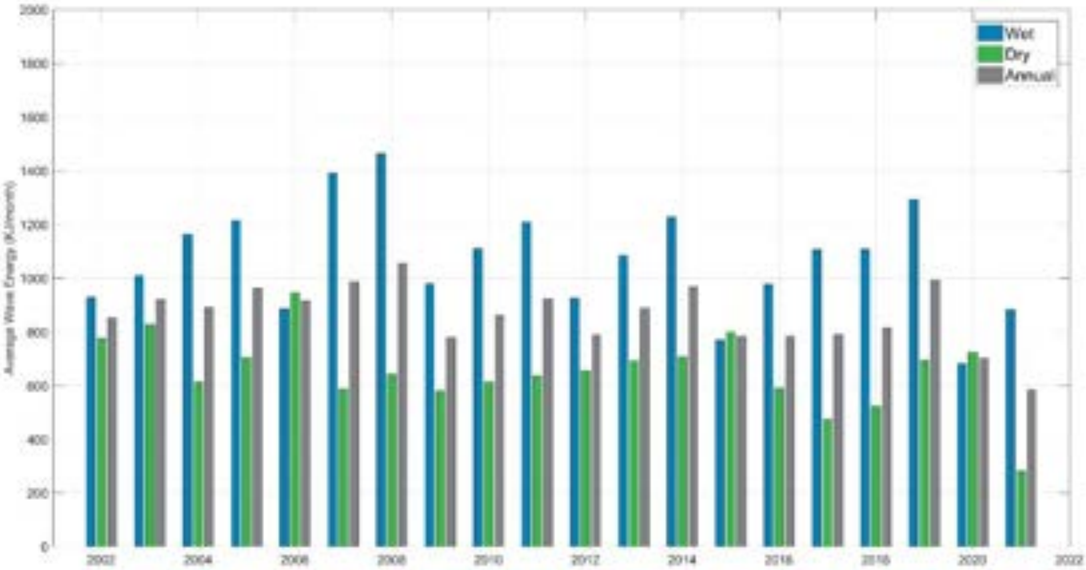


Figure 14. Average wave energy for the last 20 years for the whole year and the wet and dry seasons based on measured wave data at the Hay Point WRB.

3.5. Long-term Resuspension

The GBRMPA Modelling Guidelines specify that the modelling should represent the resuspension associated with different weather conditions that occur after placement and initial settlement (GBRMPA, 2012). As depths within the Mackay DMPA range from 12 to 16 m below LAT, resuspension of placed sediment is most likely to occur during years with more energetic wave conditions. This also agrees with the findings from the bathymetric analysis at the DMPA which estimated that 55 to 75% of the sediment placed at the Mackay DMPA was retained following the maintenance dredging and that the DMPA was stable during typical metocean conditions but erosion could occur during extreme events (PCS, 2021a). Therefore, to better understand the long-term potential for resuspension from the Mackay DMPA the model was run for the following periods:

- January to December 2019: this period was selected to better understand the potential for resuspension from the DMPA during a year with very energetic wave conditions but without an extreme wave event; and
- March 2017: the model was also run to simulate the resuspension from the DMPA during an extreme event. The model was setup to simulate TC Debbie which resulted in very large waves and strong winds in the Mackay region at the end of March 2017. The event also resulted in widespread resuspension of the seabed in the region (see Section 2.5).

For both simulations the model was setup to represent the volume of sediment that would have been placed following maintenance dredging of 250,000 m^3 assuming that the sediment was evenly placed over the entire placement site and placed sediment following some initial consolidation would have a comparable density to the sediment prior to dredging, resulting in a sediment thickness of 0.2 m. The same critical erosion threshold as adopted for the natural sediment transport model was also adopted for these simulations (0.5 N/m^2).

4. Model Calibration and Validation

Model calibration is the process of specifying model parameters so that the model reproduces observed data to a suitable level of accuracy. Model validation is used to confirm that the calibrated model continues to consistently represent the natural processes to the required level of accuracy, in periods other than the calibration period, without any additional adjustment to the model parameters. The calibration and validation processes provide confidence in the model results and are essential to ensure the accurate representation of hydrodynamics, waves and sediment transport.

This section provides details of the calibration and validation undertaken for the hydrodynamic, spectral wave and sediment transport (natural and dredge plume) models adopted as part of this assessment.

4.1. Calibration and Validation Standards

For quality control in the hydrodynamic model calibration, performance criteria have been defined to demonstrate that the model is capable of accurately representing the natural processes. For coastal waters such as around the Port of Mackay, the following performance criteria have been defined:

- modelled water levels (WL) should be within 10% of the tidal range over a spring neap tidal cycle;
- timing of high water (HW) and low water (LW) should be within 15 minutes;
- modelled peak current speeds at the time of Peak Flood (PF) and Peak Ebb (PE) should be within 10 – 20% of measured speeds over a spring neap tidal cycle; and
- modelled peak flow directions at PE and PF should be within 10 – 20º of measured directions over a spring neap tidal cycle.

Additional statistics have been considered to further quantify the model performance. These include:

- Root Mean Square (RMS) difference should be within ± 0.1 – 0.3 m for WL and within ± 0.2 m/s for flow speed; and
- phasing difference should be within 15-30 minutes.

These statistics consider the model performance throughout the full tidal period and not just at the time of peaks. Overall, these standards provide a good basis for assessing model performance, but experience has shown that they can be too prescriptive and it is also necessary for visual checks to be undertaken. Under certain conditions, models can meet statistical calibration standards but appear to perform poorly. Conversely, seemingly accurate models can fall short of the guidelines. Consequently, a combination of both statistical calibration standards and visual checks has been used to ensure that the model is representative.

For the calibration and validation of the wave model we have undertaken a qualitative comparison between measured and modelled wave height, wave period and wave direction. In addition, a quantitative comparison between modelled and measured significant wave height percentiles has been undertaken and the correlation between modelled and measured wave heights has been calculated.

Typically, a qualitative calibration and validation process is undertaken for sediment transport models to demonstrate that the numerical model is able to approximately replicate the spatial and temporal patterns in SSC. Demonstrating that the model can replicate the spatial and temporal patterns in SSC provides confidence that the model is representing the key processes which mobilise the sediment as well as the processes which transport the sediment once it is suspended. However, despite the inherent complexities associated with sediment transport modelling (including having to accurately represent the hydrodynamic and wave conditions and the properties of the sediment on the bed and in the water column), it is possible to provide a quantitative measure of the performance of a sediment transport model. By calculating the normalised mean absolute error between the model and measured data it is possible to categorise the performance of the model (Los and Blaas, 2010). The so-called OSPAR cost function (CF) has been applied. The normalisation expresses the goodness of fit in terms of the standard deviation, with the following classifications:

- CF of less than 1 being 'very good';
- CF between 1 and 2 being 'good';
- CF between 2 and 3 being 'reasonable'; and
- CF of more than 3 being 'poor'.

4.2. Hydrodynamic Model

To ensure that the hydrodynamic model accurately represents the natural conditions within the Mackay region, measured water levels and currents (speed and direction) have been compared against modelled predictions. The locations of sites where measured data have been used in the calibration and validation of the hydrodynamic and wave models are shown in Figure 15.

The hydrodynamic model used to represent the maintenance dredging at the Port of Hay Point was predominantly calibrated and validated using data collected between the Port of Hay Point and Round Top Island in 2011 and 2012. For this assessment it is important to demonstrate that the model is able to represent the hydrodynamic conditions closer to the Port of Mackay. Therefore, water level and current data collected at MK1 and MK2 (located approximately 1 km to the north and east of the entrance to Mackay Harbour) in 2017 has been used as the primary dataset to calibrate and validate the hydrodynamic model. Measured current data collected at the Slade Islet ambient water quality monitoring site (located approximately 2 km to the north-east of the entrance to Mackay Harbour) in January 2020 was also used as a secondary current validation site. Modelled water levels and currents have been compared with the measured data for the following periods:

- calibration period: a 14.5 day spring-neap cycle between the 19th January 2017 and the 3rd February 2017. Calibrated for measured water levels and currents through the water column at MK1 and MK2;
- validation period: a 14.5 day spring-neap cycle between the 3rd February 2017 and the 18th February 2017. Validated for measured water levels and currents through the water column at MK1 and MK2; and
- second validation period: a 14.5 day spring-neap cycle between the 16th January 2020 and the 31st January 2020. Validated for measured near-bed currents at Slade Islet.

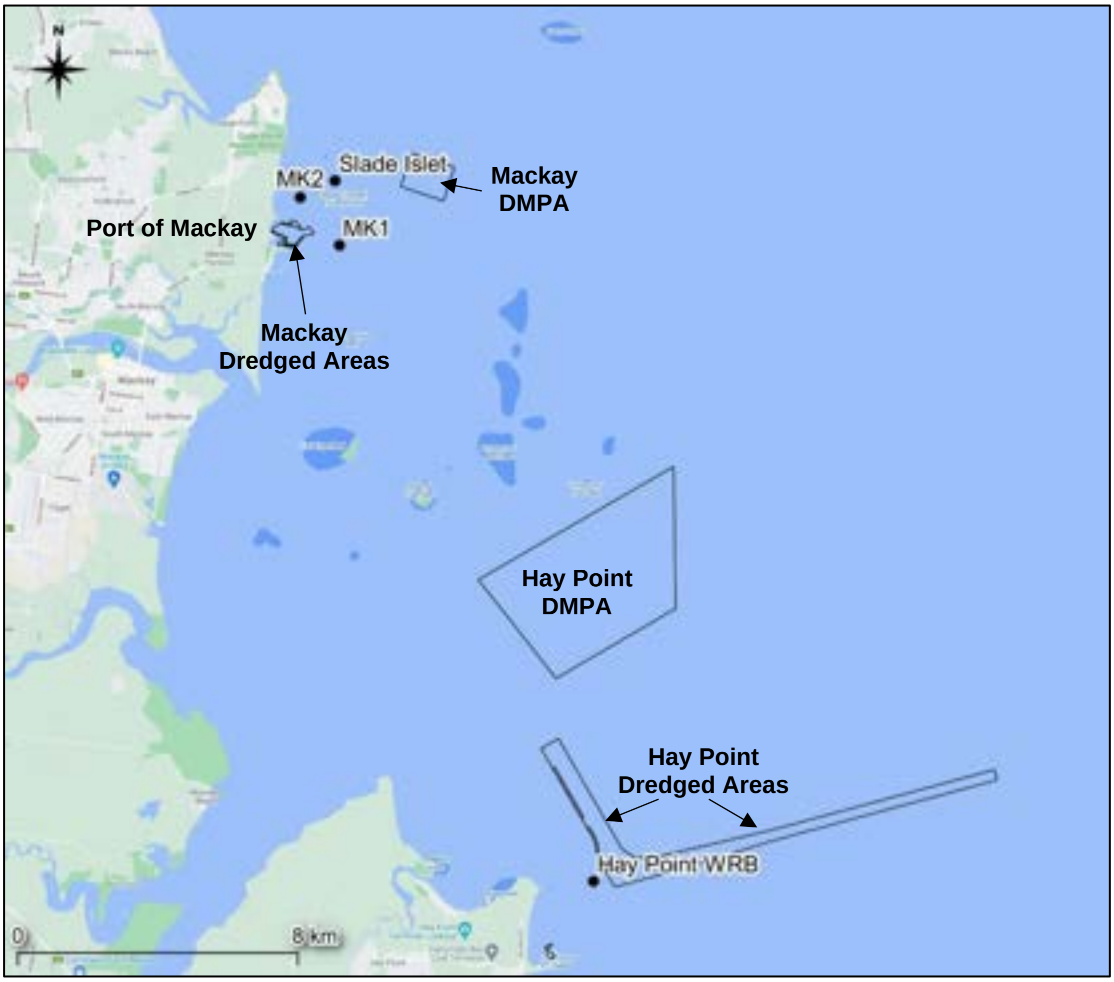


Figure 15. Locations of the measured data sites where the hydrodynamic and wave models were calibrated and validated.

4.2.1. Water Levels

Measured and modelled water levels at MK1 and MK2 are shown in Figure 16 for the model calibration period and in Figure 17 for the model validation period. The plots for both periods show that the model provides a consistently good prediction of the HW and LW levels as well as the shape of the tidal curve. For both periods there appears to be a slight offset between the measured and modelled data. This is expected to be a result of the measured water levels having been corrected to mean sea level (MSL) based on the data collected over the duration of the deployment (i.e. the mean water level over the period was considered to represent MSL), while the model water levels are relative to AHD.

A statistical analysis of the differences between the measured and modelled water levels was undertaken for the calibration and validation periods and the results are presented in Table 4. The results show that the statistics were typically within the standards detailed in Section 4.1, with the following exception:

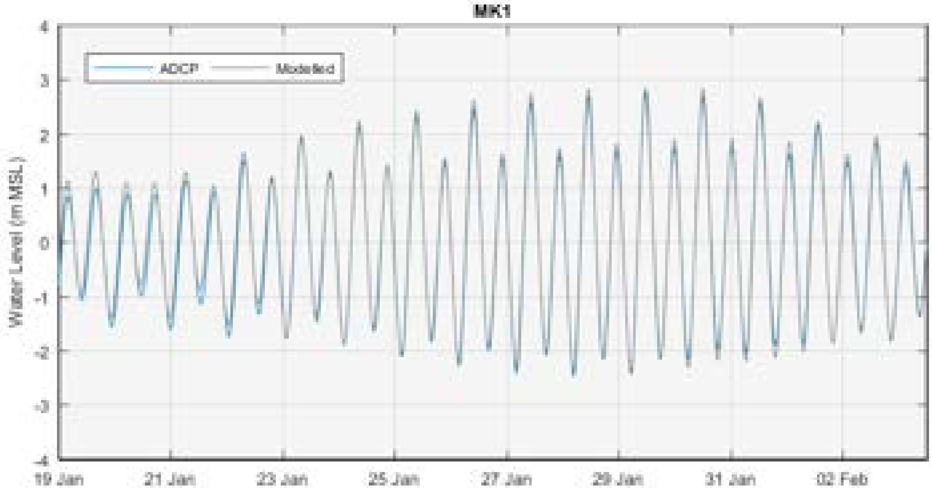
- LW phase difference: the phase difference of LW at MK2 during the model calibration period was 1 minute more than the calibration standard of 15 minutes. Visual comparison of the timeseries plots does not suggest that there is a significant phase lag in the modelled LW. Based on this and the fact that the HW and overall phase differences are within the calibration standards and all of the phase differences for the validation period are within the standards indicates that the phase difference at LW is not an issue in terms of the overall performance of the model.

Table 4. Statistics for comparison between modelled and measured water levels during the model calibration and validation periods at MK1 and MK2.

Site	WL difference (m)			WL difference (%)		Phase difference (minutes)		
	HW	LW	RMS	HW	LW	HW	LW	All
Calibration Period								
MK1	0.13	0.05	0.15	4	1	-2	-7	-3
MK2	0.14	0.04	0.15	4	1	-11	**-16**	-12
Validation Period								
MK1	0.18	-0.01	0.12	4	0	3	-4	0
MK2	0.17	-0.03	0.12	4	-1	-5	-14	-10

Notes: Differences are modelled minus measured so that positive values indicate that the model value is high/late relative to the measured data.

*Values in **blue** are outside of the calibration standard.*



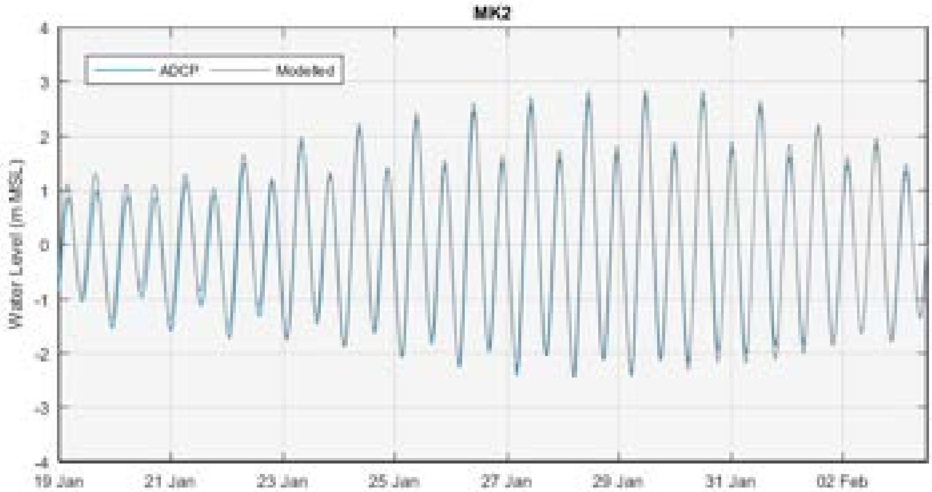


Figure 16. Modelled and measured water level at MK1 (top) and MK2 (bottom) over the model calibration period.

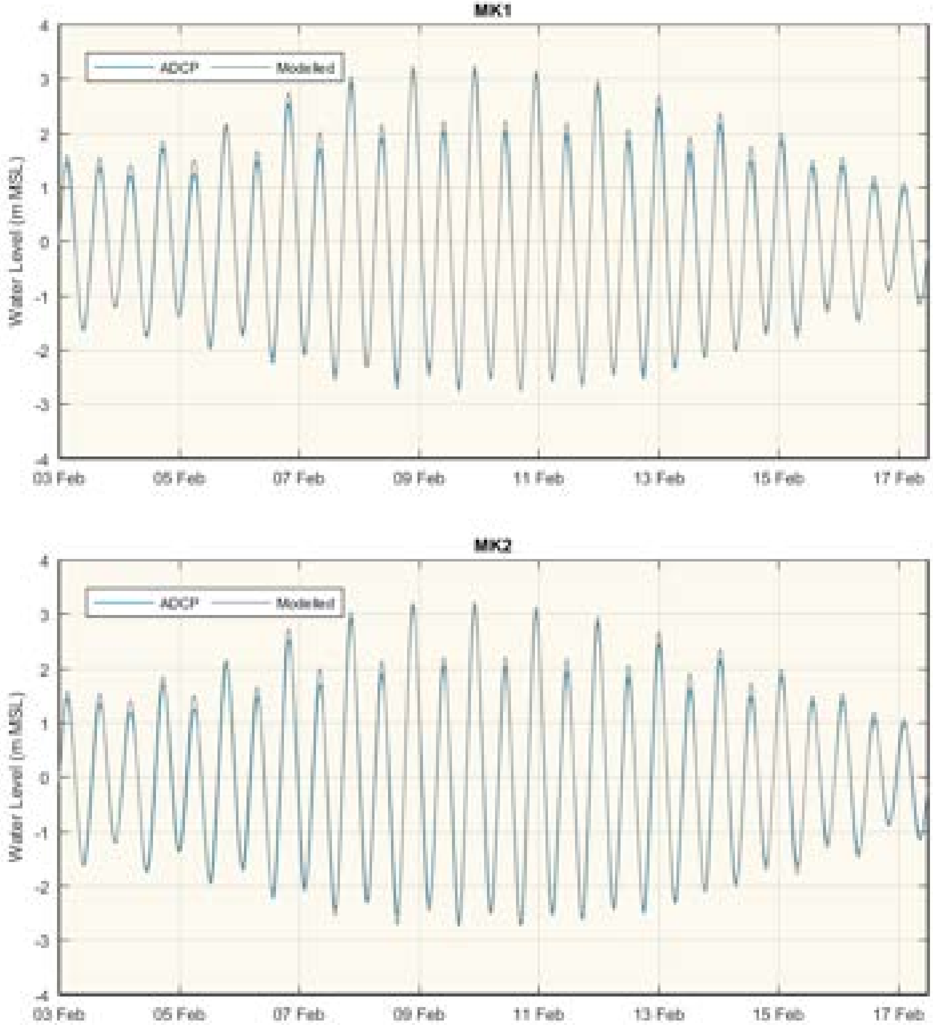


Figure 17. Modelled and measured water level at MK1 (top) and MK2 (bottom) over the model validation period.

4.2.2. Currents

Measured current data were collected at discrete bins through the water column at MK1 and MK2 in 2017. Data from layers near the surface, in the middle of the water column and near the seabed were extracted and have been used for the calibration and validation of the 3D hydrodynamic model. Time series plots of the measured and modelled surface, mid-depth and near bed current speed and direction at the ADCPs are shown in Figure 18 to Figure 20 at MK1 and Figure 21 to Figure 23 at MK2. Plots over the validation period are only shown for the near bed layer to provide a visual representation of the comparison between the modelled and measured data. The plots over the calibration and validation periods show that the model provides a good representation of the current speeds and directions at both MK1 and MK2 and replicates how the currents vary through the water column. Despite MK1 and MK2 being located within 2 km of each other, there is significant variation in the currents at the two sites, with MK1 experiencing similar current speeds on the flood (to the south) and ebb (to the north) stages of the tide while at MK2 the flood current dominates in both magnitude and duration. The plots show that the model is able to represent this local scale variation in the currents between the two sites.

A statistical analysis was undertaken to quantify the difference in magnitude and phasing between the modelled and measured current speeds and directions at MK1 and MK2 through the water column during both the calibration and validation periods (Table 5 and Table 6). For the most part the guideline standards are achieved, with the peak current speeds agreeing to within 0.1 m/s or 20%, peak current directions to within 30° and the phase of peak current speeds to within 30 minutes. However, the model is outside of the standards for some of the statistics:

- Speed Difference MK2: at MK2 the model peak ebb current speed is overpredicted by more than 20% in the mid depth layer for the both the calibration and validation periods. The difference between the measured and modelled peak speeds remain less than 0.1 m/s but due to the relatively low measured peak ebb current speeds the difference is more than 20%. As the model achieved the statistical standards for the surface and bed layers the difference is not expected to influence the models ability to replicate currents at MK2;
- Direction Difference: the statistics show that directional differences of more than 20° occur during the peak flood stage of the tide at MK1 and during the peak ebb stage of the tide at MK2. The reason for the difference is similar at both sites, with the measured current direction data at both sites showing a relatively consistent direction for one stage of the tide (peak ebb at MK1 and peak flood at MK2) and a rotating direction over the duration of the other stage of the tide. Although the plots show that the model is able to replicate the rotating current direction during the flood stage at MK1 and ebb stage at MK2, the fact that the measured directions vary by more than 90° over the duration of that stage of the tide means that there is a much higher potential for the modelled and measured current directions at the time of the peak current speed to differ by more compared to when the directions remain relatively constant over the duration of the tide. Based on the plots the model is considered to be providing a good representation of the variation in current directions at both sites and the directions being outside of the standards is not considered to be an issue; and
- Phase Difference: at MK1 the timing of the peak current speeds differ by more than 30 minutes between the measured and modelled data. However, the time series plot shows that the model timing of the flood and ebb currents along with slack water between agrees well with the measured data. As such, the difference is due to the spikes in the measured data which typically result in a peak in current speed towards the start of the flood and ebb stages of the tide while the model predicts the peak around the middle of the stages. Therefore, the model can be considered to provide a smoother representation of the currents and the phase difference and so the difference is not considered to be an issue.

Table 5. **Statistics for comparison of modelled and measured currents through the water column at MK1 and MK2 during the model calibration period.**

Site	Speed difference (m/s)			Speed difference (%)		Direction difference (°)		Phase difference (minutes)
	PF	PE	RMS	PF	PE	PF	PE	All
MK1								
Surface	-0.11	0	0.09	-15	0	**33**	8	29
Mid Depth	-0.06	0.03	0.09	-8	5	**31**	6	30
Bed	-0.09	0	0.08	-14	0	**31**	5	28
MK2								
Surface	-0.08	0.02	0.06	-15	5	-18	6	-6
Mid Depth	-0.05	0.08	0.06	-9	**25**	-17	**29**	-10
Bed	-0.05	0.05	0.06	-10	17	-17	**36**	-12

Notes: Differences are modelled minus measured so that positive values indicate that the model value is high/late relative to measured.

*Values in **blue** are above the calibration standard.*

Table 6. **Statistics for comparison of modelled and measured currents through the water column at MK1 and MK2 during the model validation period.**

Site	Speed difference (m/s)			Speed difference (%)		Direction difference (°)		Phase difference (minutes)
	PF	PE	RMS	PF	PE	PF	PE	All
MK1								
Surface	-0.11	0.01	0.09	-14	1	**36**	6	**35**
Mid Depth	-0.05	0.07	0.1	-6	11	**33**	6	**33**
Bed	-0.09	0.04	0.08	-12	7	**32**	5	**33**
MK2								
Surface	-0.06	-0.02	0.07	-11	-4	-19	9	1
Mid Depth	-0.04	0.07	0.07	-7	**22**	-18	**32**	-1
Bed	-0.04	0.05	0.06	-8	17	-19	**32**	2

Notes: Differences are modelled minus measured so that positive values indicate that the model value is high/late relative to measured.

*Values in **blue** are above the calibration standard.*

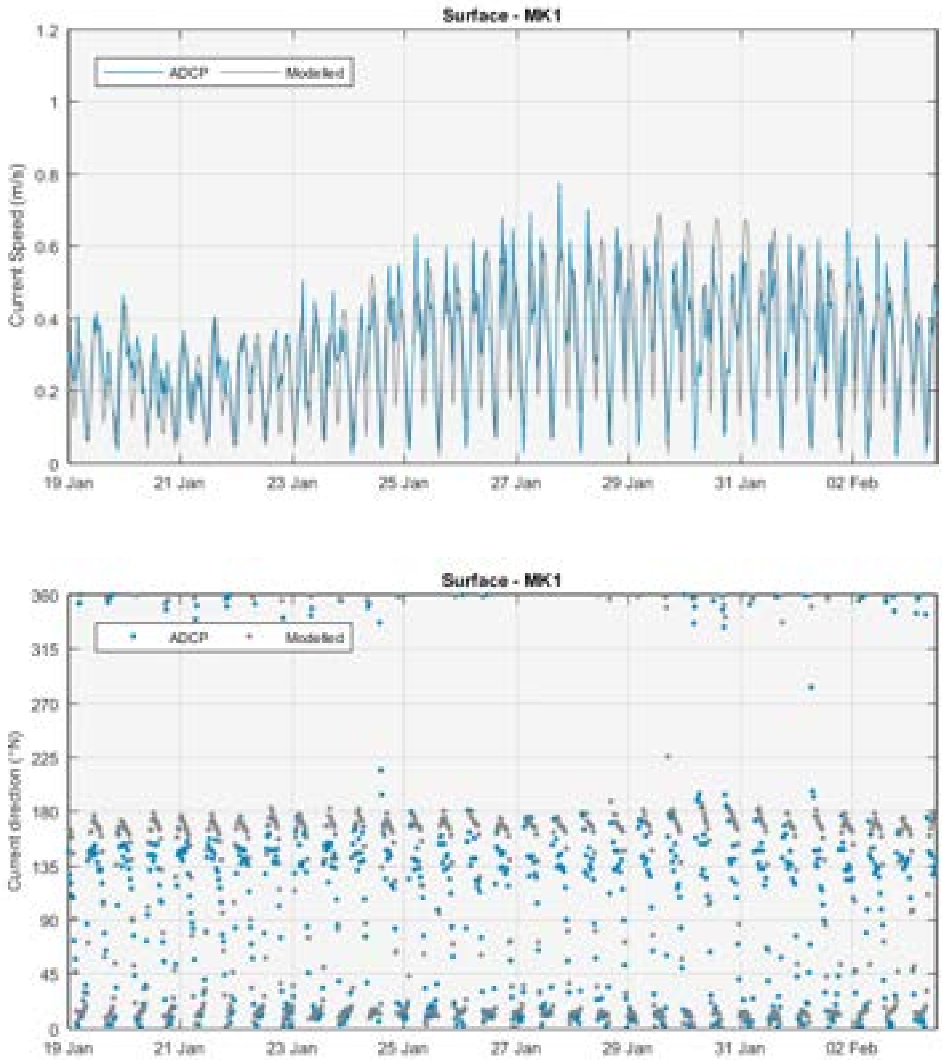


Figure 18. **Modelled and measured surface current speed (top) and direction (bottom) at MK1 over the model calibration period.**

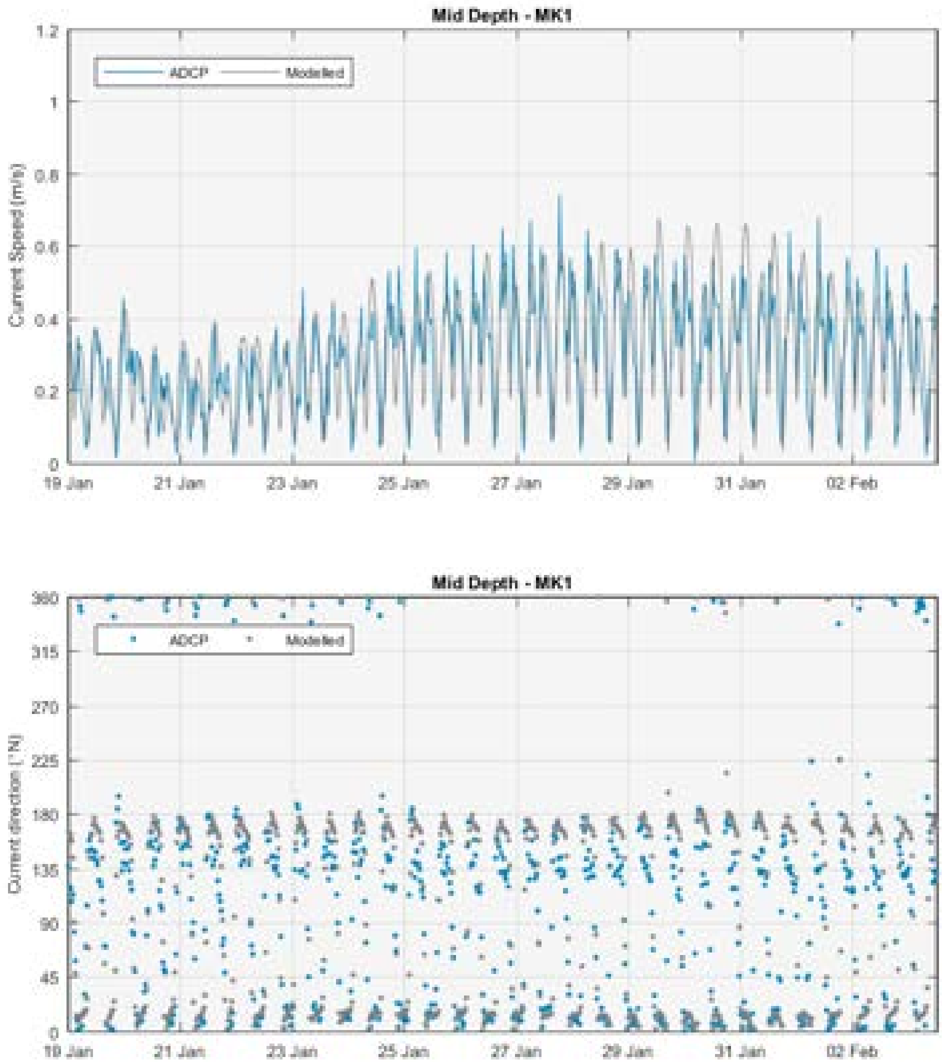


Figure 19. Modelled and measured mid depth current speed (top) and direction (bottom) at MK1 over the model calibration period.

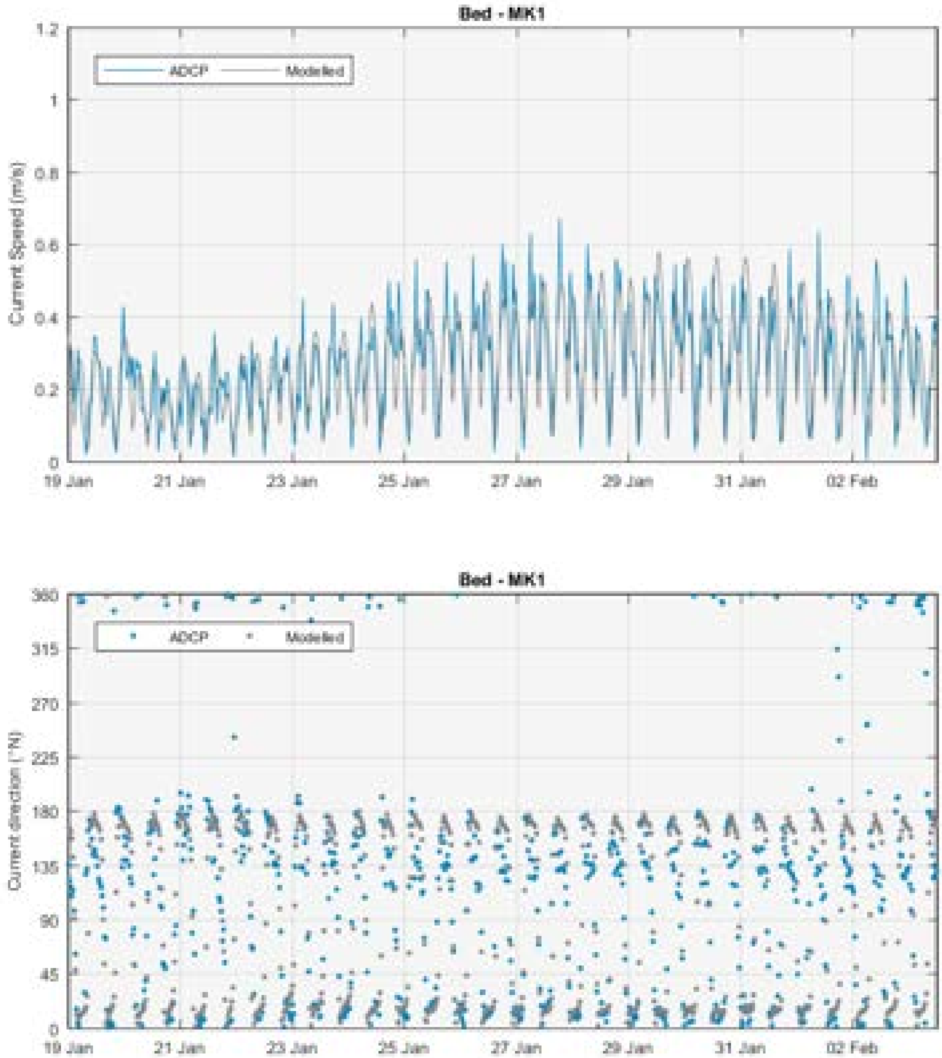


Figure 20. Modelled and measured near bed current speed (top) and direction (bottom) at MK1 over the model calibration period.

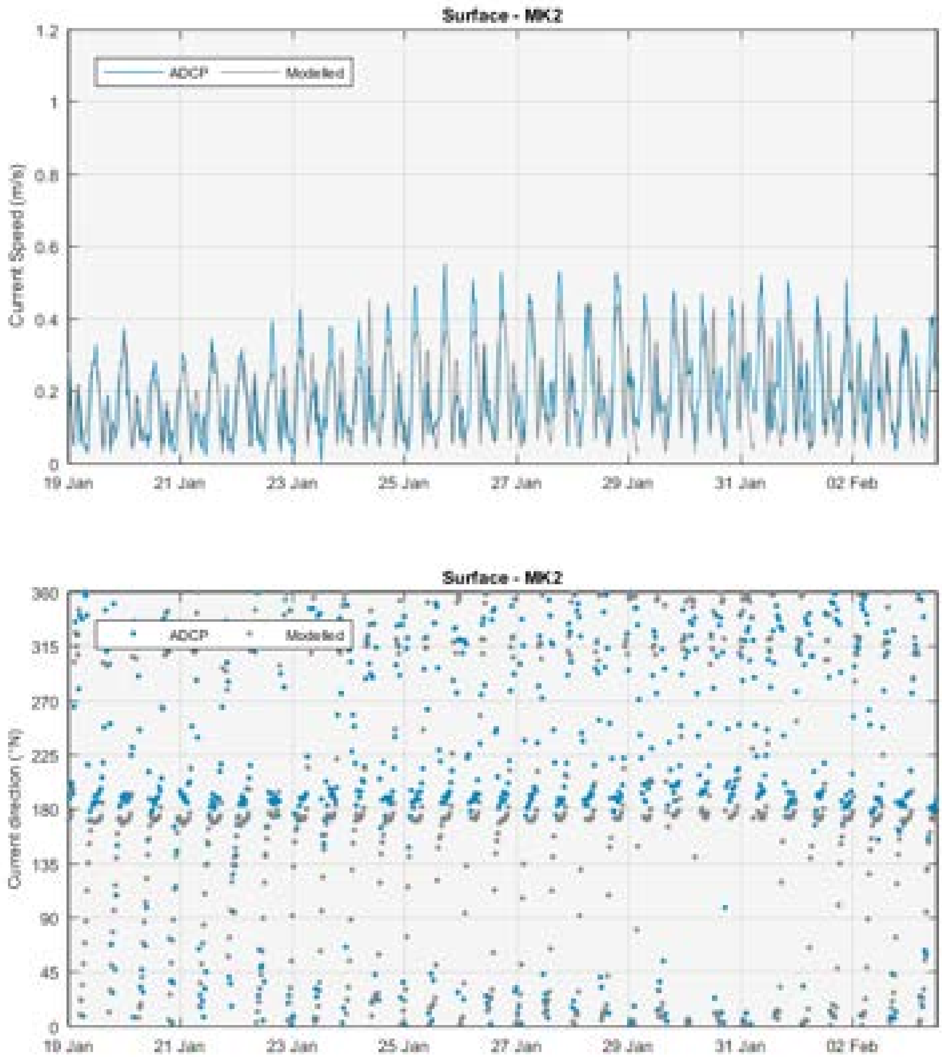


Figure 21. **Modelled and measured surface current speed (top) and direction (bottom) at MK2 over the model calibration period.**

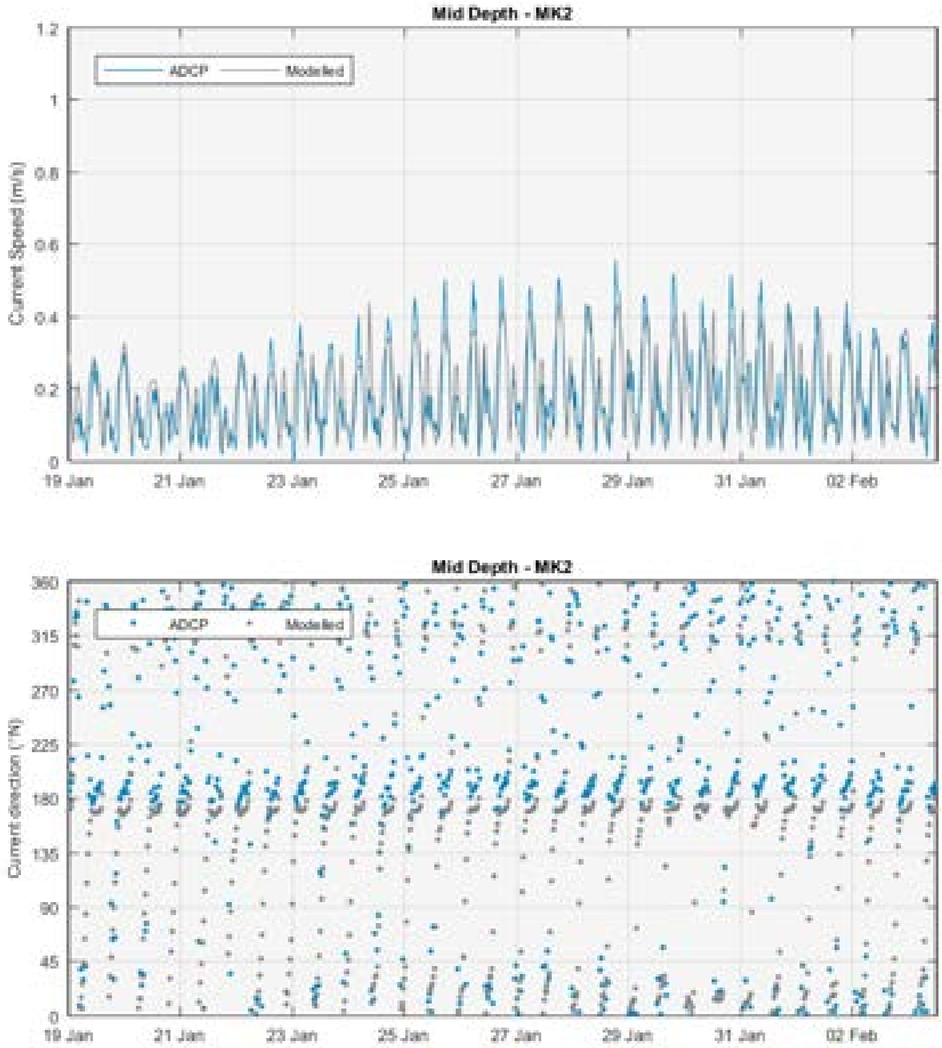


Figure 22. Modelled and measured mid depth current speed (top) and direction (bottom) at MK2 over the model calibration period.

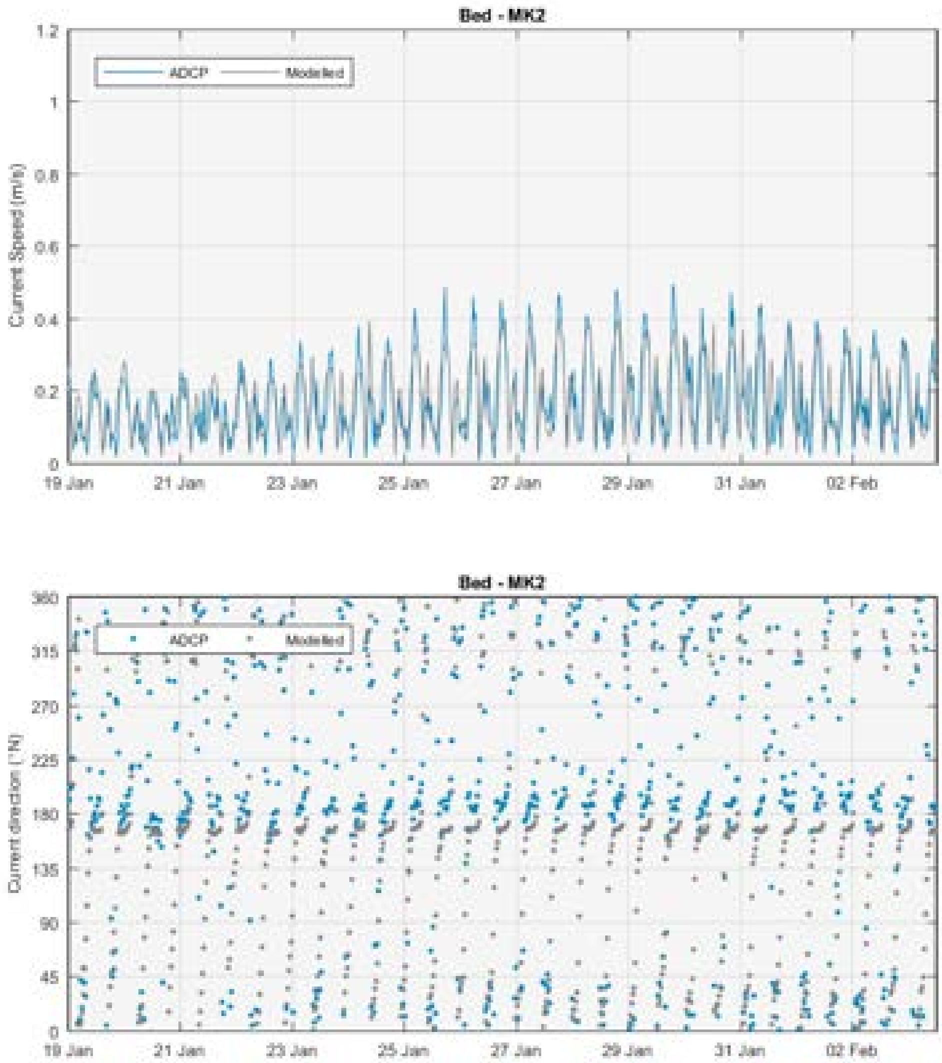


Figure 23. Modelled and measured near bed current speed (top) and direction (bottom) at MK2 over the model calibration period.

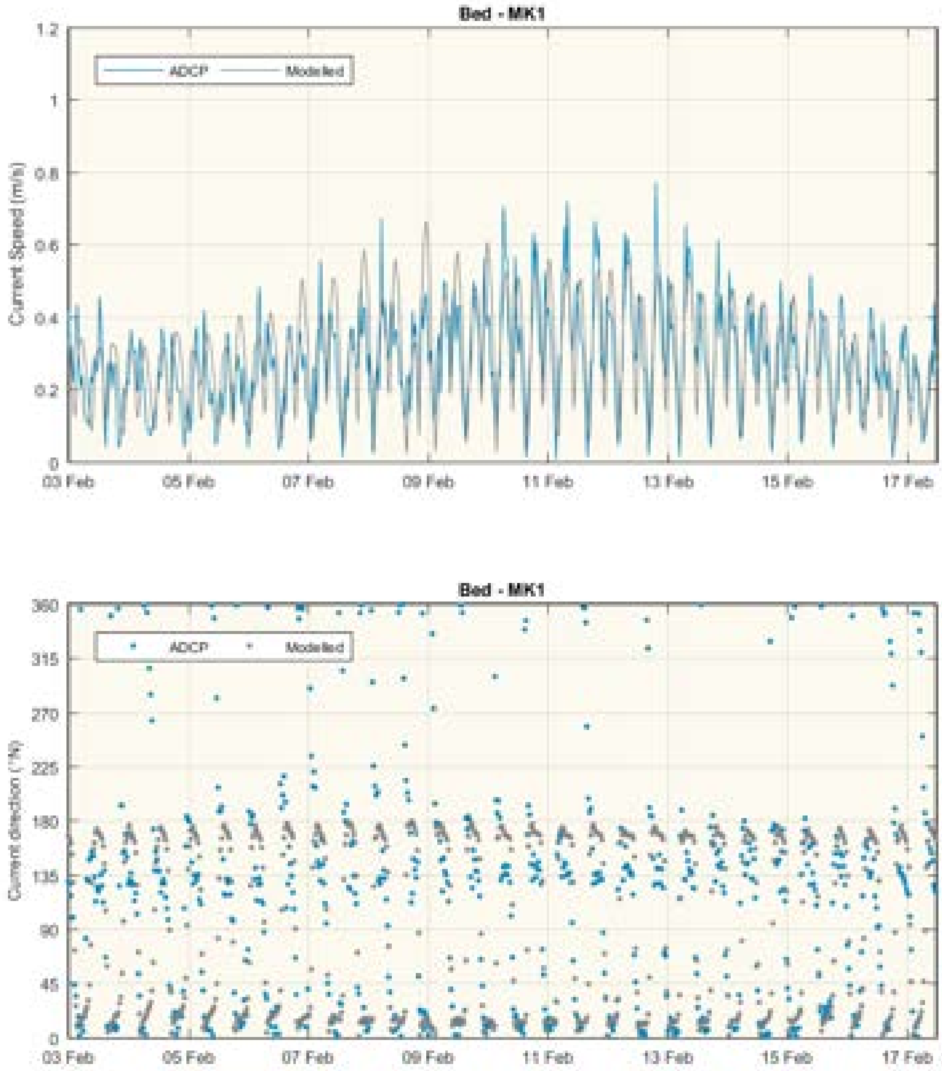


Figure 24. **Modelled and measured near bed current speed (top) and direction (bottom) at MK1 over the model validation period.**

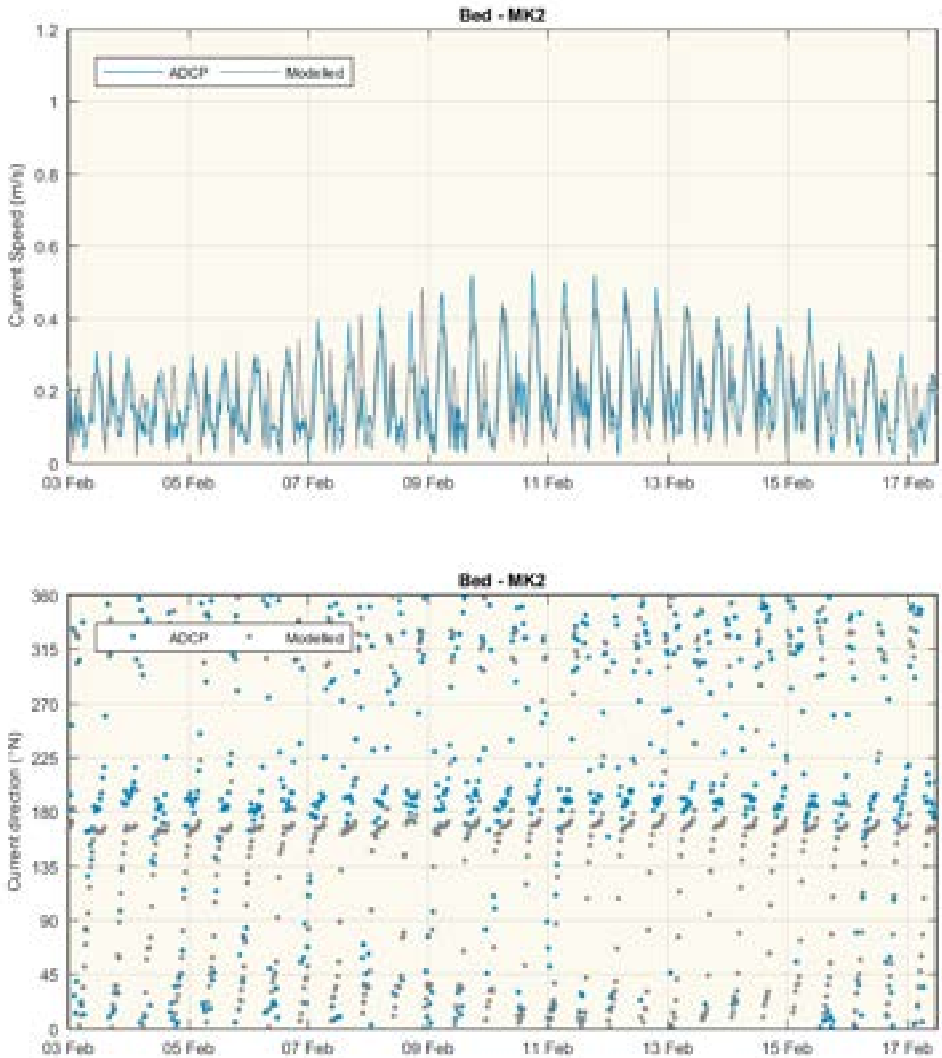
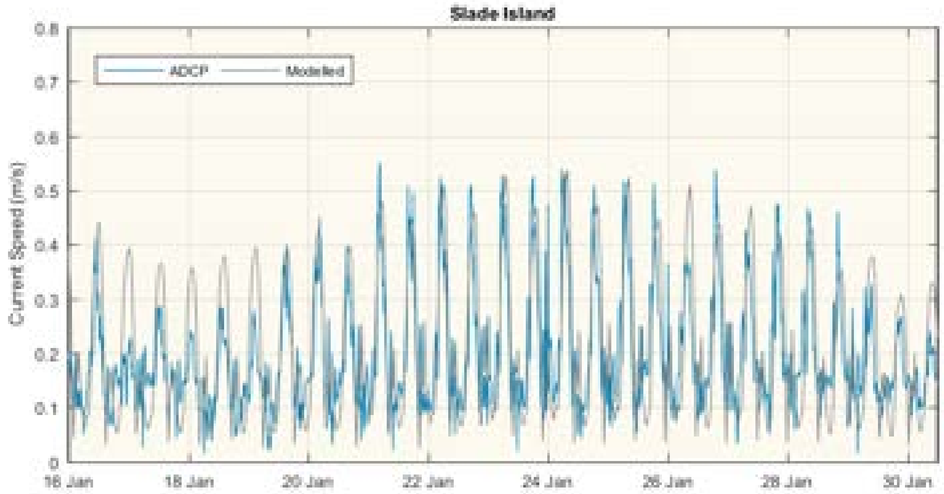


Figure 25. Modelled and measured near bed current speed (top) and direction (bottom) at MK2 over the model validation period.

Measured current data were also collected at Slade Islet using a near bed current logger in January 2020. This site is the closest sensitive receptor to the Port of Mackay and so providing a second current validation at this site will provide additional confidence in the hydrodynamic model. Plots of the modelled and measured current speed and direction are shown in Figure 26 and results from the statistical analysis are shown in Table 7. The timeseries plots show that the currents at Slade Islet are similar to those at MK2, with the southerly flood currents being significantly higher than the northerly ebb currents (due to Slade Islet sheltering the site from the ebb currents which are in a northerly direction). The plots and statistics show that the model is able to provide a good representation of the currents, with the only statistics outside of the standards being the direction difference during peak ebb and the phase difference. The reasons for these differences are the same as at MK2, that is the directional differences due to the current rotating throughout the ebb stage of the tide and the phase differences due to the spikes in the measured data. Therefore, the model can be considered to provide a good representation of the measured currents at Slade Islet.

Table 7. **Statistics for comparison of modelled and measured near-bed currents at Slade Islet during the second model validation period.**

Site	Speed difference (m/s)			Speed difference (%)		Direction difference (°)		Phase difference (minutes)
	PF	PE	RMS	PF	PE	PF	PE	All
Surface	0.02	-0.02	0.07	4	-5	-1	21	35



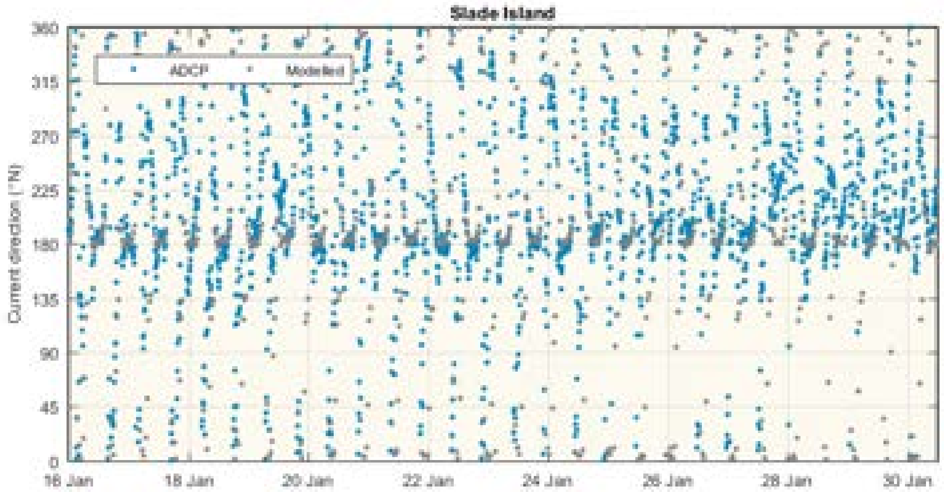


Figure 26. **Modelled and measured near bed current speed (top) and direction (bottom) at the Slade Islet monitoring site over the second model validation period.**

4.3. Waves

The SW model was set up to represent the wave conditions in the Mackay region from 01/01/2017 to 01/04/2017. This period was chosen as measured wave data were available at the nearshore Hay Point WRB and at the MK1 and MK2 sites close to Mackay Harbour (Figure 15). In addition, there is a high degree of variability in the wave conditions over the period and it includes an extreme wave event (TC Debbie).

Time series plots of the modelled and measured wave conditions at the Hay Point WRB and at MK1 and MK2 are shown in Figure 27 to Figure 29. The plots show that the model is able to provide a realistic representation of the measured wave conditions at the three sites. The plots show that when the measured peak wave period is more than around 7 seconds the model tends to underpredict the wave period. However, these periods coincide with calm wave conditions with an H_s of less than 0.5 m and as such the model underestimating the peak wave period will not influence any potential for sediment transport. Correlation plots between the measured and modelled H_s are shown in Figure 30 to Figure 32, these demonstrate that at all three sites the modelled wave heights are on average comparable to the measured wave heights.

A quantitative assessment of the model calibration at the three sites is provided in Table 8. The table shows that the model is able to provide a good representation of the measured wave conditions at the three sites, with R^2 values of 0.85 to 0.87. At MK1 and MK2 the statistics show that the model underestimates the 99th percentile. This percentile represents the wave conditions during TC Debbie at the end of March 2017 and the timeseries plots show that the model provided a good representation of the overall wave conditions throughout the event including the peak wave height, but was not able to represent some of the short duration spikes in H_s which occurred prior to the peak in the event. The plots and statistics therefore show that the model is capable of accurately replicating the nearshore wave conditions in the Mackay and Hay Point region during both typical and extreme events.

Table 8. Percentile statistics of H_s over the 2017 SW model calibration period.

Percentile	Hay Point WRB H_s (m)		MK1 H_s (m)		MK2 H_s (m)	
	Measured	Modelled	Measured	Modelled	Measured	Modelled
99th	2.85	2.93	3.11	2.76	2.52	2.28
95th	1.73	1.53	1.90	1.82	1.50	1.50
90th	1.30	1.23	1.47	1.47	1.10	1.24
80th	0.93	0.99	1.12	1.16	0.84	1.00
50th	0.50	0.64	0.66	0.71	0.50	0.62
20th	0.22	0.32	0.34	0.35	0.27	0.30
10th	0.17	0.24	0.25	0.27	0.20	0.23
5th	0.14	0.18	0.20	0.20	0.16	0.17
R^2	**0.85**		**0.87**		**0.85**	

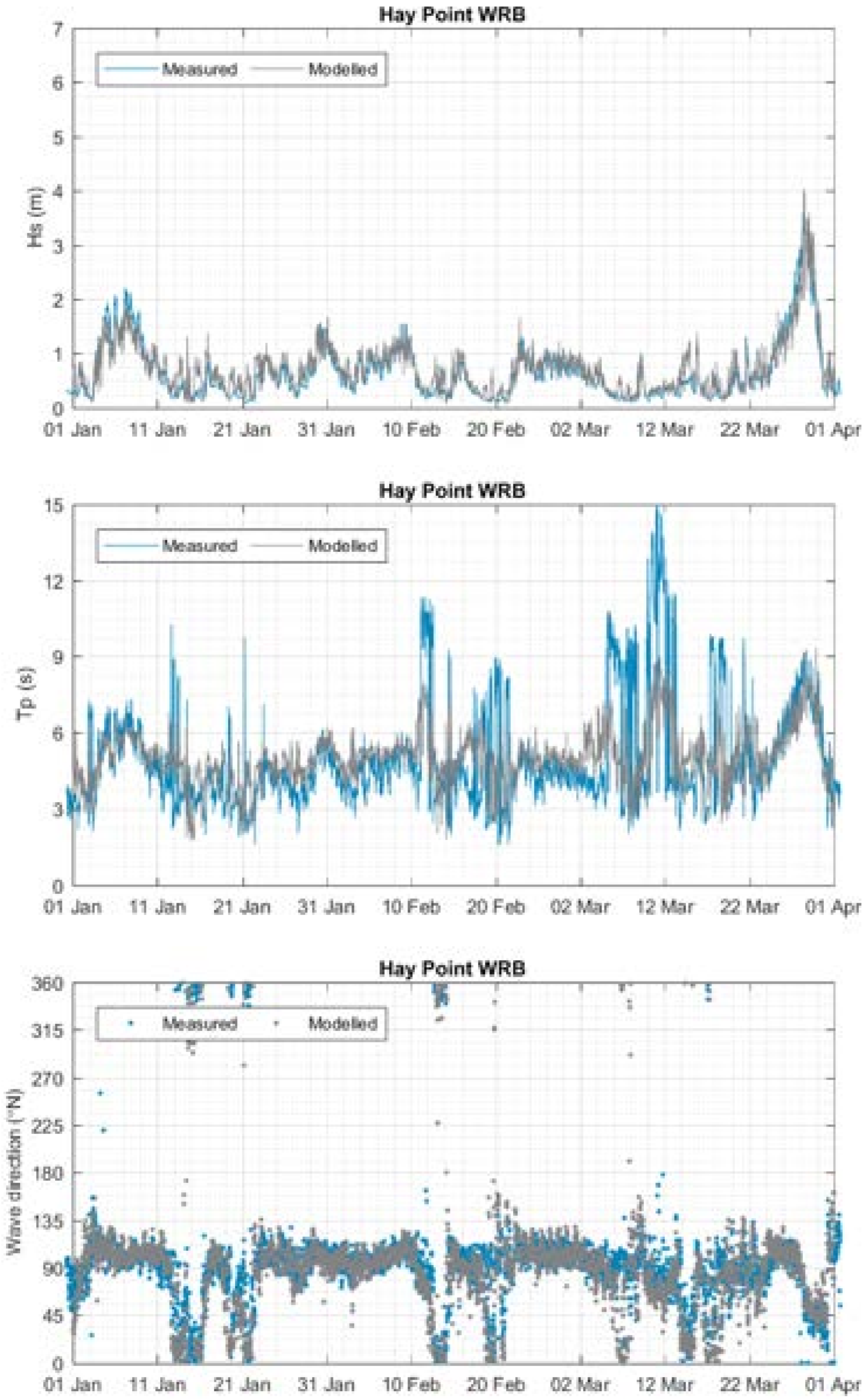


Figure 27. **Modelled and measured wave conditions at the Hay Point WRB from January to April 2017.**

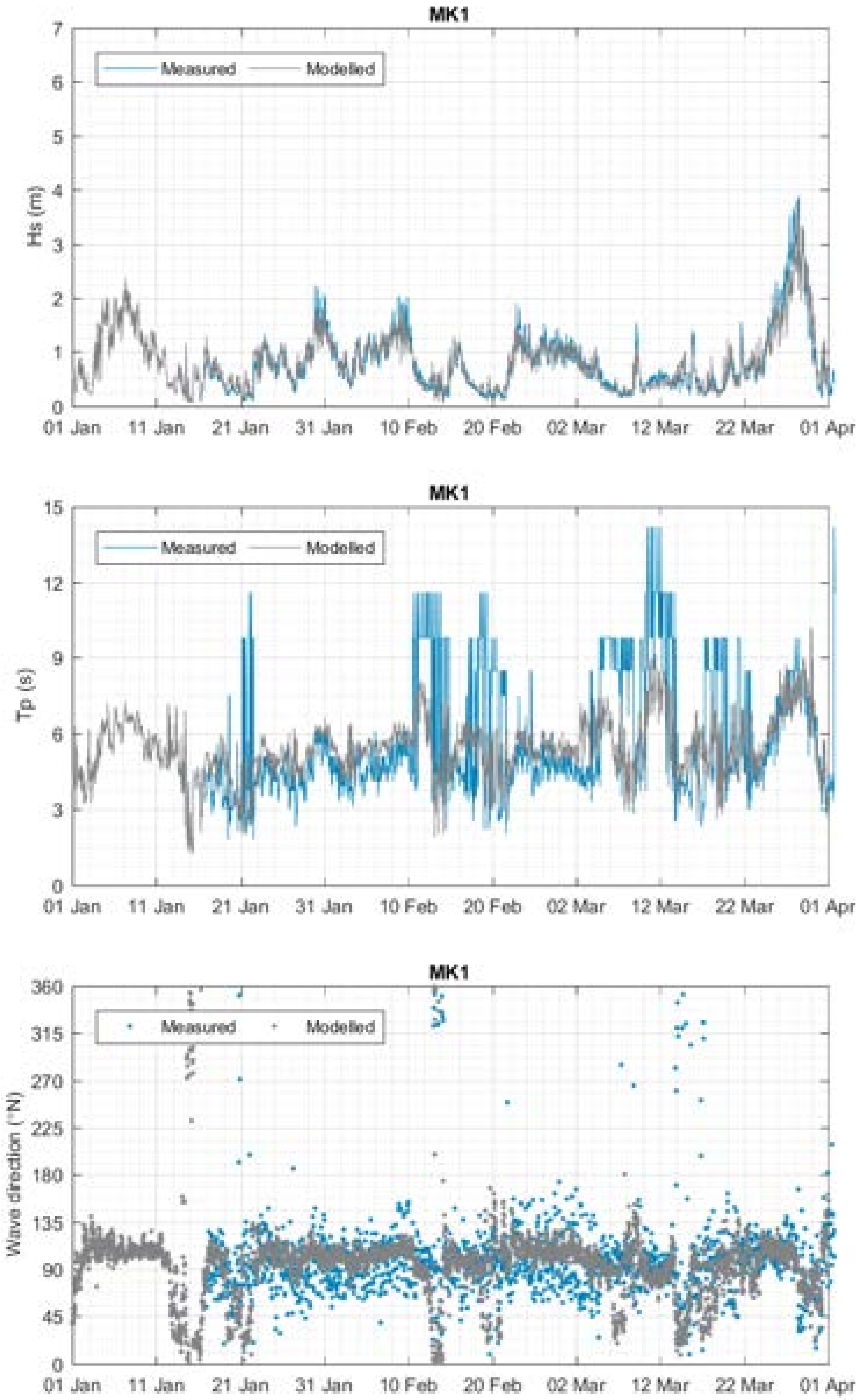


Figure 28. Modelled and measured wave conditions at MK1 from January to April 2017.

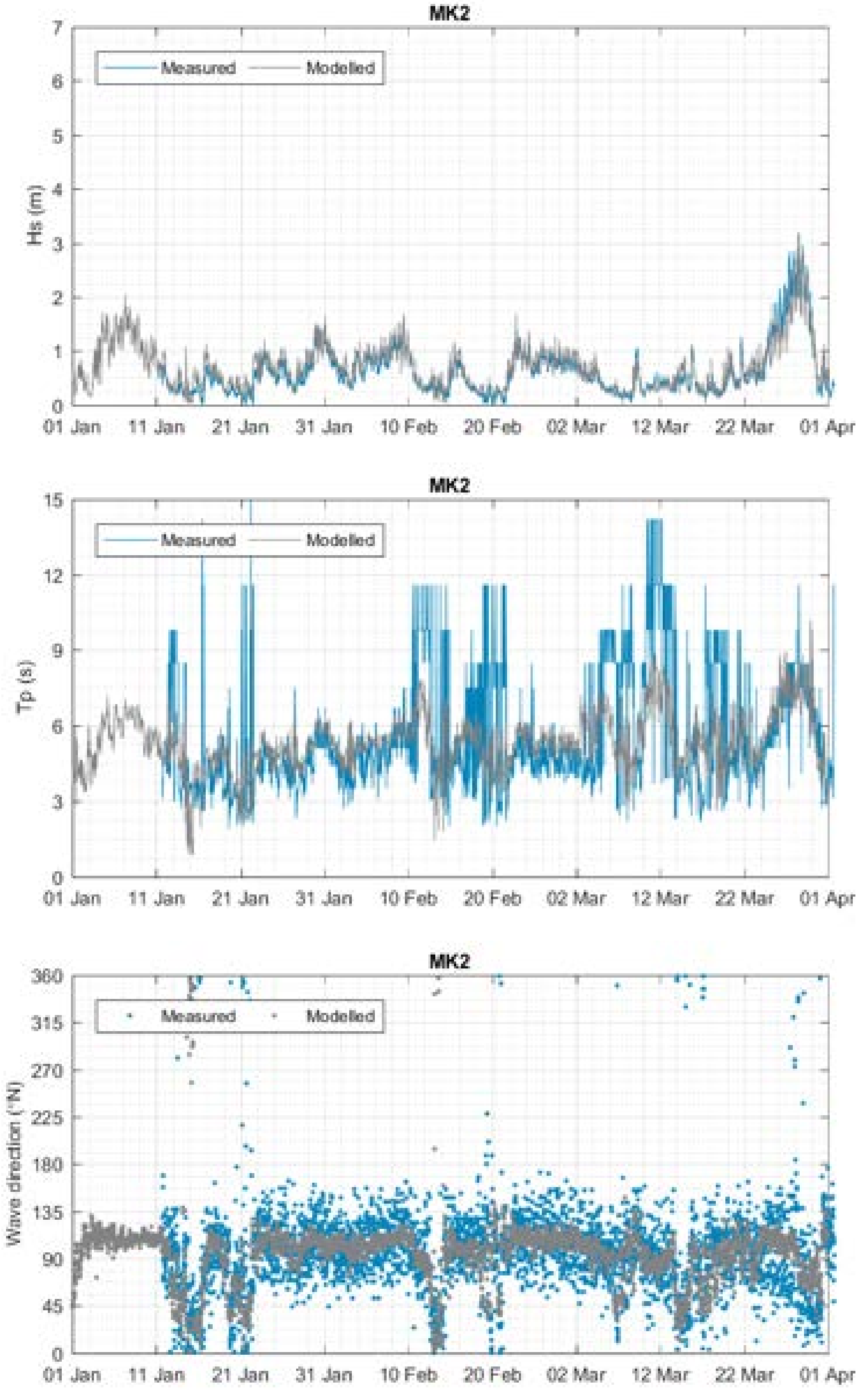


Figure 29. Modelled and measured wave conditions at MK2 from January to April 2017.

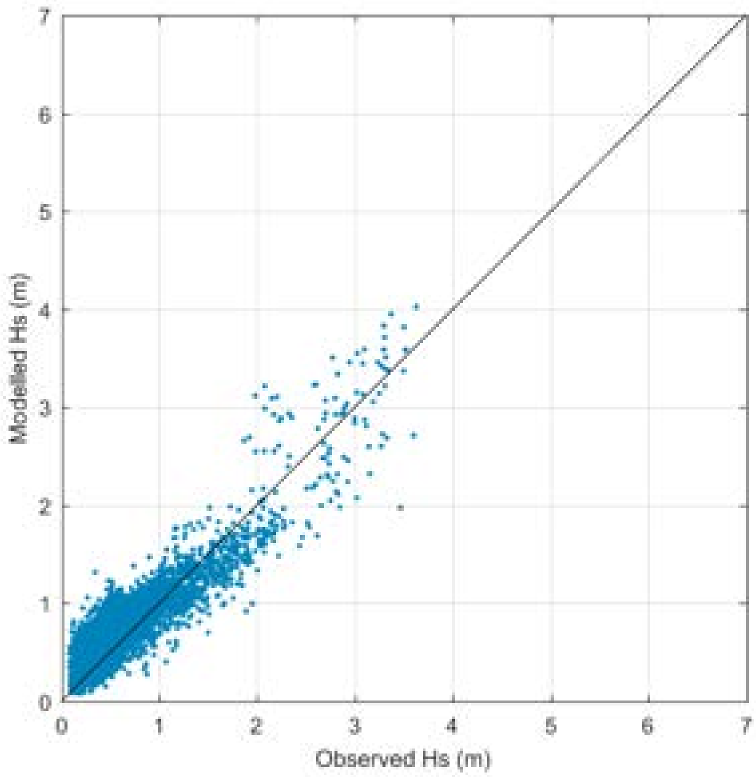


Figure 30. Correlation between measured (observed) and modelled H_s at the Hay Point WRB.

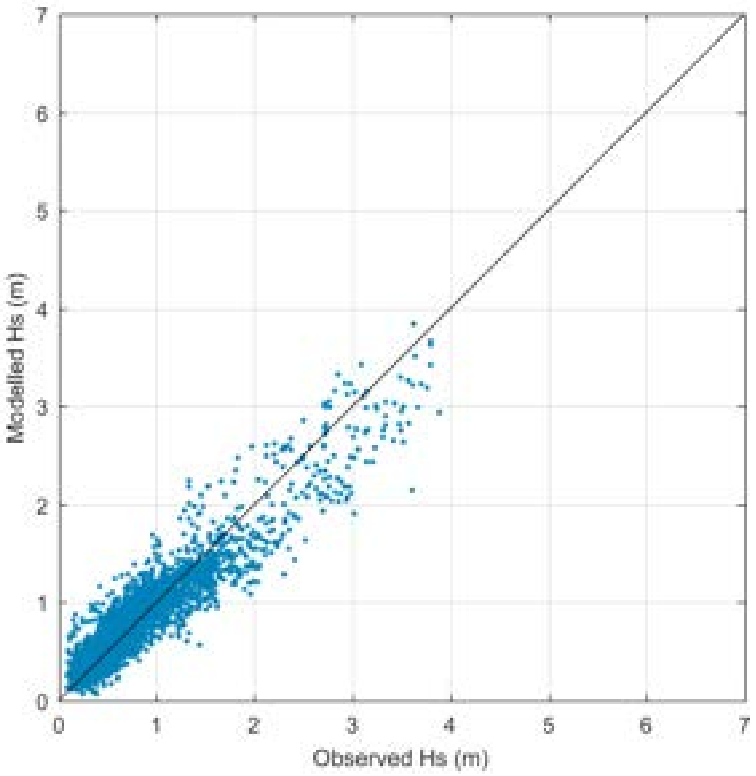


Figure 31. Correlation between measured (observed) and modelled H_s at MK1.

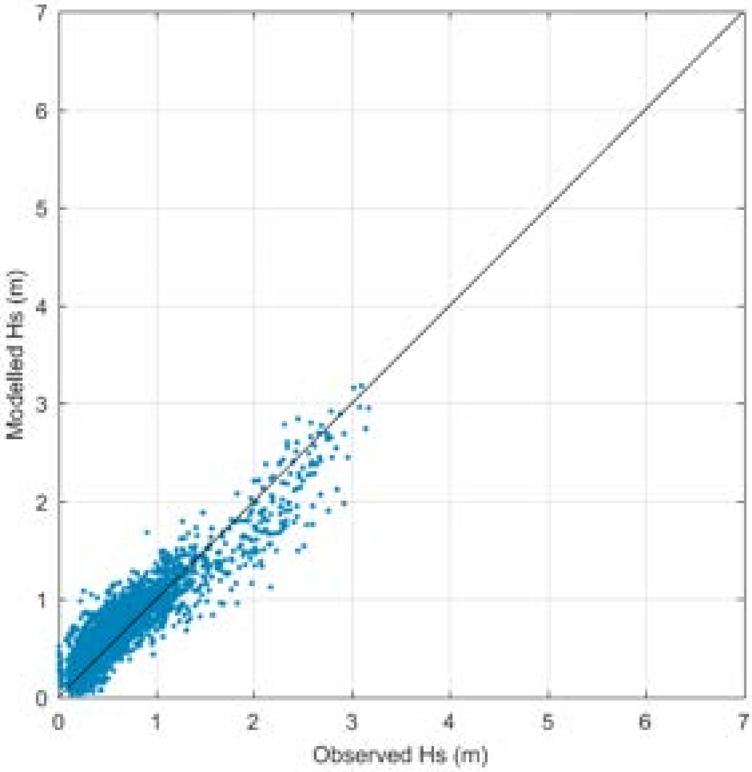


Figure 32. Correlation between measured (observed) and modelled H_s at MK2.

4.4. Sediment Transport

To ensure that the sediment transport model accurately represents the natural conditions in the Mackay region, modelled SSC has been compared against measured SSC data collected by JCU at the ambient water quality monitoring sites. The location of sites where measured SSC data have been compared with modelled SSC is shown in Figure 33.

Based on the available measured SSC data and the variability in metocean conditions in the region, modelled SSC have been compared against measured data for the following periods:

- calibration period: a one month period in November 2020 that is representative of typical wet season conditions;
- validation period: a one month period in July 2020 that is representative of typical dry season conditions; and
- second validation period: a two week period in March 2017 when TC Debbie resulted in elevated SSC throughout the region, this period is representative of an extreme TC.

The model calibration and validation for the natural sediment transport model has been focused on the sites located closest to the Port of Mackay, namely Slade Islet, Round Top Island and Victor Island. However, during TC Debbie SSC data were not captured at Slade Islet or Round Top Island and so the sites at Freshwater Point (located south of Victor Island) and Keswick Island (located north-east of Slade Islet) have been used. Timeseries plots of the measured and modelled SSC during the three calibration and validation periods are shown in Figure 34 to Figure 36. The plots show that the model provides a good representation of the measured SSC, replicating the temporal trends in SSC during wet and dry season conditions and an extreme event. This provides confidence that the model is representing the effect of the key physical processes (tidal currents and waves) on the SSC. The plots show that the model is not able to represent all of the localised short duration spikes in SSC present in the measured data and so the model can be considered to represent the smoothed SSC.

The CF has been calculated for the model calibration and validation periods and the results are given in Table 9. At all three sites and during all three model calibration/validation periods the CF is significantly lower than one, providing a statistical confirmation that the modelled SSC is in 'very good' agreement with the measured data (see Section 4.1).

Table 9. OSPAR cost function summary at the five calibration/validation sites.

Site	Wet Season CF	Dry Season CF	TC Debbie CF
Slade Islet	0.51	0.45	-
Round Top Island	0.33	0.71	-
Victor Island	0.35	0.66	0.45
Freshwater Point	-	-	0.47
Keswick Island	-	-	0.36

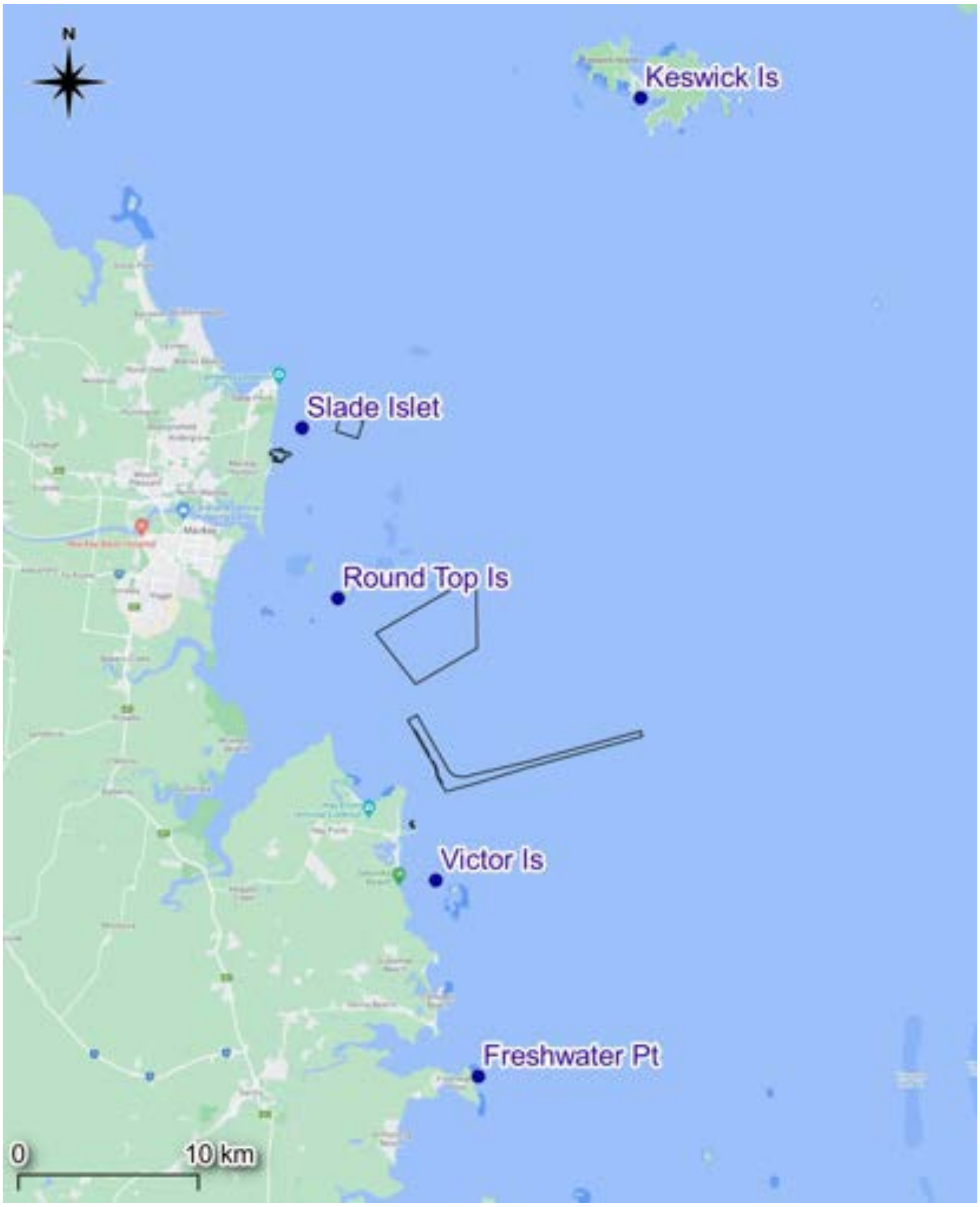


Figure 33. Location of the measured SSC data which have been used to calibrate and validate the sediment transport model.

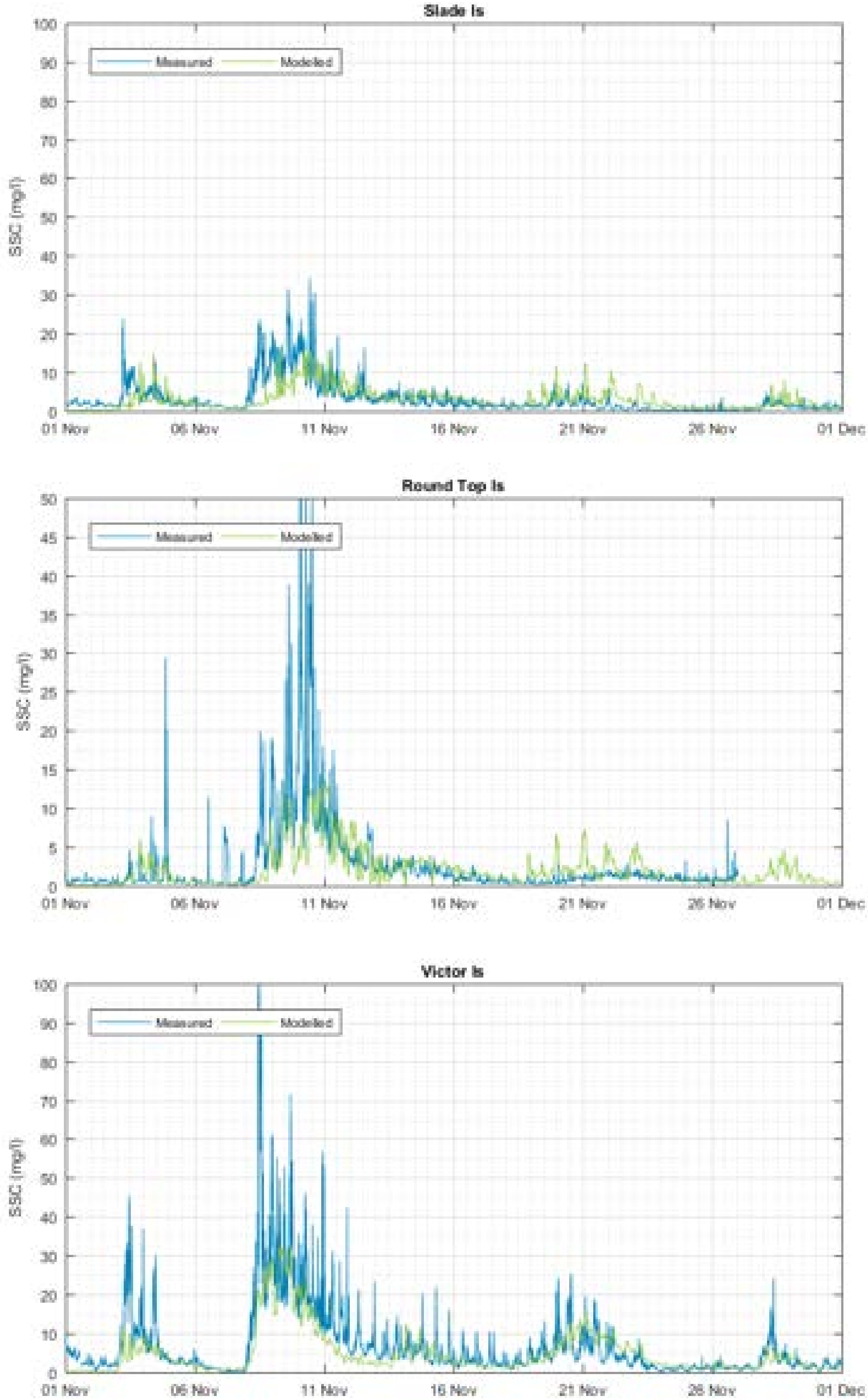


Figure 34. Modelled and measured SSC at Slade Islet, Round Top Island and Victor Island during the November 2020 calibration period. *Note: the Round Top Island plot has different vertical axis to the other two plots.*

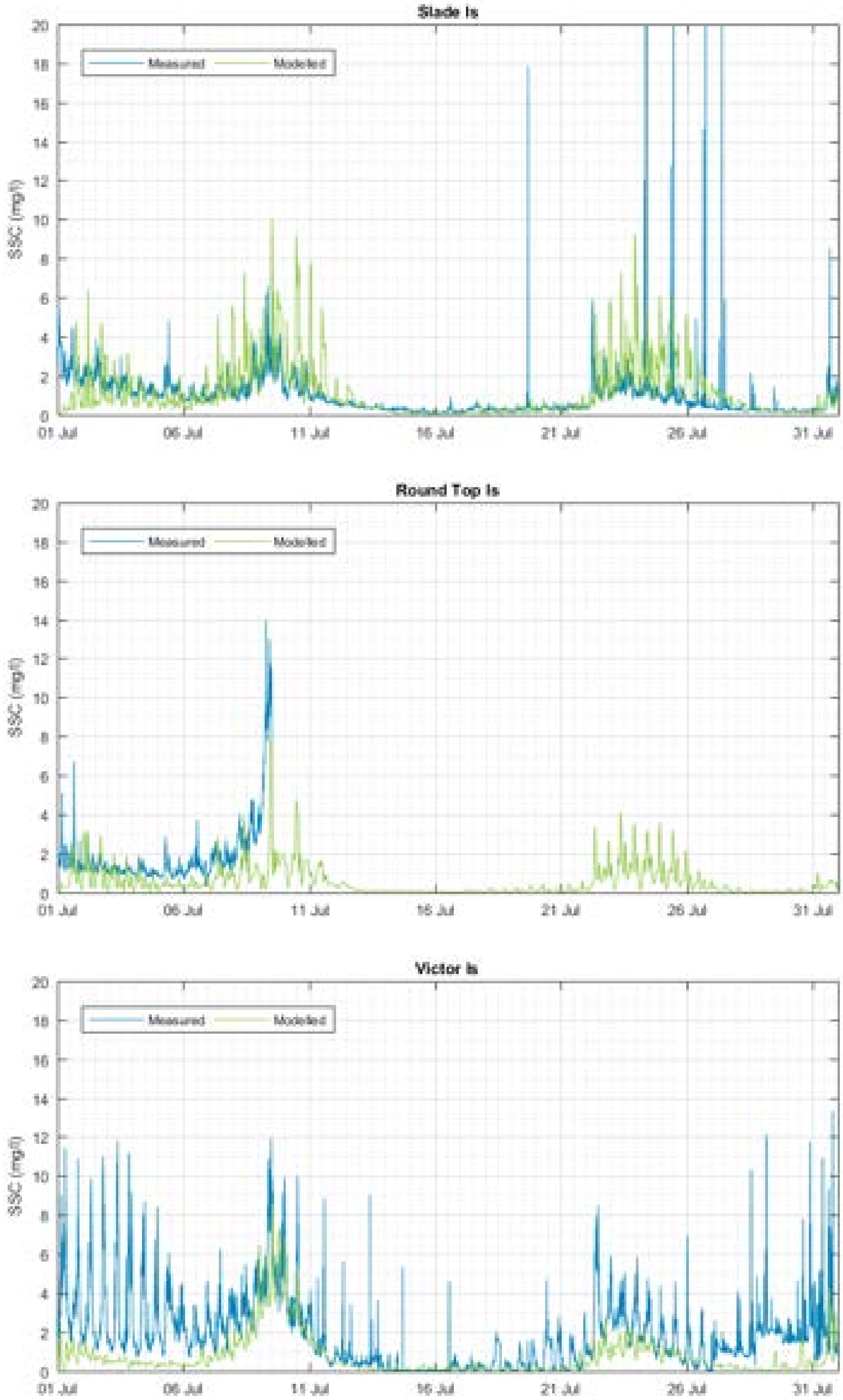


Figure 35. Modelled and measured SSC at Slade Islet, Round Top Island and Victor Island during the July 2020 validation period.

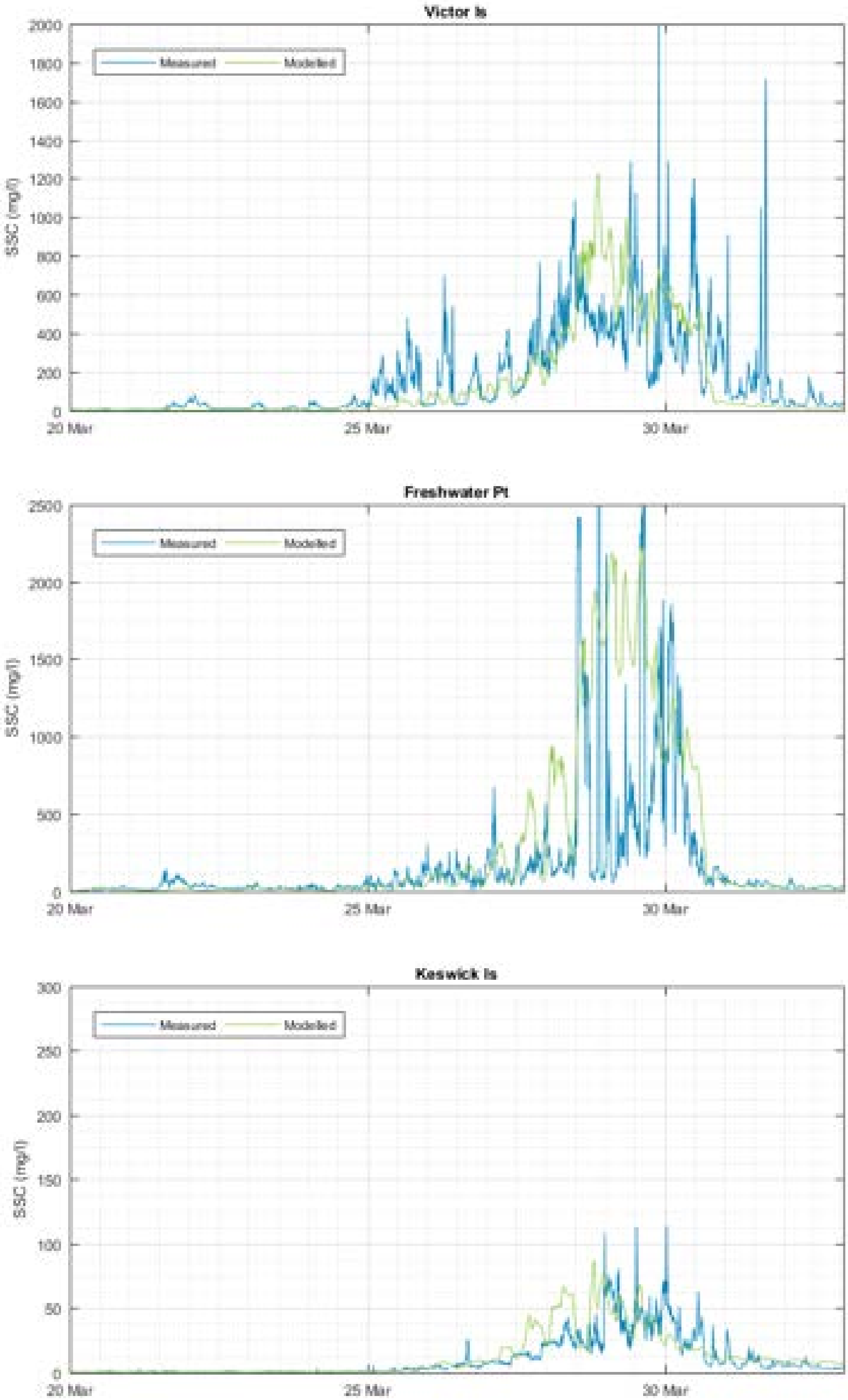


Figure 36. Modelled and measured SSC at Victor Island, Freshwater Point and Keswick Island during the March 2017 extreme event validation period. *Note: all plots have different vertical axes.*

4.5. Dredge Plume

Maintenance dredging of approximately 122,000 m^3 of sediment from the Port of Mackay was undertaken over a 12 day period in December 2020 by the Trailing Suction Hopper Dredger (TSHD) Brisbane. The ambient water quality monitoring during the 2020 maintenance dredging program at the Port of Mackay did not show any increase in the duration that the turbidity thresholds were exceeded at the water quality monitoring sites (PCS, 2021d). However, satellite imagery was used to identify visible plumes from the dredging and placement activity and the imagery showed that any plumes remained close to where they were created (within 2 to 3 km). It was found that although the dredging could have resulted in a slight increase in SSC at the Slade Islet site, the SSC at the site remained relatively low for the time of year and the temporal variability corresponded with the tide and wave conditions. Therefore, it has not been possible to calibrate the dredge plume model using in-situ measured data, but a qualitative validation has been undertaken using satellite derived total suspended matter (TSM) imagery from during the 2020 maintenance dredging program.

The dredge plume model was setup to represent the 2020 maintenance dredging campaign as accurately as possible based on the dredge logs from the TSHD Brisbane. The mass of sediment suspended by the dredging and placement activity was initially based on the percentage losses adopted for the previous Port of Hay Point (2% of fines suspended by draghead, 10% by overflow and 15% during placement). However, the resultant modelled extent and concentration of the plume resulting from the placement of sediment at the Mackay DMPA was found to be much greater than shown by the satellite imagery and so sensitivity testing was undertaken to optimise the source term for the placement of sediment. Based on the sensitivity testing it was found that the results agreed better with the measured data when 7.5% of the fine-grained sediment in the hopper was suspended in a plume during the placement activity as opposed to the 15% previously adopted at the Port of Hay Point, this is discussed further in Section 5.5.

Plots of the satellite derived TSM and modelled excess SSC due to the maintenance dredging at the corresponding time to the satellite derived TSM are shown in Figure 37 to Figure 40. There were only two usable high resolution satellite derived TSM images from during the dredging program due to the frequency the high resolution sensors covered the region combined with high cloud cover over much of the dredge period. At the time of the two high resolution satellite derived TSM images the natural TSM is low in the area around the Port of Mackay and the Mackay DMPA and so comparing the imagery to just excess SSC from the dredging is considered applicable. Comparison between the satellite imagery and modelled excess SSC shows that the model is able to replicate the elevated SSC which occurs within Mackay Harbour due to the dredging and the pattern of the SSC as it is exported from the Harbour during the ebb stage of the tide. In addition, the model is also able to represent the elevated SSC which can occur to the north, south and within the DMPA due to the placement of the dredged sediment. The modelled SSC around the DMPA appears to be higher than the satellite derived TSM, but this could be related to the modelled SSC being depth averaged and the satellite imagery only being able to provide an indication of the TSM in the surface layers of the water column. Sensitivity testing was undertaken to test further reducing the source term and this was found to result in the plume extent reducing which would have resulted in an underestimation on the 23rd December.

This validation provides confidence that the sediment transport model is able to represent the excess SSC resulting from maintenance dredging activity and placement at the Mackay DMPA. The results suggest that the model could be slightly overpredicting the SSC resulting from the placement of sediment at the Mackay DMPA, although this could also be an artefact of the difference between depth averaged (modelled) and surface SSC (satellite imagery), and so could potentially be representing an upper estimate of the SSC and plume extent.

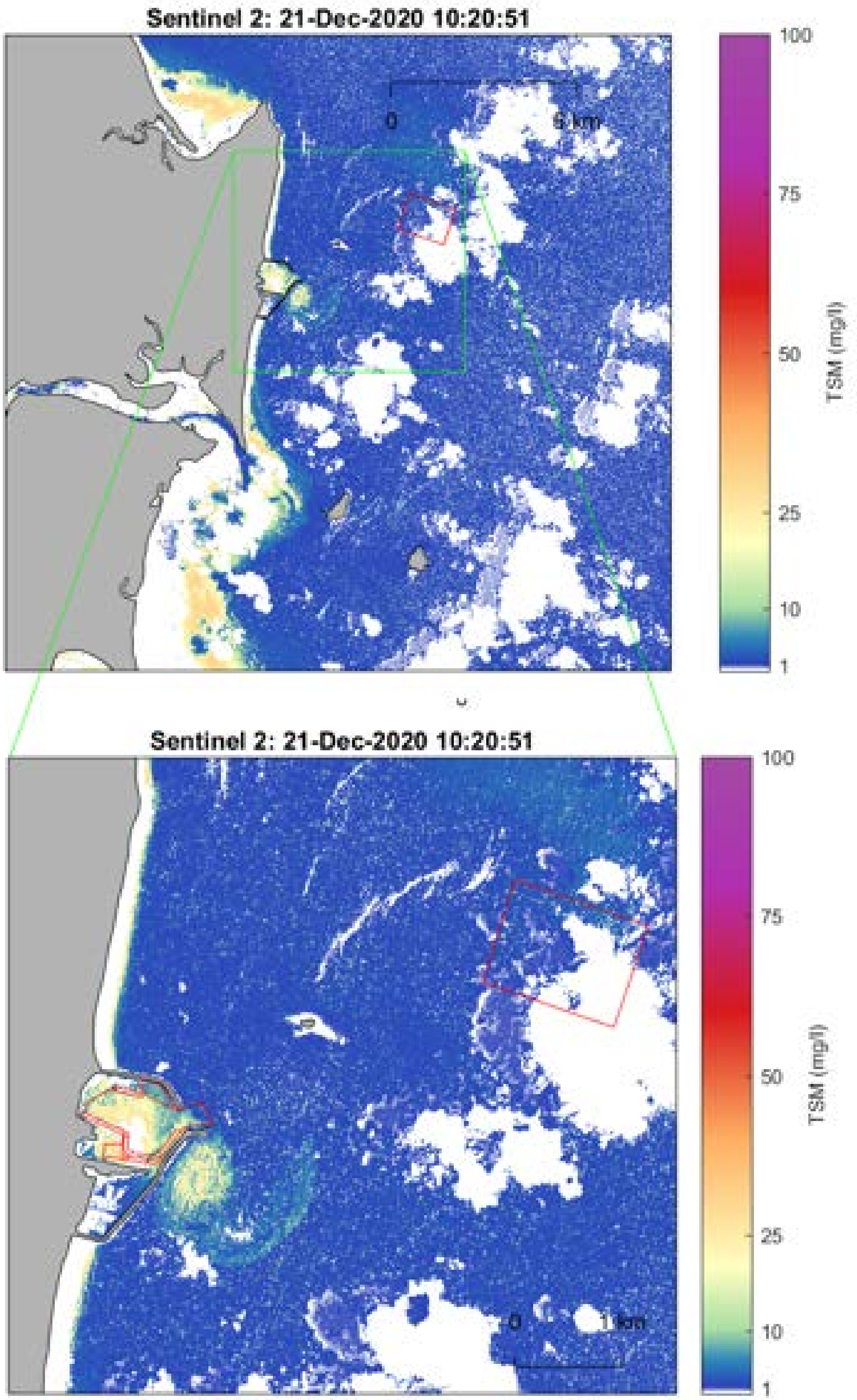


Figure 37. Satellite-derived TSM from the Sentinel 2 sensor for the Port of Mackay on 21/12/2020 10:20 AEST (PCS, 2021d).

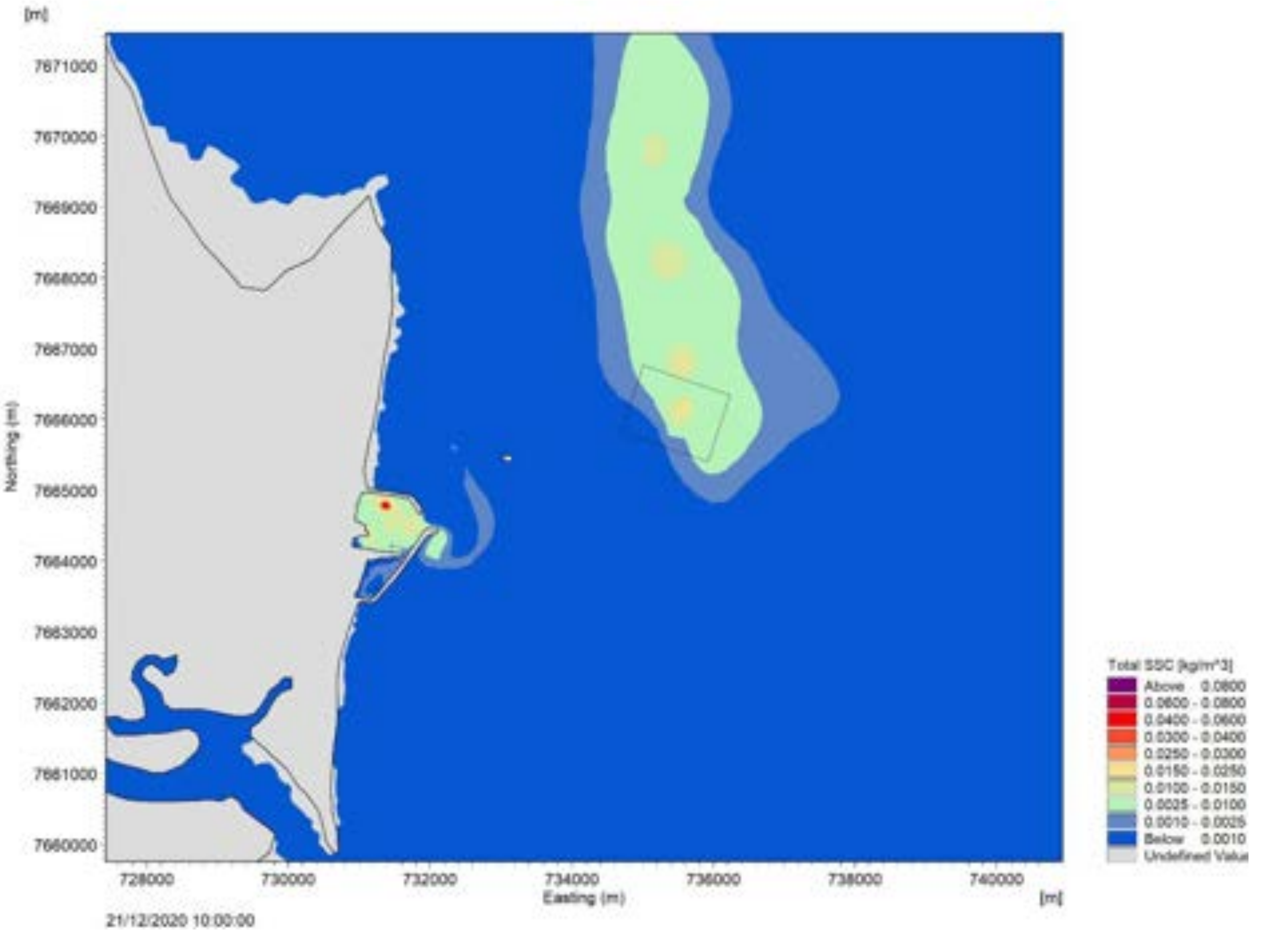


Figure 38. **Modelled excess SSC due to maintenance dredging activity at the Port of Mackay on 21/12/2020 10:00 AEST.**

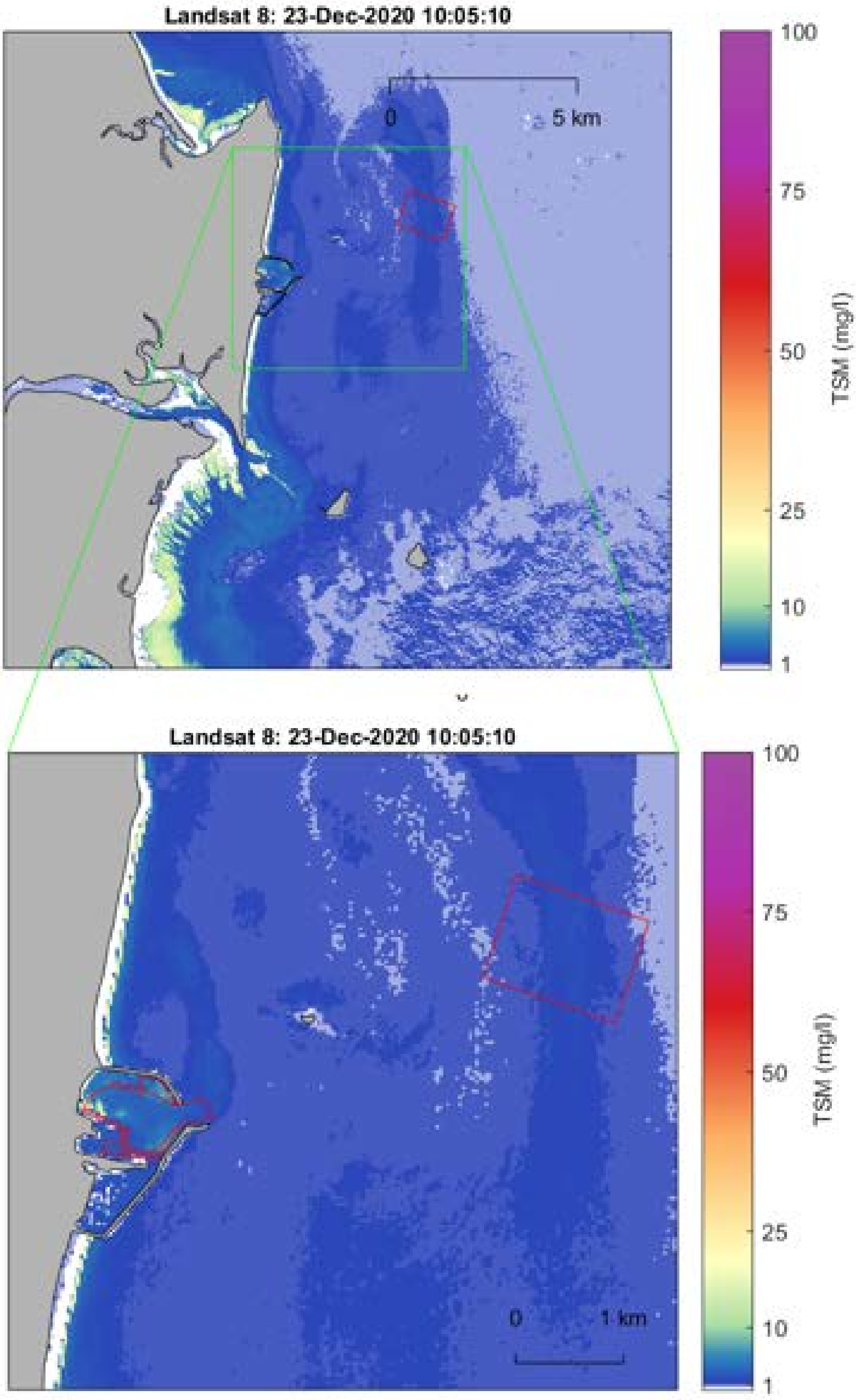


Figure 39. Satellite-derived TSM from the Landsat 8 sensor for the Port of Mackay on 23/12/2020 10:05 AEST (PCS, 2021d).

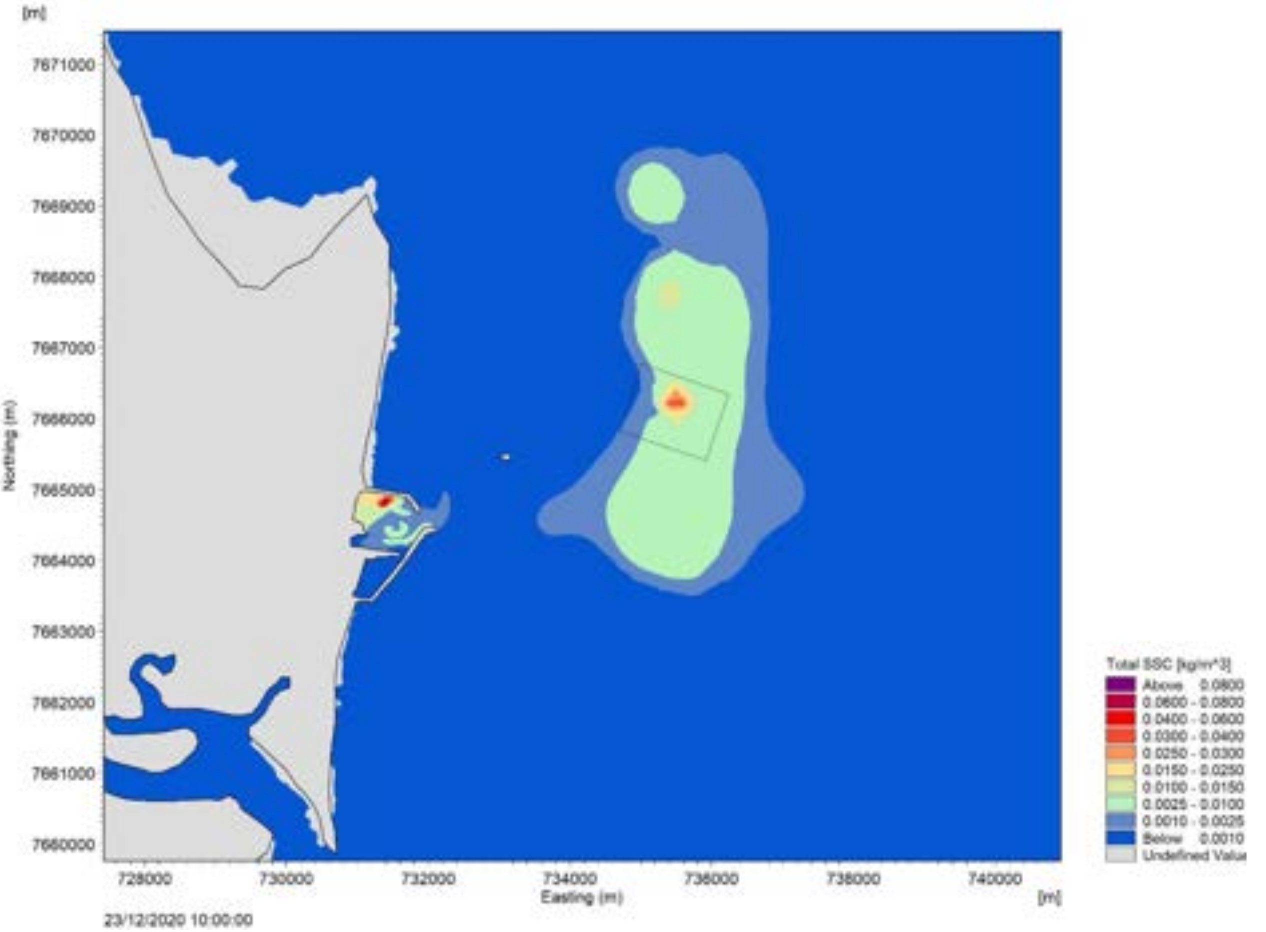


Figure 40. Modelled excess SSC due to maintenance dredging activity at the Port of Mackay on 23/12/2020 10:00 AEST.

5. Dredging Description

This section provides details of the maintenance dredging activity which the model will represent as well as an overview of how the dredging has been conceptualised for inclusion in the numerical model.

5.1. Dredge Volumes

As part of this assessment a range of maintenance dredging volumes are being considered to help understand how the volume being dredged and placed at the Mackay DMPA influences any resultant plumes and potential impacts. The in-situ maintenance dredging volumes of sediment which are being considered as part of this assessment are 125,000, 250,000, 500,000, 750,000 and 1,000,000 m^3. Future maintenance dredging programs are not expected to be as large as 1,000,000 m^3, but the larger volumes are being modelled to understand if/when maintenance dredging could result in potential impacts to nearby sensitive receptors.

The bathymetric analysis noted that regular sedimentation above design depths occurs in the berths and swing basin (specifically in the siltation trench section adjacent to berth 1) (PCS, 2021a). Therefore, maintenance dredging has been assumed to be required in all these areas for the maintenance dredging volumes simulated.

5.2. Sediment Composition

As noted in Section 2.4, previous sampling of the sediment in the Port of Mackay has shown that the sediment accumulating in the Port is predominantly made up of fine-grained silt and clay. Sediment sampling from the Berths and Old Tug Basin provide the best indication of the typical composition of the sediment which is deposited in Mackay Harbour as regular ongoing sedimentation occurs in these areas. Based on this and the percentage composition of the samples it has been assumed that the composition of the sediment which is deposited throughout the Port of Mackay is 90% silt and clay and 10% sand. A breakdown of the fine-grained silt and clay present was not provided in the 2018 sediment sampling, but previous sampling found that the percentage of silt and clay in the deposited sediment was approximately equal (38% clay and 36% silt) (NQBP, 2011). Based on this it has been assumed that all of the sediment to be dredged is made up of 45% clay, 45% silt and 10% sand.

5.3. Dredge Vessel

As noted in Section 1.2, since 2004 the *TSHD Brisbane* has undertaken the majority of the maintenance dredging at the Port of Mackay. A TSHD is considered to be the most suitable type of dredger to undertake the intermittent maintenance dredging required at the Port because they:

- have high production rates (i.e. they can remove the sedimentation quicker than other dredgers);
- are self-propelled and can operate in offshore and trafficked areas without the need for support vessels; and
- are well suited to dredging recently deposited sediment ranging from sand to silt and clay.

The *TSHD Brisbane* was specifically designed to undertake maintenance dredging for the Queensland Ports and has numerous environmental management mechanisms to ensure any environmental impacts are minimised. In the future it is likely that either the *TSHD Brisbane*, or a similar TSHD, would undertake the majority of the maintenance dredging at the Port of Mackay. Therefore, for the modelling it has been assumed that a vessel with the same specifications as the *TSHD Brisbane* is used for the dredging and placement. Vessel specifications for the *TSHD Brisbane* are shown in Table 10.

Table 10. Vessel specifications for the *TSHD Brisbane*.

Specifications	TSHD Brisbane
Length Overall (m)	84
Beam (m)	16
Draft – Fully Laden (m)	6.3
Hopper Capacity (m^3)	2,900
Vessel Average Speed (kts)	12

5.4. Dredge Material Placement Area

Sediment dredged during previous maintenance dredging programs by the *TSHD Brisbane* at the Port of Mackay has historically been placed at the Mackay DMPA which is located approximately 3.5 km offshore and to the east north-east of Mackay Harbour. For this assessment it is assumed that all dredged sediment will continue to be placed at the Mackay DMPA. The modelling has assumed random placement locations within the DMPA so that the placement location varies over time and a uniform distribution of placed sediment occurs over the DMPA.

5.5. Dredging Conceptualisation

To represent the dredging and placement activities in the numerical model it is necessary to conceptualise it, whilst ensuring that the dredge timings and release rates assumed in the model are realistic based on the information available.

Information on the dredge cycle times were based on the dredge vessel specifications along with the dredge logs from the 2020 maintenance dredging program. Based on this, the following assumptions were made:

- on average it takes one hour to fill the hopper, with no overflow from the hopper occurring during the first 20 minutes and overflow occurring for the following 40 minutes;
- it typically takes the dredger 10 minutes to place its load at the Mackay DMPA; and
- operational downtime of half a day per week has been assumed (approximately 7% of the time) to allow for bunkering, crew changes and any minor technical issues.

Based on the assumptions detailed above the average dredge cycle time was defined. A breakdown of the dredge cycle timing is provided in Table 11.

Table 11. Dredge cycle times for the *TSHD Brisbane* dredging the Port of Mackay.

Details	Duration
Dredging – No Overflow	20 mins
Dredging – Overflow	40 mins
Sailing Laden	20 min
Placement	10 min
Sailing Unladen	20 min
Average Dredge Cycle	**110 min (1.83 hrs)**

Extensive monitoring of the plumes resulting from dredgers have shown that a proportion of the sediment disturbed by the dredging activity and released by the placement can remain in suspension as part of a passive plume which is available for transport (Becker *et al.*, 2015; Mills and Kemps, 2016). For a TSHD the major sources of sediment released are noted by Kemps and Masini (2017) to typically be from:

- the dredger draghead(s) disturbing fine-grained sediment on the seabed during the dredging activity;
- resuspension of fine-grained sediment on the seabed from the propeller wash of the dredger (this source is typically combined with the draghead);
- fine-grained sediment released as part of the overflow from the hopper during dredging; and
- fine-grained sediment suspended into a passive plume as part of the dynamic descent of the sediment from the hopper to the seabed during placement.

Table 12 provides a summary of the typical ranges of source terms which have been defined as part of previous studies for general TSHDs from Becker *et al.* (2015) and Kemps and Masini (2017) and for the *TSHD Brisbane* from BMT (2017). The table also details the source terms originally assumed for the dredge plume validation and the final validated values adopted for the modelling. The source terms originally assumed for the dredge plume validation were taken from the source terms which were defined for the Port of Hay Point 2019 maintenance dredging program (RHDHV, 2018). The source terms were adjusted so that the extent and concentration of the plumes resulting matched the plumes shown in the satellite imagery as closely as possible. This resulted in a reduction in the source term for the plume resulting from the placement of sediment at the DMPA from 15% to 7.5%. The same lower source term for the placement of dredged sediment was adopted for the *TSHD Brisbane* at the Port of Weipa (where the majority of the dredged sediment is fine-grained silt and clay like at the Port of Mackay) following a validation process using satellite imagery (PCS, 2019b).

Table 12. Summary of TSHD source terms from the literature and those assumed for this assessment.

Source Type	Spill Rate (% of fines in sediment)		
	Literature Range	Original Values	Validated Values
Draghead and Propeller Wash	<5%	2%	2%
Overflow	5-15%	10%	10%
Offshore Placement	0-15%	15%	7.5%

6. GBRMPA Guidelines

The GBRMPA Hydrodynamic Modelling Guidelines (GBRMPA, 2012) specify how numerical modelling for dredging projects in the GBRMP should be undertaken. Table 13 demonstrates how the modelling approach which has been developed and adopted for this assessment has met the relevant GBRMPA requirements.

Table 13. Summary of modelling adherence to GBRMPA guidelines.

GBRMPA Requirement	Modelling Approach Adherence
3D hydrodynamic and sediment transport modelling is required.	All of the modelling has been undertaken using 3D hydrodynamic and sediment transport models.
Hydrodynamic model should take into account the tides, the wind, the waves and the mean prevailing circulation and potential stratification from river discharges.	The hydrodynamic model has been setup and calibrated to include astronomical tides, wind and waves. Although the GBR Lagoon circulation processes could intermittently influence currents in the region, their impacts are considered to be minor relative to tidal and wind generated currents. Stratification from river discharges is not required due to the setting of the Port of Mackay.
The model must be calibrated and validated against collected baseline information.	The hydrodynamic, wave and sediment transport models have been calibrated to measured data (collected using ADCPs, WRBs and turbidity loggers) to demonstrate that the model can accurately replicate the natural conditions (see Section 4). The dredge plume model has been validated based on observations during the 2020 maintenance dredging campaign.
The modelling must include all types of potential resuspension including current and wave-induced bottom shear stress and wave-induced mud fluidization.	These are all included in the modelling. Both currents and waves are included as driving forces for the sediment transport model. The MIKE3 FM MT module also includes liquefaction by waves as a weakening of the bed due to the breakdown of the bed structure.
Baseline data must at a minimum be twice the duration of the dredging campaign. Data must be measured in close proximity to the disposal sites and include tidal range, wave height, current, wind direction and intensity and sediment dynamics.	Three months of hydrodynamic and wave data were collected close to Mackay Harbour and the Mackay DMPA from January 2017 to April 2017. Ambient water quality monitoring has been ongoing since 2014 and as part of this near-bed current data have also been collected at the monitoring sites from time to time. Future maintenance dredging programs at the Port are expected to be less than 1.5 months, meaning that sufficient baseline data are available to fulfill the guidelines.
Sediment transport modelling must consider the range of particle sizes and take into account the process of flocculation.	The sediment transport modelling considers all clay and silt sized sediment (assumed to make up 90% of the maintenance dredge material). The process of flocculation has been included for the silt and clay particles.
Accurately represent the ambient conditions at the time of year in which dredging occurs.	Future maintenance dredging could occur at any time through the year as it is dependent on availability of a suitable dredger. To account for this the hydrodynamic and wave models have been calibrated for a range of conditions and the natural sediment transport model has been calibrated and validated using measured data for both the wet and dry seasons.
Include additional dispersion and re-suspension from both dredging operations and dredge disposal activities. This must be completed for a range of probable hydrodynamic conditions, weather events and expected dredge equipment scenarios.	The advection and dispersion of suspended fine-grained sediment from the dredging activity (suction head and overflow) and the dredge disposal activities have been included. The proposed matrix approach takes into account wet and dry season and calmer and more energetic metocean conditions. The *TSHD Brisbane* has been adopted for the model simulations as this type and size of

	dredger is likely to undertake any future maintenance dredging.
Numerical modelling must be performed for a duration of time that is long enough to establish the resuspension associated with different weather conditions that occurs after dumping and initial settling.	A specific long-term resuspension simulation has been undertaken over a 12 month duration. The simulation includes the placed sediment evenly spread over the bed of the Mackay DMPA at the start of the simulation. This has been used to identify the potential resuspension and transport of the sediment following placement. The model has also been used to predict the resuspension and subsequent fate of placed sediment from the Mackay DMPA during a tropical cyclone.

7. Results

The results from the dredge plume model simulations have been processed and are presented in the following sections as:

- spatial maps of percentile values of the predicted SSC due to maintenance dredging, due to natural conditions and combined maintenance dredging and natural. The 80th and 95th percentiles are presented in Section 7.1 and Appendix A. The percentiles have been calculated over a 14 day moving analysis window throughout the model simulation durations (90 days) and the maximum of all the calculated 14 day percentiles was adopted for each grid cell in the model. This approach ensures that any elevated SSC due to ongoing resuspension and transport of sediment released by the dredging is still captured without artificially reducing the percentile SSC from the dredging and placement activity by calculating percentiles over a longer time period. In addition, as well as being the approximate duration of a spring-neap tidal cycle the 14 day window can also be considered to be an ecologically relevant timescale for considering potential impacts to sensitive receptors;
- tabulated percentile values of the predicted increase in SSC at sensitive receptors and at the dredging and placement locations, with the 20th, 80th and 95th percentiles presented (Section 7.1);
- time series plots of the natural and natural plus dredging SSC during the dredging program at sensitive receptors (Section 7.1 and Appendix B);
- tabulated durations of threshold exceedance at sensitive receptors (Section 7.2); and
- spatial maps of the mass of sediment deposited during the dredging program due to dredging, natural sedimentation and natural plus dredging (Section 7.3 and Appendix C).

The following sensitive receptors have been identified as being the closest to the Port of Mackay and have therefore been adopted for this assessment:

- Slade Islet: closest area of coral to the Port of Mackay; and
- Round Top Island: another area of coral which is to the south of Mackay Harbour and the Mackay DMPA and could potentially be influenced by plumes from either. In addition, there are seagrass meadows located close to Round Top Island and to its east and so the site can also be used to indicate the potential for any impacts to seagrass.

In addition to the sensitive receptors, timeseries results have also been extracted within Mackay Harbour and in the centre of the Mackay DMPA to show the resultant increase in SSC at the dredging and placement locations.

The results from the assessment of the long-term resuspension of material deposited at the offshore DMPA are presented in Section 7.4 as time series plots of the sediment volume within the DMPA.

7.1. Suspended Sediment

The SSC results from the model simulations are relevant to predicting any potential ecological impacts, primarily as a result of elevated SSC due to the dredging reducing benthic Photosynthetically Active Radiation (PAR).

A full set of spatial statistical maps showing percentiles of the predicted increase in SSC due to each of the dredge plume modelling simulations are provided in Appendix A. The increase in SSC due to the maintenance dredging is shown along with the modelled natural SSC and the natural plus maintenance dredging. Selected plots are duplicated here to provide an overview of the results and to show the effect of the metocean conditions and dredge volumes on the SSC. It is important to note that the plots do not show an actual representation of the SSC at any point in time, rather they are duration-based plots which show statistical based summaries of the SSC over the model simulation period (with percentiles calculated over a moving 14 day window). The percentile plots show the value which the SSC is below for a given percentage of time in a 14 day period. For example, the 80th percentile plot shows the value that the SSC is below for 80% of the time in 14 days.

Plots are presented for the following:

- spatial maps of the 80th and 95th percentile SSC for the four different metocean conditions (ambient dry, energetic dry, ambient wet and energetic wet) when dredging 125,000 m^3 are shown in Figure 41 to Figure 48. The results are presented to help understand how the extent and concentration of the area with elevated SSC will differ depending on the metocean conditions; and
- spatial maps of the 95th percentile SSC for the energetic wet season period for a dredge volume of 500,000 m^3 and 1,000,000 m^3 in Figure 49 and Figure 50, respectively. These are shown for the energetic wet season as the results for the 125,000 m^3 dredge volume showed that these metocean conditions resulted in the largest extent and highest 95th percentile SSC. The results are presented to allow comparison of the percentile SSC results across a range of the dredge volumes modelled.

To provide quantification of the effect of the different variables on the SSC, percentile values of the increase in SSC due to the maintenance dredging are presented for all five of the dredge volumes and the four different metocean conditions at Mackay Harbour, Mackay DMPA and the two closest sensitive receptor sites at Slade Islet and Round Top Island in Table 14. Time series plots for the same metocean conditions and dredge volumes as the map plots are also shown for the same four sites in Figure 51 to Figure 56. Time series plots of the SSC at the four sites are provided for all the dredge plume modelling simulations in Appendix B.

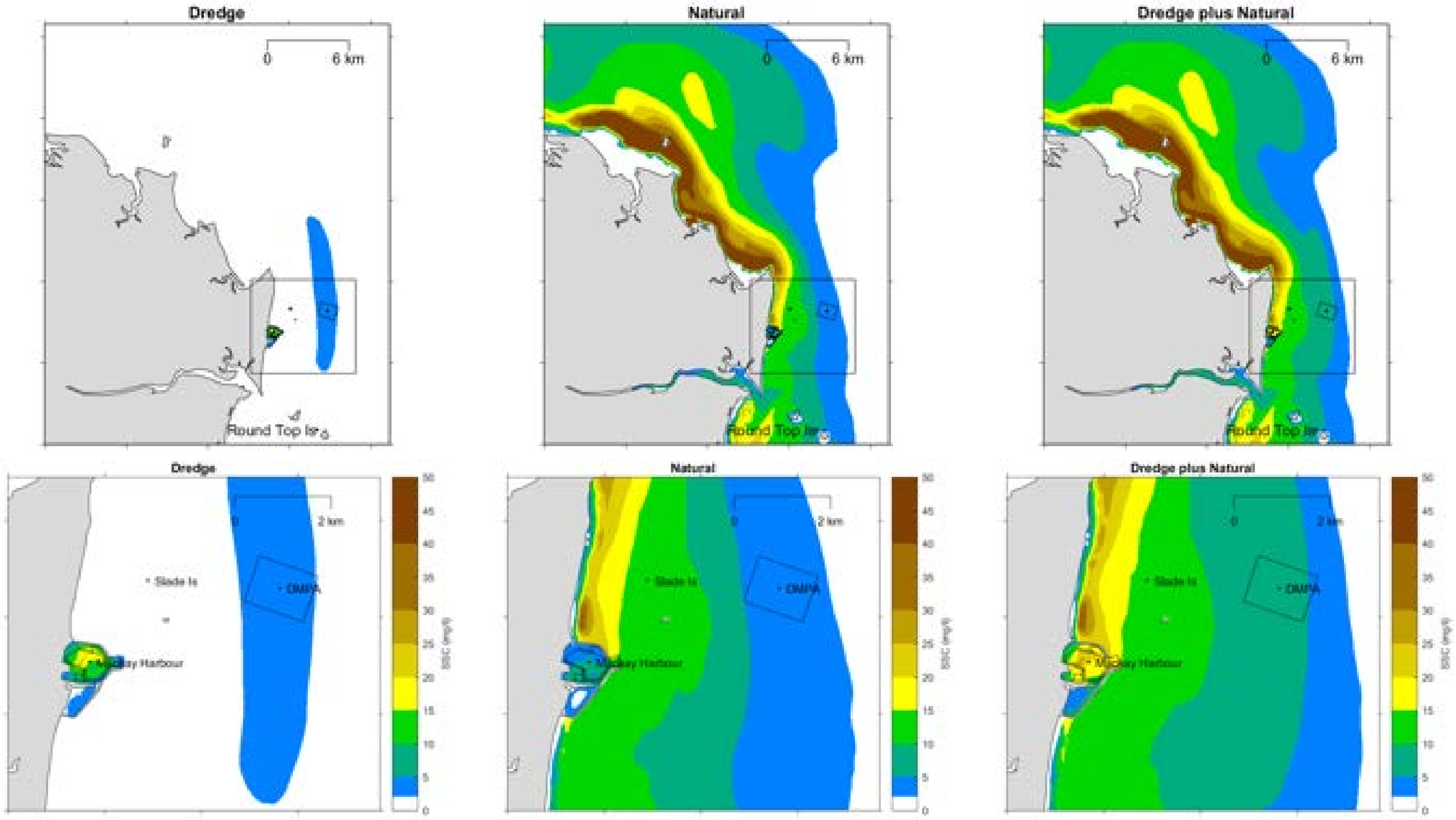


Figure 41. 80th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient dry season.

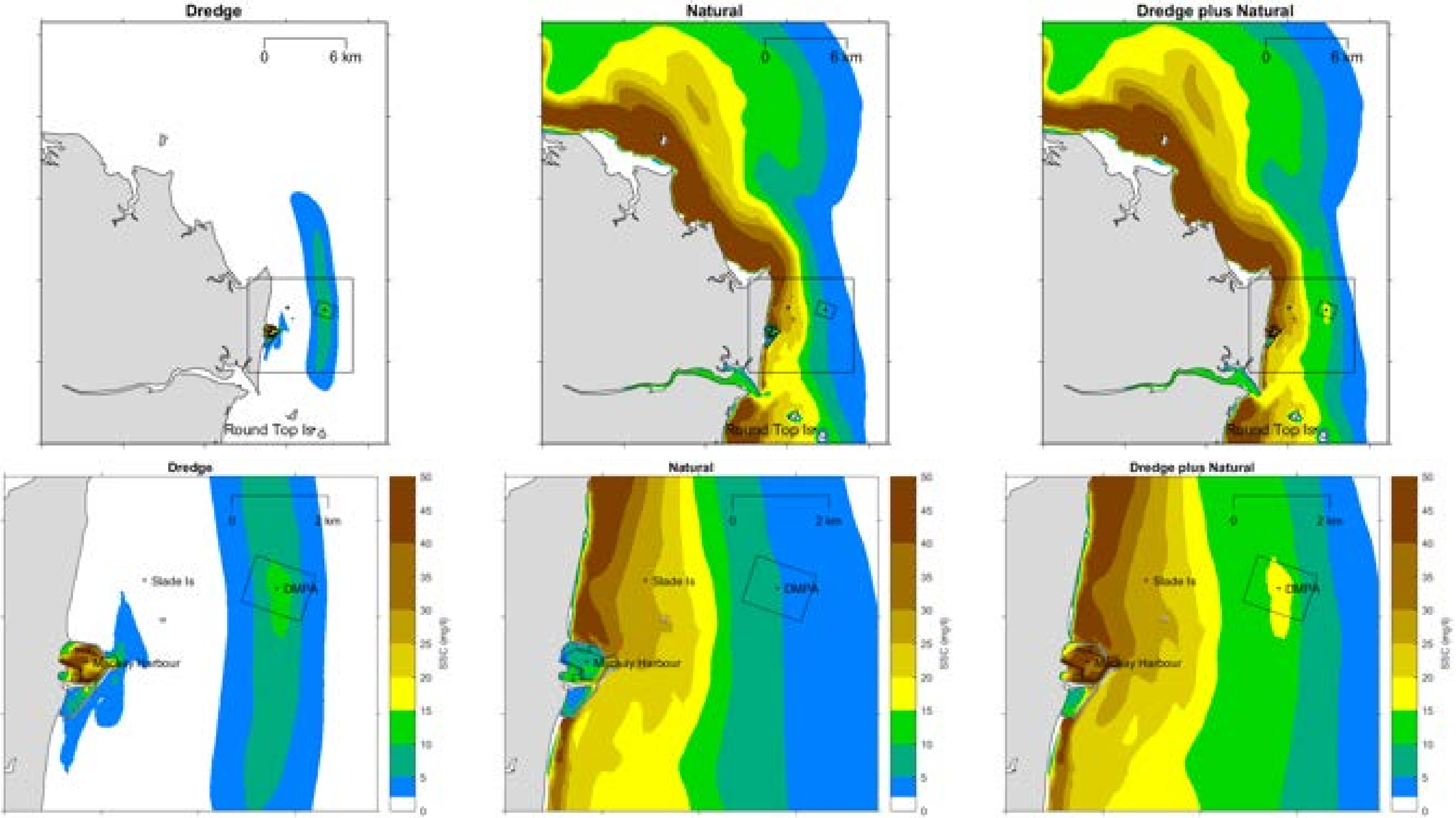


Figure 42. 95th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient dry season.

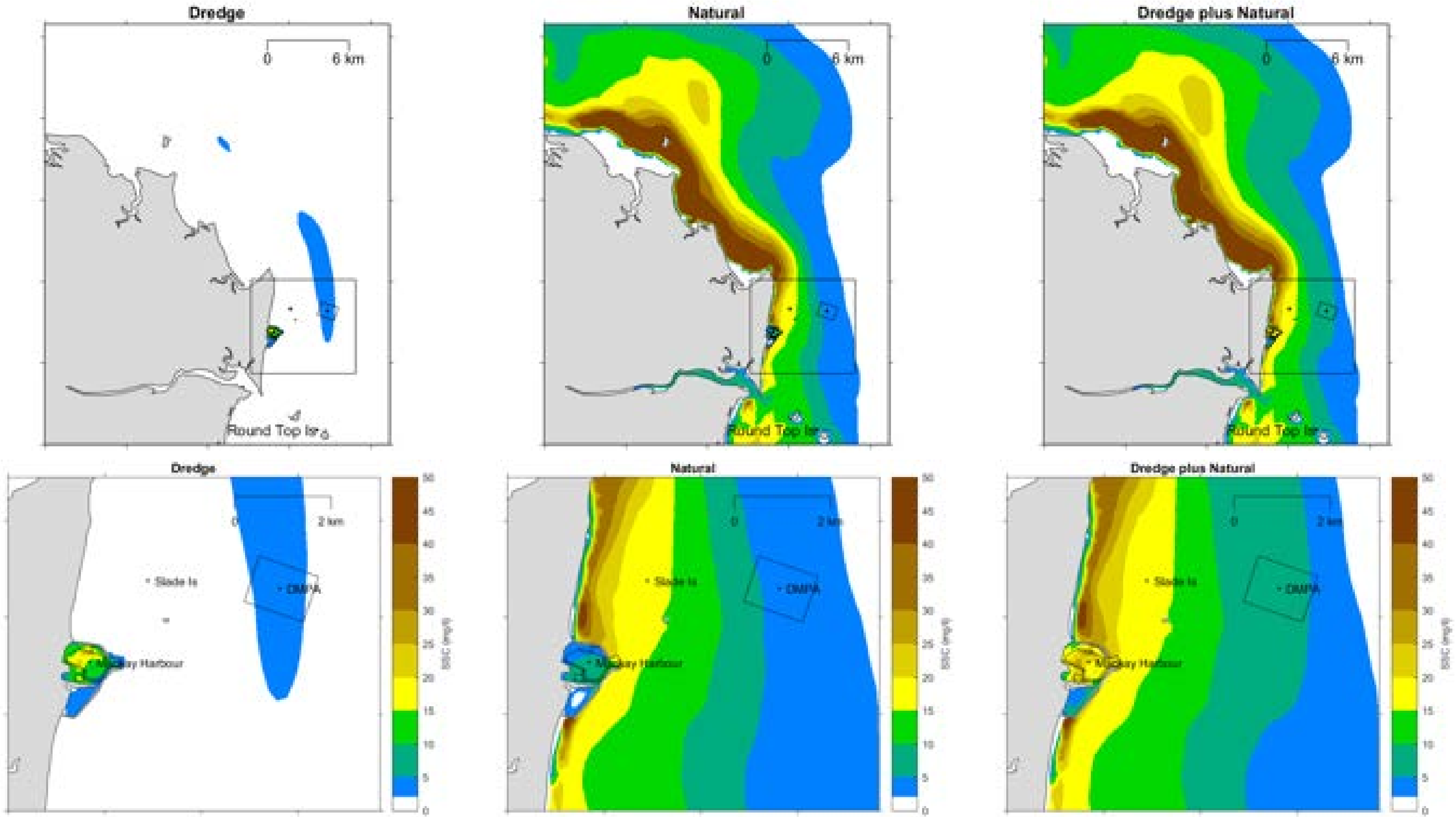


Figure 43. 80th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic dry season.

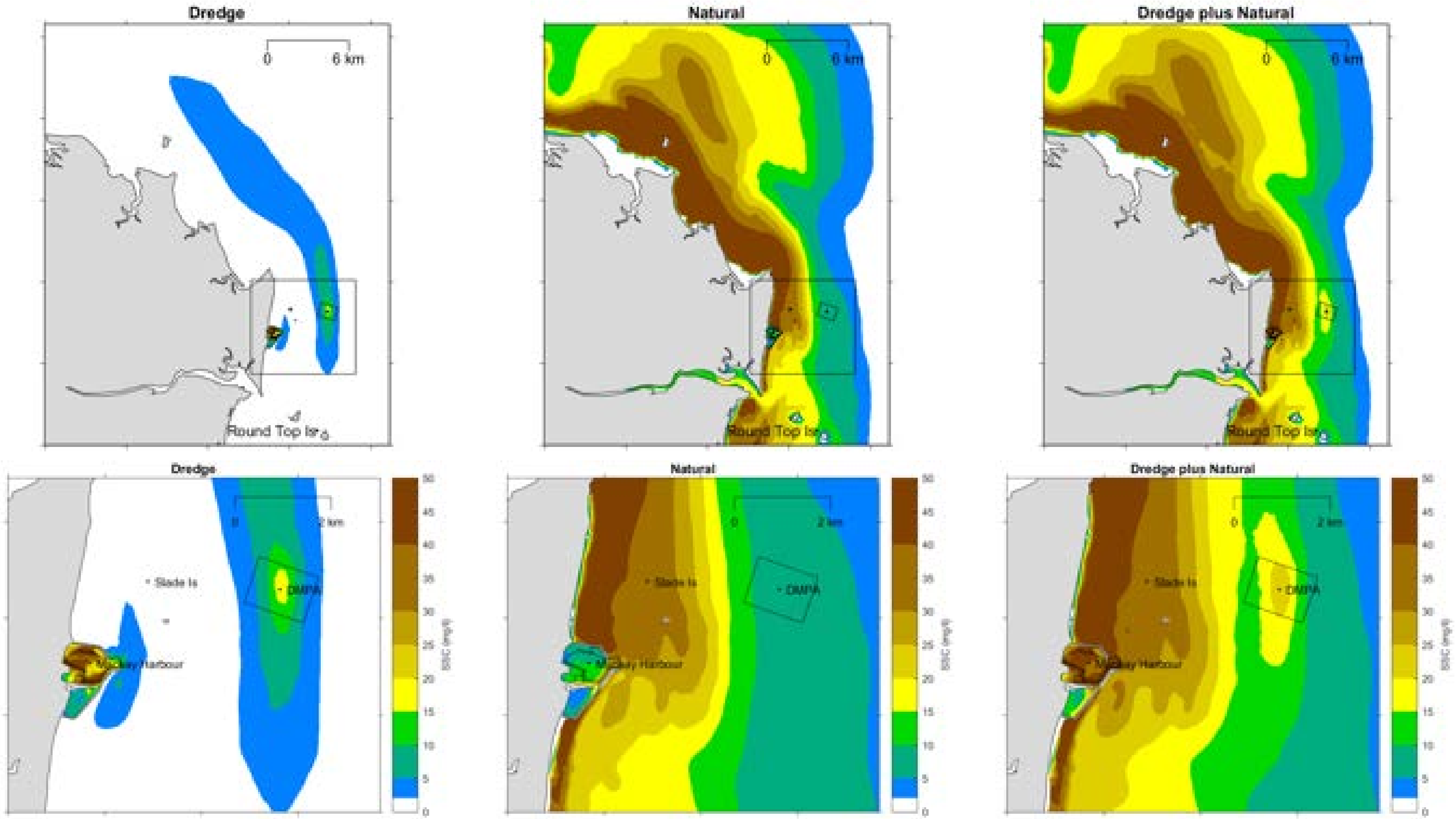


Figure 44. 95th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic dry season.

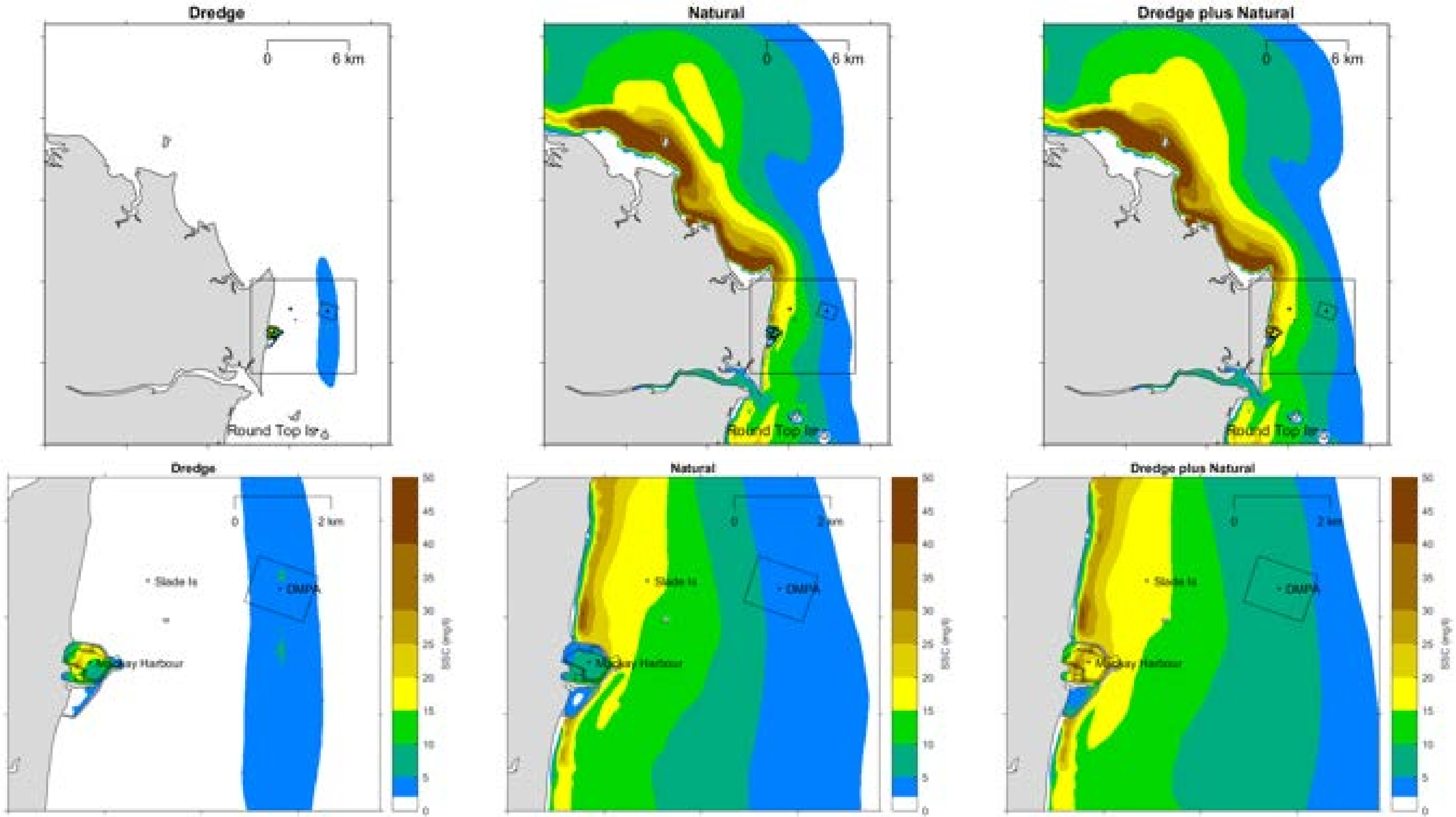


Figure 45. 80th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient wet season.

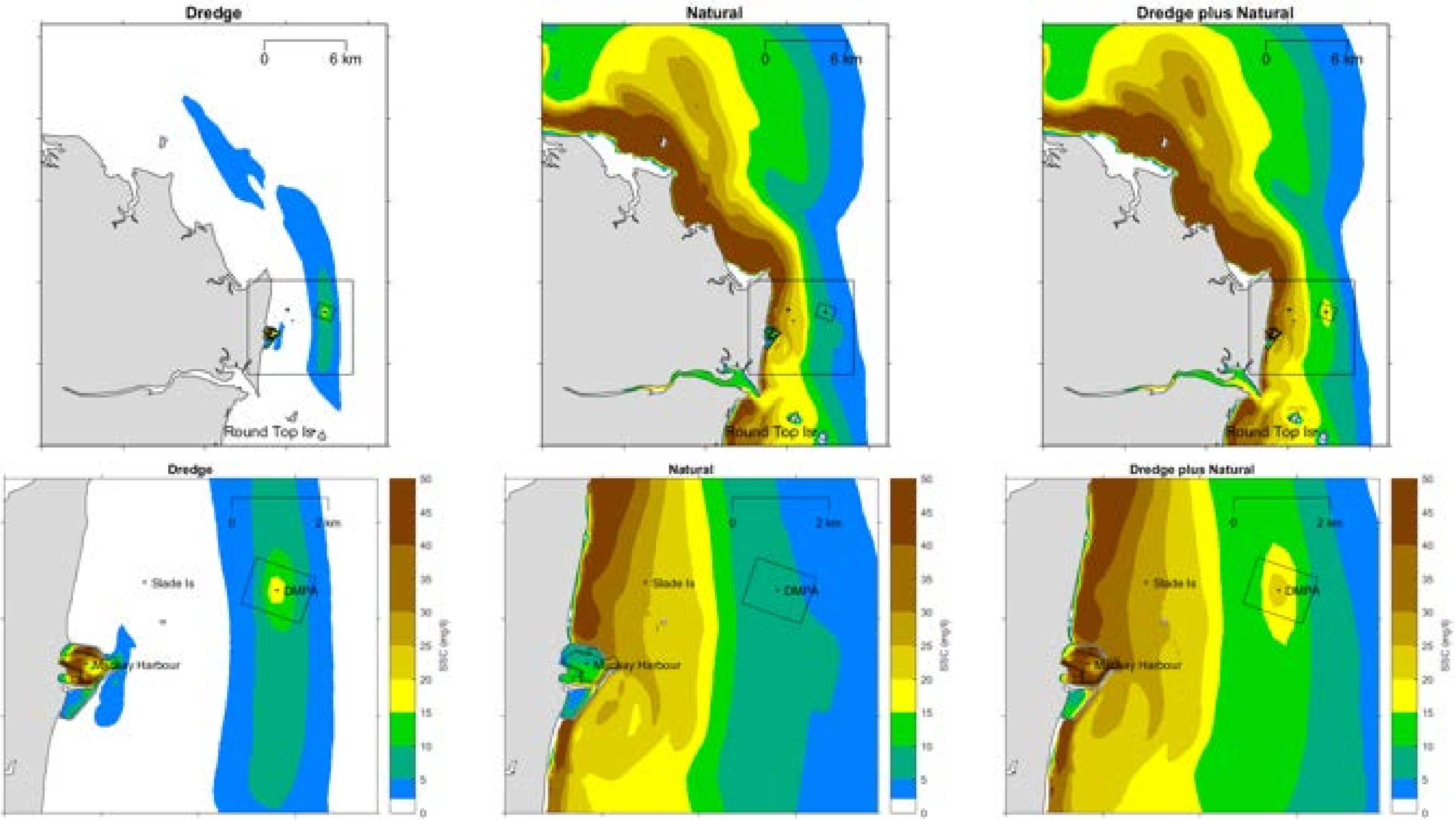


Figure 46. 95th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient wet season.

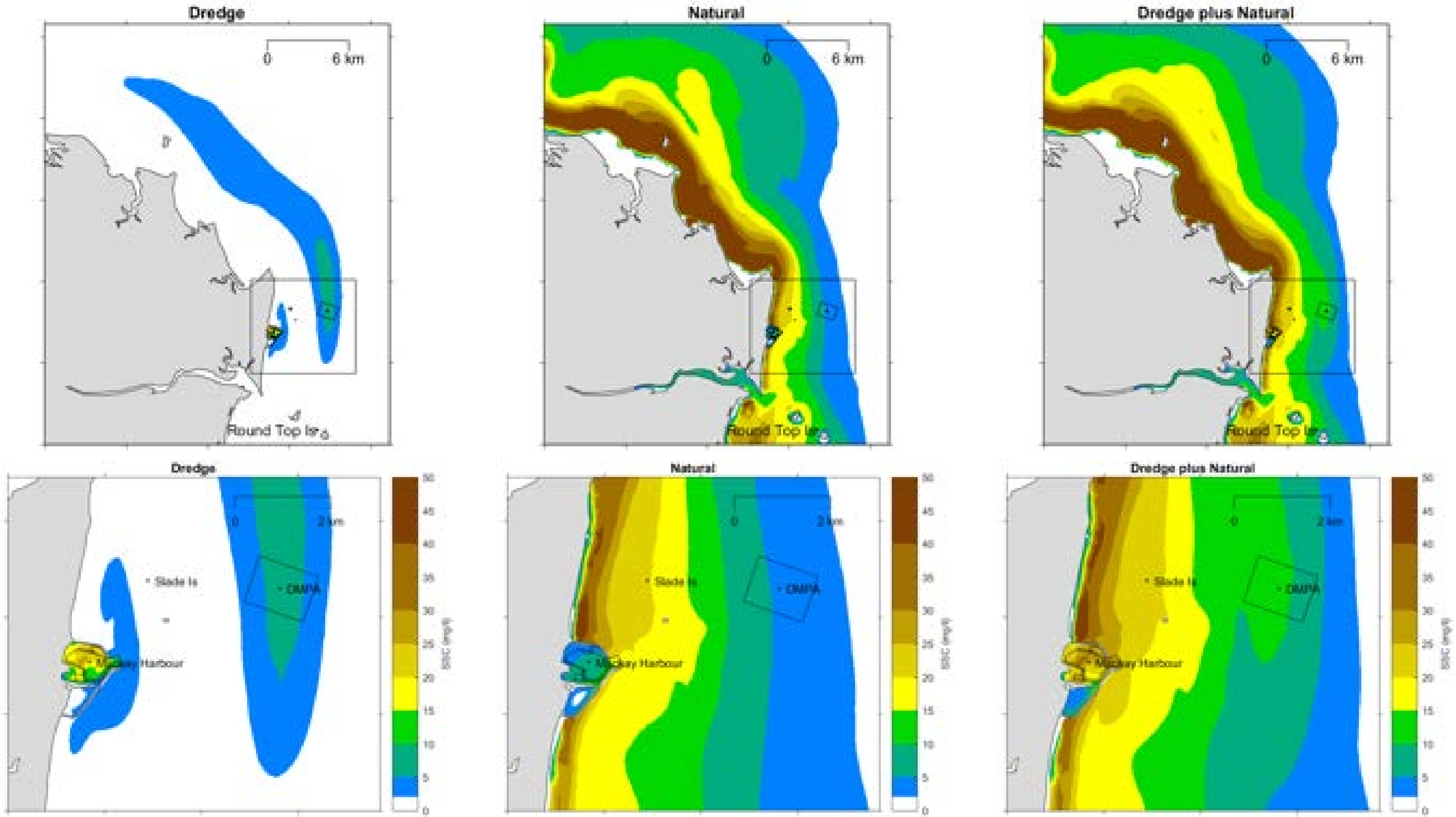


Figure 47. 80th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season.

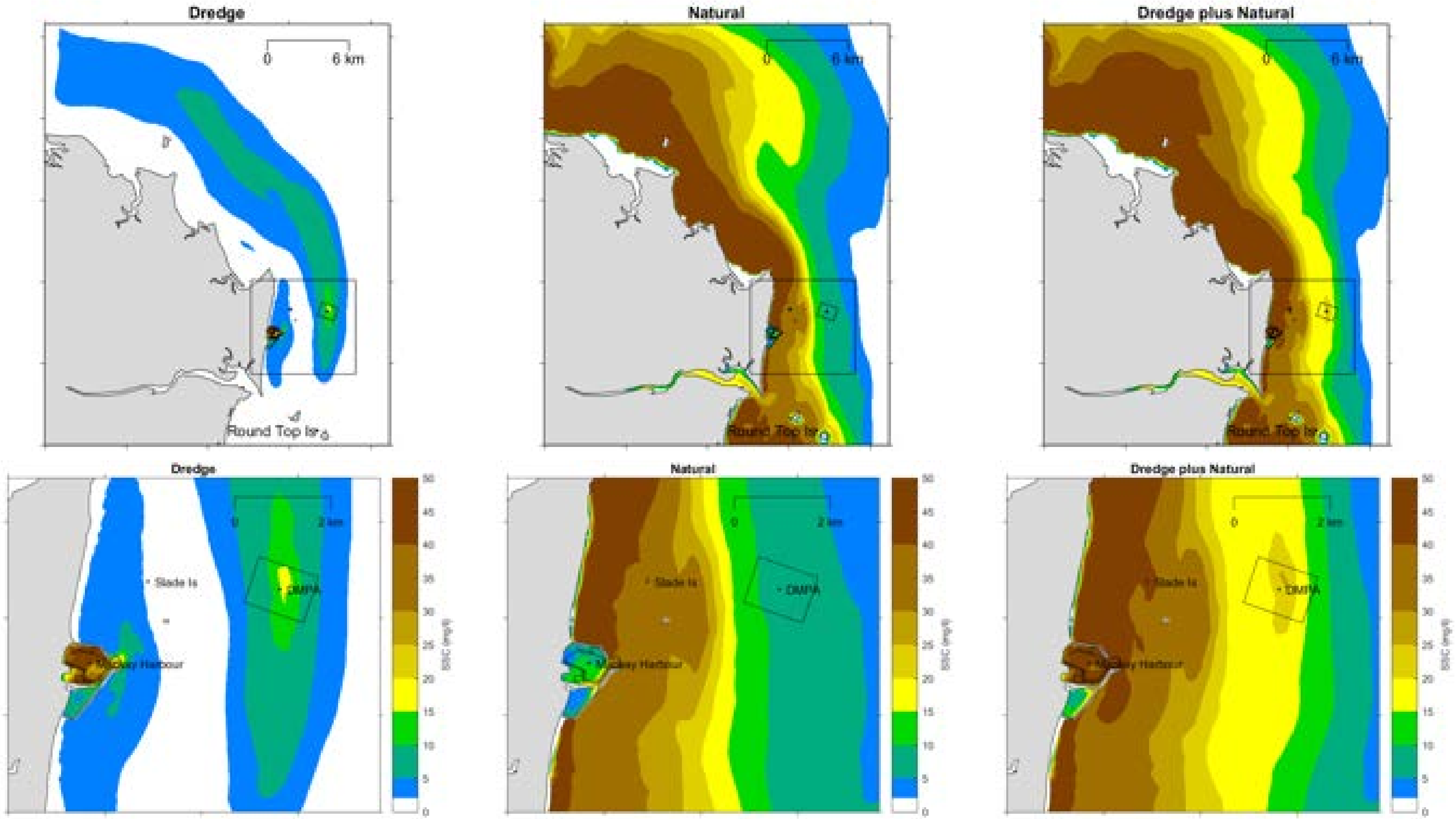


Figure 48. **95th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season.**

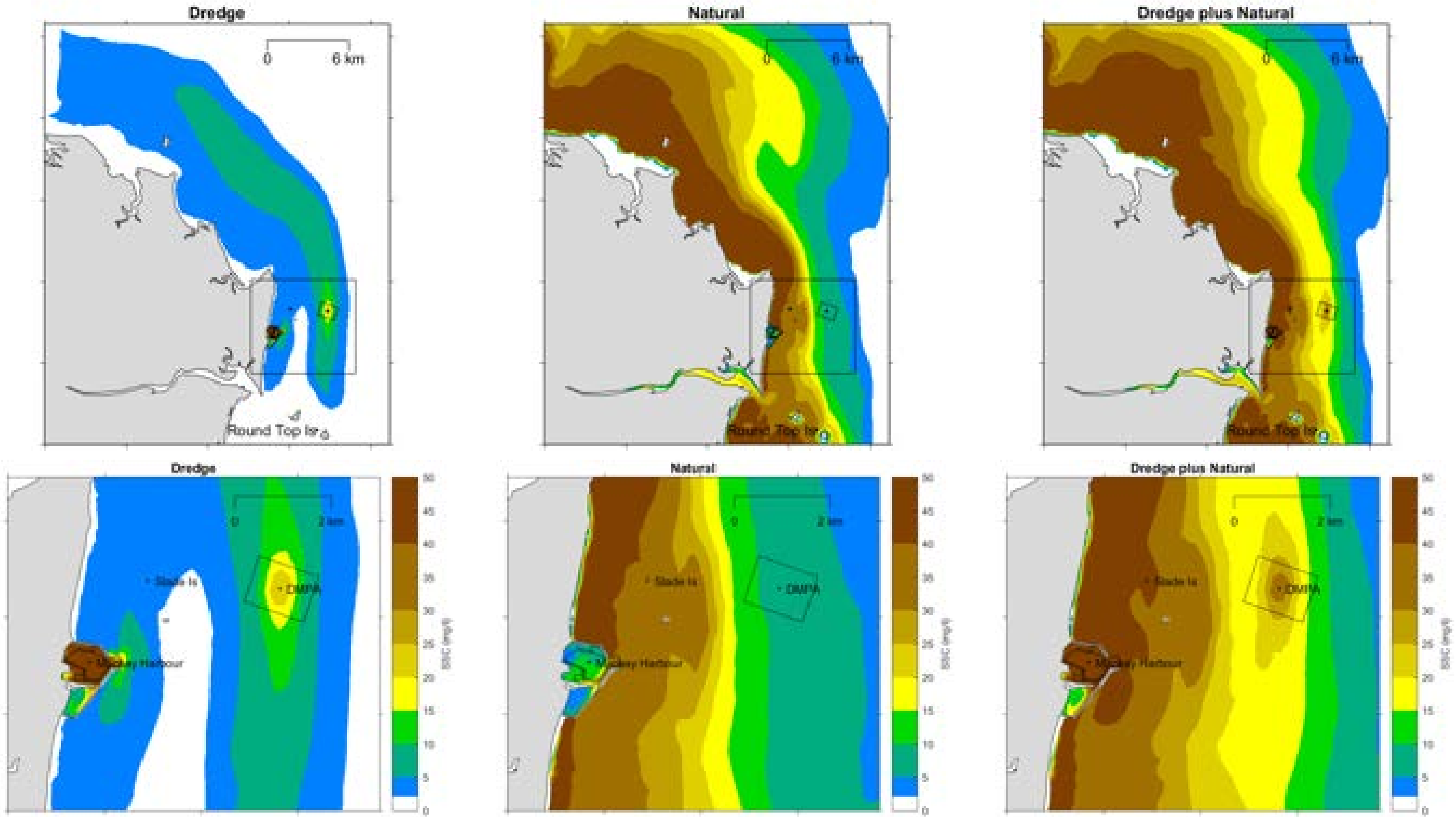


Figure 49. 95th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the energetic wet season.

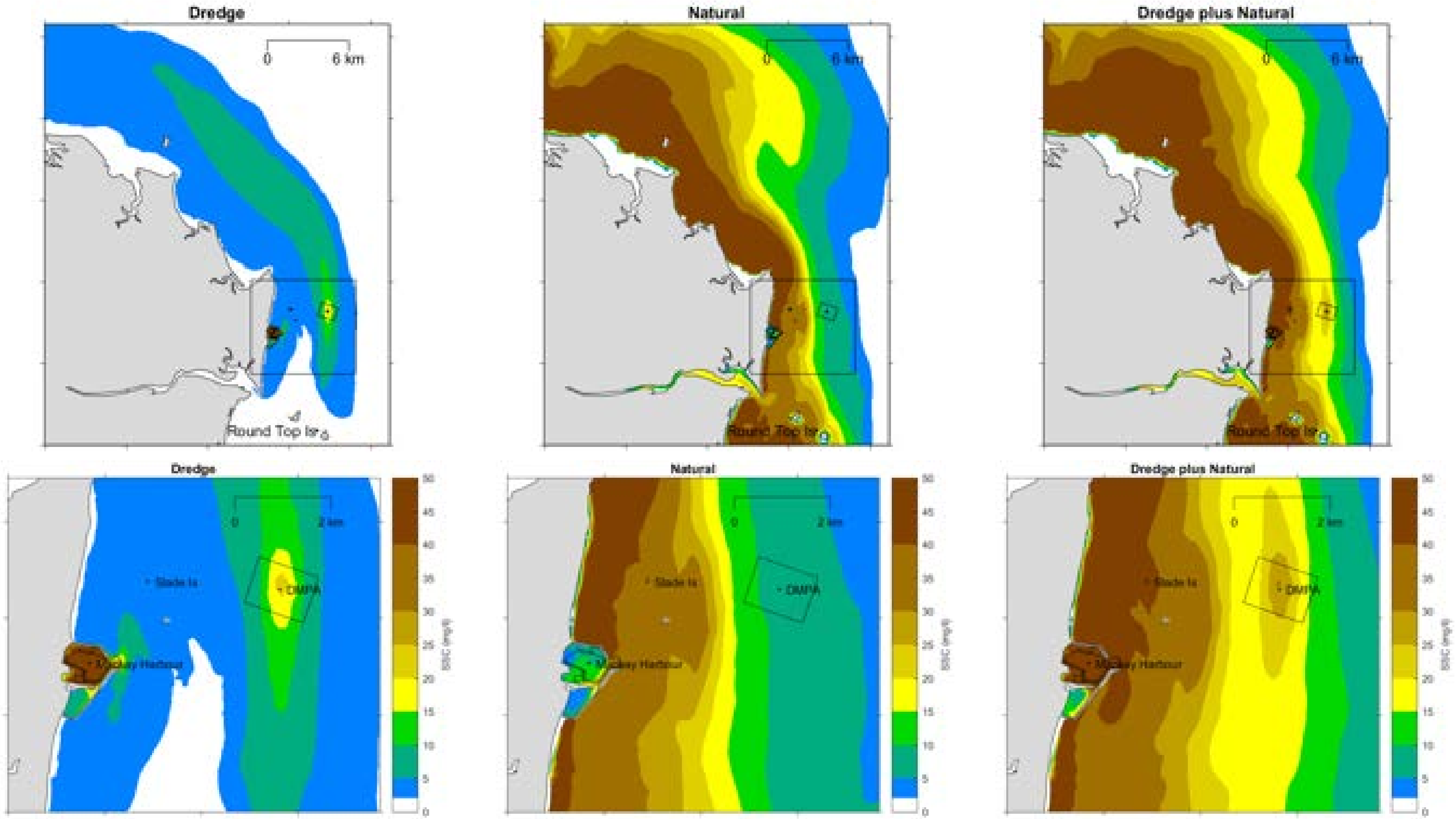


Figure 50. 95th percentile SSC for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic wet season.

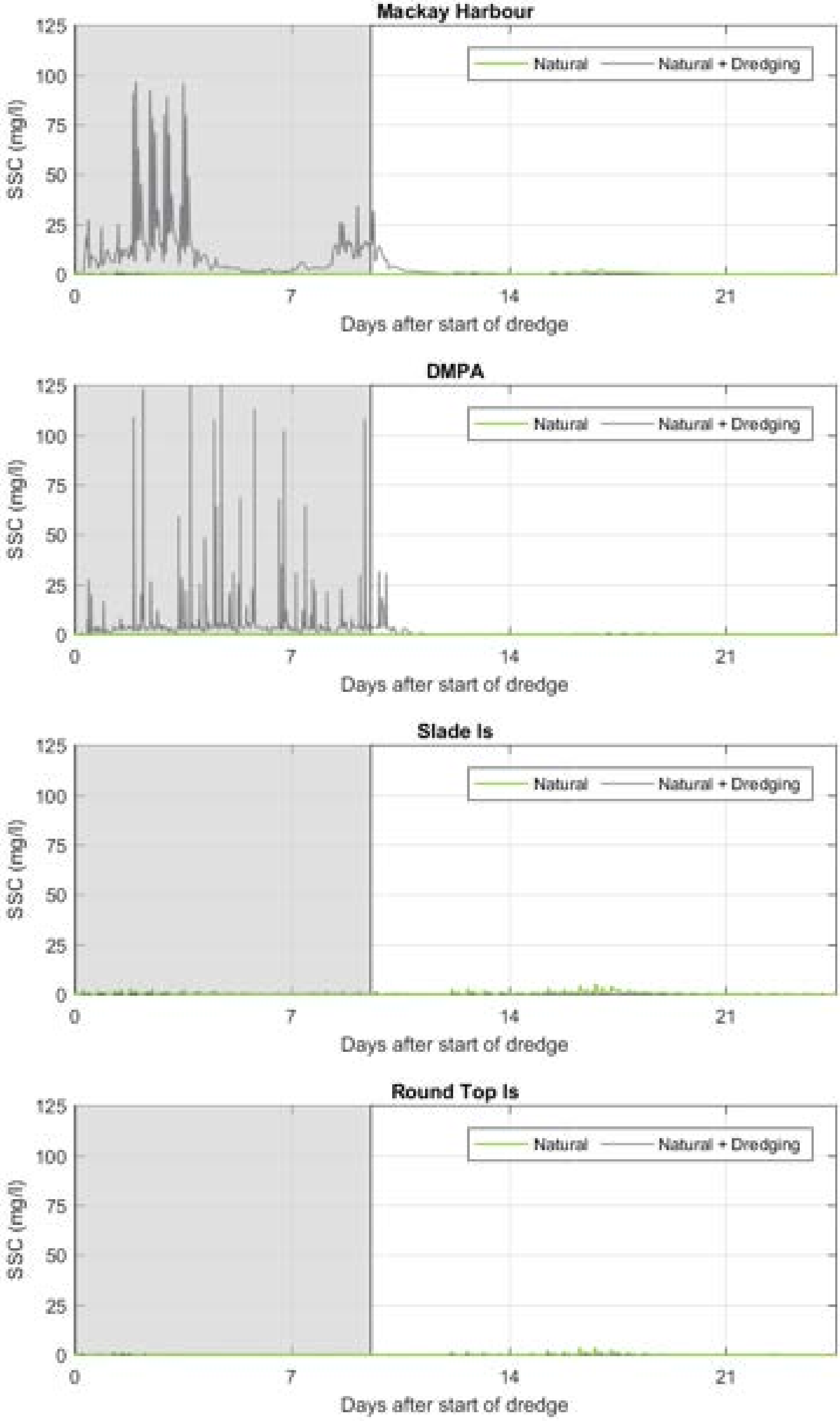


Figure 51. **Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the ambient dry season.** *Note: grey box shows dredge period.*

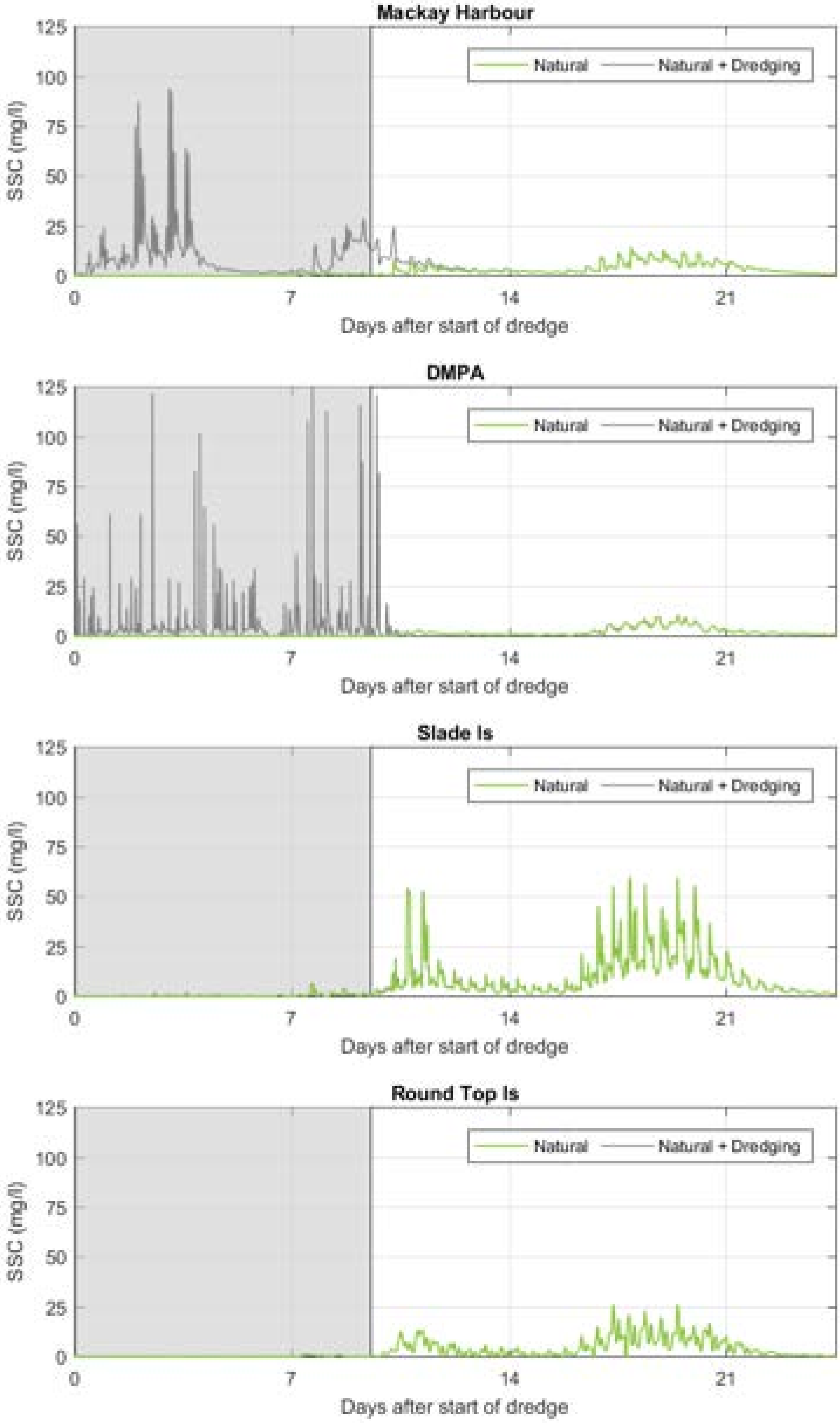


Figure 52. **Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the energetic dry season.** *Note: grey box shows dredge period.*

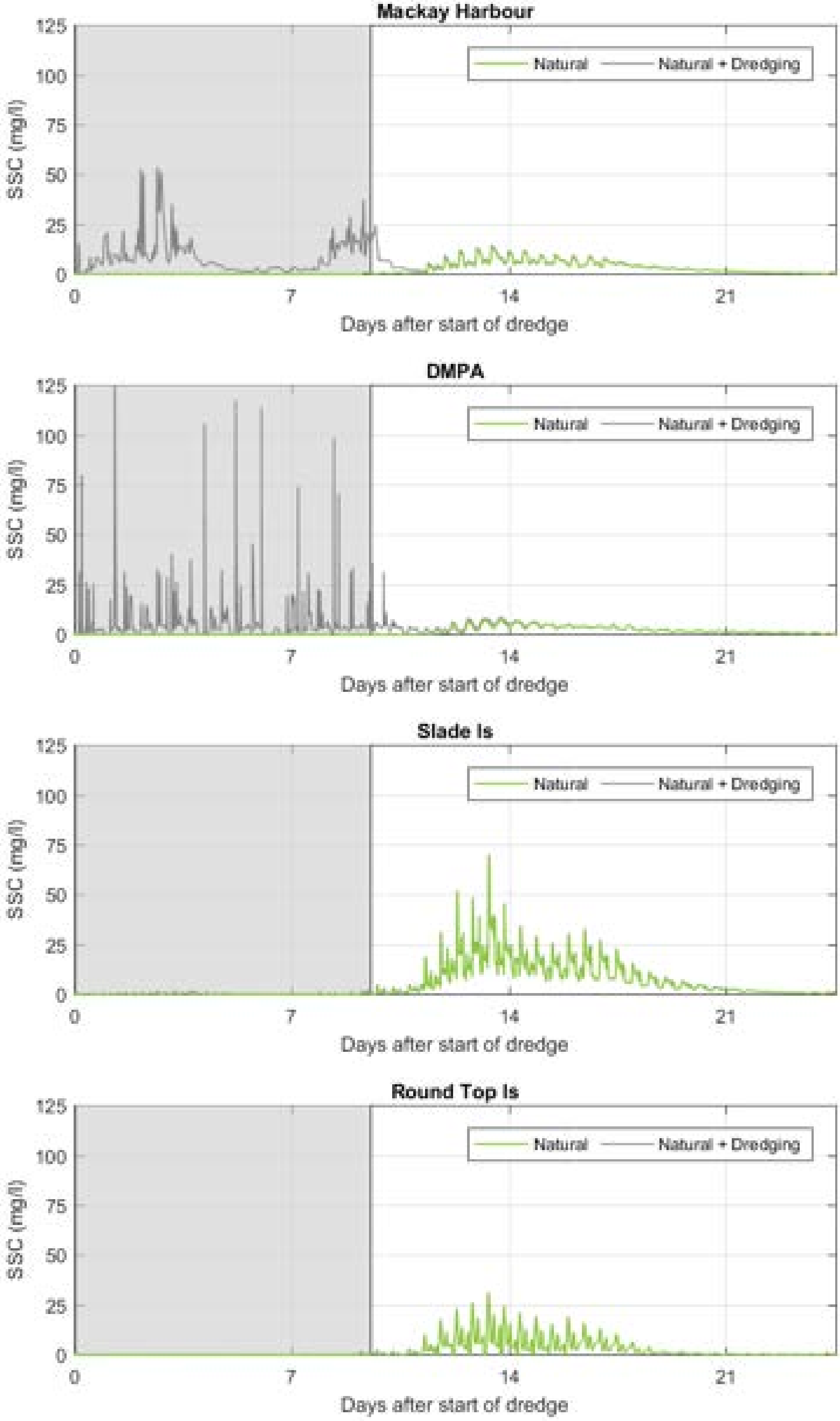


Figure 53. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the ambient wet season. *Note: grey box shows dredge period.*

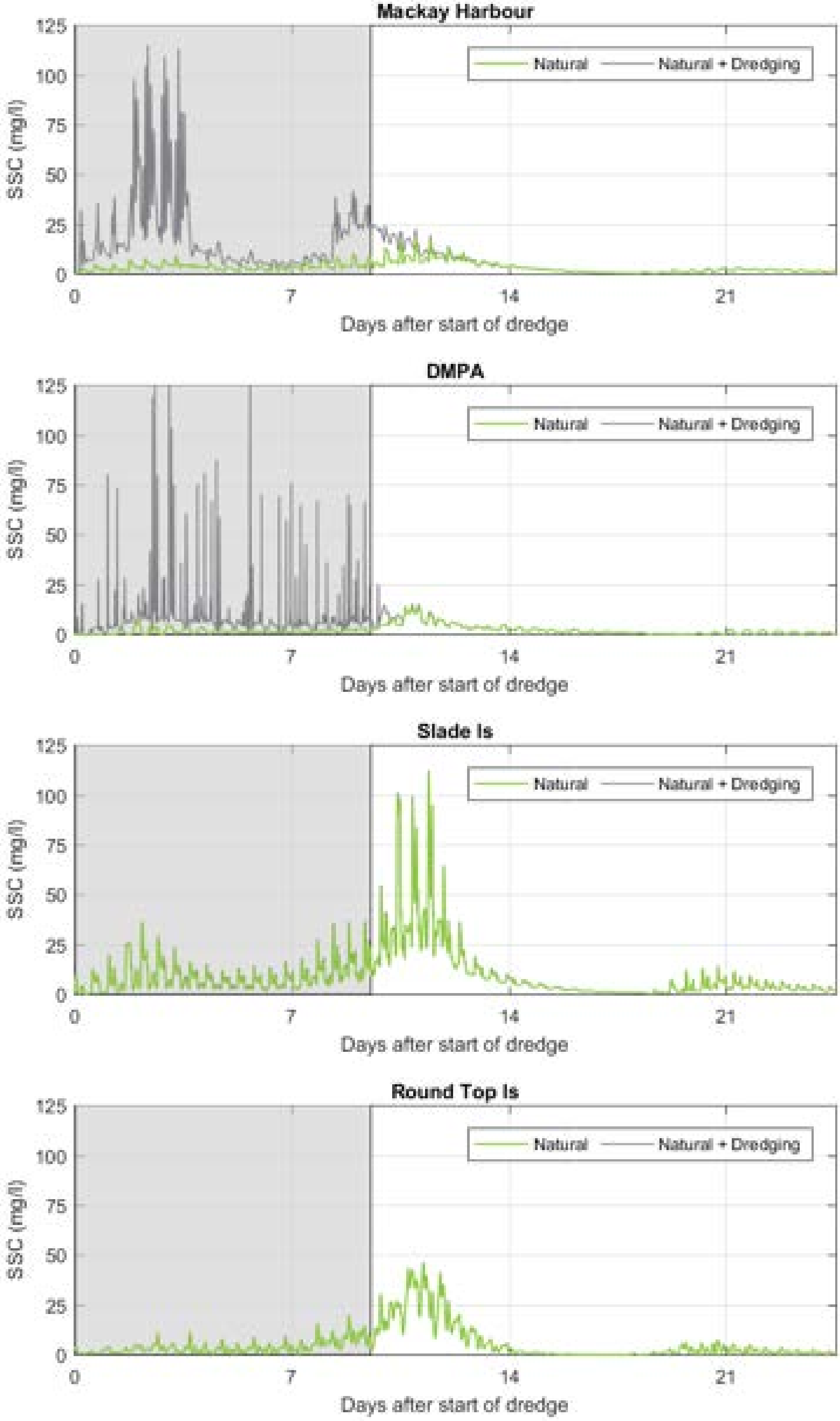


Figure 54. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season. *Note: grey box shows dredge period.*

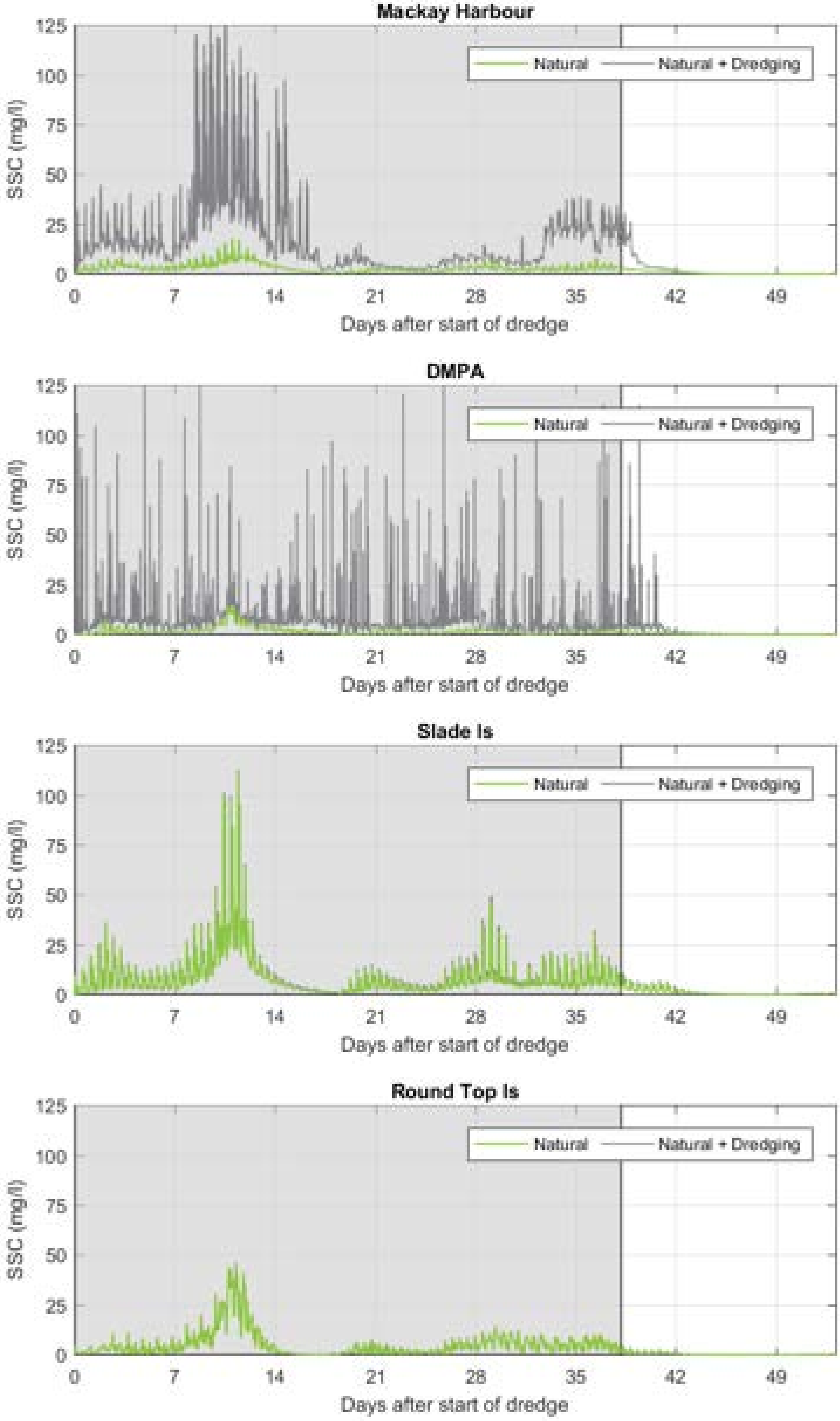


Figure 55. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 500,000 m^3 of sediment in the energetic wet season. *Note: grey box shows dredge period.*

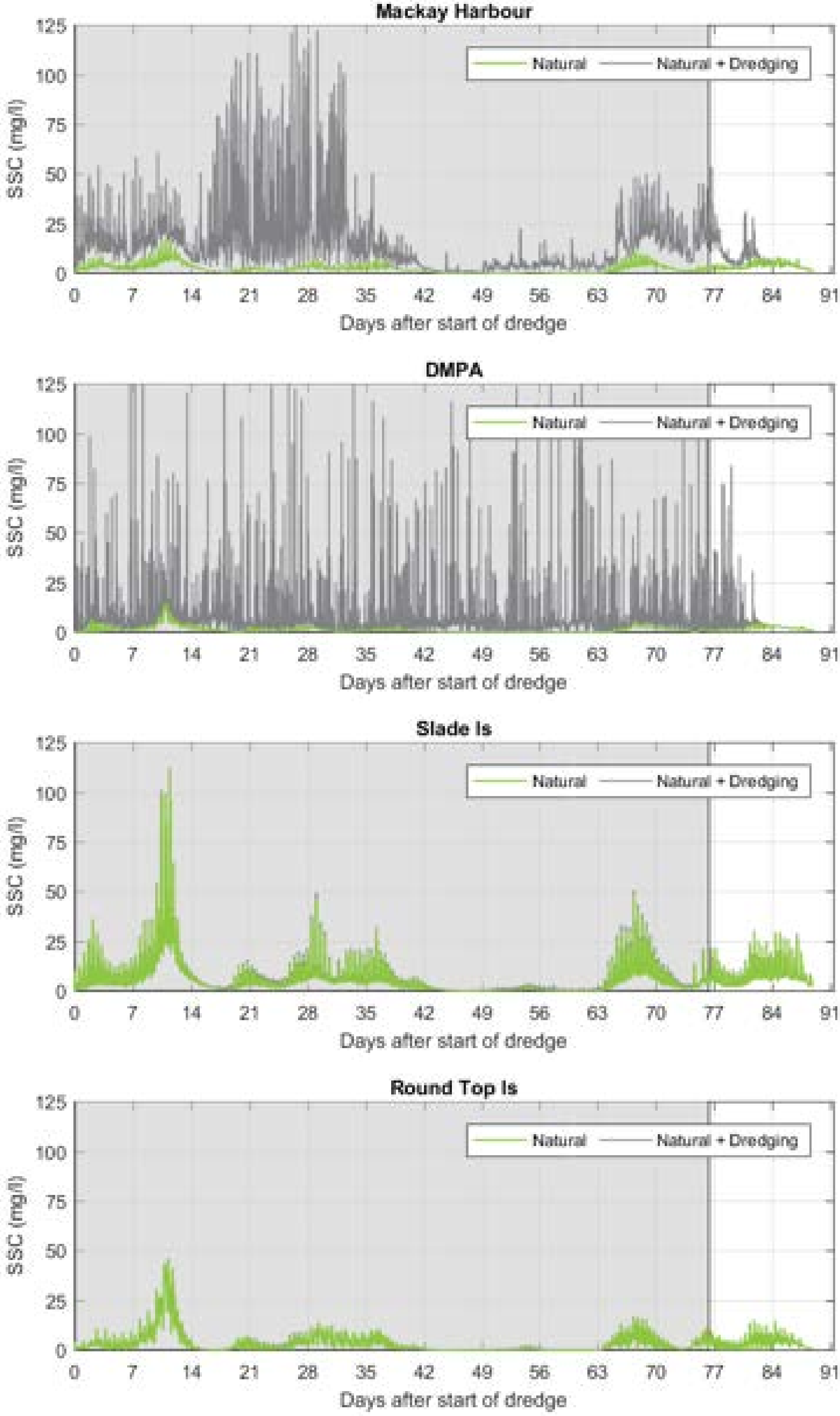


Figure 56. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic wet season. *Note: grey box shows dredge period.*

Table 14. **SSC percentile results at model output locations for all of the dredge plume modelling scenarios.**

Placement Volume (m^3)	SSC percentile (mg/l)											
	Slade Islet			Round Top Island			Mackay Harbour			Mackay DMPA		
	20th	80th	95th	20th	80th	95th	20th	80th	95th	20th	80th	95th
Ambient Dry Season												
125,000	0.2	0.9	1.1	0.0	0.3	0.7	1.0	11.8	20.5	0.9	5.0	18.1
250,000	0.5	1.4	2.1	0.0	0.3	0.8	3.0	14.8	22.7	2.5	6.3	22.4
500,000	0.6	1.9	2.7	0.0	0.4	1.0	4.9	33.8	71.1	2.9	7.3	26.1
750,000	0.6	1.6	2.2	0.0	0.5	0.9	10.1	40.0	71.9	2.2	8.2	27.9
1,000,000	0.6	1.6	2.3	0.0	0.4	0.9	10.3	41.1	73.1	2.0	7.9	26.4
Energetic Dry Season												
125,000	0.1	0.5	0.8	0.0	0.0	0.1	0.7	13.0	29.5	0.0	4.1	14.4
250,000	0.2	0.9	1.5	0.0	0.2	0.4	2.2	17.9	40.1	1.9	4.9	17.9
500,000	0.3	1.7	2.5	0.0	0.2	0.5	5.8	26.3	59.5	2.2	7.0	22.7
750,000	0.3	1.8	2.5	0.0	0.2	0.7	7.2	33.6	60.2	1.0	7.4	23.7
1,000,000	0.4	1.7	2.5	0.0	0.2	0.6	9.6	37.8	69.5	1.1	7.0	22.3
Ambient Wet Season												
125,000	0.2	1.2	1.7	0.0	0.0	0.1	2.1	18.0	46.7	0.2	6.4	16.8
250,000	0.4	1.5	2.3	0.0	0.1	0.2	6.6	30.4	63.1	2.3	7.2	26.5
500,000	0.5	1.5	2.4	0.0	0.2	0.5	10.0	36.6	74.1	2.7	7.3	24.1
750,000	0.6	1.8	2.4	0.0	0.4	0.9	10.5	34.4	66.4	2.0	7.4	23.7
1,000,000	0.6	1.9	2.5	0.0	0.4	0.9	9.5	43.0	73.9	2.0	7.8	25.8
Energetic Wet Season												
125,000	0.1	0.5	1.0	0.0	0.0	0.0	1.2	12.4	23.5	0.0	4.1	17.0
250,000	0.4	1.3	2.1	0.0	0.1	0.2	4.2	22.5	40.7	0.9	6.0	24.5
500,000	0.5	1.7	2.4	0.0	0.1	0.3	7.9	36.4	62.7	1.7	6.5	23.8
750,000	0.3	1.3	2.1	0.0	0.2	0.5	10.7	39.9	74.1	1.4	7.2	25.6
1,000,000	0.3	1.1	1.7	0.0	0.2	0.5	10.0	38.0	72.6	1.4	7.0	25.4
Averaged Over Four Periods												
125,000	*0.2*	*0.8*	*1.2*	*0.0*	*0.1*	*0.2*	*1.3*	*13.8*	*30.1*	*0.3*	*4.9*	*16.6*
250,000	*0.4*	*1.3*	*2.0*	*0.0*	*0.2*	*0.4*	*4.0*	*21.4*	*41.7*	*1.9*	*6.1*	*22.8*
500,000	*0.5*	*1.7*	*2.5*	*0.0*	*0.2*	*0.5*	*7.2*	*33.3*	*66.8*	*2.4*	*7.0*	*24.2*
750,000	*0.5*	*1.6*	*2.3*	*0.0*	*0.3*	*0.7*	*9.6*	*37.0*	*68.1*	*1.7*	*7.6*	*25.2*
1,000,000	*0.4*	*1.6*	*2.2*	*0.0*	*0.3*	*0.7*	*9.8*	*40.0*	*72.3*	*1.6*	*7.4*	*25.0*

The spatial maps, tabulated percentiles and time series SSC plots show the following:

- the sediment released in suspension during the dredging activity in Mackay Harbour is predicted to mainly be retained within the Harbour, with the 95th percentile SSC remaining below 15 mg/l in the areas adjacent to the entrance to the Harbour;
- the sediment released in suspension during the material placement activity is predicted to result in localised areas within the DMPA with an SSC of more than 15 mg/l, with a relatively low concentration SSC beyond these areas. There is predicted to be a net northerly residual transport of the suspended sediment from the Mackay DMPA, with the plume generated by the placement activity predicted to follow the shoreline alignment with dominant transport occurring in a north to north-westerly direction;

- when dredging 125,000 m^3 (typical historical dredge volume), the 80th percentile SSC (the SSC which is exceeded for 20% of the time over the duration of the dredging program) is less than 2 mg/l directly offshore of Mackay Harbour and the plume from the placement typically remains below 5 mg/l around Mackay DMPA for all metocean conditions except for the energetic wet season. For the energetic wet season the extent and concentration of the 80th percentile SSC is greater suggesting less deposition and more resuspension than the other metocean conditions. Under these conditions the 80th percentile SSC is between 2 and 5 mg/l for 2 km to the north and south of the entrance to Mackay Harbour and it is predicted to be between 5 and 10 mg/l for approximately 6 km to the north of Mackay DMPA;
- as with the 80th percentile SSC, the 95th percentile SSC (the SSC which is only exceeded for 5% of the time over the duration of the dredging program) when dredging 125,000 m^3 has a larger extent and higher concentration for the energetic wet season compared to the other three metocean periods. For the energetic wet season the 95th percentile SSC is predicted to be 2 to 5 mg/l for approximately 4 km to the north and south of the entrance to Mackay Harbour, although as the currents are deflected around Slade Islet this area of elevated SSC is not predicted to extend either to Slade Islet or to the Slade Islet monitoring site. At Mackay DMPA the 95th percentile SSC is predicted to be 10 to 15 mg/l for a distance of 3 km to the north and south of the DMPA;
- comparison between the 80th and 95th percentile SSC plots show that any increases in SSC associated with the dredging are short-lived, with smaller extents and intensities for the 80th percentile SSC compared to the 95th percentile SSC;
- the spatial maps show that when the dredge volume increases there is not predicted to be a significant increase in the SSC magnitude, with only localised changes predicted in the 95th percentile SSC at the entrance to Mackay Harbour (larger extent between 5 and 10 mg/l) and Mackay DMPA (increase in SSC within the DMPA from less than 20 mg/l for typical dredge volume to 20 to 25 mg/l for larger volumes). The most noticeable change is an increase in the extent of the 2 to 5 mg/l region for the larger volumes, with the SSC from the dredge activity in the Harbour connecting with the SSC from the placement at the DMPA and the overall region also extending further to the north-west and being transported closer to the shoreline. This is because the longer dredge duration results in a larger volume of sediment being suspended meaning sediment further from the source is remobilised at a higher SSC;
- the table summarising the percentile SSC for all the volumes and metocean conditions shows that there is predicted to be an increase in SSC at the four sites as the volume dredged increases. At Slade Islet there is predicted to be an increase in SSC percentiles between 125,000 m^3 and 500,000 m^3, but then a reduction for larger volumes (due to periods with calmer metocean conditions resulting in less SSC at Slade Islet for the longest duration simulations). At Round Top Island there is predicted to be an increase in SSC percentiles between 125,000 m^3 and 750,000 m^3, but little difference between 750,000 m^3 and 1,000,000 m^3. Within Mackay Harbour and Mackay DMPA the SSC percentiles are predicted to increase between 125,000 m^3 and 500,000 m^3, but with little change in SSC for volumes above 500,000 m^3; and
- the tabulated percentiles predict that the dredging results in a 95th percentile increase in SSC at Round Top Island of up to 1 mg/l, while at Slade Islet the increase is predicted to be less than 3mg/l. In contrast, the 95th percentile results within Mackay Harbour where the dredging is undertaken is predicted to be up to 75 mg/l and at Mackay DMPA where the sediment is being placed it is predicted to be up to 30 mg/l. The results therefore show that although elevated SSC is predicted to occur where the dredging and placement activity is undertaken, the increase in SSC at the sensitive receptors is predicted to be at least an order of magnitude lower.

Comparing the percentile and time series plots of the natural SSC to the natural plus dredging SSC provides additional context to the relative influence of the increase in SSC from the maintenance dredging on the marine environment. The results show:

- the natural SSC is generally much higher than the SSC resulting from maintenance dredging. The only areas where the natural plus dredging shows a clear increase to the natural SSC is within Mackay Harbour and within and adjacent to Mackay DMPA;
- the natural SSC is highest during the energetic wet season compared to the ambient wet season or the energetic or ambient dry seasons, with this period being the only one where the 95th percentile SSC 30 mg/l contour extended offshore of Slade Islet and Round Top Island. The natural SSC spatial maps show that the area is naturally turbid even during ambient dry season conditions, with the nearshore region adjacent to the shoreline to the north of Mackay Harbour having a natural 95th percentile SSC of more than 40 mg/l for all metocean conditions. These spatial maps demonstrate that the effect of the dredging on the SSC is small in comparison to the natural SSC and in the context of variations in SSC that naturally occur even during relatively ambient dry season conditions. It is important to note that the natural variations in SSC during the wet season are much larger than those which occur during the dry season; the wet season 95th percentile SSC at Slade Islet and Round Top Island are approximately double the dry season 95th percentile (PCS, 2021b);
- the timeseries plots show that within Mackay Harbour and at Mackay DMPA the SSC resulting from the dredging over the duration of the dredging and placement is significantly higher than the natural SSC, with peaks in SSC of more than 100 mg/l occurring as a result of the dredging at both. Peaks of up to 125 mg/l occur in Mackay Harbour with an SSC of more than 50 mg/l occurring for approximately 40 minutes per dredge cycle, while peaks of up to 150 mg/l occur at Mackay DMPA with an SSC of more than 50 mg/l occurring for approximately 20 minutes per dredge cycle. Conversely, the timeseries plots of SSC at the sensitive receptor sites of Slade Islet and Round Top Island show that the natural SSC dominates, with the increases in SSC due to dredging typically also associated with an increase in natural SSC meaning that the excess SSC from the dredging only results in a small increase in SSC on top of the natural peaks in SSC; and
- the timing of the highest peaks in SSC within Mackay Harbour and at Mackay DMPA vary between the different dredge volumes modelled, this is because the locations where dredging and placement occurs varies between the volumes (the percentage breakdown of the dredging and placement remains the same for all volumes) and the highest peaks only occur when the dredging or placement occurs very close to the selected model output location.

The SSC percentile and time series plots for all scenarios modelled are presented in Appendices A and B.

7.2. Threshold Exceedance

The plume modelling results presented in Section 7.1 show that maintenance dredging at the Port of Mackay is not predicted to increase the 95th percentile SSC at the closest sensitive receptor (Slade Islet) by more than 3 mg/l. Slade Islet is the closest sensitive receptor to the Port of Mackay (approximately 1.5 km to the north-east of the entrance to Mackay Harbour), with coral (predominantly hard coral and some soft coral) present at the site (Ayling *et al.*, 2020). Coral is also present at Round Top Island (located 8 km to the south south-east of the entrance to Mackay Harbour), with more soft coral present at this location compared to Slade Islet. Seagrass monitoring in the region has not identified any coastal seagrass in the region of the Port of Mackay, but offshore seagrass meadows have been identified within a monitoring region with a boundary located 1 km east (offshore) of the Mackay DMPA and adjacent to and to the east (offshore) of Round Top Island (York and Rasheed, 2020). A deep-water seagrass meadow has been identified up to the landward extent of the monitoring region to the east of the Mackay DMPA (i.e. 1 km offshore of the Mackay DMPA), but it is unknown how far the seagrass meadow extends towards the DMPA beyond this point. The plume modelling results show that the placement of dredged sediment at the Mackay DMPA primarily results in elevated SSC within and to the north and south of the DMPA, with the 95th percentile SSC due to dredging remaining below 2 mg/l where the offshore seagrass bed is located. Therefore, the modelling suggests that the known offshore seagrass meadow located to the east of the Mackay DMPA will not be impacted by maintenance dredging. However, the modelling results do predict that the maintenance dredging can increase the 95th percentile SSC at Slade Islet by up to 3 mg/l and at Round Top Island by up to 1 mg/l. The results from the plume modelling therefore have shown that Slade Islet and Round Top Island are the sensitive receptors where an increase in SSC could occur during maintenance dredging programs. The monitoring site at Round Top Island can be used to represent potential increases in SSC for both the coral and seagrass in the region. As a result, the threshold exceedance at these two sensitive receptors will be calculated for natural and natural plus dredging to understand any potential impacts.

PCS (2021b) reviewed existing literature on coral thresholds and analysed data from the water quality monitoring undertaken by JCU to propose suitable thresholds at Slade Islet and Round Top Island to consider during maintenance dredging activities. The adoption of percentile SSC values with associated durations based on the measured data was considered to provide the best approach, enabling a comparable interpretation of natural SSC and dredge related changes in intensity and duration between sites. The approach assumes that as long as the SSC remains within the natural range when no impacts to sensitive receptors have occurred then no additional impacts to sensitive receptors would be expected. The 91st percentile SSC was adopted as the SSC intensity threshold for the wet season and the 97th percentile SSC was adopted as the SSC intensity threshold for the dry season (Table 15). As the proposed SSC thresholds are on average only naturally exceeded for 9% and 3% of the time, they can be considered to be representative of a threshold for short duration acute impacts due to high turbidity/SSC, as opposed to longer duration chronic impacts due to prolonged periods of lower SSC.

Table 15. Wet and dry season SSC intensity thresholds for Slade Islet and Round Top Island.

Site	Wet Season SSC (mg/l)	Dry Season SSC (mg/l)
Slade Islet	53	41
Round Top Island	15	16

The analysis proposed that the total duration that the SSC intensity threshold is naturally exceeded over the dredge duration could be monitored during a dredge program and then used to inform adaptive management (when required). To allow this, a number of different durations were calculated using the measured data so that the duration exceedance can be tracked throughout the dredging and when duration thresholds are exceeded a range of pre-defined management measures would be initiated as part of the adaptive management process. Duration triggers were defined for the different plume modelling cases simulated in this study based on PCS (2021b), although the 90th percentile duration and maximum durations have been estimated based on a scaling relative to the average duration presented in PCS (2021b) as the durations were not calculated for the specific dredge durations simulated here (Table 16). If the cumulative duration that the SSC exceeds the SSC intensity threshold remains below the average duration then no measures would be required and if it exceeded the duration triggers then management measures would be required, example measures detailed by PCS (2021b) include:

- average duration exceeded: investigate to determine if the exceedance is dredging related or natural;
- 90th percentile duration exceeded: investigate to determine if the exceedance is dredging related or natural and if potential for it to be dredging related then instigate management actions; and
- maximum duration exceeded: if the exceedance is dredging related then cease dredging and placement.

The durations detailed in Table 16 can be applied to the model results to determine when any increase in SSC due to the maintenance dredging results in the intensity and duration thresholds being exceeded at the sensitive receptors.

Table 16. Threshold duration applicable at the sensitive receptors for the dredge duration periods (calculated from the water quality monitoring data collected by JCU).

Dredge Volume (m^3)	Duration of natural exceedance (hours) over defined period					
	Wet Season			Dry Season		
	Average Duration	90th Percentile Duration	Maximum Duration	Average Duration	90th Percentile Duration	Maximum Duration
125,000	21	66	132	7	22	44
250,000	41	132	264	14	44	88
500,000	82	263	525	27	88	175
750,000	124	396	792	41	132	264
1,000,000	165	528	1056	55	176	352

The natural and natural plus dredging exceedance of the intensity thresholds has been quantified at the two sensitive receptors and for each dredge plume simulation (Table 17). Exceedance calculations are very sensitive to the natural exceedance and the models ability to accurately replicate the natural SSC. The sediment transport model calibration and validation presented in Section 4.4 shows that the model is able to replicate the average SSC at Slade Islet and Round Top Island, but is not always able to represent all of the higher spikes in SSC which the measured data show. Therefore, it is likely that the model will slightly underestimate the duration exceedance for the natural conditions, but it is able to show the potential for the dredging to increase the SSC above the defined SSC intensity thresholds and the relative magnitude of any duration exceedance increases. The tabulated values show:

- the duration exceedance at both sensitive receptor sites is predominantly a result of the natural conditions;
- at Slade Islet the excess SSC due to the maintenance dredging is predicted to result in an increase in duration exceedance of up to 2 hours, but is typically between 0 and 1 hours;
- at Round Top Island the excess SSC due to the maintenance dredging is predicted to result in an increase in duration exceedance of up to 1 hour for all metocean conditions except for during the ambient wet season when it can result in an increase of 4 hours for the 750,000 and 1,000,000 m^3 dredge volumes. This metocean condition had a combination of some northerly winds and calm winds which would have allowed a slight increase in SSC from the dredging being transported to the south towards Round Top Island;
- the only simulation which predicted that the average duration trigger would be exceeded was the energetic wet season when the duration exceedance at Round Top Island was 14 hours more than the average duration. However, the exceedance was just due to natural conditions, with maintenance dredging not predicted to result in any increase to the natural duration exceedance; and
- the threshold exceedance results show that maintenance dredging at the Port of Mackay is not predicted to result in an increase in SSC at either Slade Islet or Round Top Island which could result in the SSC being beyond the natural range. This agrees with the SSC percentiles due to maintenance dredging at the two sites presented in Table 14. These showed increases in the 95th percentile of less than 3 mg/l at Slade Islet and 1 mg/l at Round Top Island. These increases are approximately 7% of the SSC intensity threshold at the sites and so the excess SSC from the maintenance dredging would only be able to increase the duration exceedance when the natural SSC was already close to or above

the SSC intensity threshold and this could also only occur for a short period of the dredge duration (as the 95th percentile SSC is only exceeded for 5% of the time).

Table 17. Exceedance of the intensity thresholds at the two sensitive receptors for all the dredge plume modelling simulations.

Dredge Volume (m^3)	Average Duration Trigger (hours)	Exceedance (hours)			
		Natural		Natural plus dredging	
		Slade Islet	Round Top Island	Slade Islet	Round Top Island
Ambient Dry Season					
125,000	*7*	0	0	0	0
250,000	*14*	0	0	0	0
500,000	*27*	0	0	0	0
750,000	*41*	0	0	0	0
1,000,000	*55*	3	15	5	16
Energetic Dry Season					
125,000	*7*	0	0	0	0
250,000	*14*	11	11	12	12
500,000	*27*	11	12	12	12
750,000	*41*	11	12	12	13
1,000,000	*55*	11	12	12	13
Ambient Wet Season					
125,000	*21*	0	0	0	0
250,000	*41*	1	15	1	17
500,000	*82*	1	17	1	20
750,000	*124*	1	20	1	24
1,000,000	*165*	1	20	1	24
Energetic Wet Season					
125,000	*21*	3	16	3	17
250,000	*41*	10	**55**	11	**55**
500,000	*82*	10	55	11	55
750,000	*124*	10	55	11	55
1,000,000	*165*	10	56	11	57

7.3. Deposition

The sediment deposition results from the model simulations are relevant for assessing potential ecological impacts to both coral and seagrass. For context, literature values for potential sub-lethal and lethal impacts for the coral families in the Mackay region range from 10 mg/cm^2/day for sub-lethal to more than 50 mg/cm^2/day for lethal when maintained for an extended period of time (up to 14 days) (PCS, 2021b). An average sedimentation rate of 1.6 mg/cm^2/day was noted as a threshold for potential impacts for a range of seagrass species (PCS, 2021b). However, analysis by PCS (2021b) of the JCU measured data indicated that natural sedimentation rates at the monitoring locations were approximately equivalent to the seagrass sedimentation threshold, with median values of around 2 mg/cm^2/day at Slade Islet and 1 mg/cm^2/day at Round Top Island. The natural sedimentation rates at Slade Islet and Round Top Island can also exceed the thresholds noted for both sub-lethal and lethal impacts to coral, with the 95th percentile sedimentation rate ranging from 20 to 40 mg/cm^2/day and the 99th percentile ranging from 80 to 100 mg/cm^2/day at the two sites, although these rates are unlikely to be maintained over 14 days. The difference between measured sedimentation rates and literature thresholds are likely to be due to a combination of factors including:

- limitations in the measurement method, whereby the instrument can only account for the cumulative deposition (i.e. any erosion resulting after the deposition is not included in the measurements);
- the JCU monitoring sites potentially not being located directly adjacent to the areas of coral and seagrass; and
- potentially a greater tolerance of the coral and seagrass in the Mackay region to sediment deposition rates than the literature values suggest due to the naturally turbid nearshore environment where they are located.

Due to the limitations with collecting accurate deposition data, PCS (2021b) recommended against using deposition data for adaptive management purposes and no attempt was made to define more applicable thresholds at the Port of Mackay. However, it is useful to understand how the predicted sedimentation associated with dredging relates to both naturally occurring deposition and the literature based thresholds for coral and seagrass.

The average daily sedimentation rate over the duration of the dredging program is presented as spatial maps for the dredging, natural and natural plus dredging cases. The sedimentation mass on the seabed at the end of the dredging program was divided by the duration of the dredging to calculate the average daily sedimentation rate over the duration of the dredge program. For reference, the reported sub-lethal threshold for the coral present at Slade Islet and Round Top Island is 10 $mg/cm^2/day$ and for the threshold for potential impacts to seagrass is reported as 1.6 $mg/cm^2/day$. The spatial maps clearly show the spatial distribution and magnitude of the modelled deposition which has been predicted to occur naturally and due to maintenance dredging.

The following plots are shown:

- spatial maps of the average daily deposition over the duration of the dredging program for the four different metocean periods for dredging 125,000 m^3 (Figure 57 to Figure 60); and
- spatial maps of the average daily deposition over the duration of the dredging program for the ambient dry season period (as this shows the lowest natural sedimentation and therefore the largest potential contribution to sedimentation due to the maintenance dredging) for the 500,000 m^3 and 1,000,000 m^3 dredge volumes (Figure 61 and Figure 62).

The plots show:

- for the 125,000 m^3 dredge volume all sedimentation above 1 $mg/cm^2/day$ due to the dredging activity occurred within Mackay Harbour. Sedimentation due to the placement of sediment at Mackay DMPA was only above 10 $mg/cm^2/day$ within the extent of the DMPA, while sedimentation of above 1 $mg/cm^2/day$ occurred up to 6 km to the north and south of the DMPA, but did not extend to the east or west;
- for the 125,000 m^3 dredge volume the natural sedimentation was smaller than the sedimentation resulting from placement at Mackay DMPA for all cases except for the energetic wet season where widespread natural sedimentation occurred in the Mackay region. In all cases the sedimentation due to maintenance dredging only resulted in a visible increase in the Mackay DMPA and the region 6 km to the north and south of it;
- the results show that for the larger dredge volumes of 500,000 and 1,000,000 m^3 the average daily sedimentation over the duration of the dredge program due to maintenance dredging was similar to the average daily sedimentation for the 125,000 m^3 dredge volume but the natural daily sedimentation was higher. The natural daily sedimentation rate was only increased above 10 $mg/cm^2/day$ due to the maintenance dredging within Mackay Harbour and within Mackay DMPA. Sedimentation of above 1 $mg/cm^2/day$ due

to the maintenance dredging was predicted to occur approximately 6 km to the north and south of the Mackay DMPA;

- none of the modelling results predict sedimentation due to maintenance dredging of more than 1 $mg/cm^2/day$ at Slade Islet or Round Top Island or at the mapped seagrass meadow located 1 km east of the Mackay DMPA. When natural sedimentation is combined with sedimentation due to maintenance dredging the results still generally show sedimentation of less than 1 $mg/cm^2/day$ at the sensitive receptor sites, which is below the reported threshold sedimentation rates for both seagrass and coral; and
- the results indicate that increased sedimentation resulting from maintenance dredging at the Port of Mackay is predominantly constrained within Mackay Harbour and Mackay DMPA and areas immediately to the north and south. The combined sedimentation from maintenance dredging and from natural processes is not predicted to exceed the sedimentation thresholds for coral and seagrass at the known sensitive receptor locations in the region.

Deposition plots for all model simulations are presented in Appendix C.

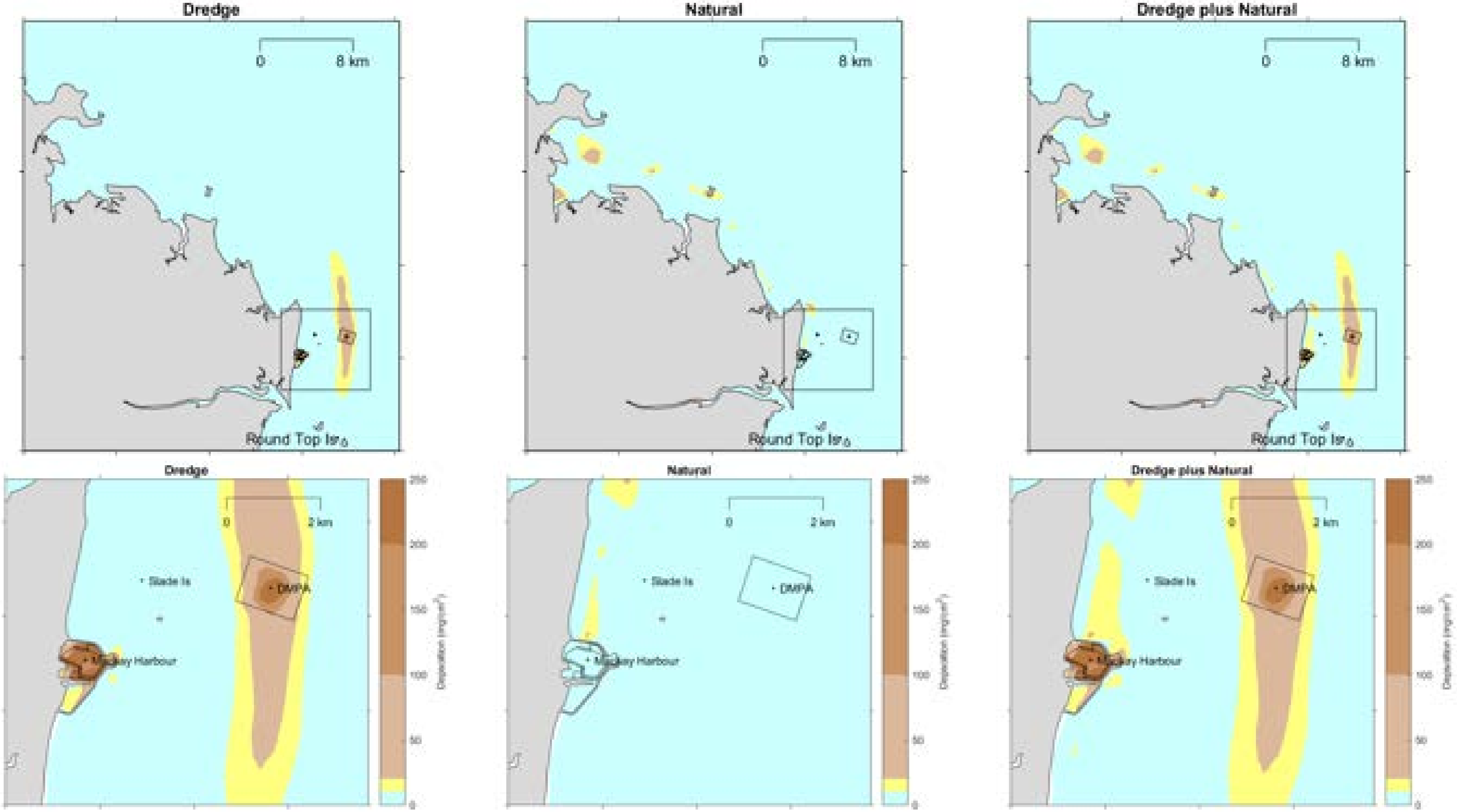


Figure 57. Deposition for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient dry season (10 days of dredging).

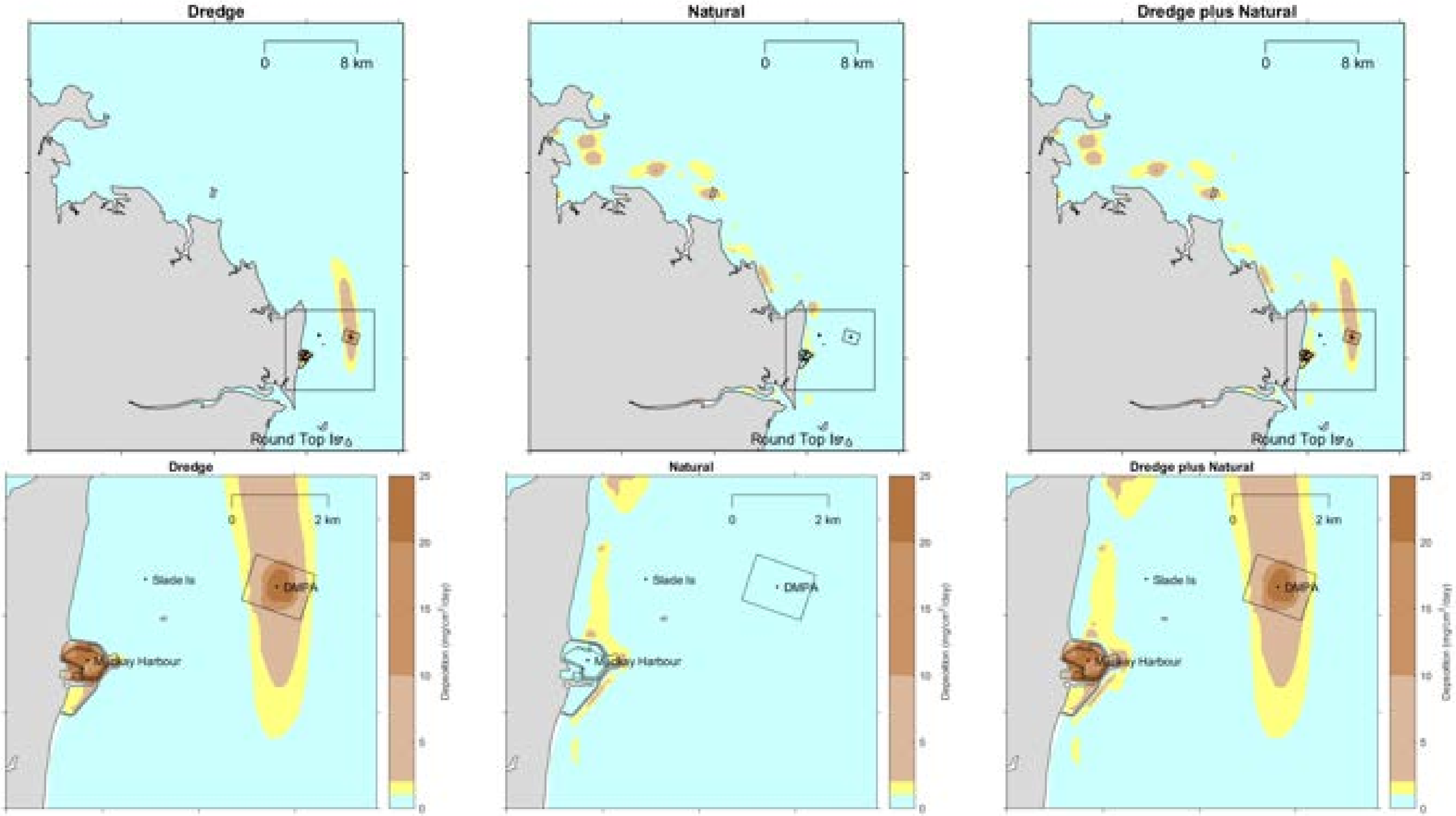


Figure 58. **Deposition for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic dry season (10 days of dredging).**

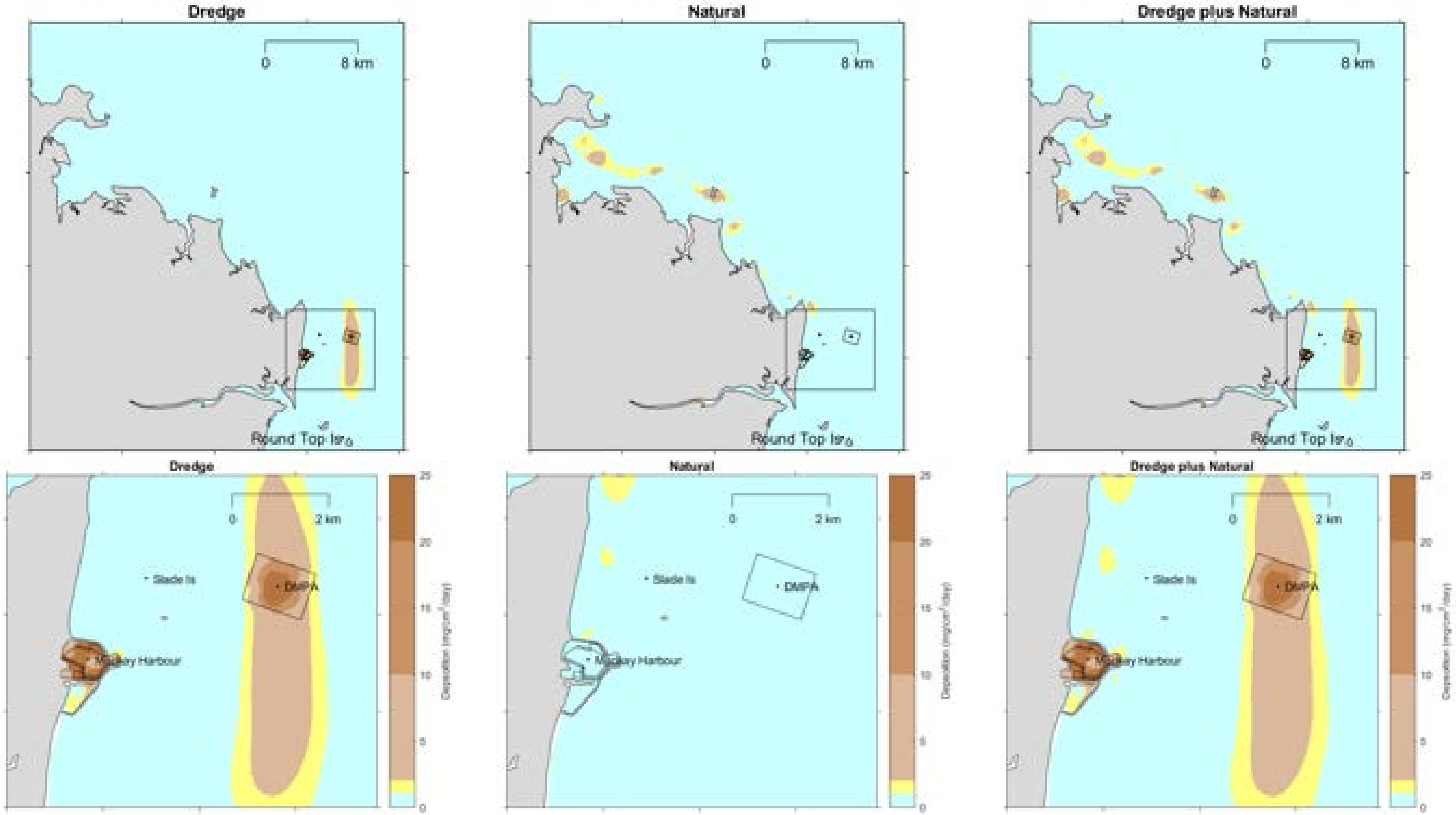


Figure 59. Deposition for dredging, natural and natural plus dredging for 125,000 m³ of sediment in the ambient wet season (10 days of dredging).

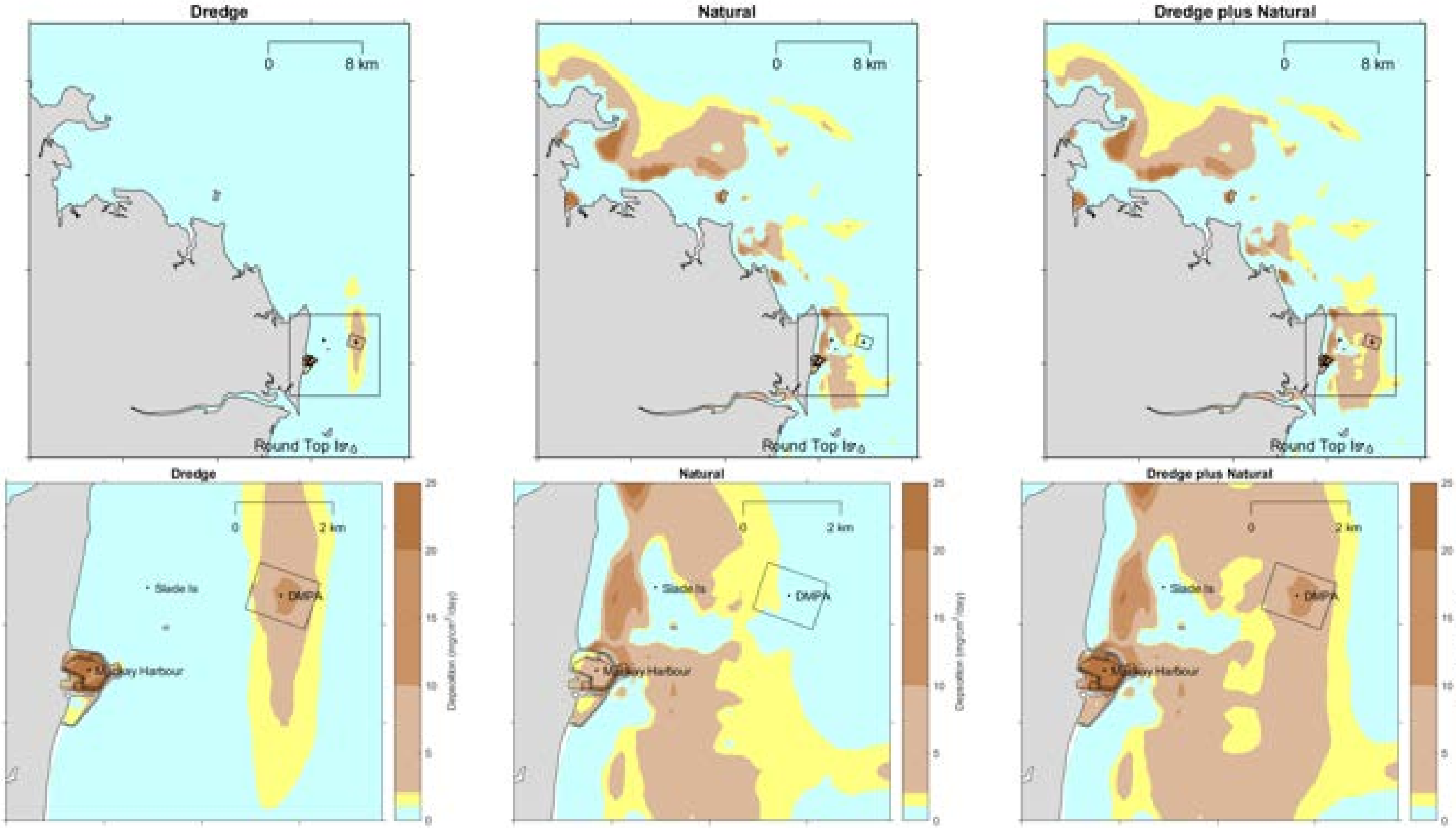


Figure 60. Deposition for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season (10 days of dredging).

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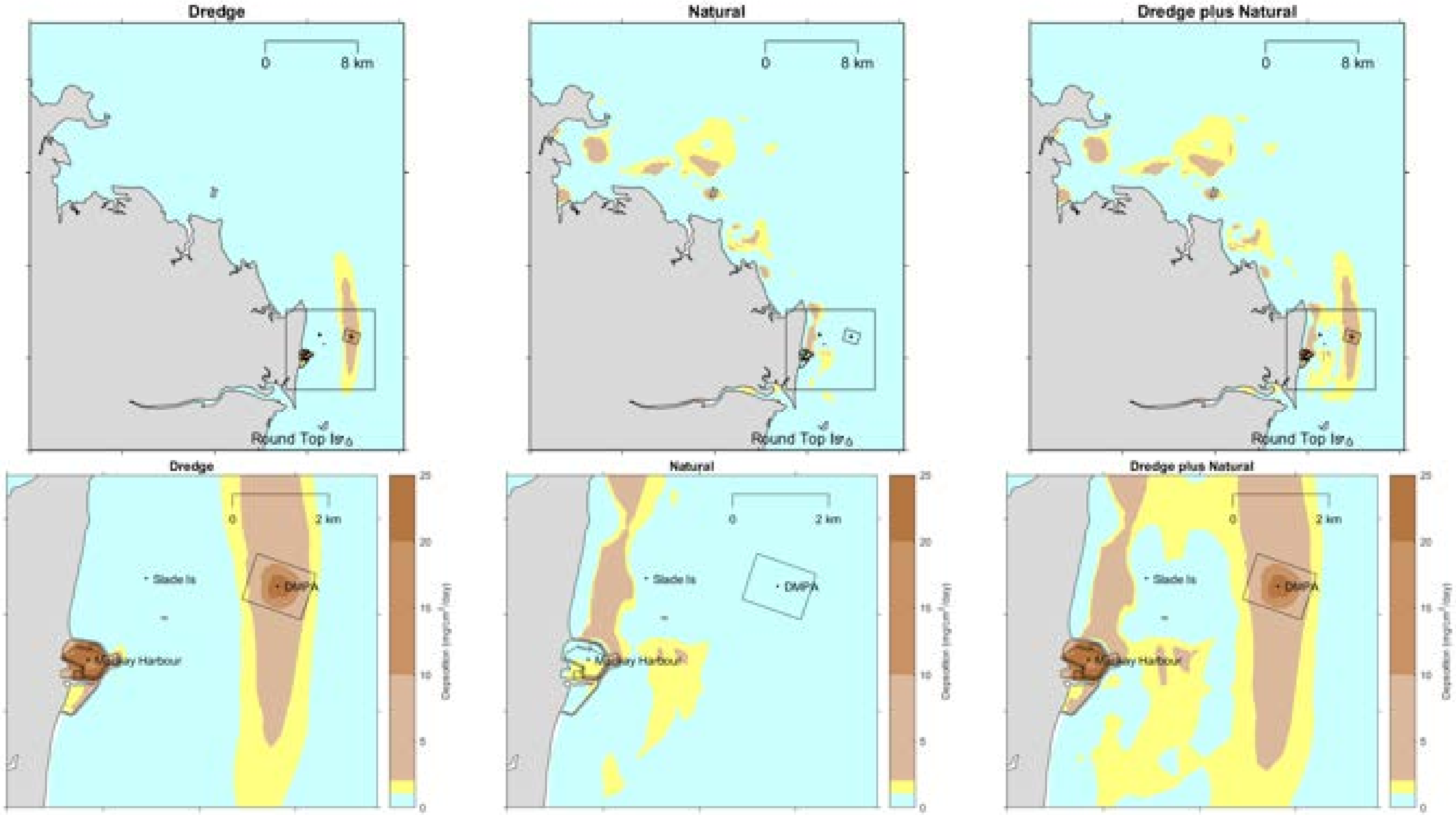

Figure 61. Deposition for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the ambient dry season (38 days of dredging).

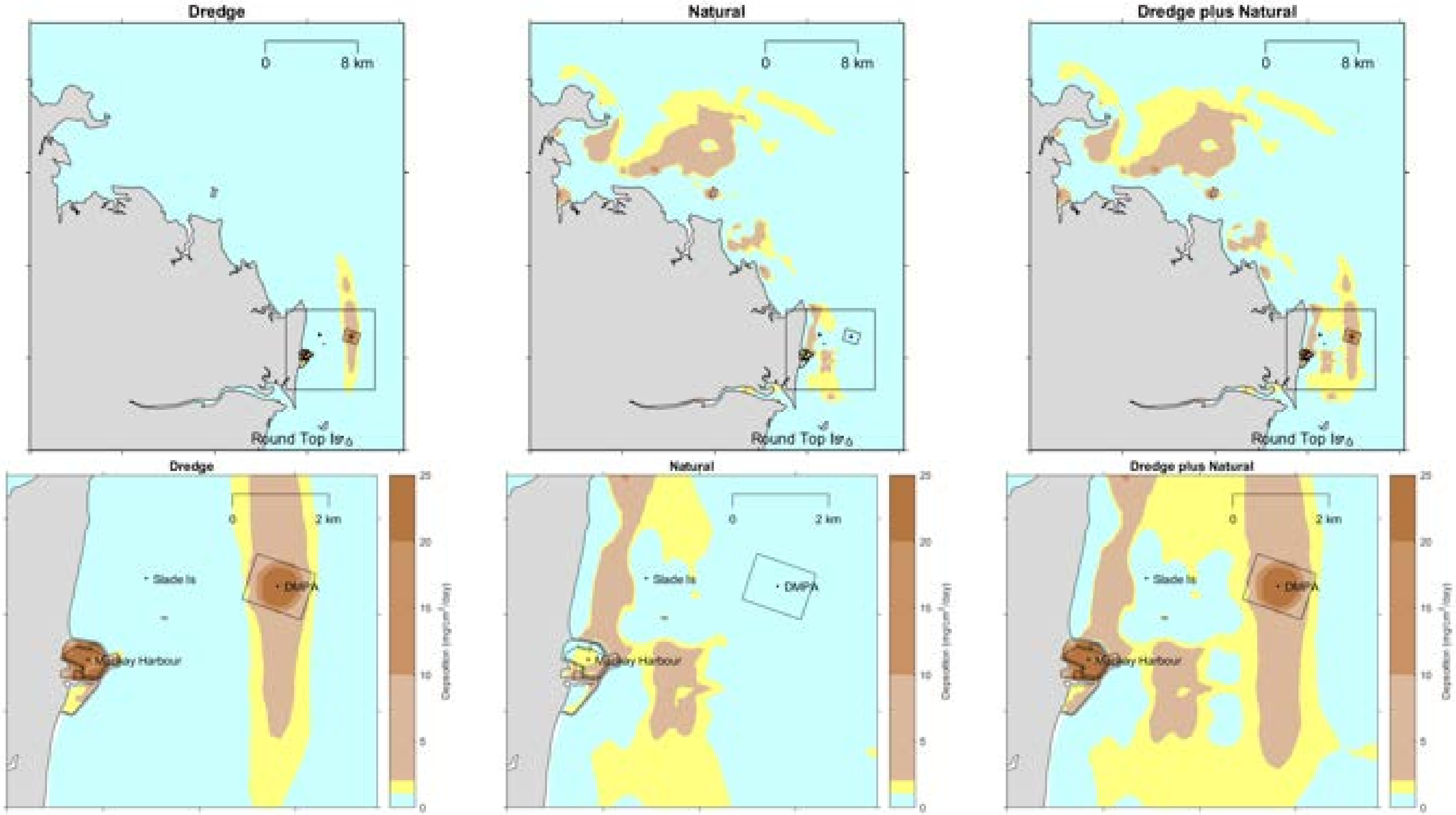

Figure 62. Deposition for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the ambient dry season (76 days of dredging).

7.4. Long-term Resuspension

Results from the long-term resuspension simulations have been processed to show the retainment of sediment placed at the Mackay DMPA during an energetic 12 month period without any extreme events and during an extreme TC. The model was setup to have approximately 250,000 m^3 of dredged sediment within the Mackay DMPA at the start of the simulations and to then predict the long-term resuspension and fate of the sediment[1]. Time series plots showing how the volume of sediment retained within the DMPA changes over time are shown for the 12 month period and the TC in Figure 63 and Figure 64, respectively. The plots show that:

- over the 12 month simulation there was minimal resuspension and transport of the placed sediment beyond the DMPA, with the total volume of sediment lost from the DMPA less than 3,000 m^3 which is approximately 1% of the total volume of sediment placed at the DMPA. The loss of sediment occurred during discrete wave events as opposed to gradually over time during typical conditions; and
- over the TC event there was approximately 20,000 m^3 of placed sediment removed from the Mackay DMPA, which is 8% of the total volume placed at the DMPA.

The results therefore show that once dredged sediment placed at the Mackay DMPA has been deposited and been subject to some initial consolidation it is only resuspended and transported away from the DMPA during periods with large waves. The timing of the resuspension events during the 12 month simulation indicates that an H_s of around 1.8 m is required at the Mackay DMPA for resuspension of bed sediment to occur. Based on the modelling results it can be estimated that in the order of 90% of the sediment which is deposited on the seabed at the DMPA following placement is retained over an energetic year with a TC. However, this percentage retention does not account for any losses during the dredging and placement activities which could be in the order of 15% of the total volume dredged.

The sediment which was resuspended and transported away from the Mackay DMPA was shown to be deposited as a very thin layer of sediment (less than 0.00001 m thick) over the area to the north of the Mackay DMPA, with sedimentation in the Port of Mackay being very low. During the events when sediment is predicted to have been eroded from the DMPA there would also have been widespread natural resuspension of the seabed. As a result, the sediment resuspended from the DMPA would mix with the sediment resuspended from the adjacent natural seabed, both as flocs in suspension (made up of sediment from both sources) and once its deposited on the seabed. Therefore, the fate of the dredged sediment resuspended from the Mackay DMPA can be considered to be to mix with the natural sediment in the system, and then to act in the same way as the natural sediment in the system (i.e. some of the sediment will continue to be available for resuspension and some will either be buried or deposited in a sheltered location).

Bathymetric analysis of the Mackay DMPA as part of the 2020 maintenance dredging program estimated that 66% of the sediment dredged from the Port of Mackay was retained at the DMPA following completion of the 2020 dredge program (PCS, 2021e). Analysis of historical bathymetric data at the DMPA by PCS (2021a) estimated that between 55% and 75% of the sediment placed at the DMPA had been retained at the end of the dredge programs and that over the longer term the DMPA had been stable during typical metocean conditions, but erosion could occur during extreme events with large waves (e.g. TCs). These findings agree with the long-term resuspension modelling undertaken as part of this study, with limited resuspension occurring during typical wave conditions, but increased

[1] the results can also be applied to smaller or larger volumes as the total mass resuspended over the periods would not change, the only change would be the percentage of the total volume that the mass resuspended represents

resuspension and subsequent erosion of the DMPA occurring during very large wave events associated with a TC.

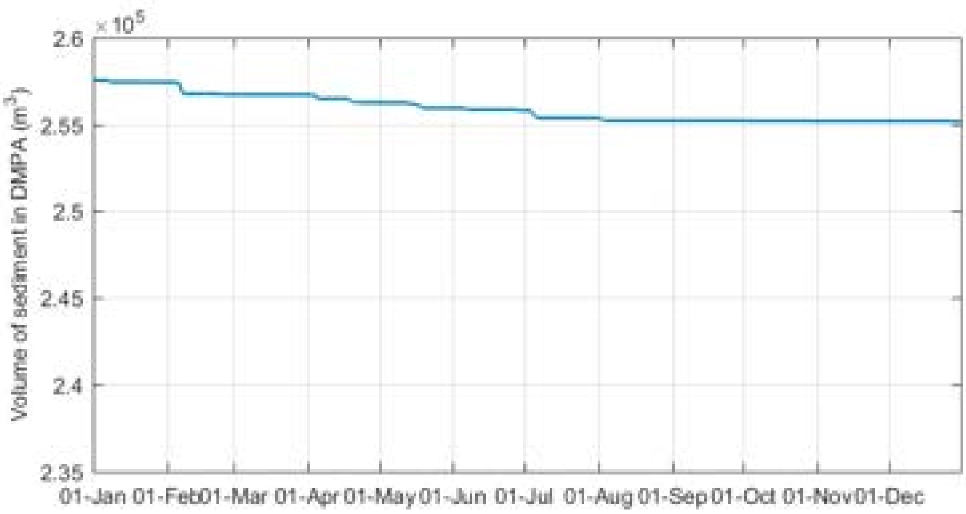

Figure 63. Time series showing the change in volume of placed sediment in the Mackay DMPA over 12 months.

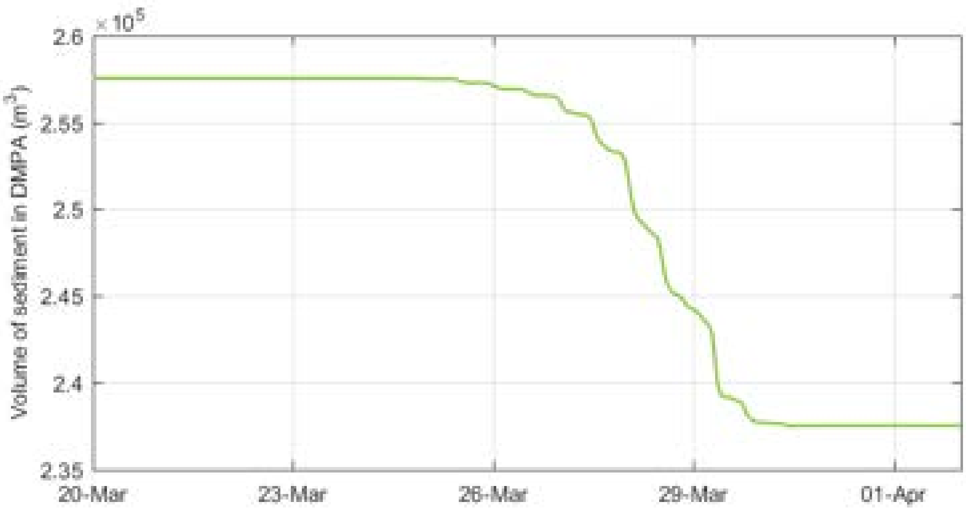

Figure 64. Time series showing the change in volume of placed sediment in the Mackay DMPA over a TC.

7.5. Summary

The plume modelling has shown that:

- although the 95th percentile SSC within Mackay Harbour is predicted to increase up to 75 mg/l during dredging programs (instantaneous SSC of up to 125 mg/l, with elevated SSC of more than 50 mg/l lasting for less than 1 hour). However, the plume resulting from the maintenance dredging activity in Mackay Harbour is predicted to predominantly remain within the Harbour with the harbour breakwaters preventing the majority of the suspended sediment from being transported out of the Harbour. As a result, the majority of the sedimentation resulting from the suspended sediment is also predicted to occur within the Harbour;

- due to the location of the Mackay DMPA and the local tidal currents, the elevated SSC which results from the placement of dredged sediment is predicted to be advected to the north and south of the DMPA, with limited dispersion to the east and west. Although the timeseries plots show that an instantaneous SSC of up to 150 mg/l can occur during placement, this concentration occurs for a short duration (elevated SSC of more than 50 mg/l occurs for up to 20 minutes per placement) and so the SSC of the plume outside of the DMPA is much lower due to initial advection and dispersion processes along with some localised sedimentation. The 95th percentile SSC shows that for 95 percent of the time the plume outside of the DMPA is predicted to be less than 20 mg/l. There are no sensitive receptors located within the areas to the north and south of the DMPA where an elevated SSC of more than 2 mg/l is predicted to occur for 5 percent of the time due to the placement of dredged sediment;
- the known coral and seagrass sensitive receptors in the region are not predicted to be impacted by maintenance dredging at the Port of Mackay;
- the SSC from maintenance dredging at the sensitive receptors is predicted to increase as the maintenance dredging volume increases, but the increases are not predicted to result in impacts to the sensitive receptors. There is a potential risk that long-term low level increases in SSC during a 76 day dredge program (1,000,000 m^3) could result in chronic impacts to coral. However, previous research has shown that corals (including *Montipora* which occurs at Round Top Island) are able to withstand an SSC of 10 mg/l over a 12 week duration with no impacts (Flores *et al.*, 2012). Therefore, as the 80th percentile predicts elevated SSC of less than 2 mg/l at Slade Islet and 0.5 mg/l at Round Top Island due to the dredging the risks of long-term chronic impacts are considered to be low;
- the average duration trigger was only exceeded for one of the modelled simulations and the results show that it was exceeded in response to natural conditions with maintenance dredging not resulting in any increase in the duration exceedance. This trigger would only require an investigation to determine the cause of the exceedance and not the initiation of any measures; and
- the model predicts that the SSC remained within natural conditions at both sensitive receptors for all dredge scenarios considered, with the 90th percentile and maximum natural duration thresholds not being exceeded for any of the simulations.

With respect to the long-term resuspension of sediment placed at the DMPA, the modelling results have shown that:

- sediment placed within the DMPA is only resuspended and transported outside of the DMPA during relatively short, discrete large wave events (H_s of more than 1.8 m at Mackay DMPA);
- the retainment of sediment which was deposited on the seabed in the DMPA following the placement activity was estimated to be approximately 90% over an energetic year with a TC. If it is assumed that in the order of 15% of the dredged sediment is not deposited at the DMPA (i.e. this is the sediment which is in a plume during dredging and during placement) then it can be estimated that in the order of 75% of the sediment dredged from the Port of Mackay would still be present at the DMPA one year after placement;
- the deposition of dredged sediment predicted to be eroded from the DMPA is expected to be very small compared to the natural deposition which occurs in the Mackay region; and
- the effect of resuspension of sediment placed at the Mackay DMPA is not predicted to result in significant deposition within the Port of Mackay or at any nearby sensitive receptors, with the results predicting the sediment to be deposited as a very thin layer of sediment (less than 0.00001 m thick) over the area to the north of the Mackay DMPA.

8. Conclusions

This report has presented numerical modelling results of the transport in the marine environment of sediment resuspended by natural processes and by maintenance dredging at the Port of Mackay.

The modelling approach adopted for this assessment was developed to ensure that it met the relevant Great Barrier Reef Marine Park Authority (GBRMPA) Hydrodynamic Modelling Guidelines (GBRMPA, 2012). The modelling included an extensive model calibration and validation process to demonstrate that the model could accurately represent the natural hydrodynamic, wave and sediment transport processes within the study area. Numerical modelling was undertaken for 20 different scenarios, these considered four different metocean conditions which could occur during the dredging program and five different dredge volumes (to account for variations in sedimentation rates and assess sensitivity).

The modelling undertaken as part of this assessment has shown that:

- the nearshore natural SSC was predicted to generally be much higher than the SSC resulting from maintenance dredging. The plume resulting from the maintenance dredging activity in Mackay Harbour was shown to predominantly remain within the Harbour with the harbour breakwaters preventing the majority of the suspended sediment from being transported out of the Harbour. The only area outside of the Harbour where increases in SSC from maintenance dredging were predicted to result in a clear increase in total SSC (natural plus dredging) was within and adjacent to the Mackay DMPA where the natural SSC is typically low;
- due to the location of the Mackay DMPA and the local tidal currents, the elevated SSC which results from the placement of dredged sediment at the DMPA was predicted to be advected to the north and south with limited dispersion to the east and west. There are no sensitive receptors located within the areas to the north and south of the DMPA where an elevated SSC of more than 2 mg/l was predicted to occur for 5 percent of the time due to the placement of dredged sediment;
- the known coral and seagrass sensitive receptors in the region were not predicted to be impacted by maintenance dredging at the Port of Mackay;
- the modelling predicted that the increase in 95th percentile SSC (exceeded for 5% of the time) at the sensitive receptors at Slade Islet and Round Top Island were less than 3 mg/l and 1 mg/l, respectively. These relatively low increases in SSC due to dredging meant that the combined natural plus dredging SSC was predicted to remain within natural conditions for the sensitive receptors for all dredge scenarios considered;
- the deposition resulting from maintenance dredging showed a similar pattern to the SSC, with the majority of the sedimentation associated with the dredge activity contained within Mackay Harbour and sedimentation occurring within and to the north and south of Mackay DMPA. It was therefore only within Mackay Harbour and to the north and south of Mackay DMPA where it was possible to clearly distinguish between the natural and natural plus dredging deposition;
- although the SSC from maintenance dredging at the sensitive receptors was predicted to increase as the maintenance dredging volume increased (from 125,000 to 1,000,000 m^3), the increases were not predicted to result in impacts to the sensitive receptors;
- the long-term resuspension modelling predicted that sediment placed within the DMPA was only resuspended and transported outside of the DMPA during relatively short, discrete events coinciding with large wave events. The modelling was also used to estimate that in the order of 75% of the sediment dredged from the Port of Mackay would still be present at the DMPA one year after placement; and
- the long-term resuspension modelling predicted that the sediment resuspended from the Mackay DMPA would be deposited as a very thin layer of sediment and was not

predicted to result in increased deposition at any nearby sensitive receptor or within the dredged areas of the Port of Mackay.

Overall, the results have predicted that maintenance dredging at the Port of Mackay would result in elevated SSC within Mackay Harbour and Mackay DMPA throughout the duration of the dredging. Mackay Harbour acts to retain the majority of the SSC resulting from the dredge activity, with limited suspended sediment predicted to be transported outside of the Harbour. The SSC resulting from the placement of sediment at Mackay DMPA was predicted to result in short-duration plumes which could be advected to the north or south of the DMPA by the prevailing tidal and wind driven currents. Due to the location of Mackay DMPA relative to the sensitive receptors, the local tidal currents and the short-duration of the plumes any increases in SSC at the sensitive receptors were considered to be small in relation to the natural conditions.

9. References

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Appendices

Appendix A – Spatial SSC Maps

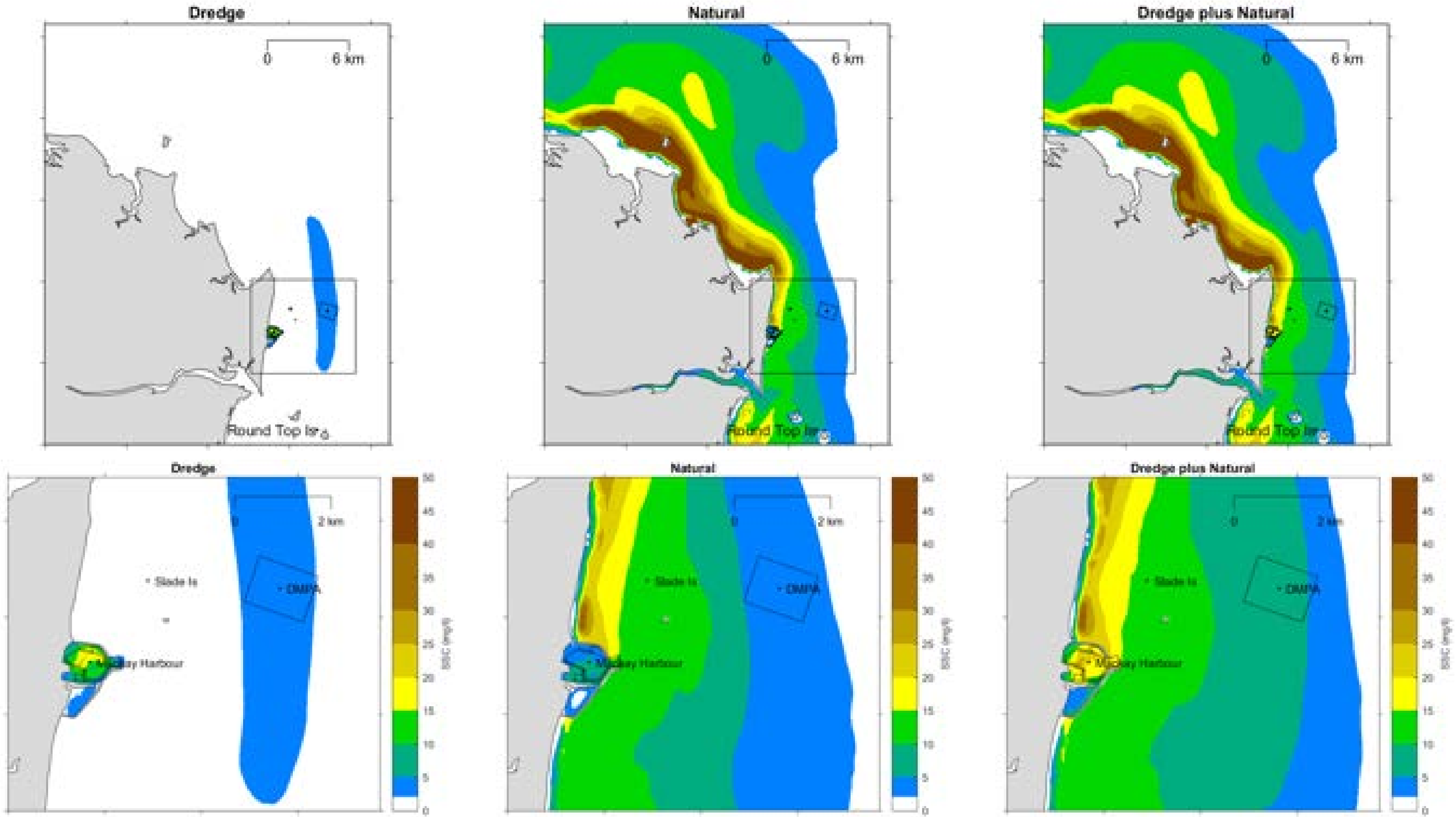
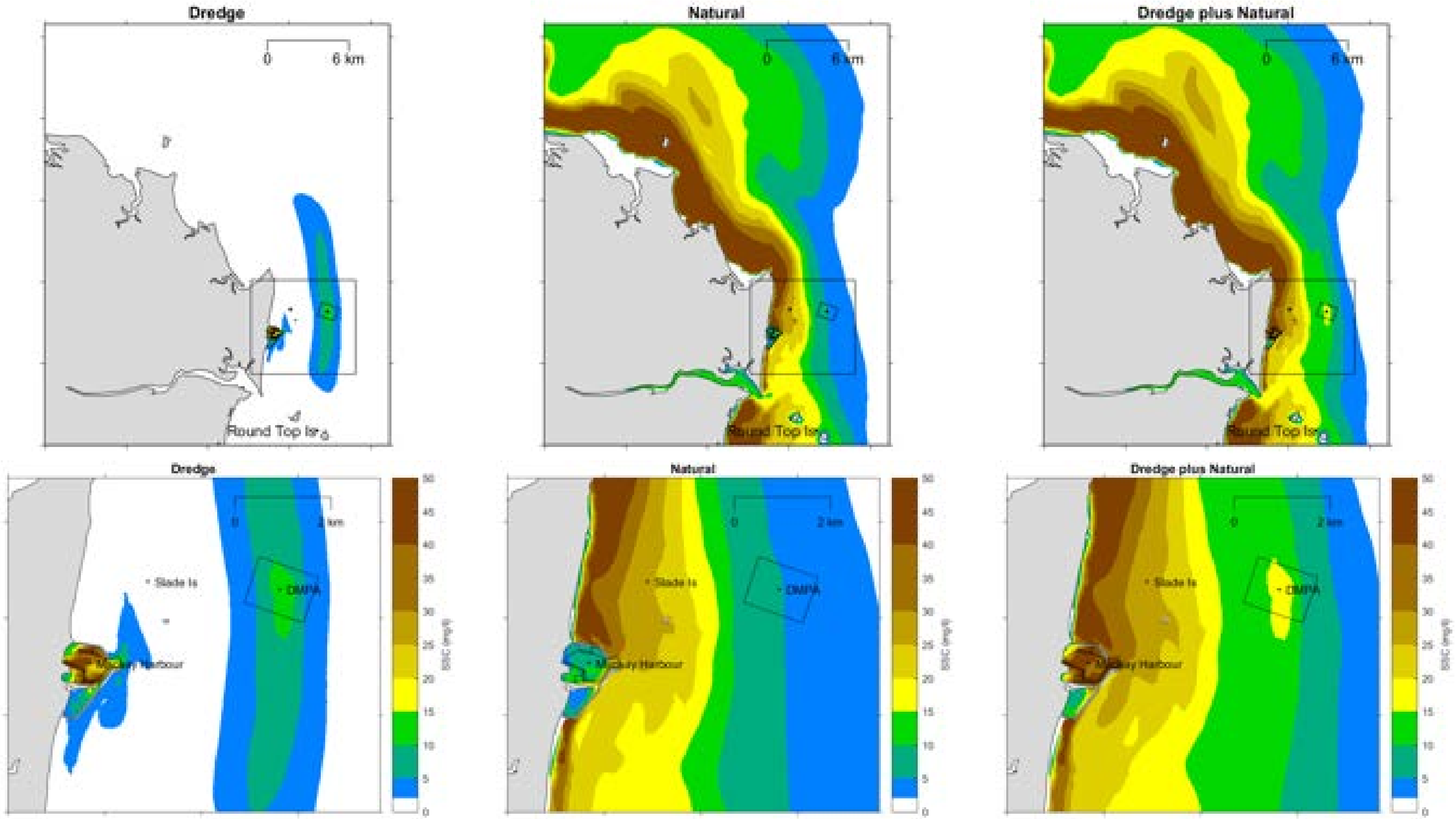


Figure A1. 80th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient dry season.



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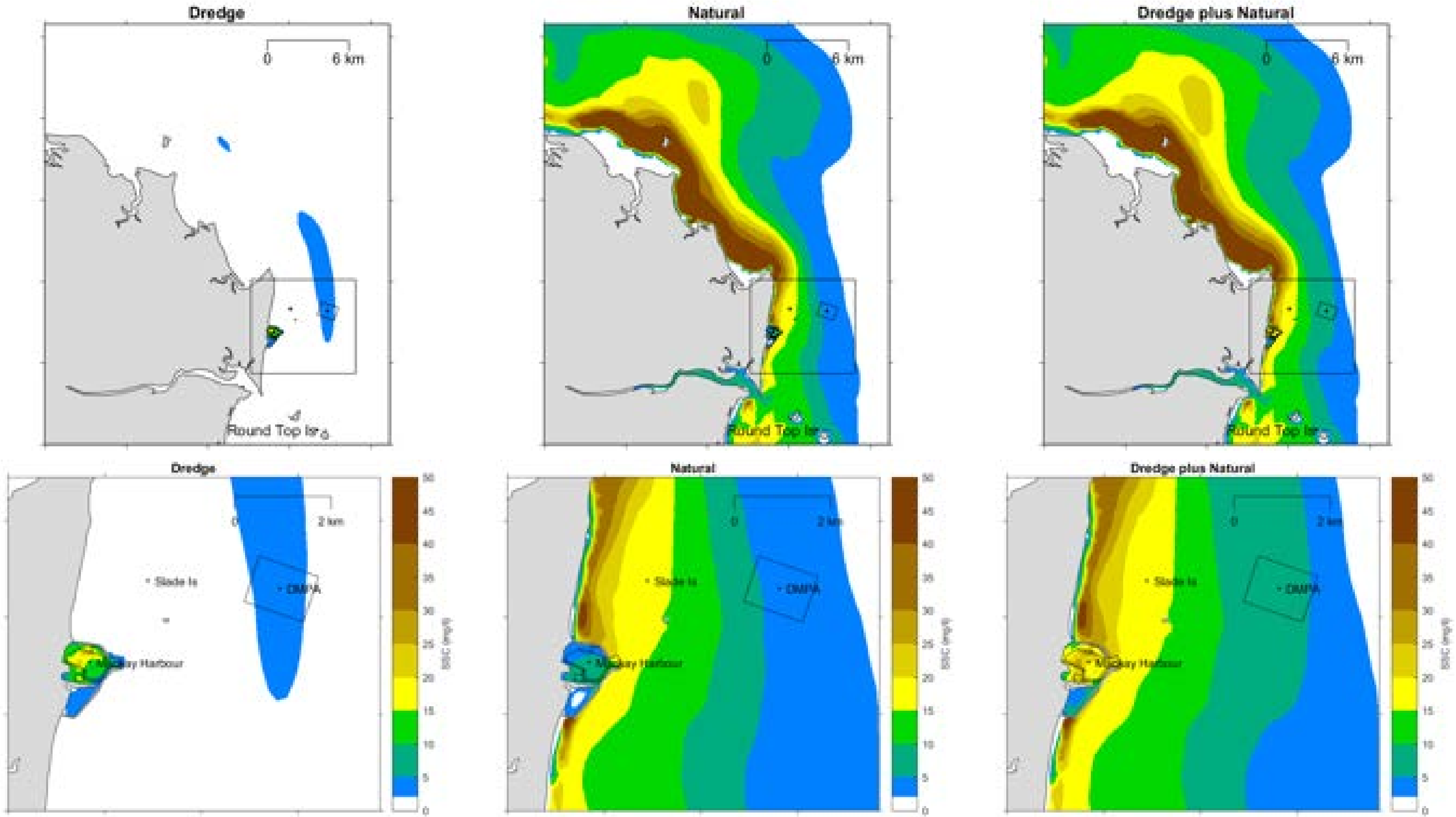

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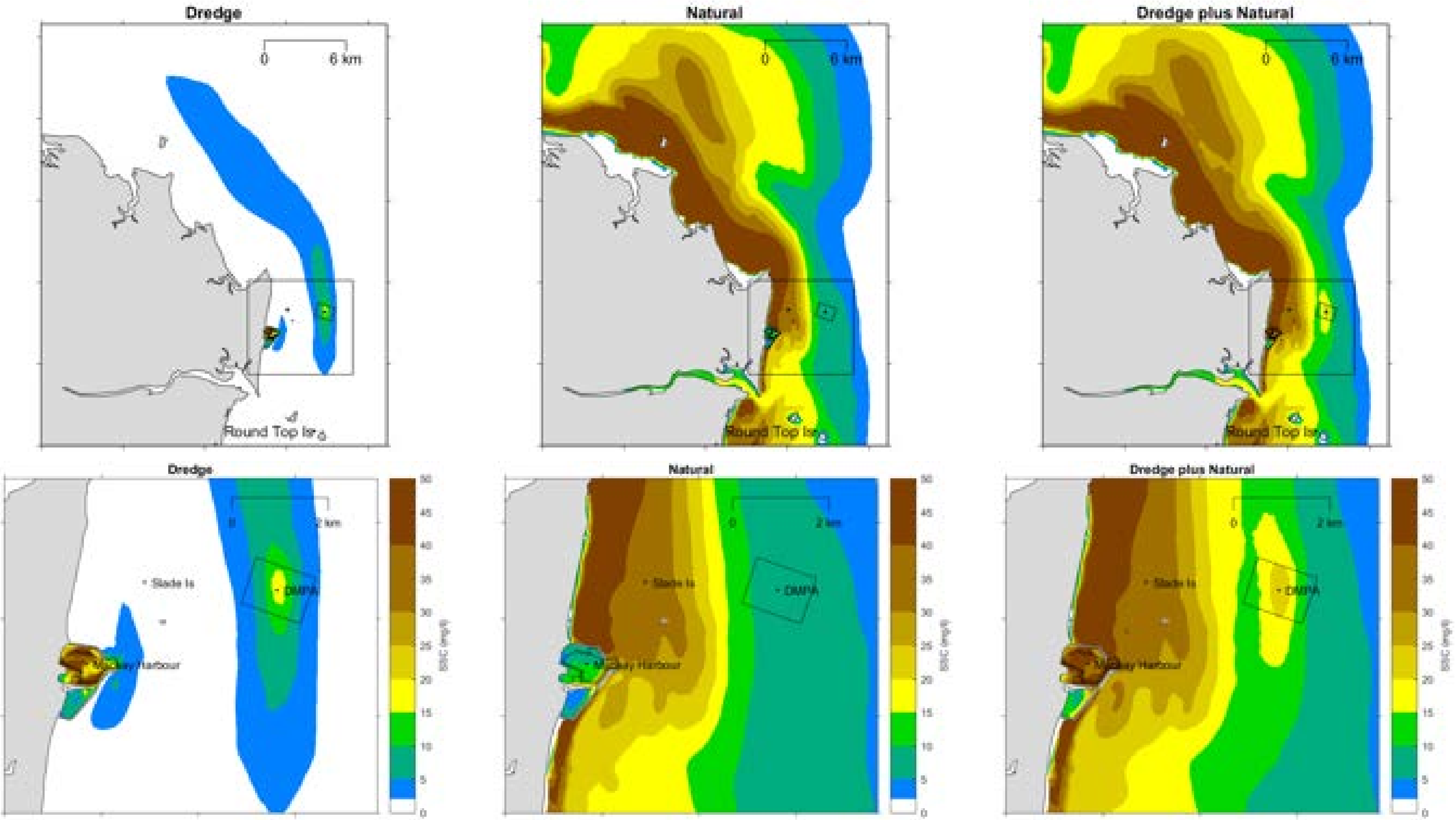

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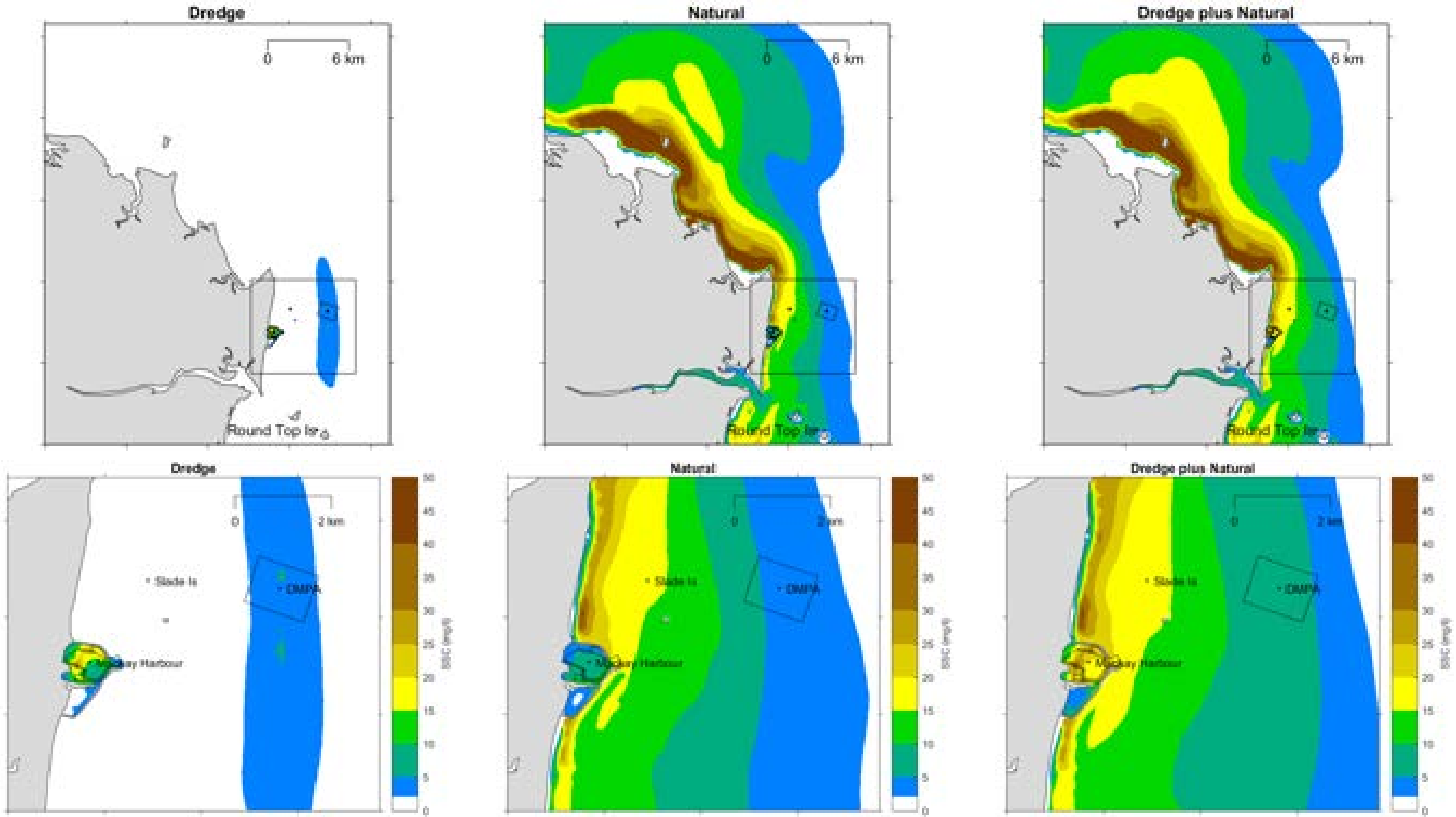
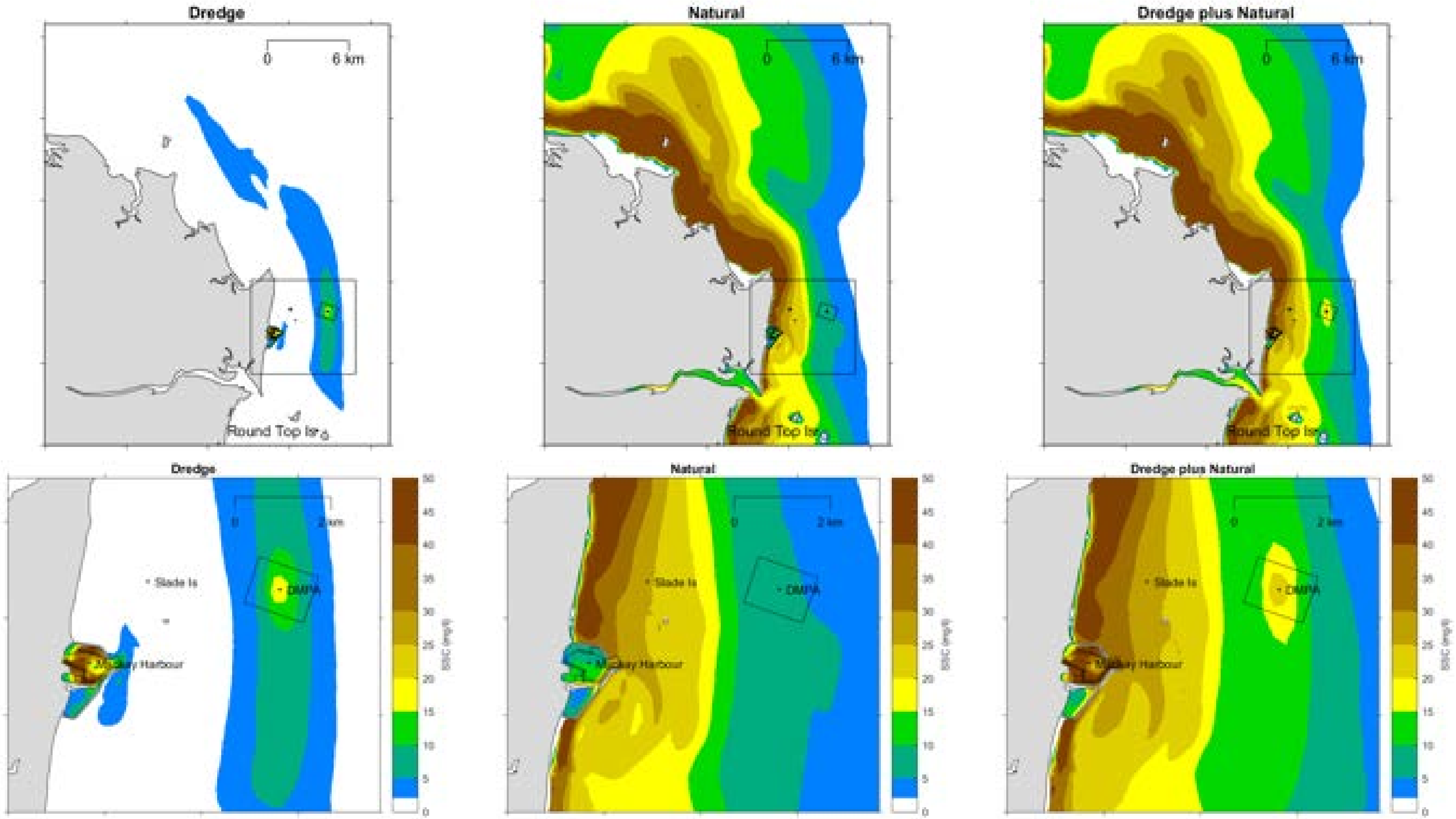


Figure A5. **80th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient wet season.**



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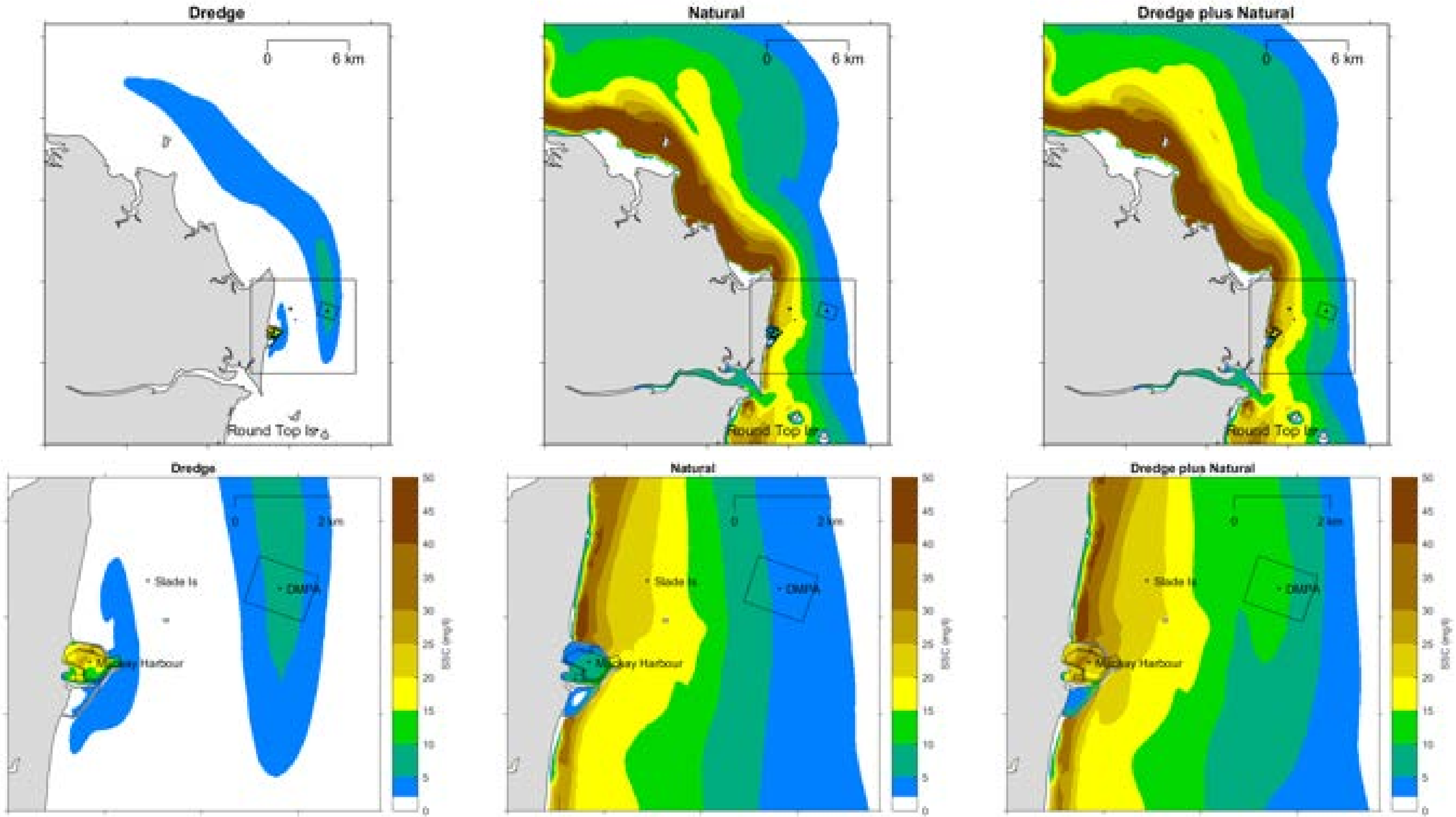

Figure A7. 80th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season.

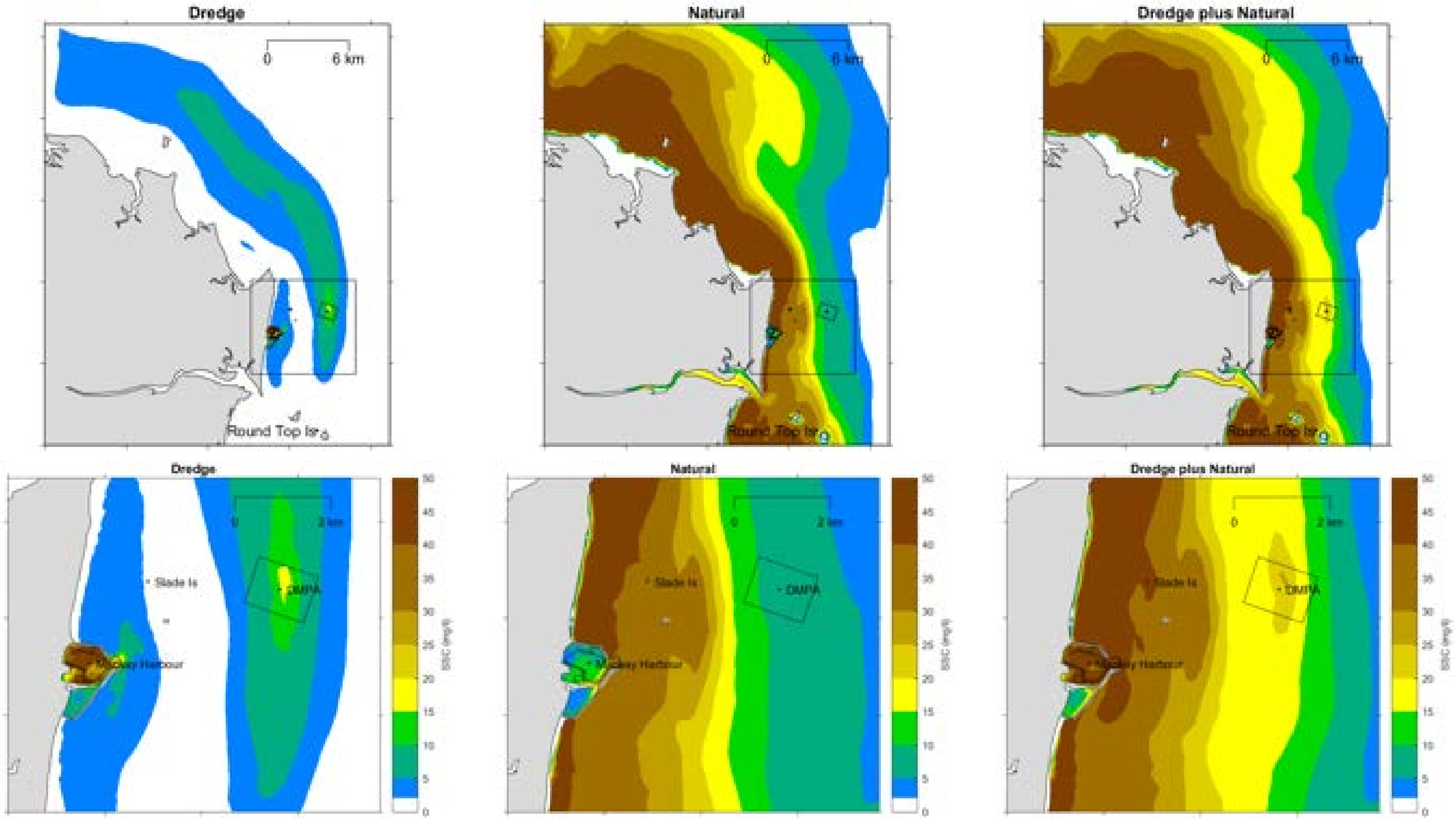

Figure A8. 95th percentile SSC for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season.

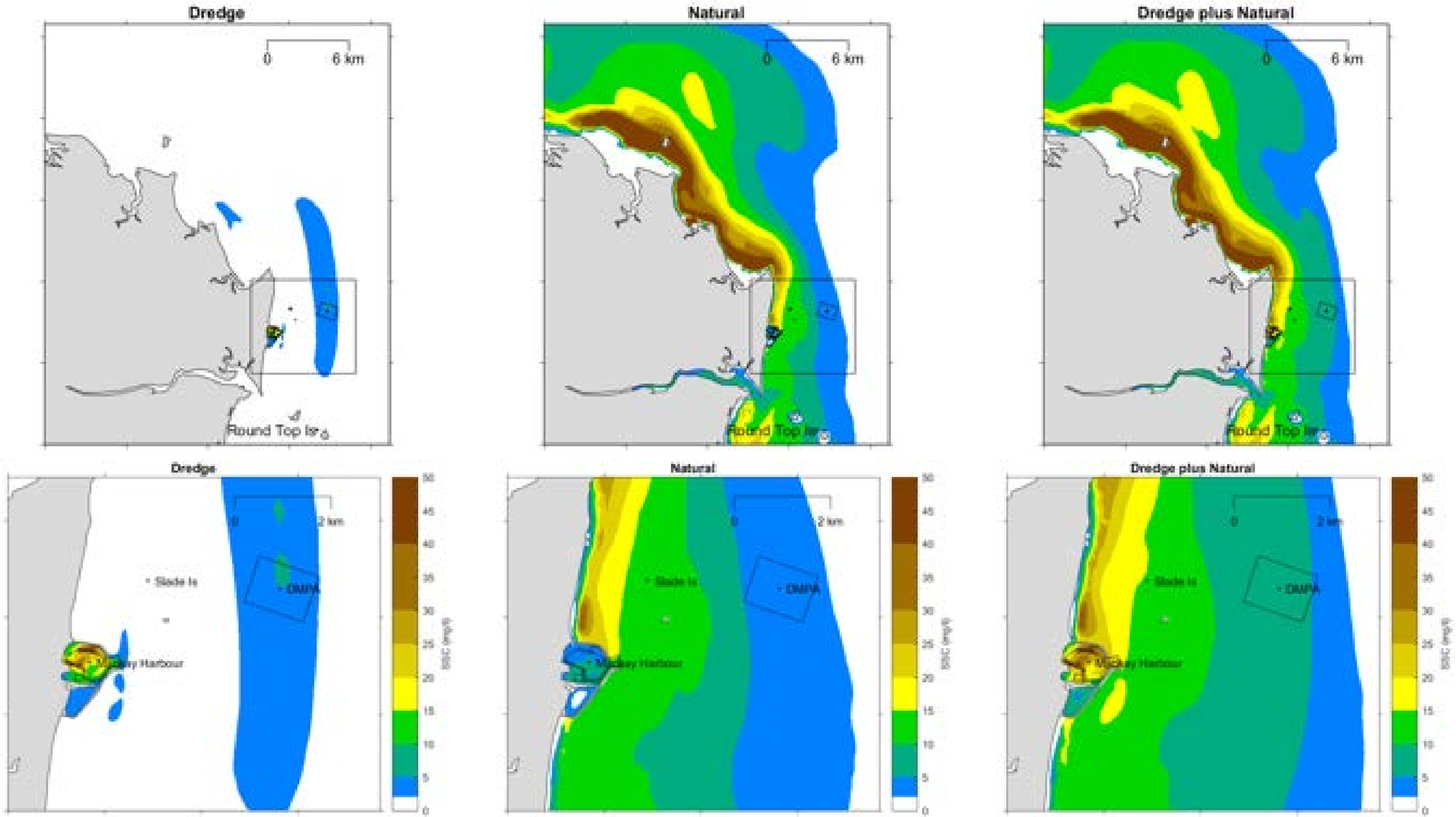

Figure A9. 80th percentile SSC for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the ambient dry season.

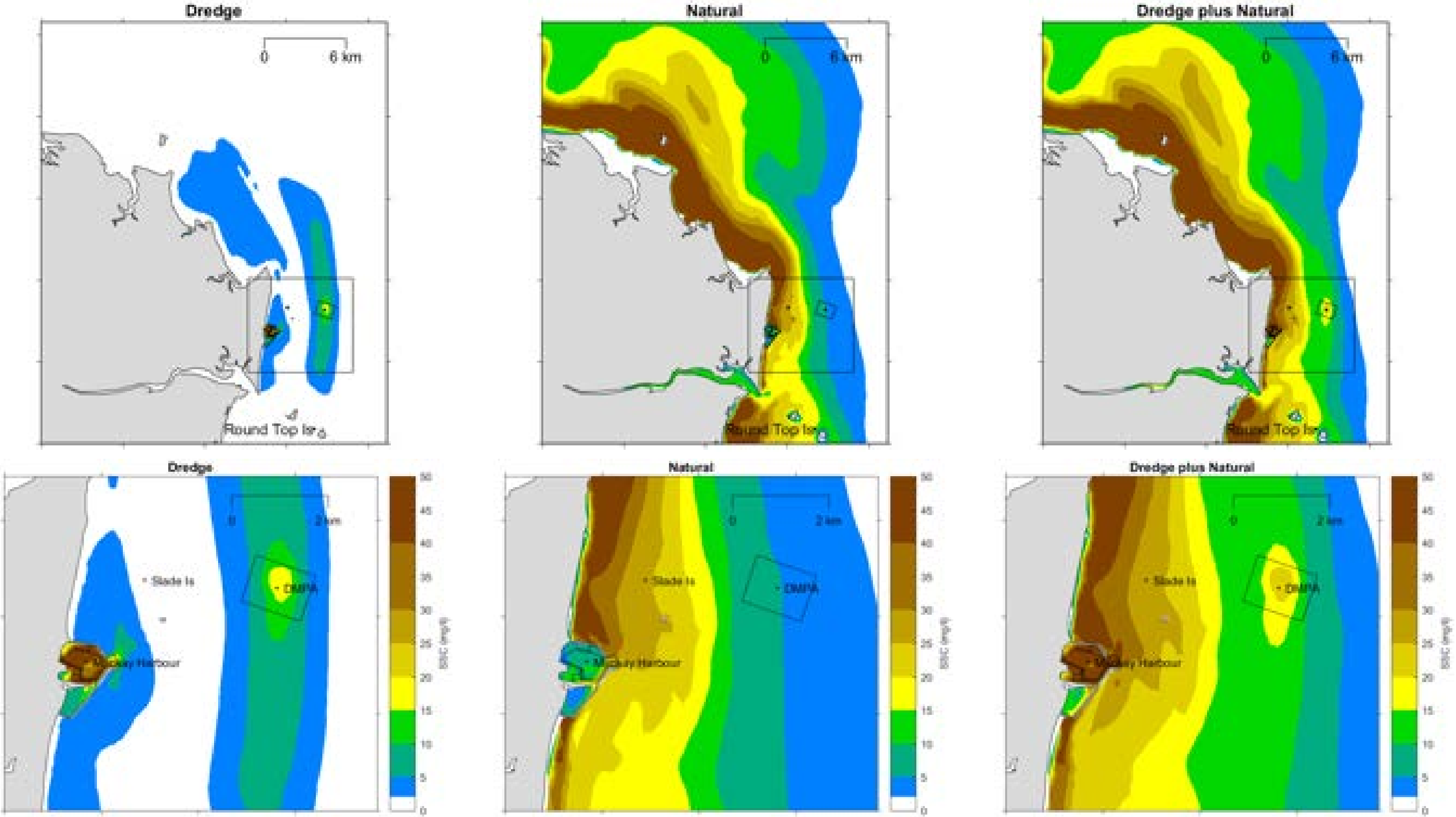

Figure A10. 95th percentile SSC for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the ambient dry season.

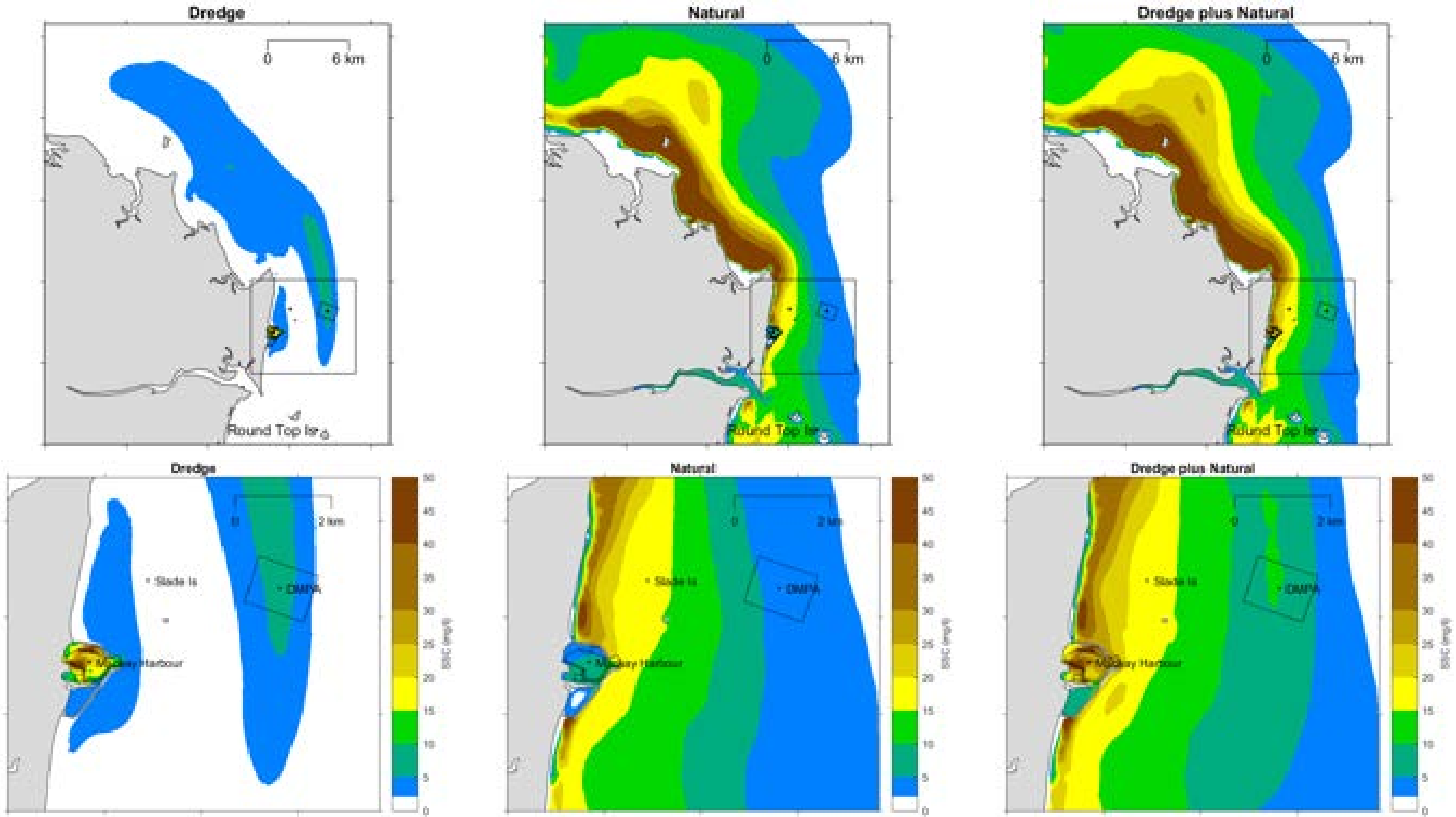

Figure A11. 80th percentile SSC for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the energetic dry season.

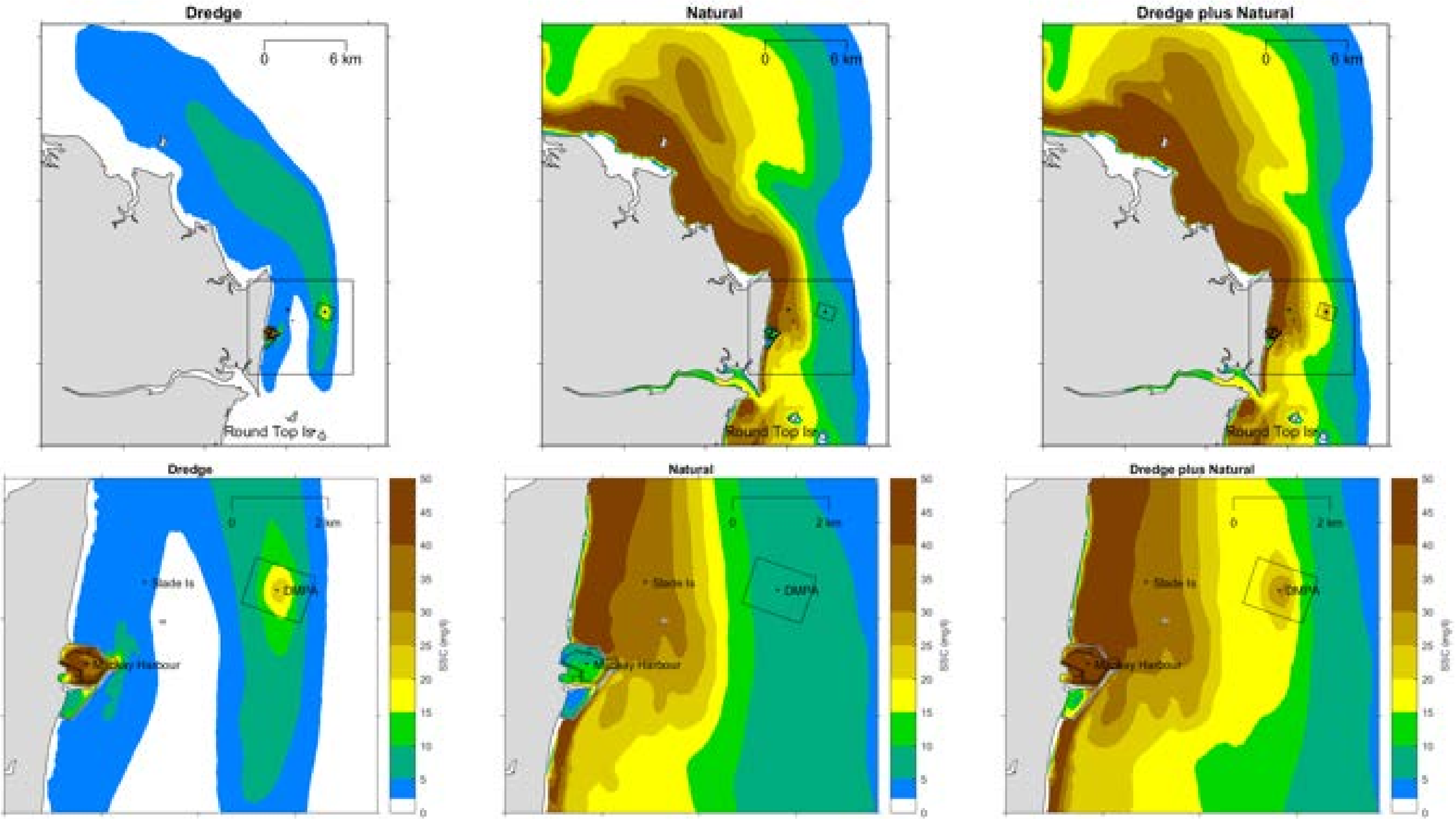

Figure A12. 95th percentile SSC for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the energetic dry season.

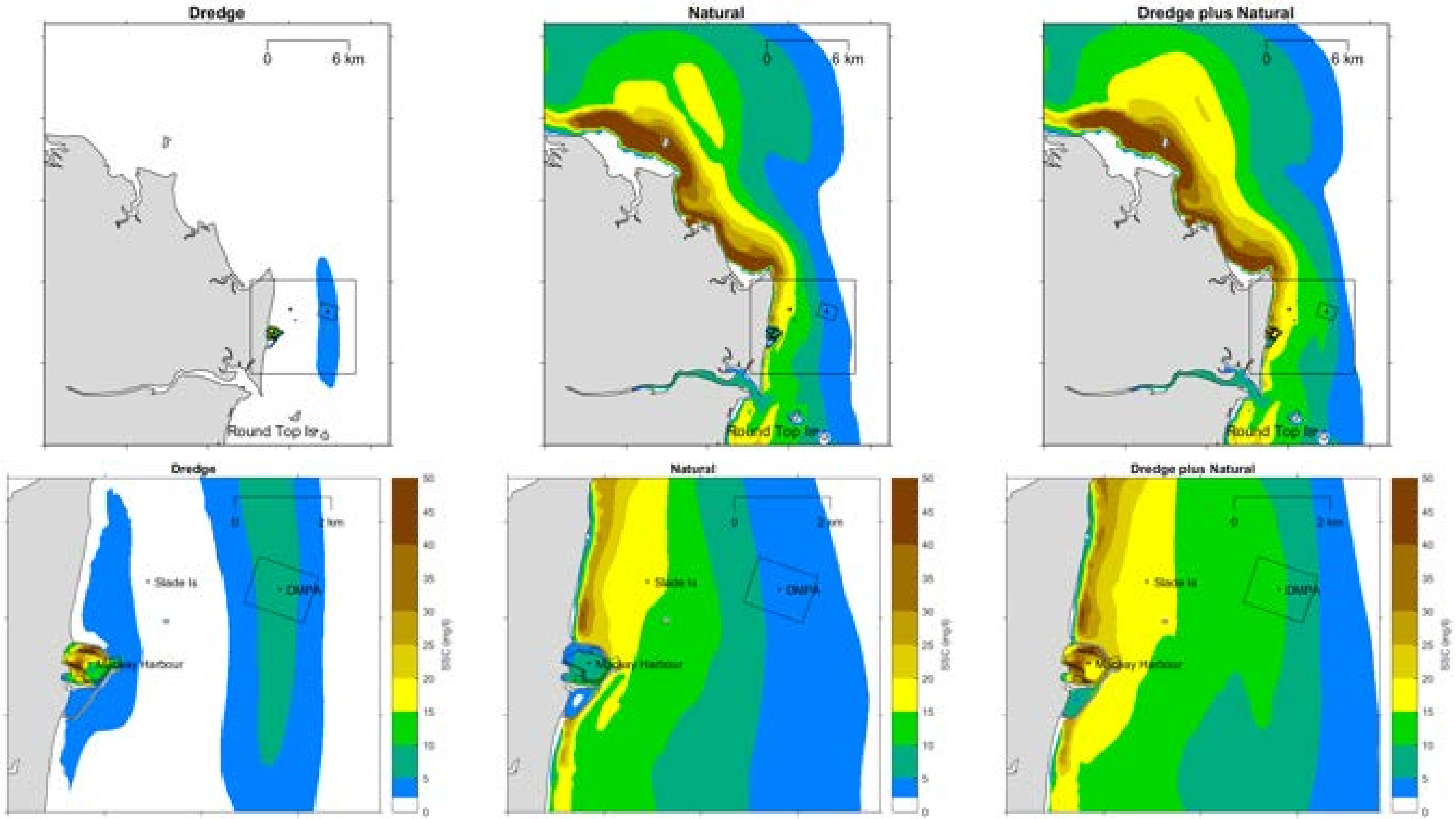

Figure A13. 80th percentile SSC for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the ambient wet season.

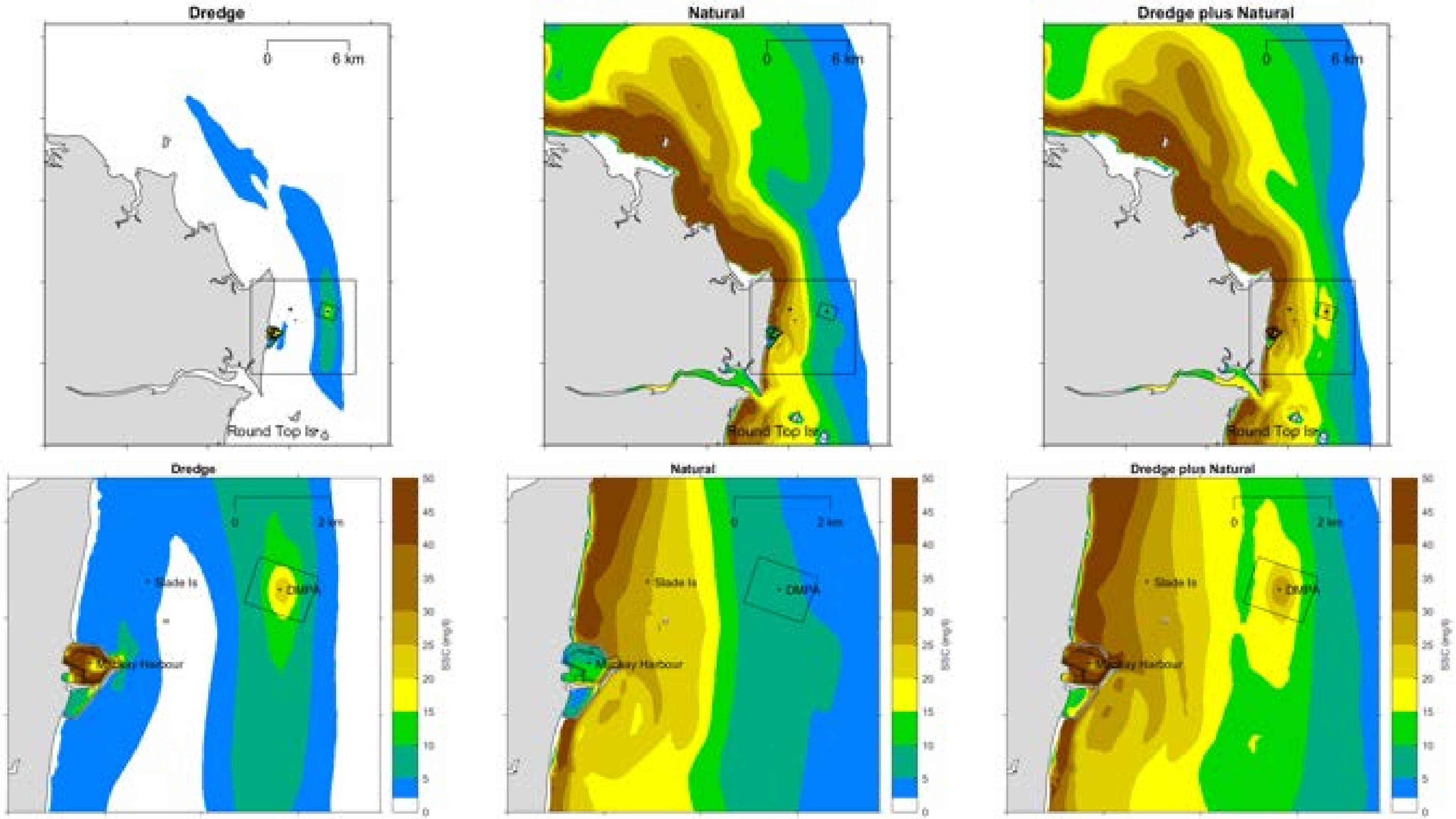

Figure A14. 95th percentile SSC for dredging, natural and natural plus dredging for 250,000 m³ of sediment in the ambient wet season.

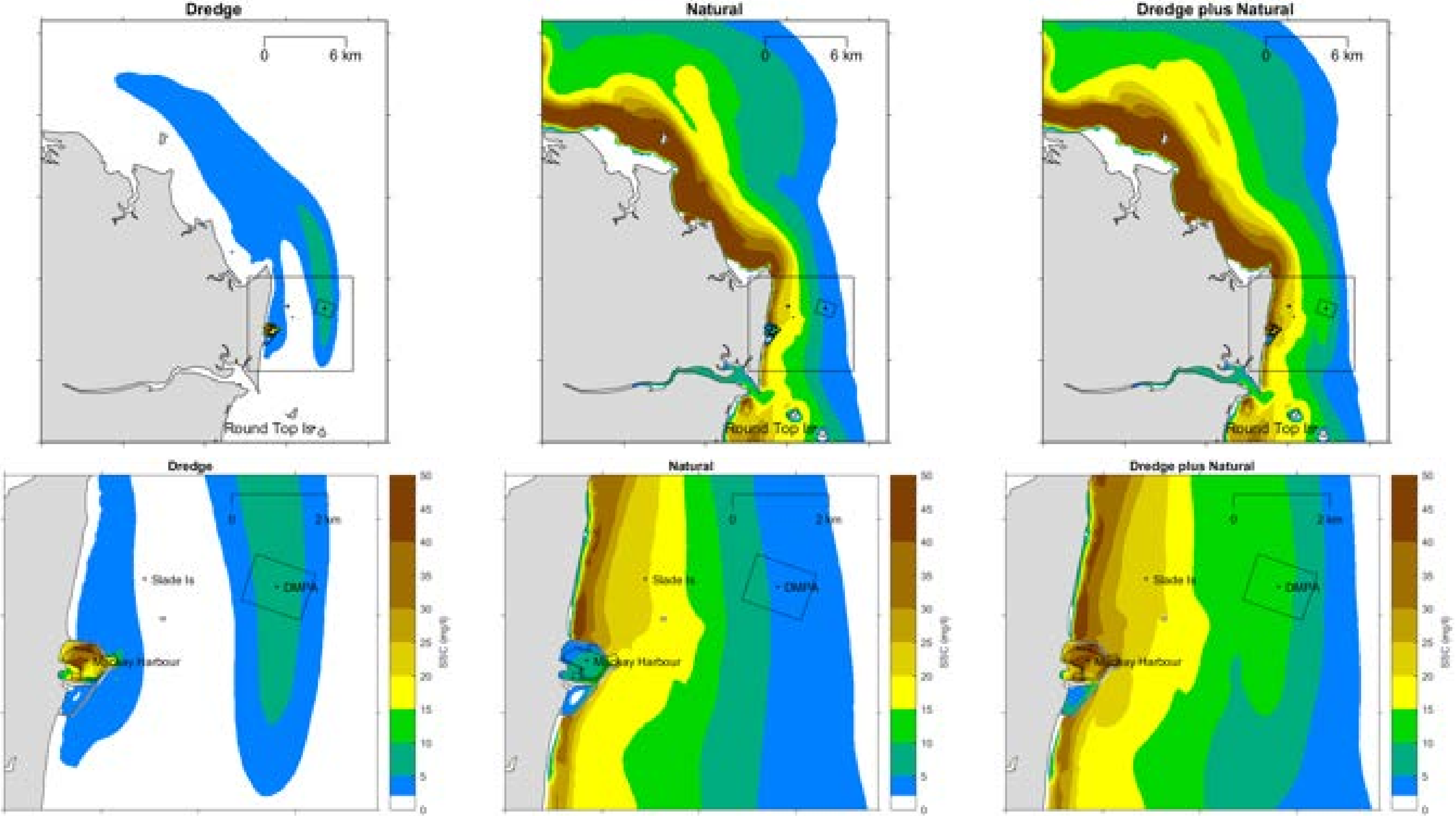

Figure A15. 80th percentile SSC for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the energetic wet season.

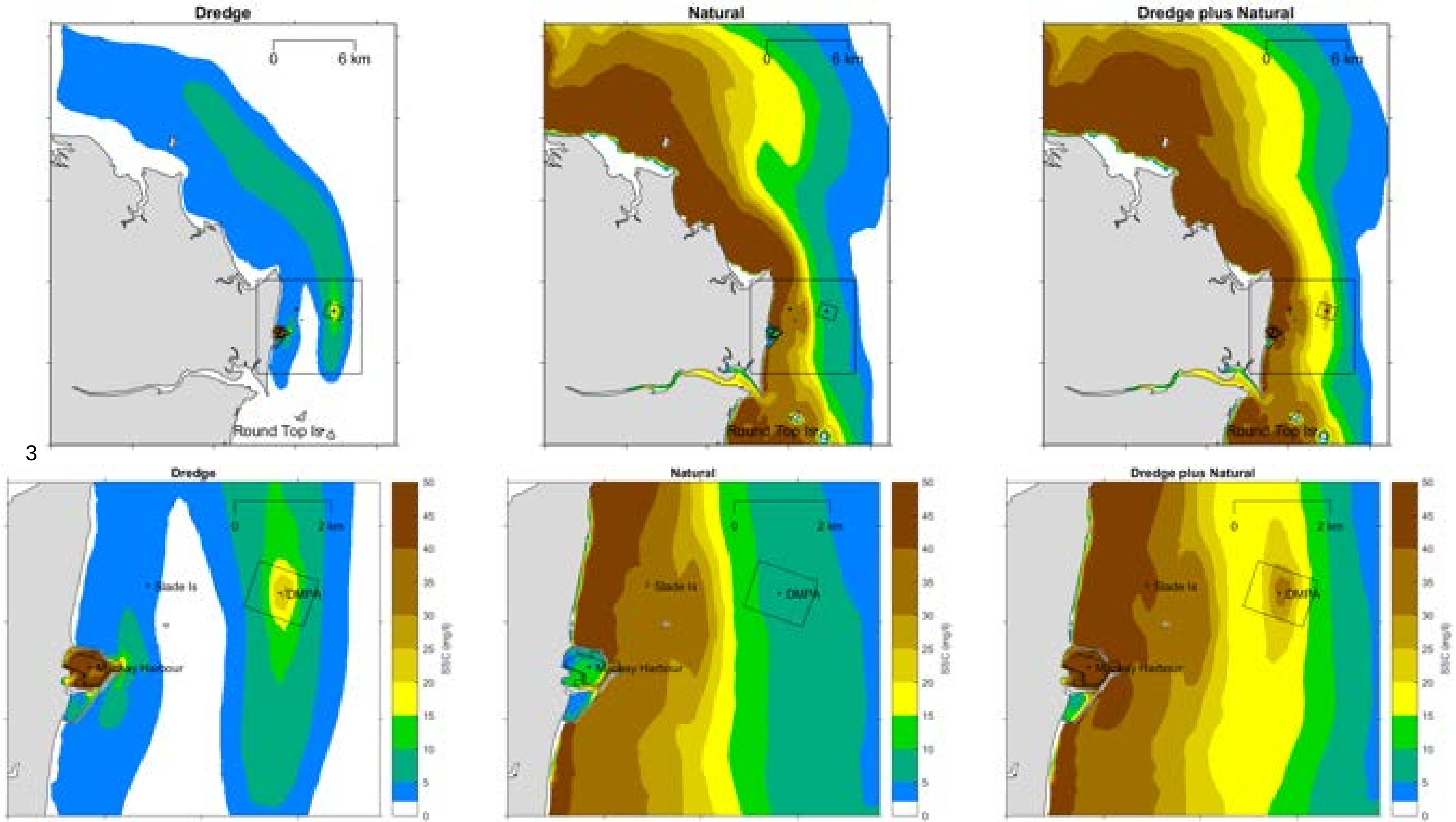

Figure A16. 95th percentile SSC for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the energetic wet season.

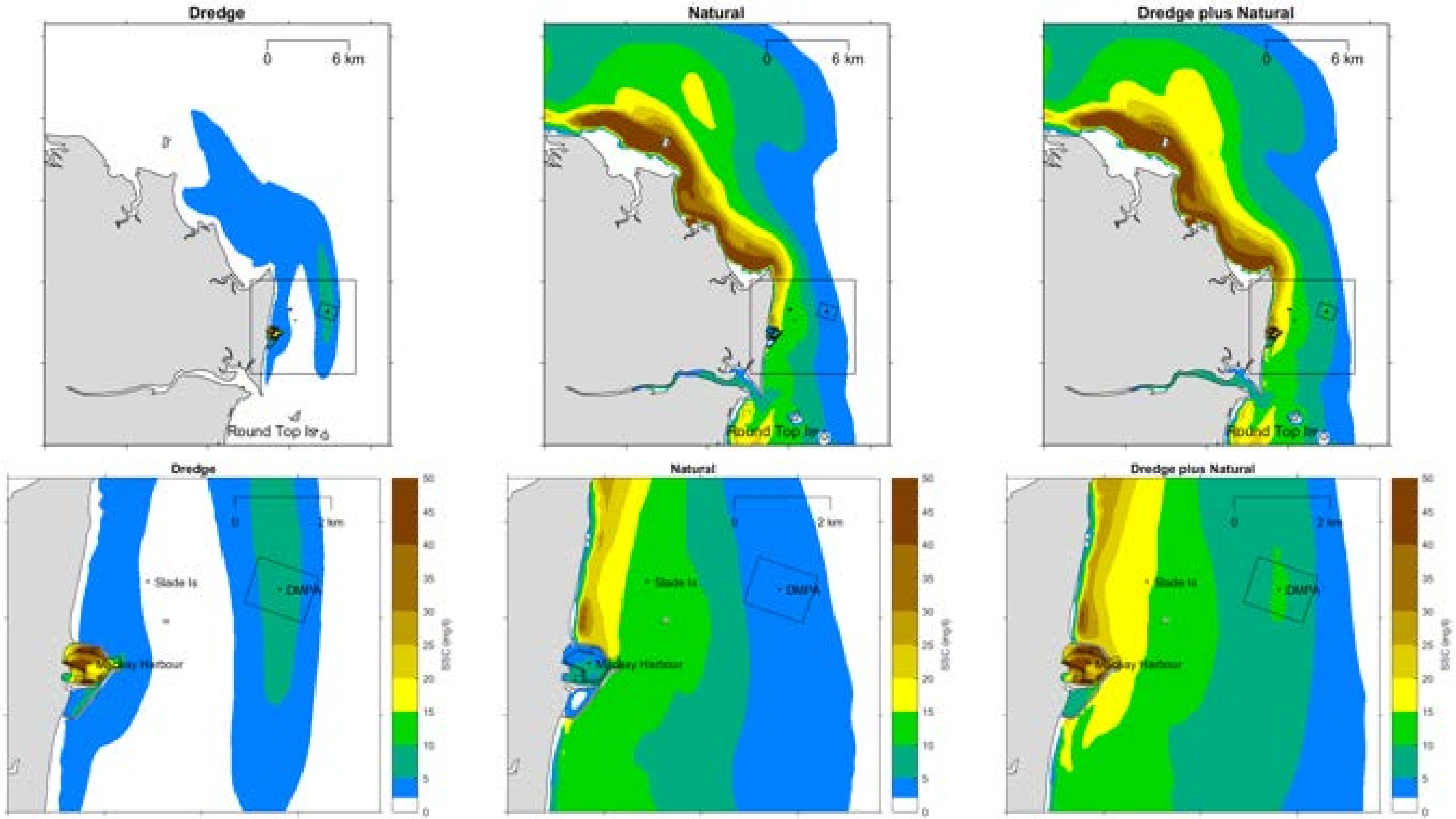

Figure A17. 80th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the ambient dry season.

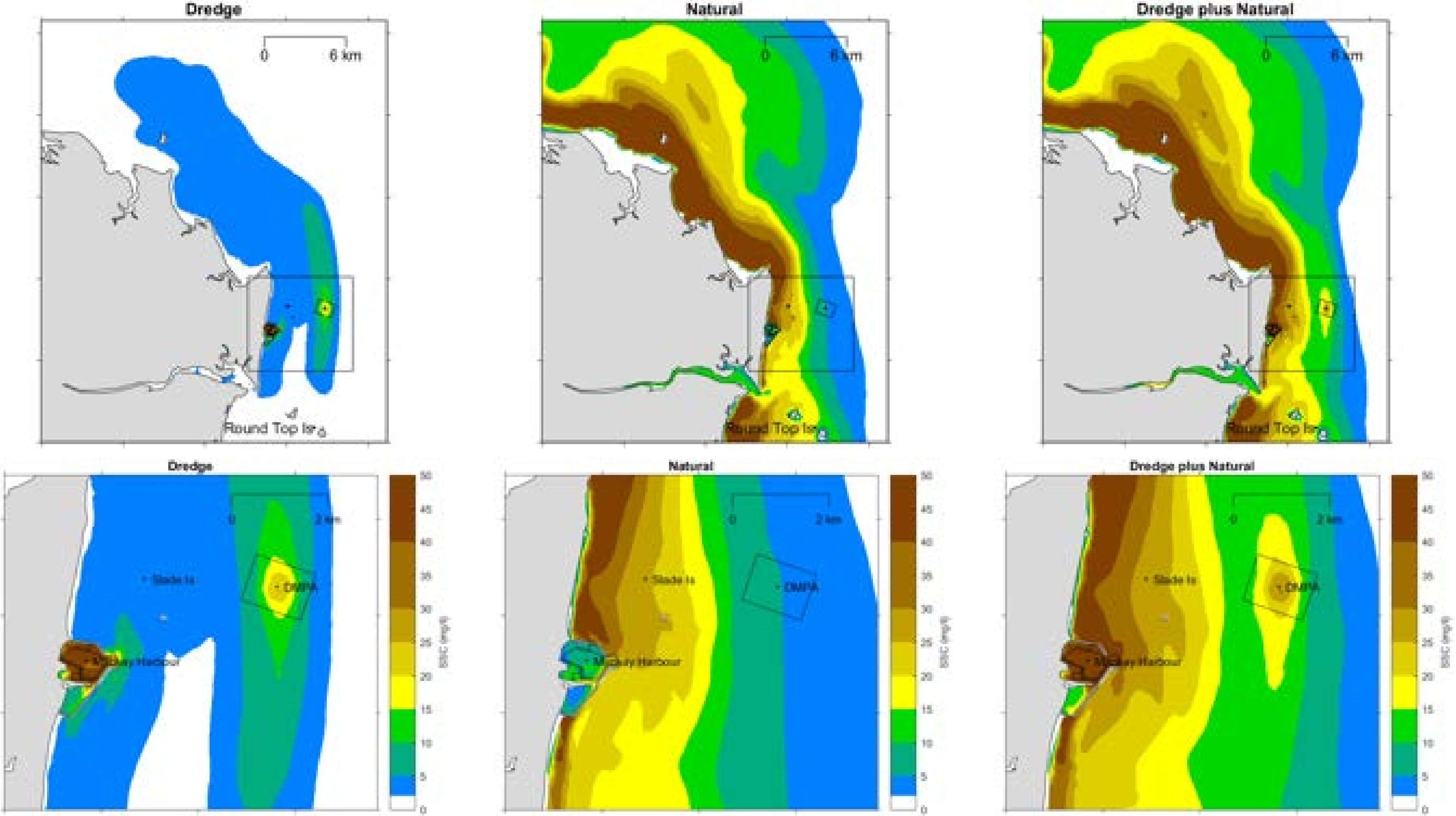

Figure A18. **95th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the ambient dry season.**

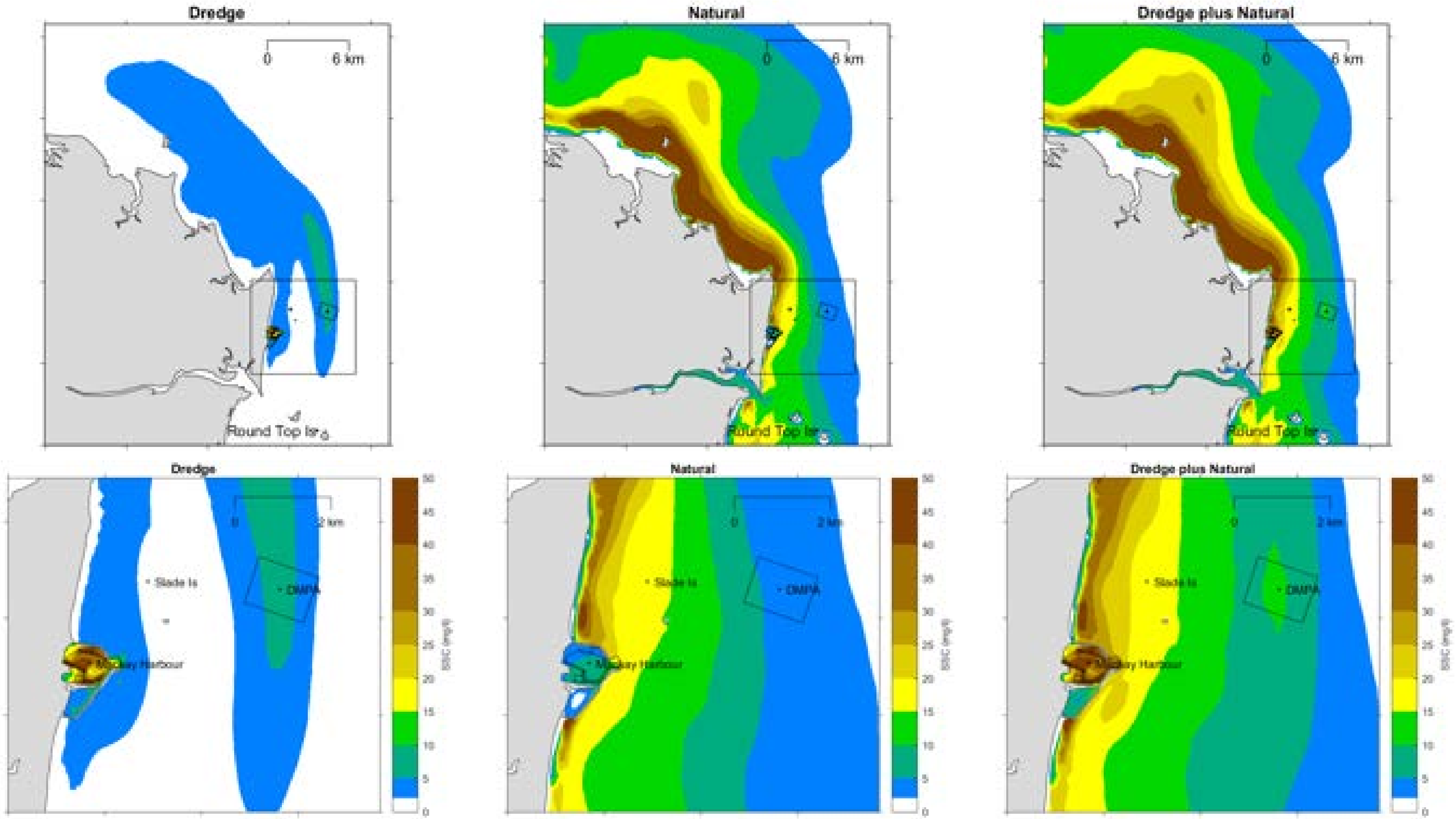

Figure A19. 80th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the energetic dry season.

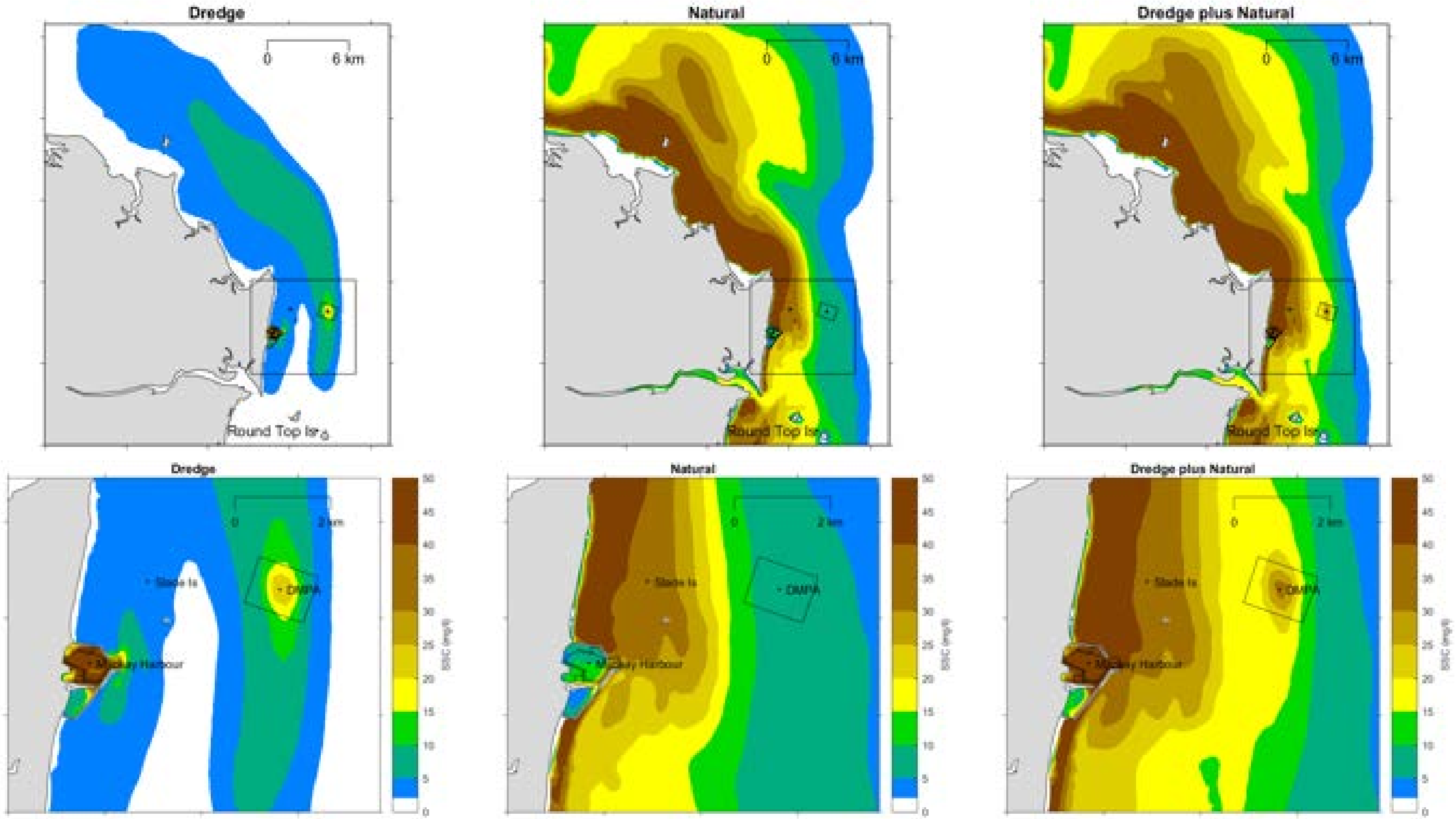

Figure A20. 95th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the energetic dry season.

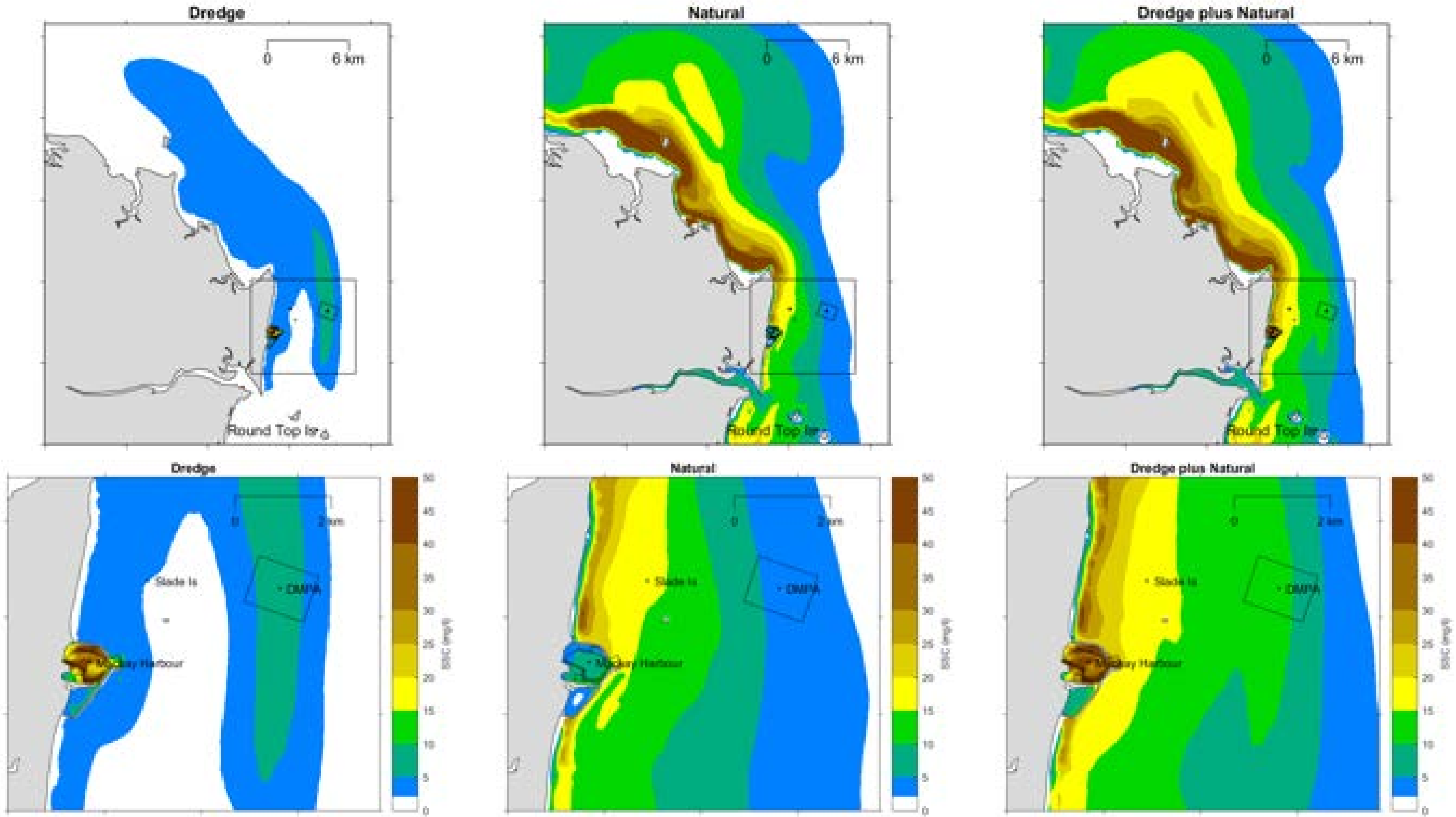

Figure A21. 80th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the ambient wet season.

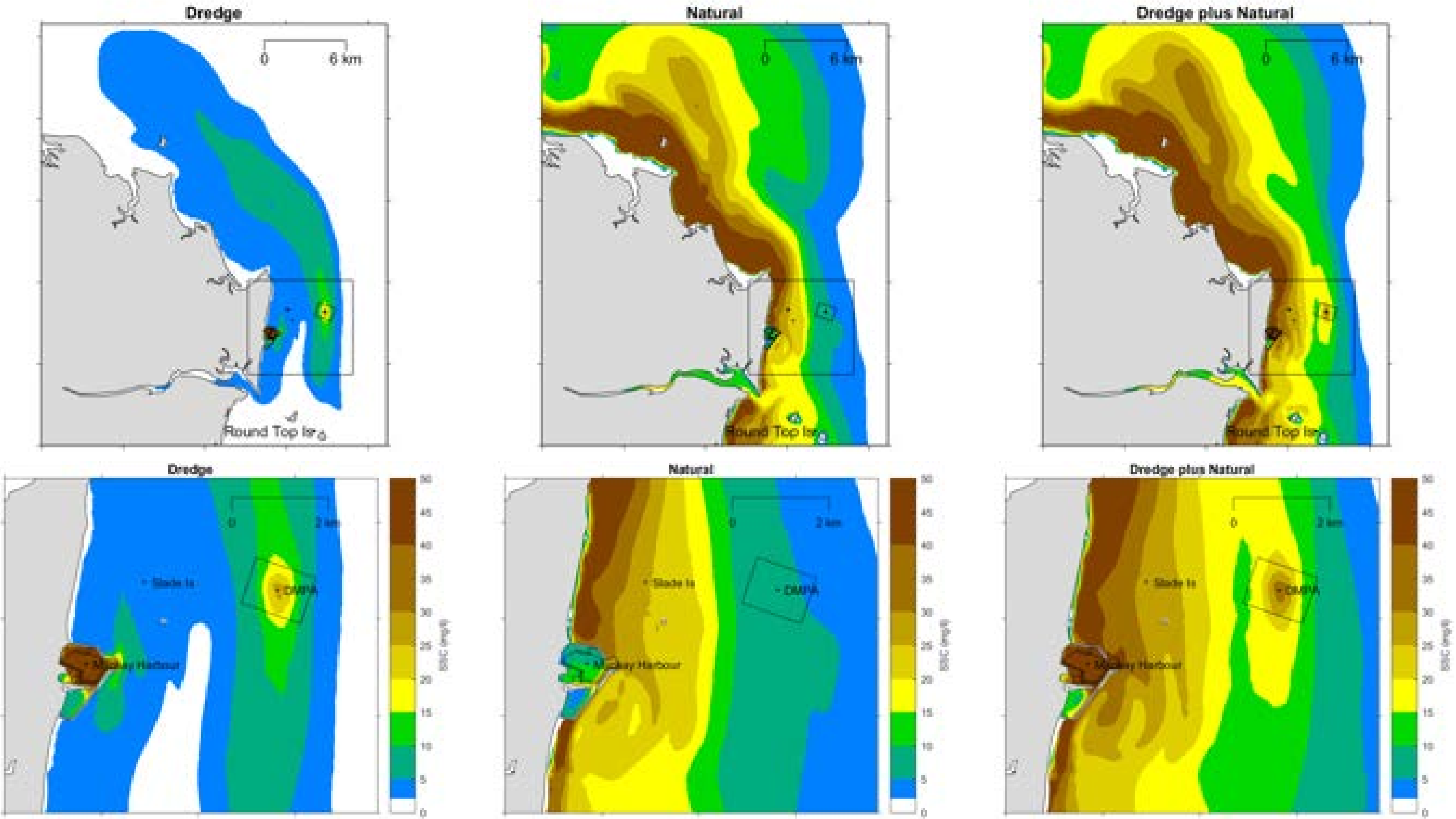

Figure A22. 95th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the ambient wet season.

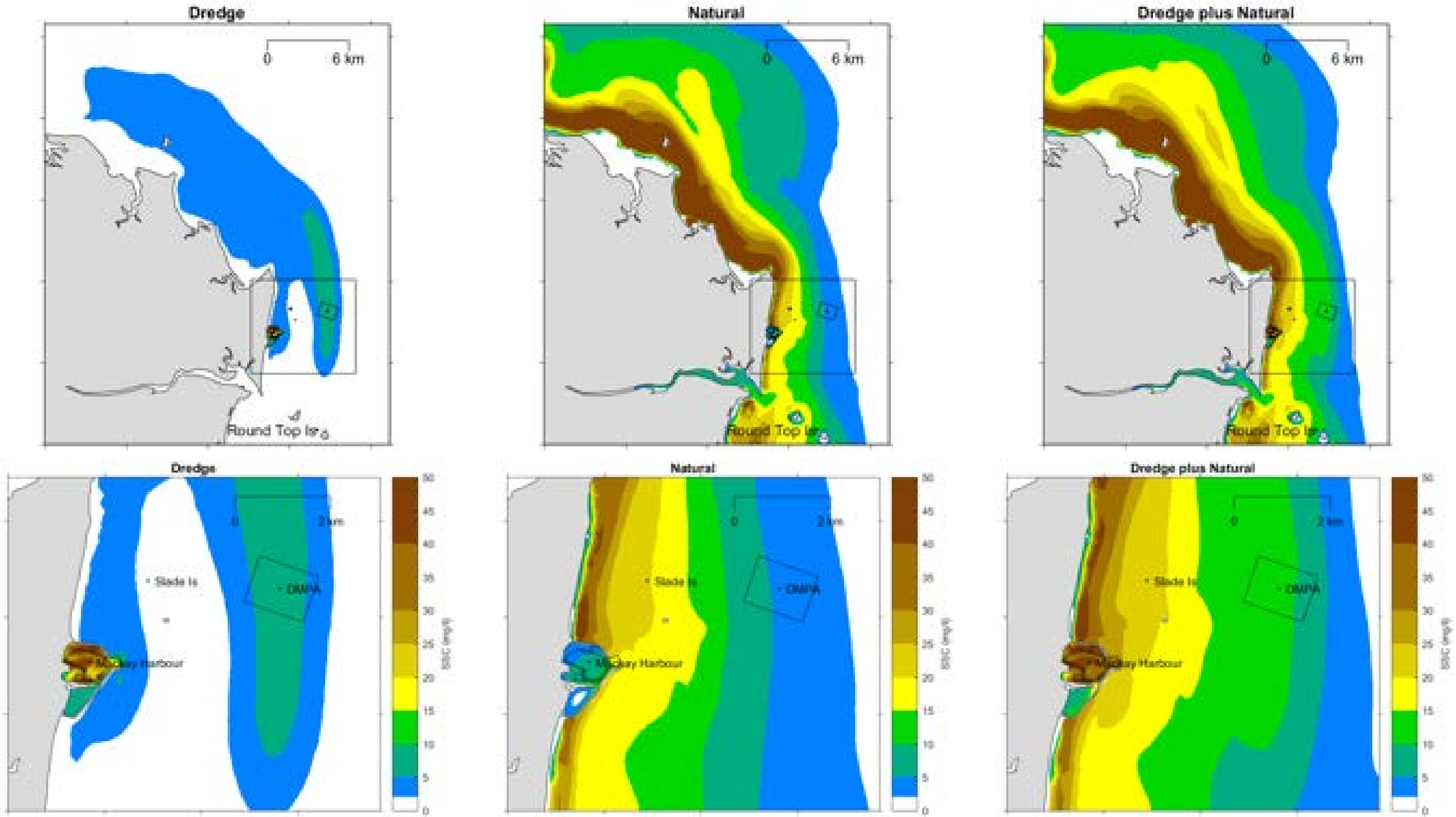

Figure A23. 80th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the energetic wet season.

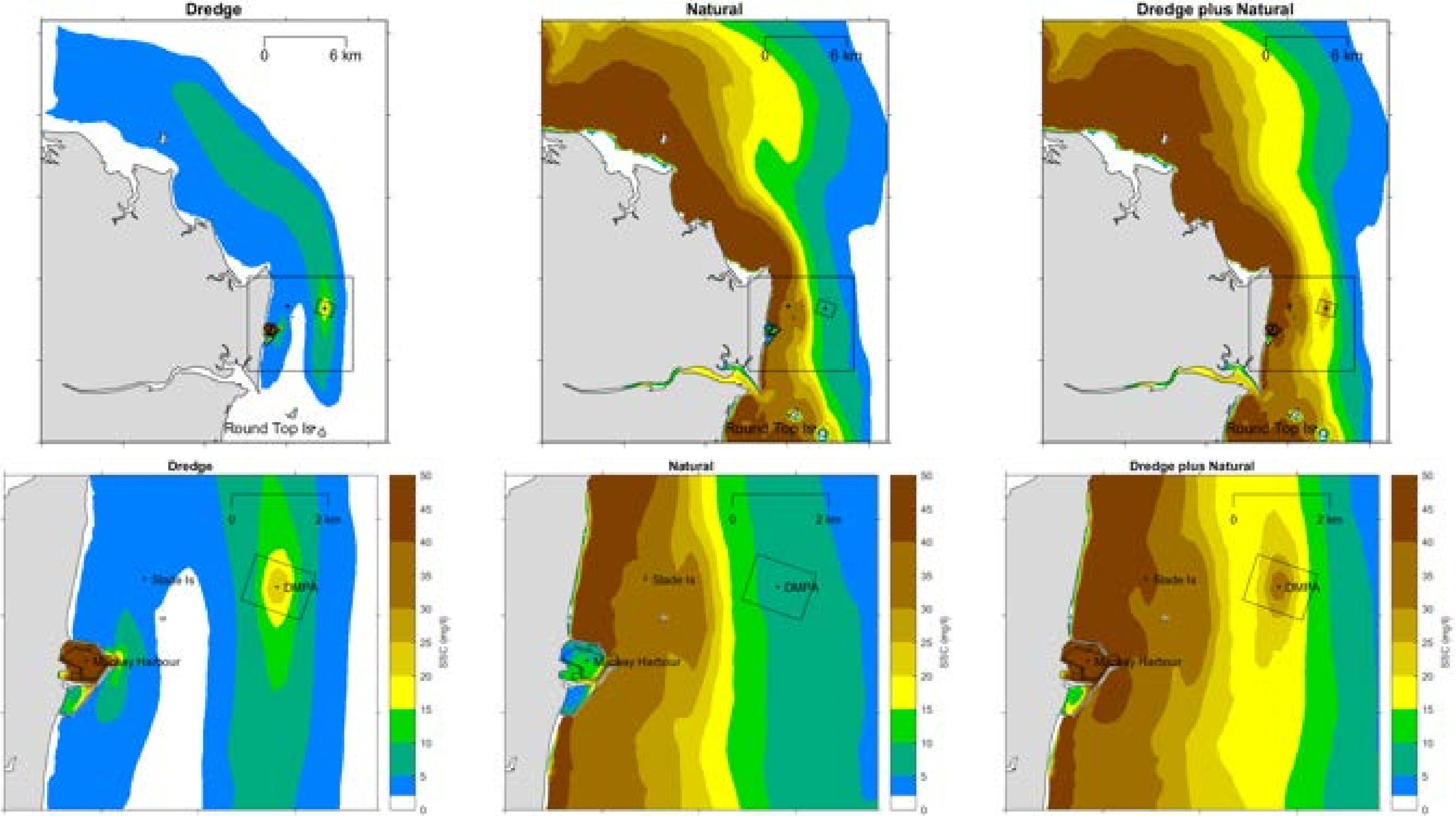

Figure A24. 95th percentile SSC for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the energetic wet season.

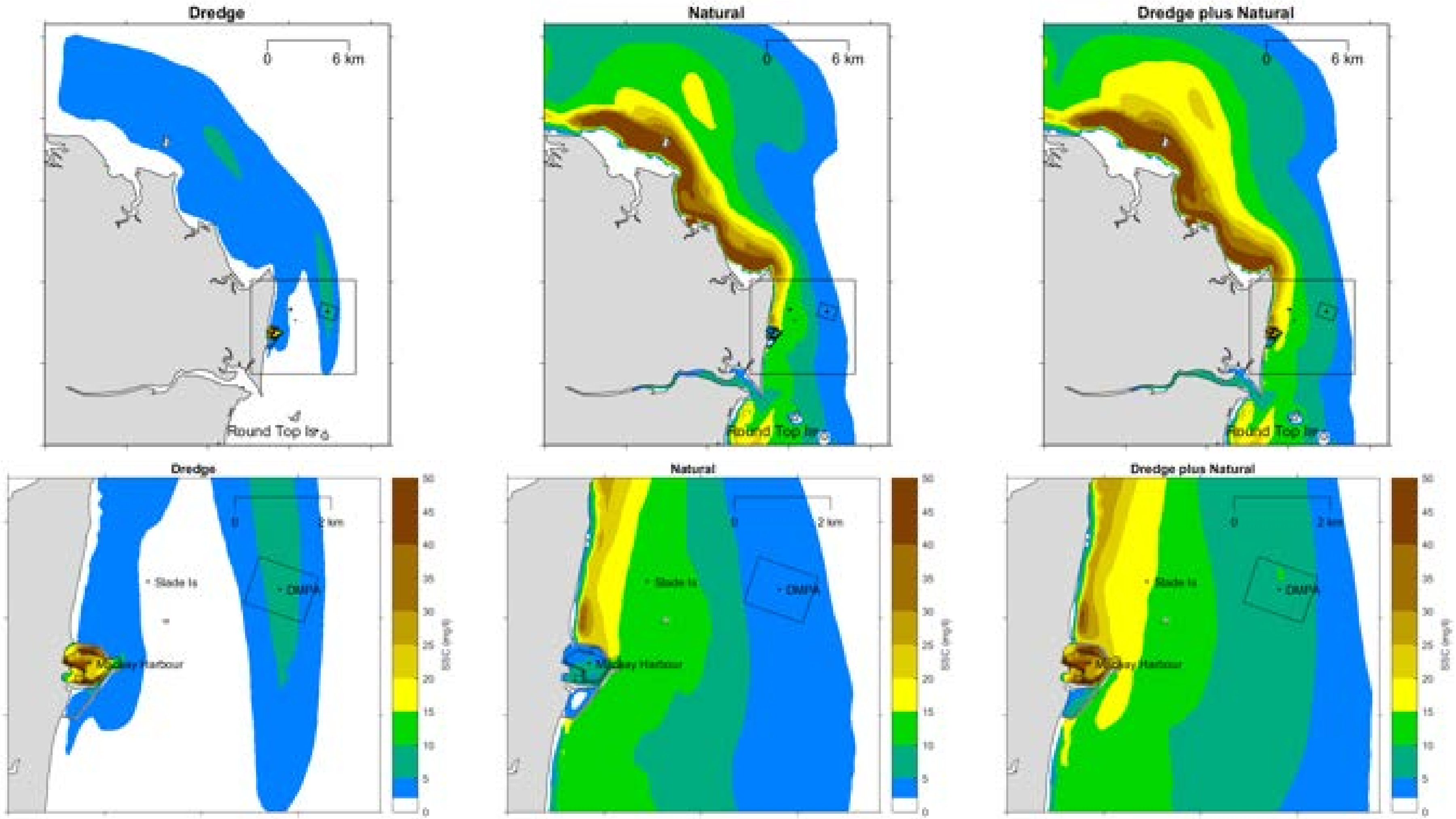

Figure A25. 80th percentile SSC for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the ambient dry season.

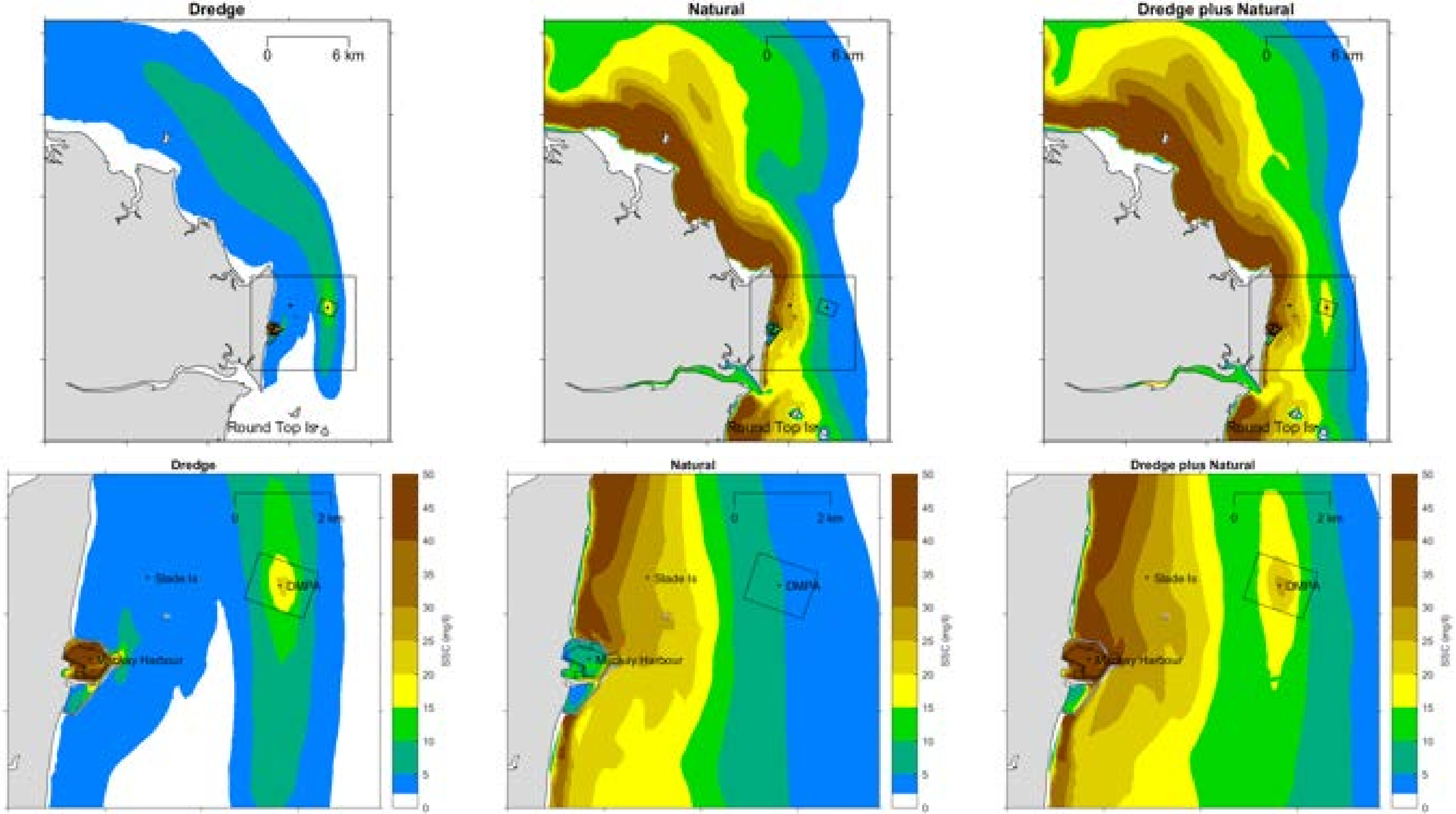

Figure A26. 95th percentile SSC for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the ambient dry season.

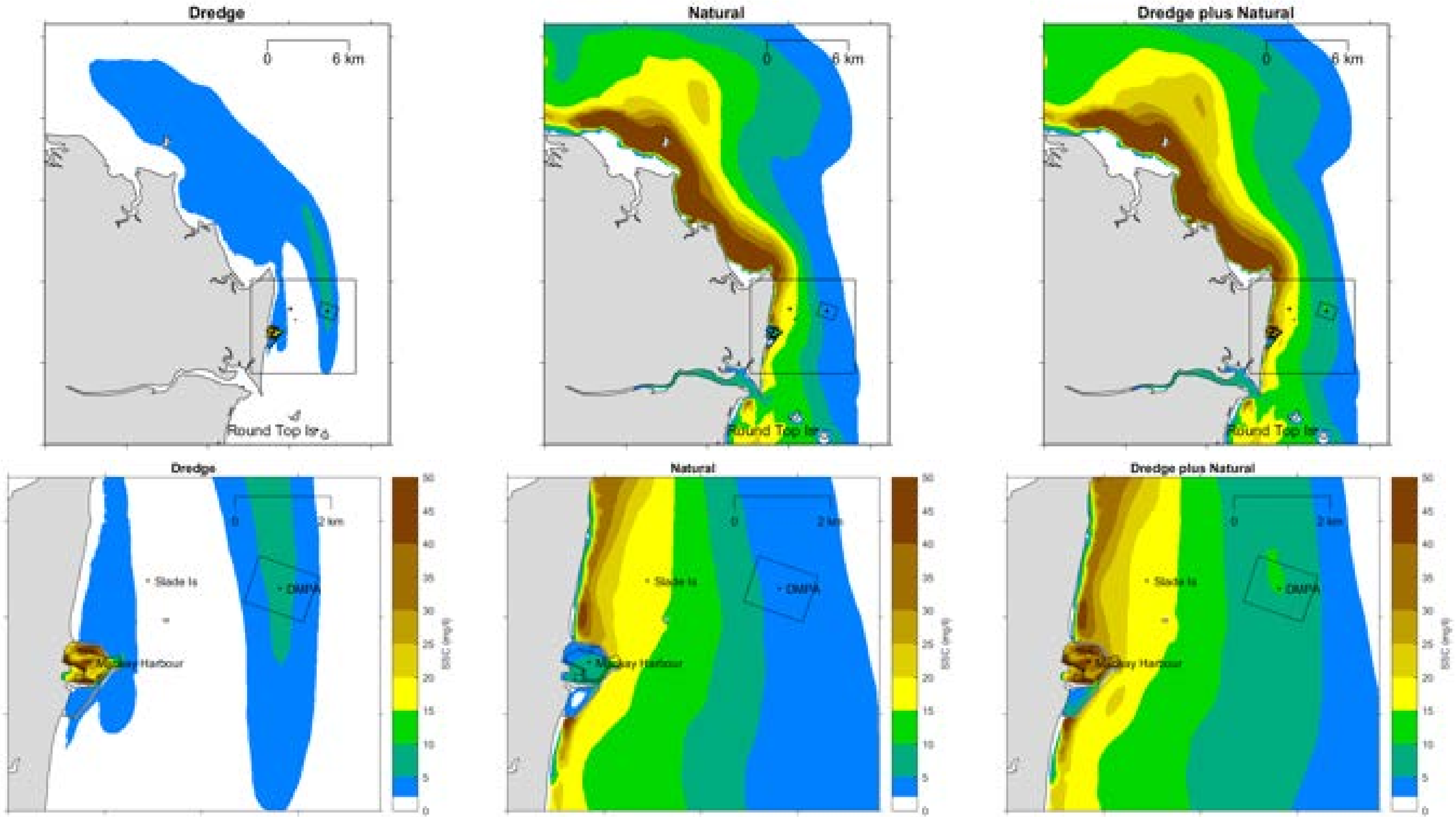

Figure A27. **80th percentile SSC for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the energetic dry season.**

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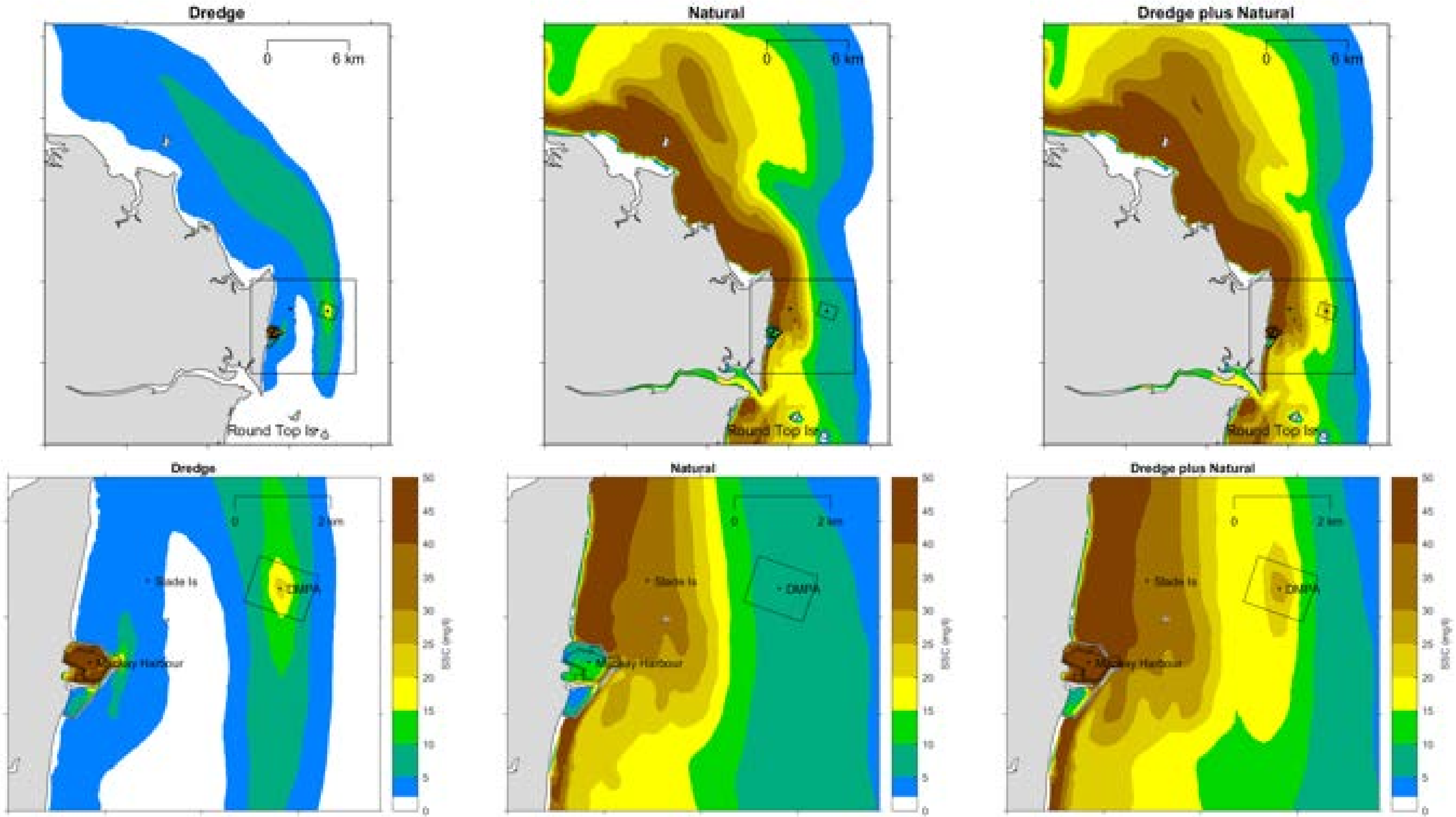


Figure A28. 95th percentile SSC for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the energetic dry season.

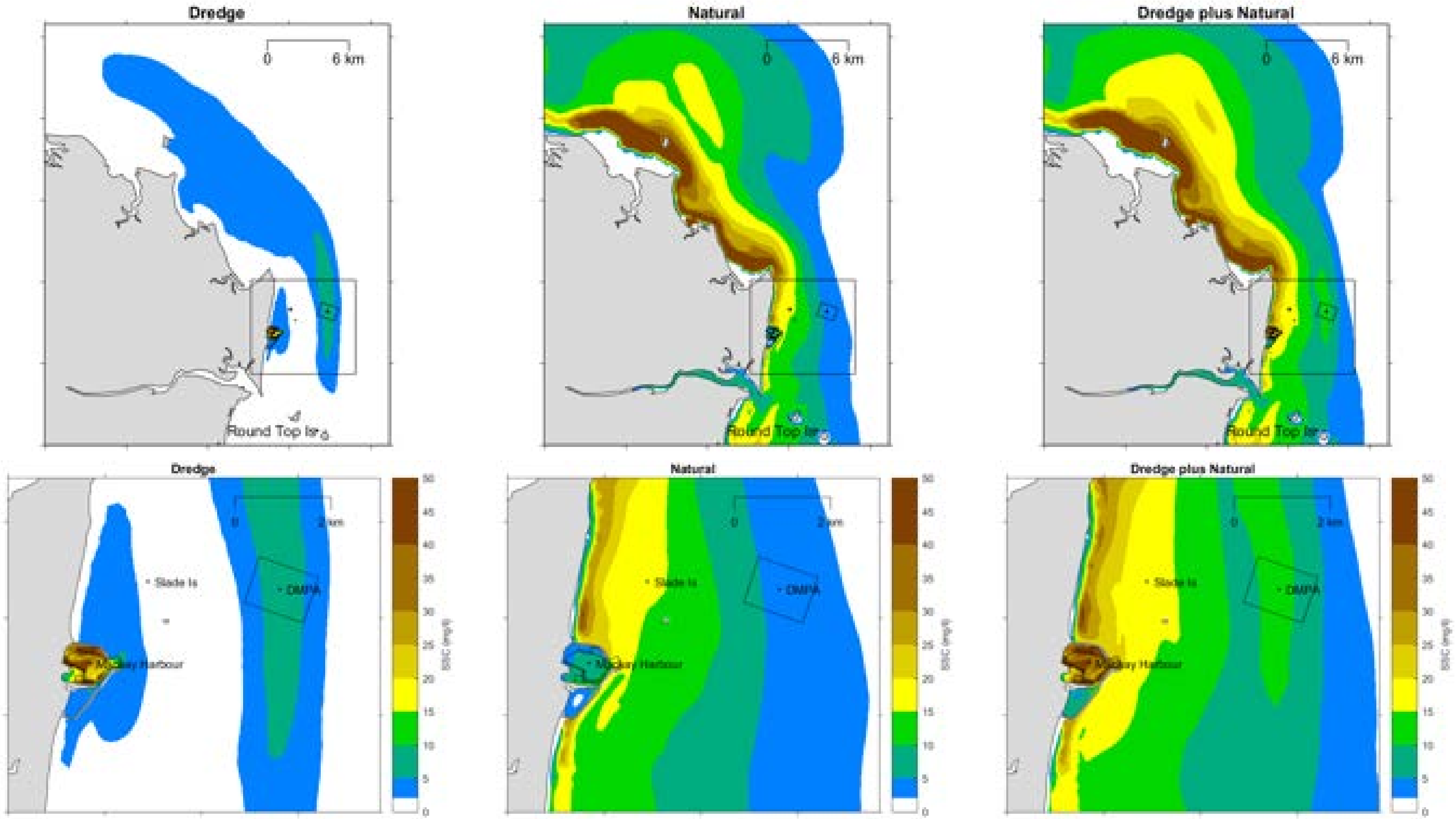


Figure A29. 80th percentile SSC for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the ambient wet season.

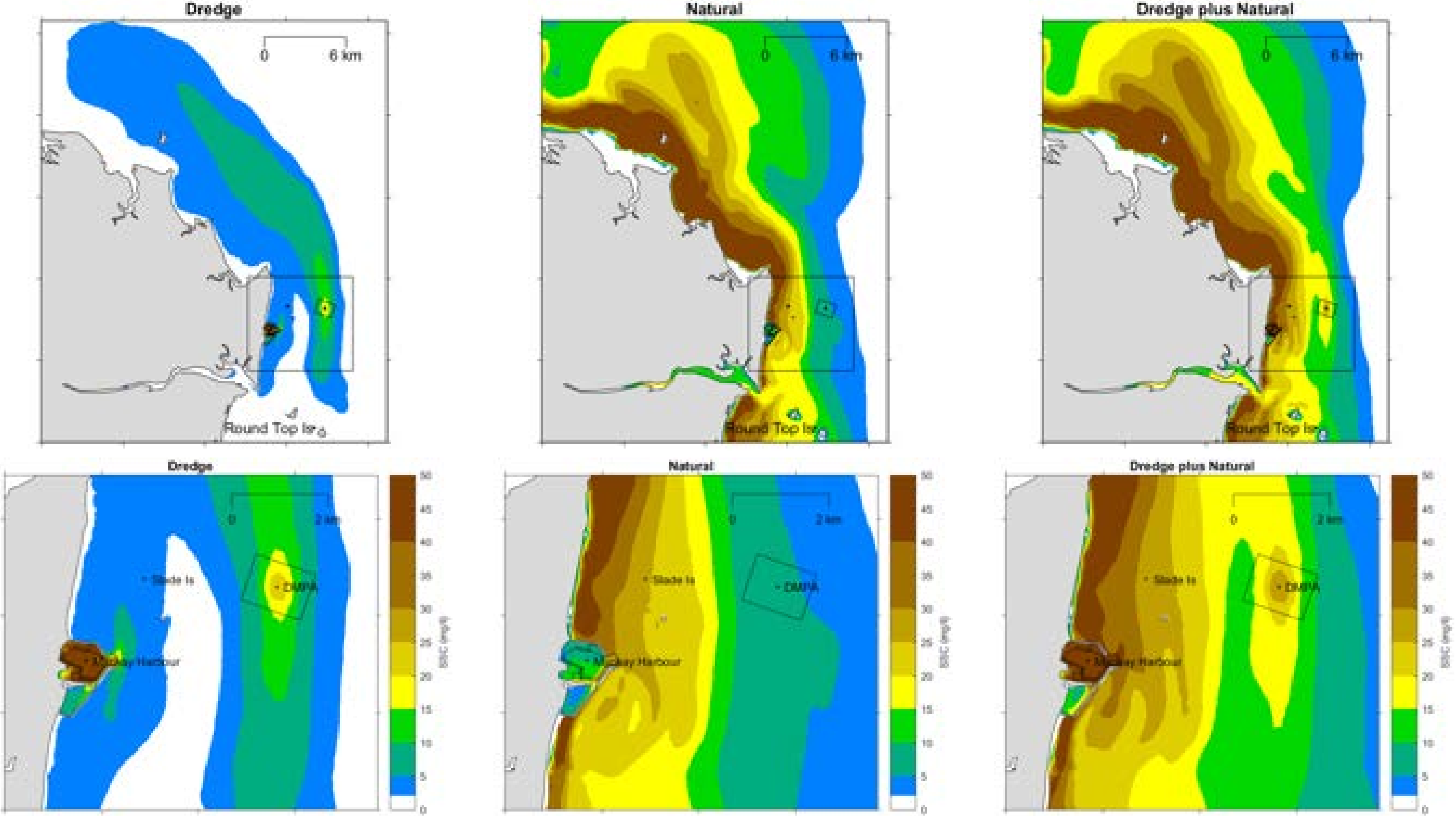


Figure A30. 95th percentile SSC for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the ambient wet season.

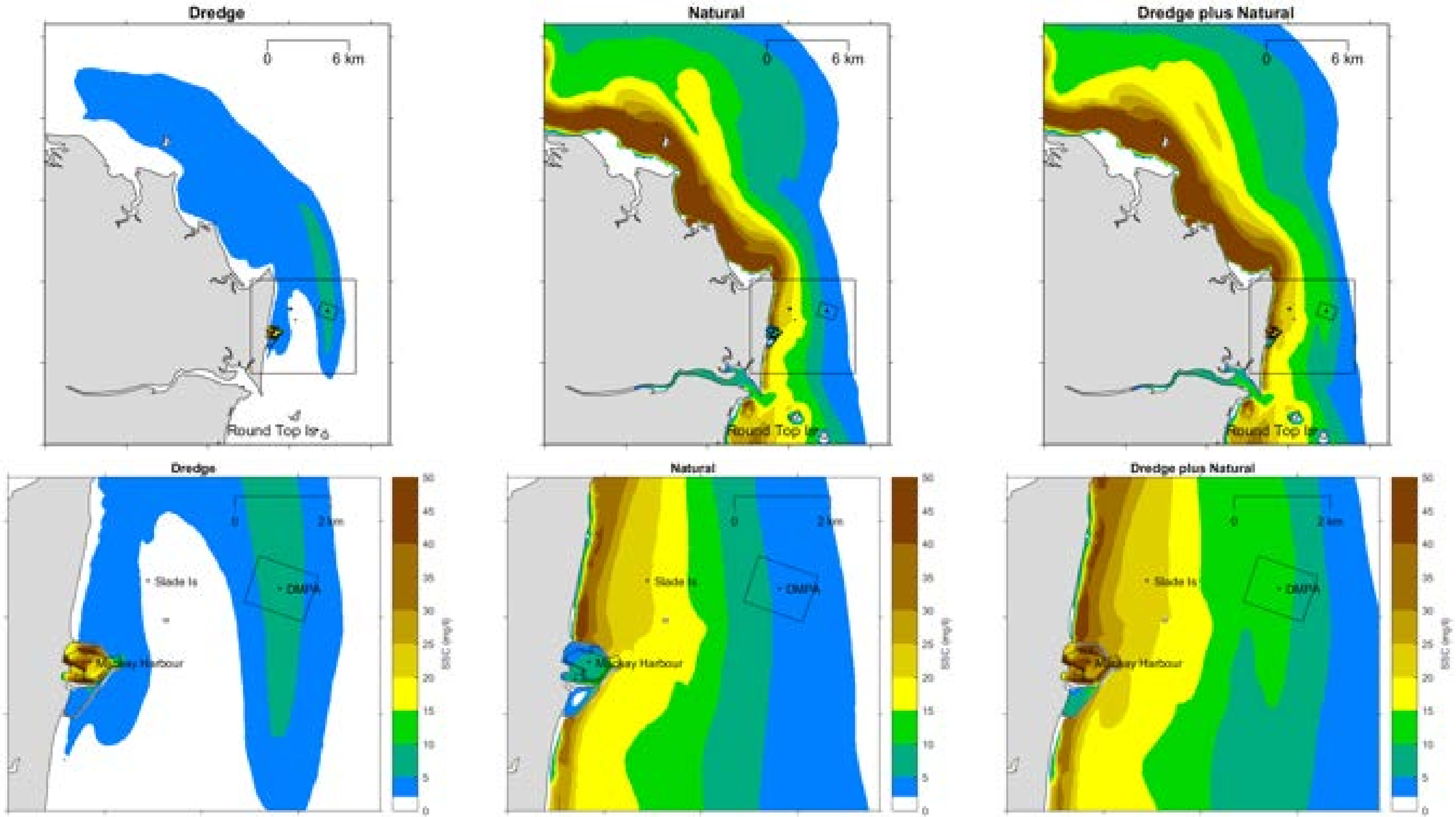


Figure A31. 80th percentile SSC for dredging, natural and natural plus dredging for 750,000 m³ of sediment in the energetic wet season.

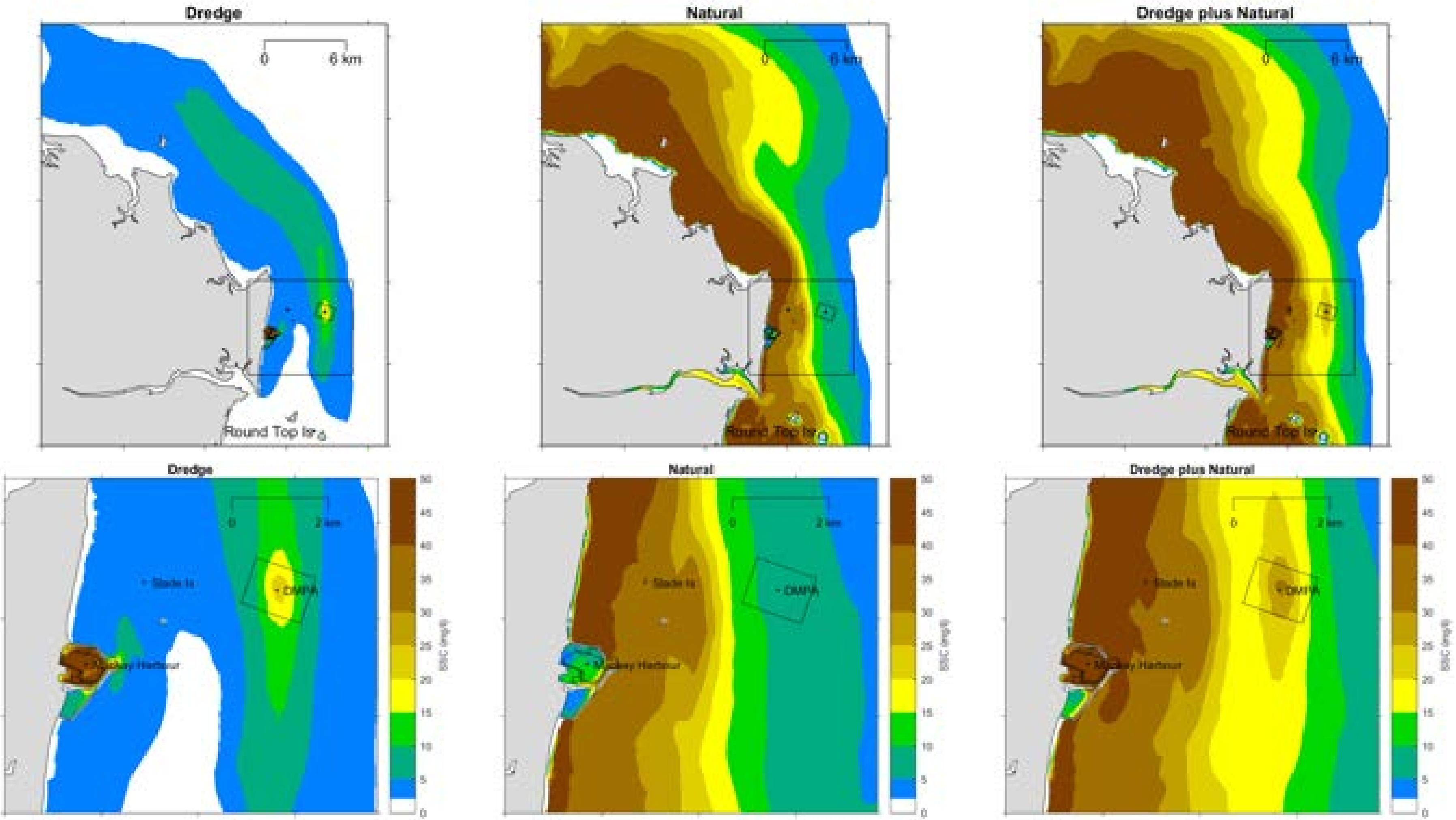


Figure A32. 95th percentile SSC for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the energetic wet season.

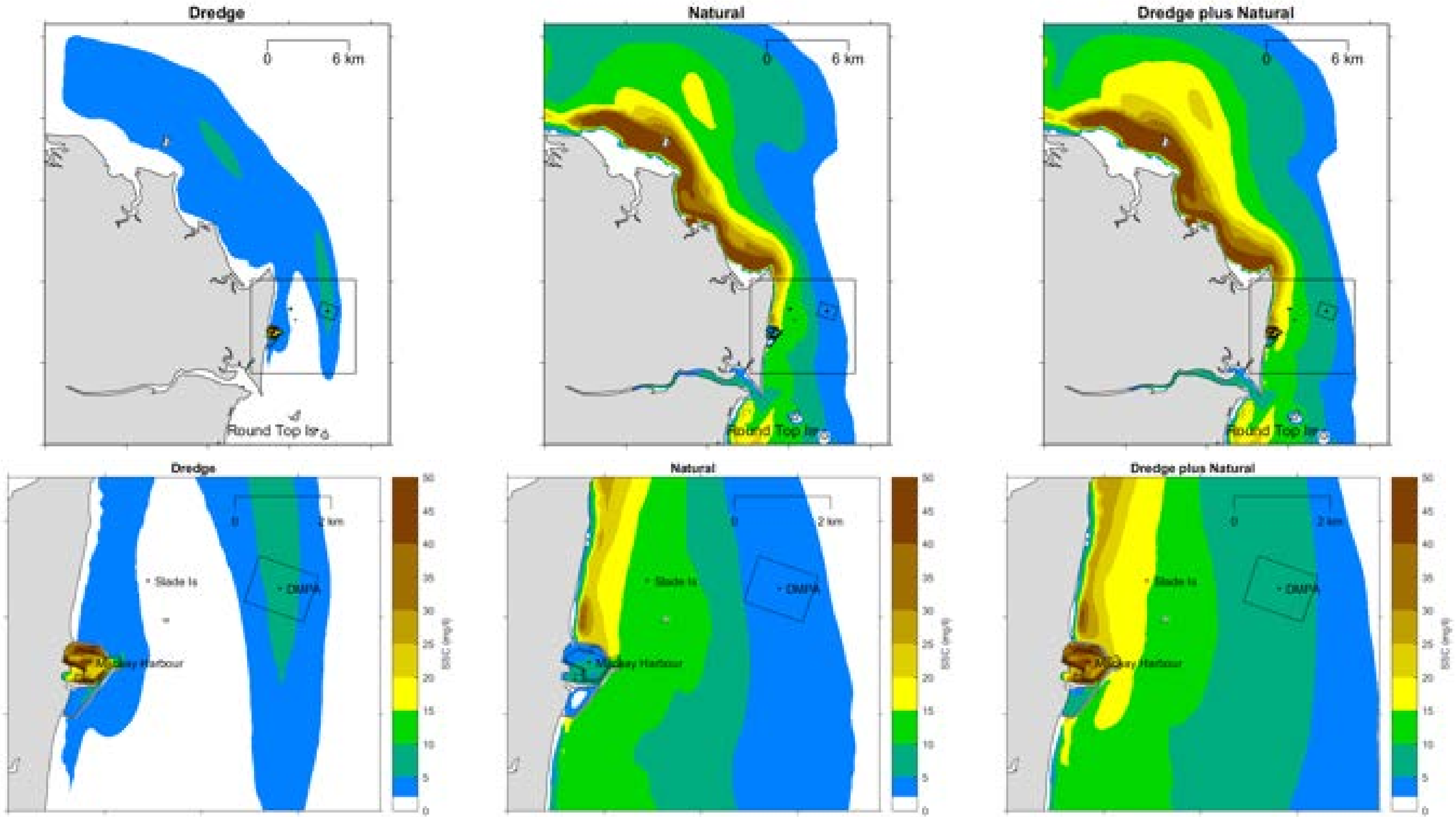
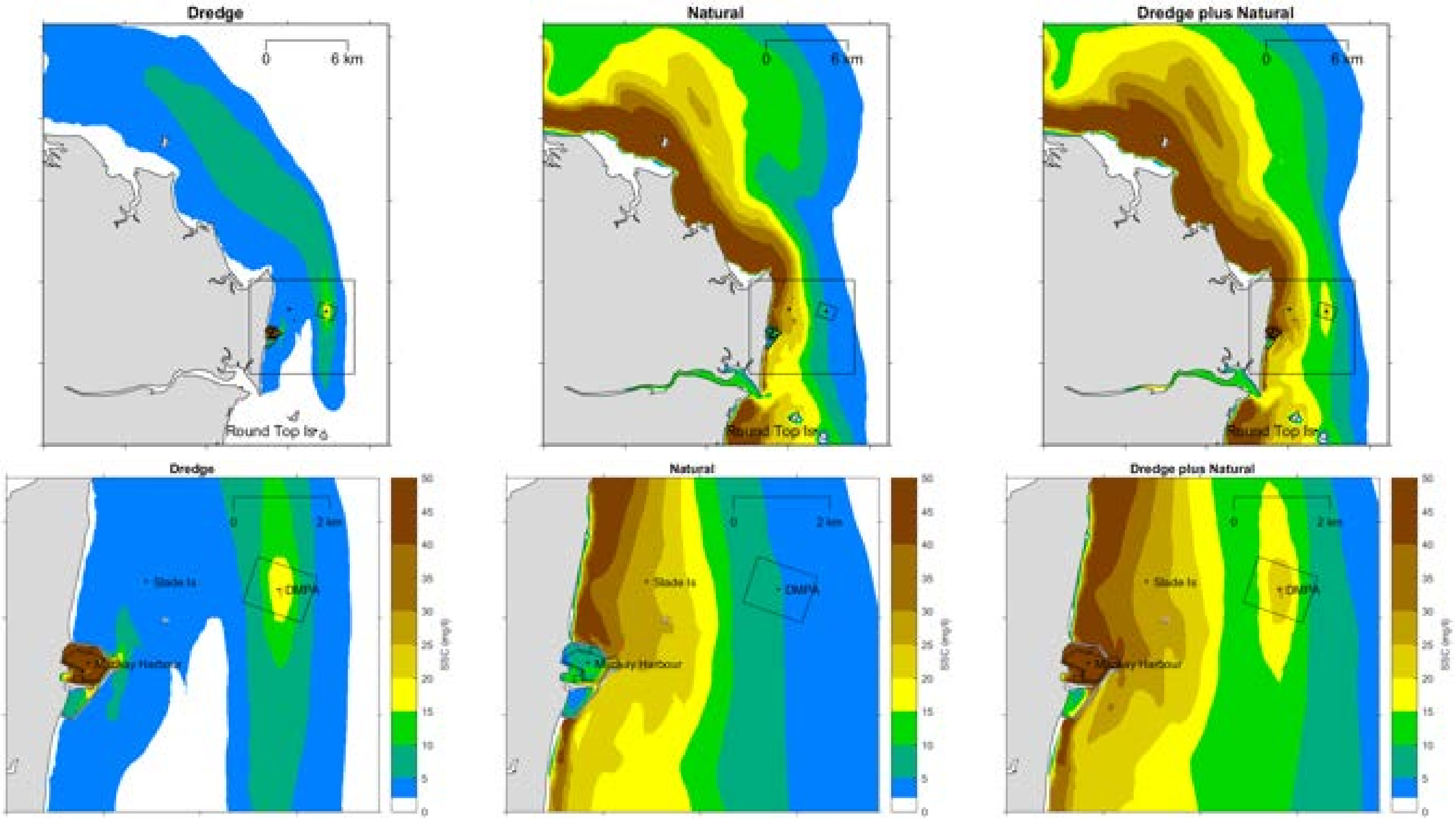


Figure A33. 80th percentile SSC for dredging, natural and natural plus dredging for 1,000,000 m³ of sediment in the ambient dry season.



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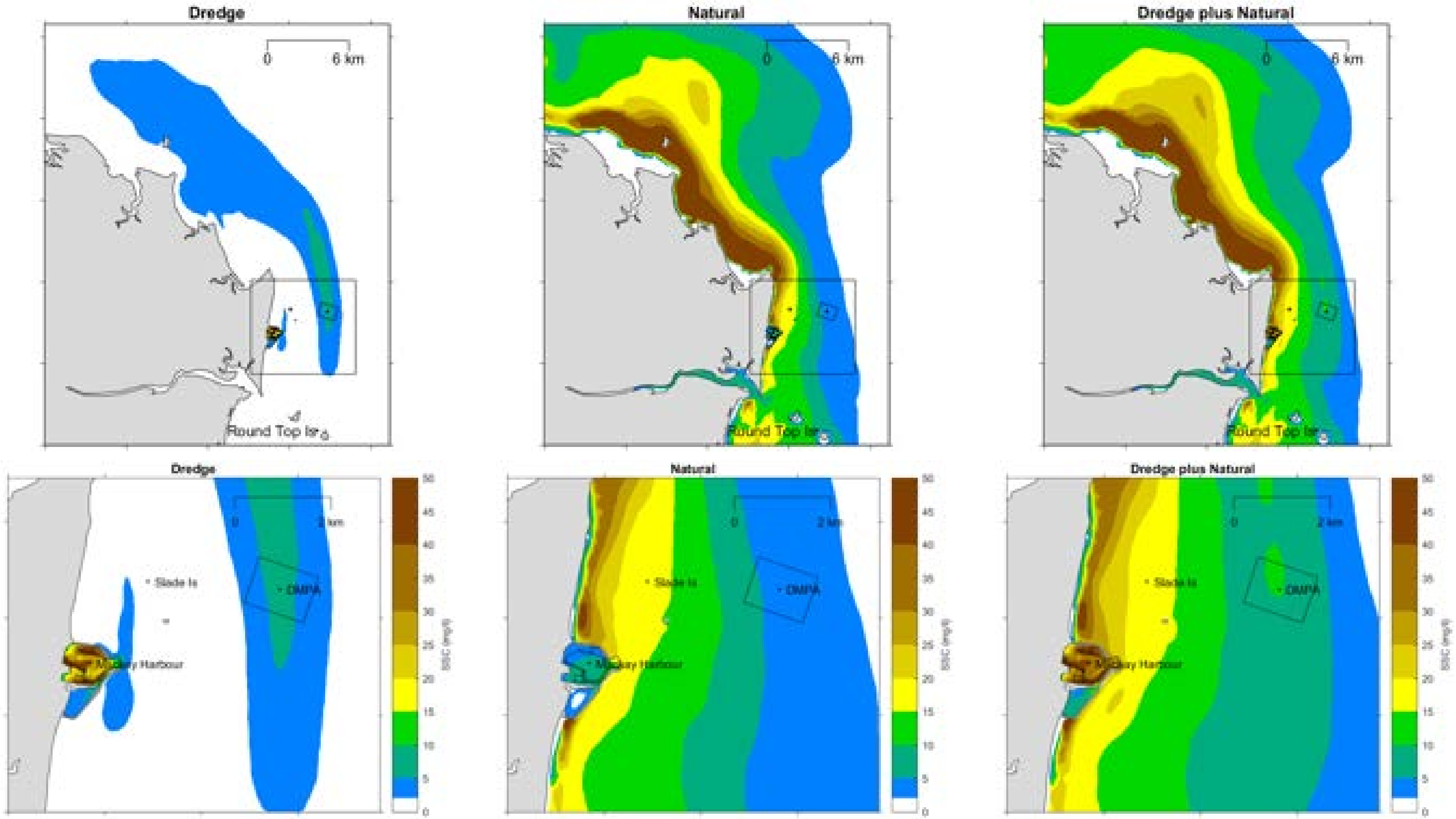

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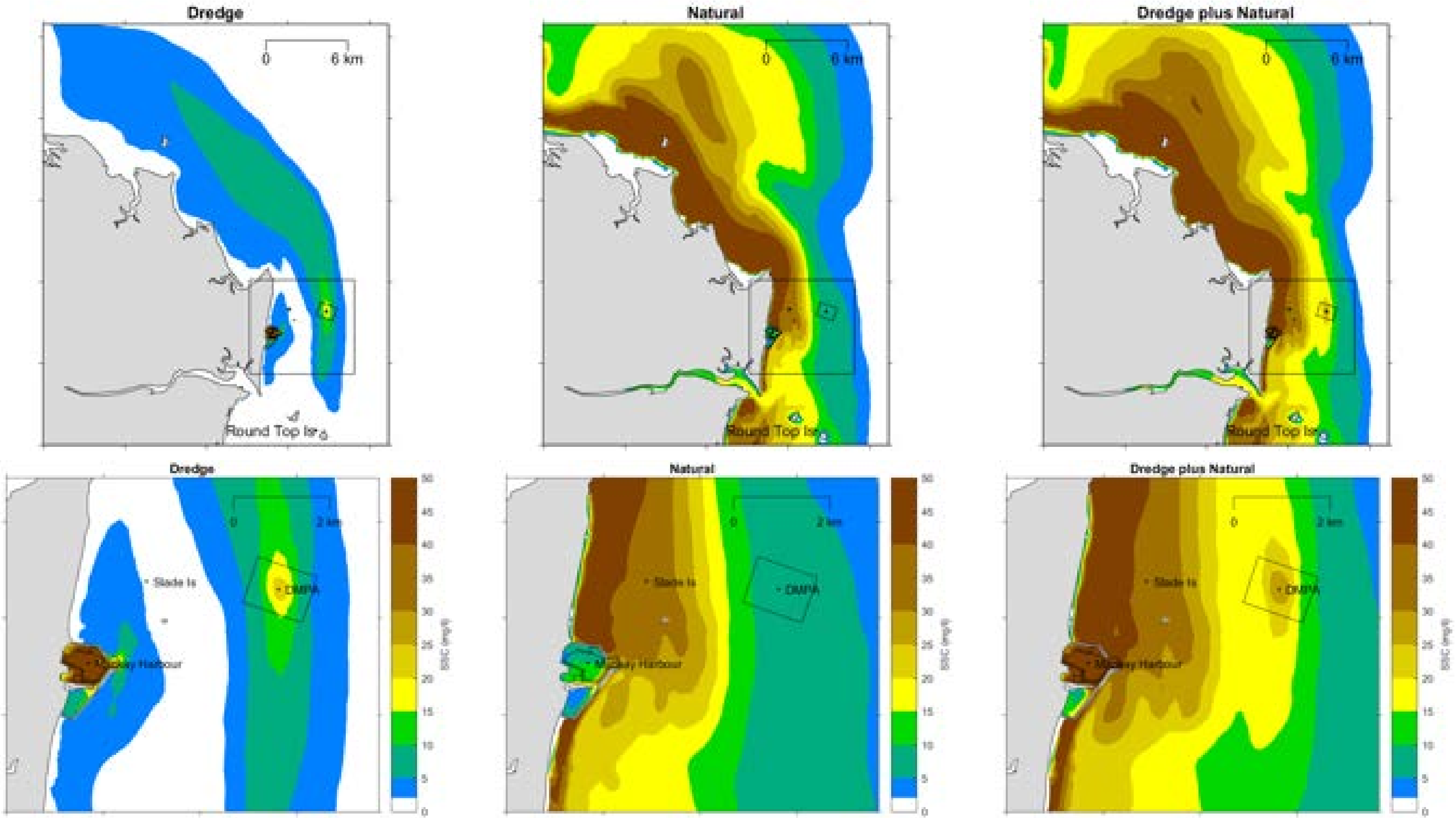

Figure A36. **95th percentile SSC for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic dry season.**

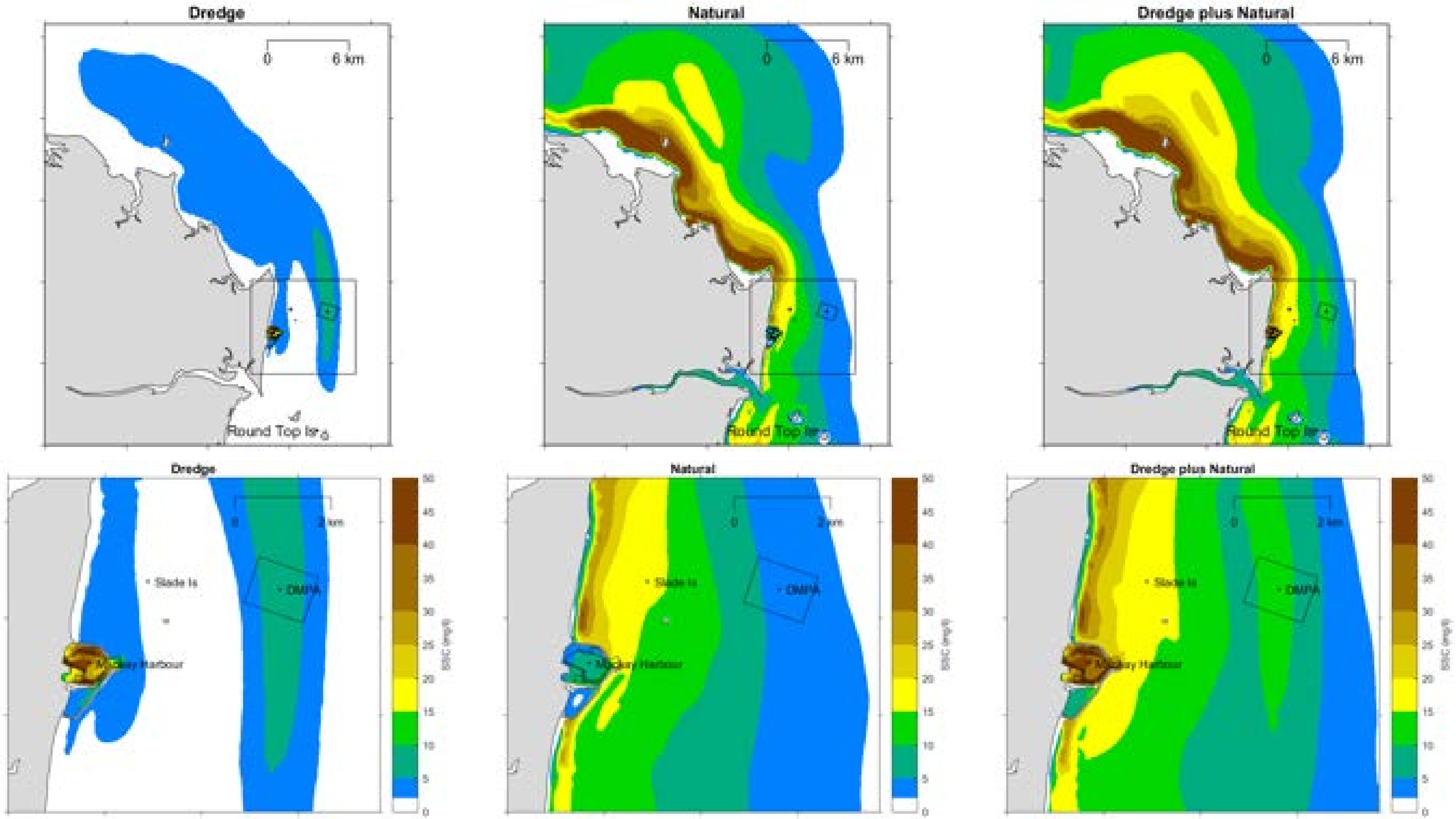

Figure A37. 80th percentile SSC for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the ambient wet season.

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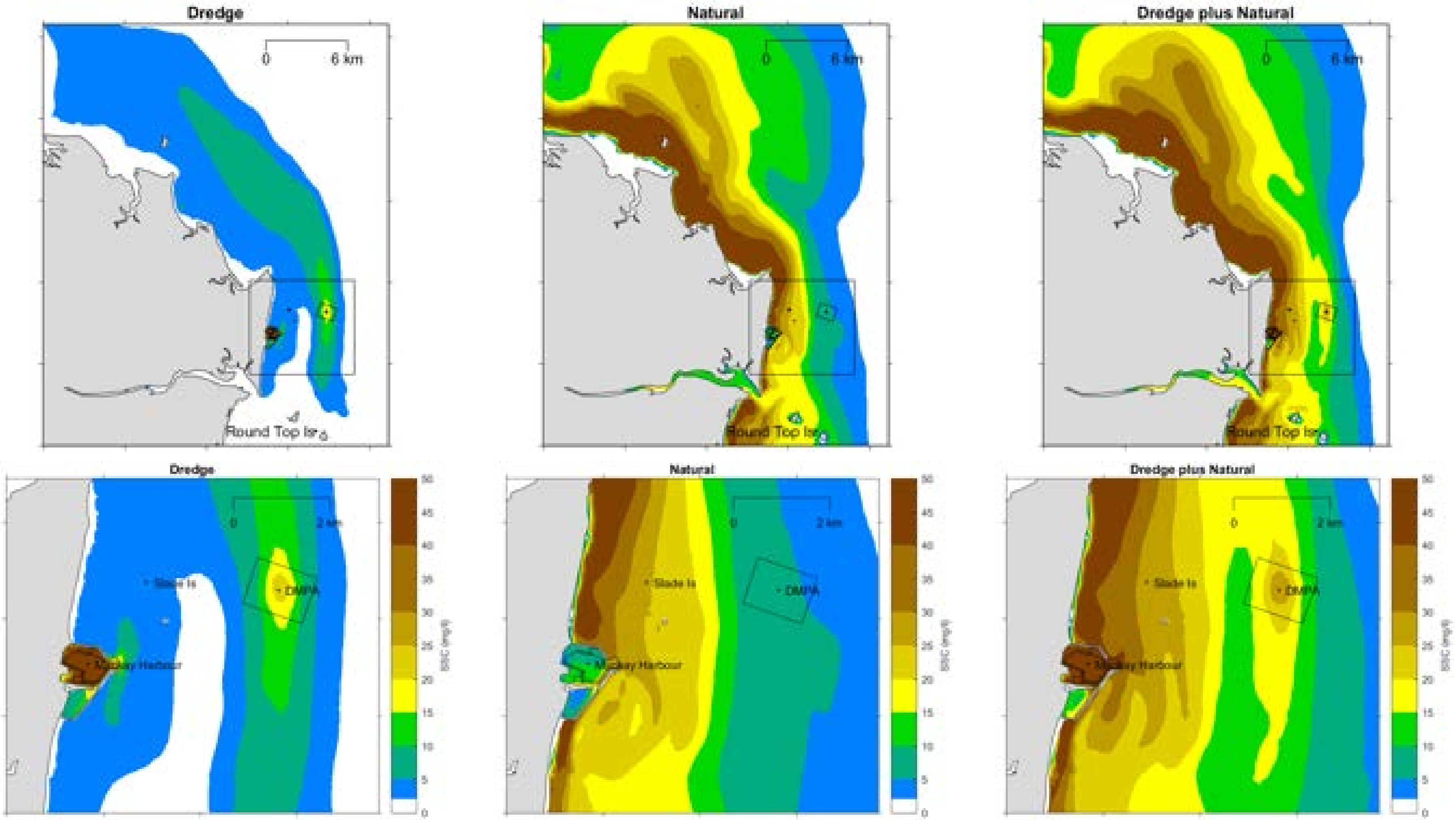

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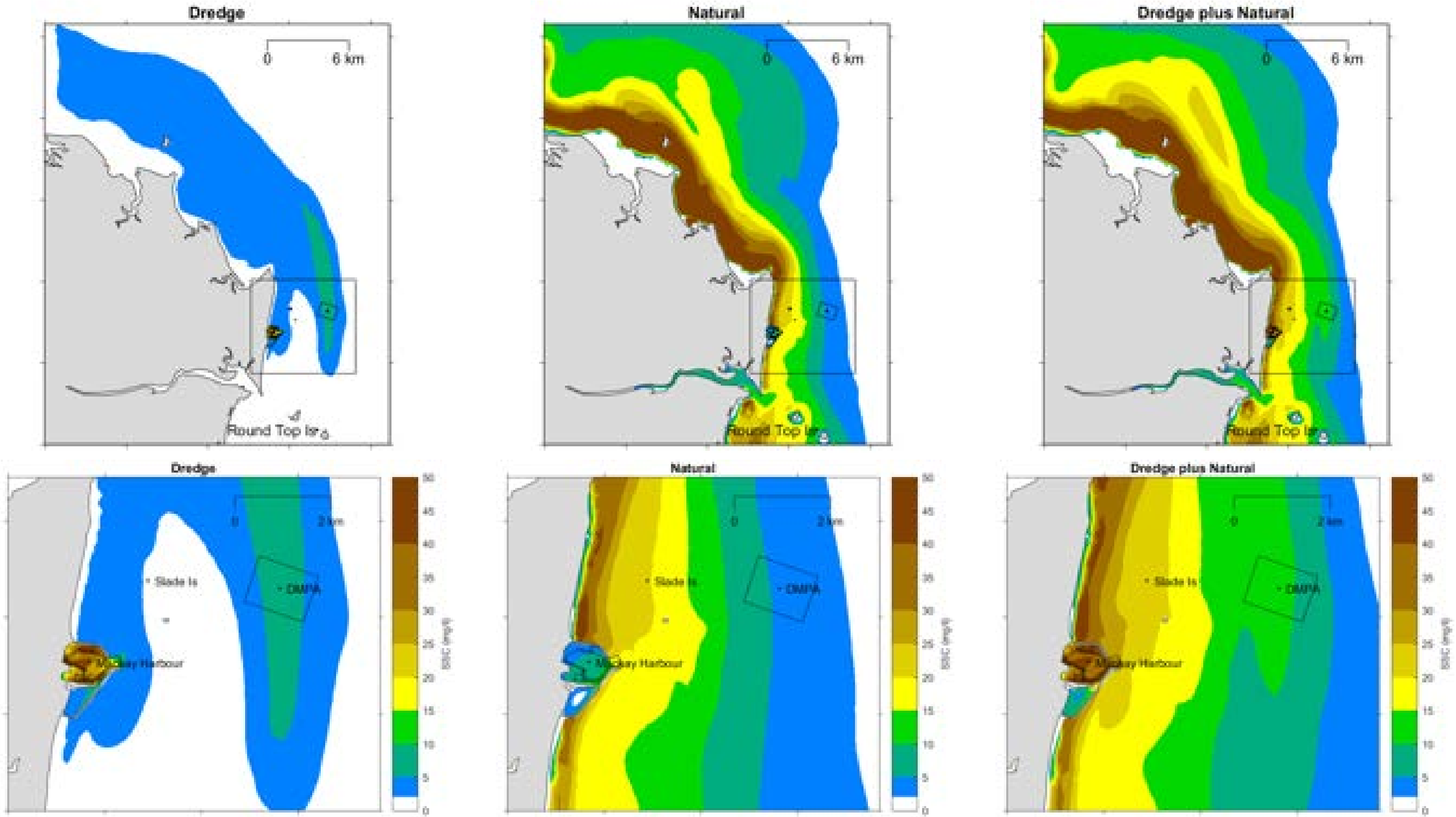

Figure A39. 80th percentile SSC for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic wet season.

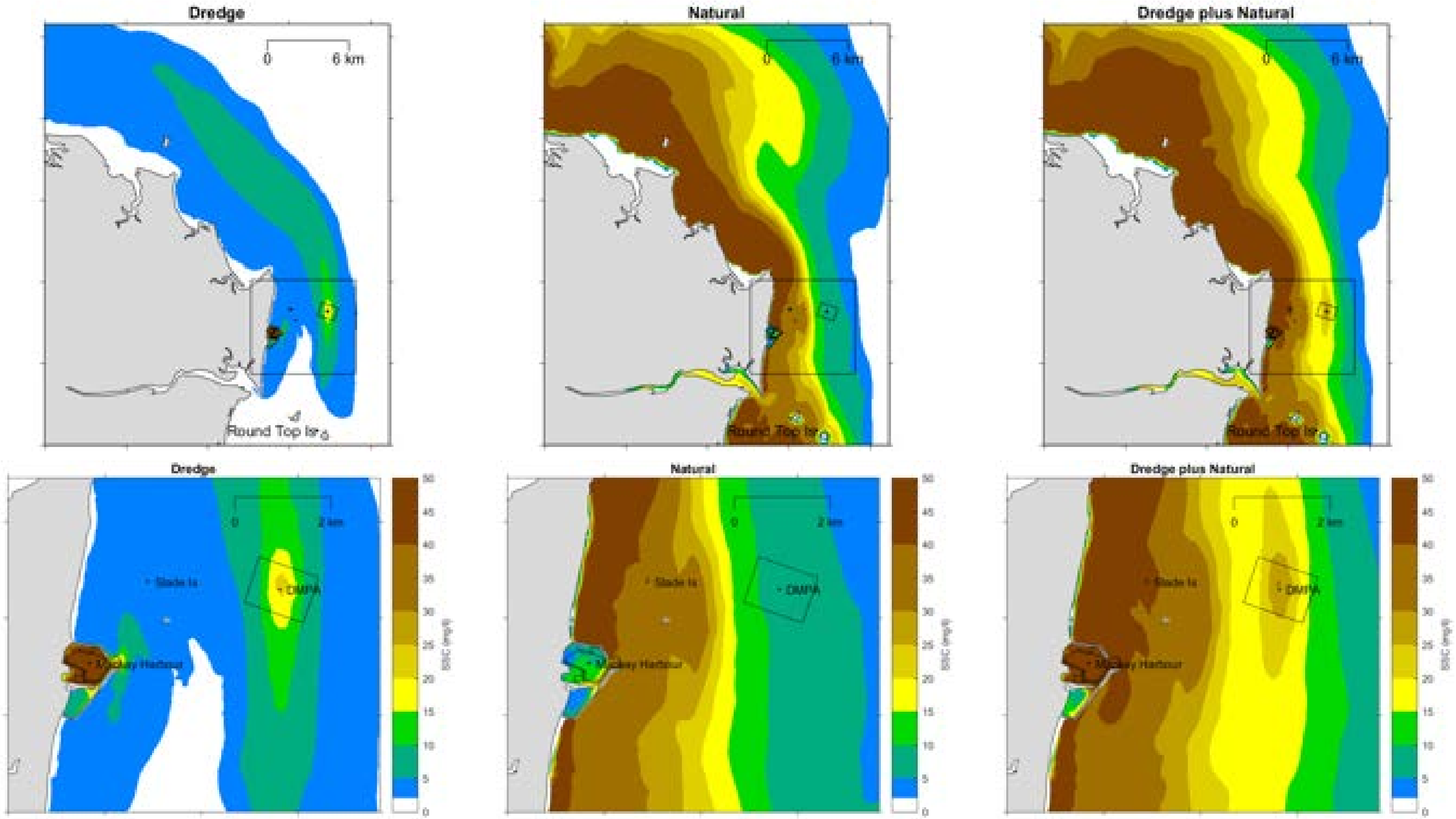

Figure A40. 95th percentile SSC for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic wet season.

Appendix B – Time Series Plots

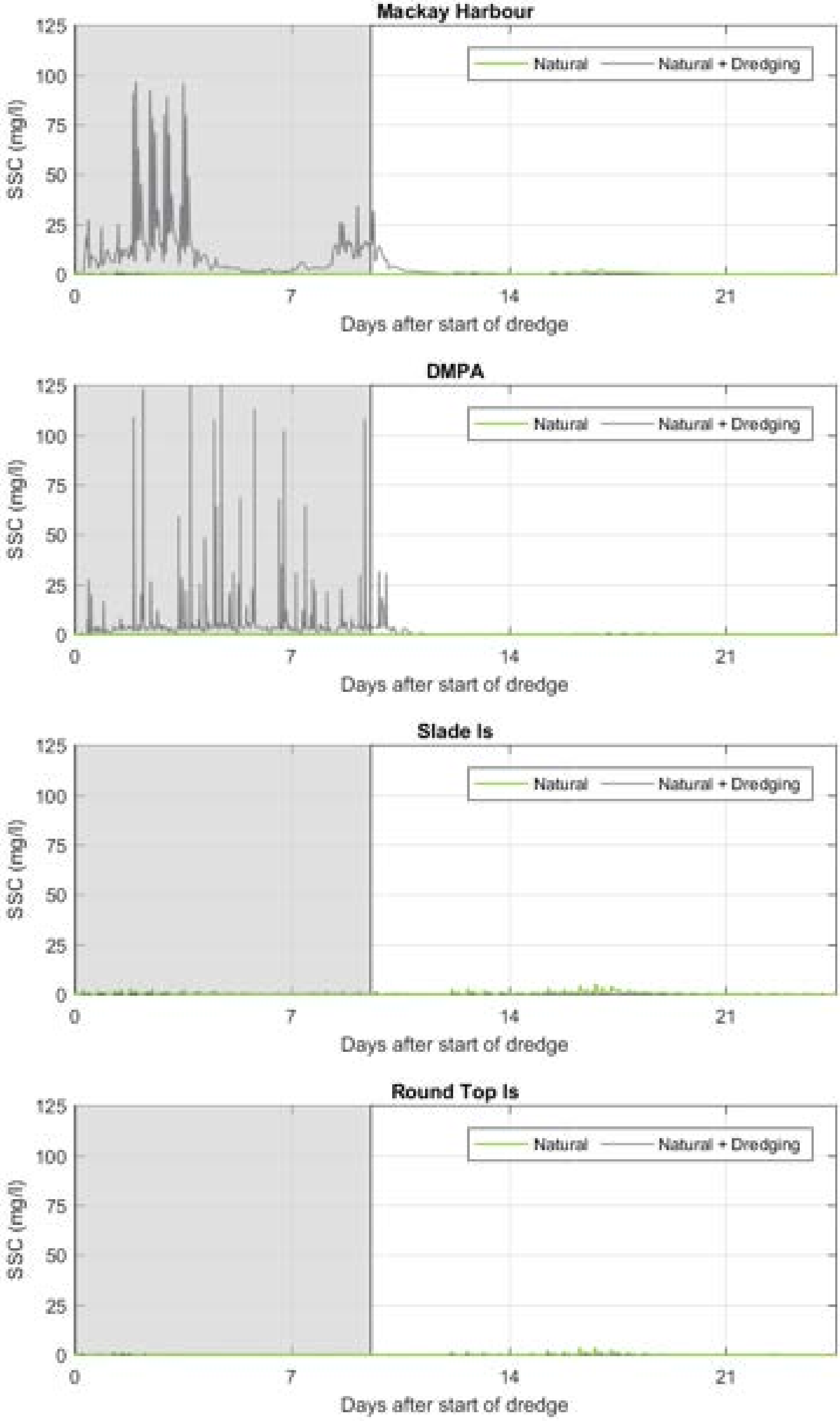

Figure B1. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the ambient dry season. *Note: grey box shows dredge period.*

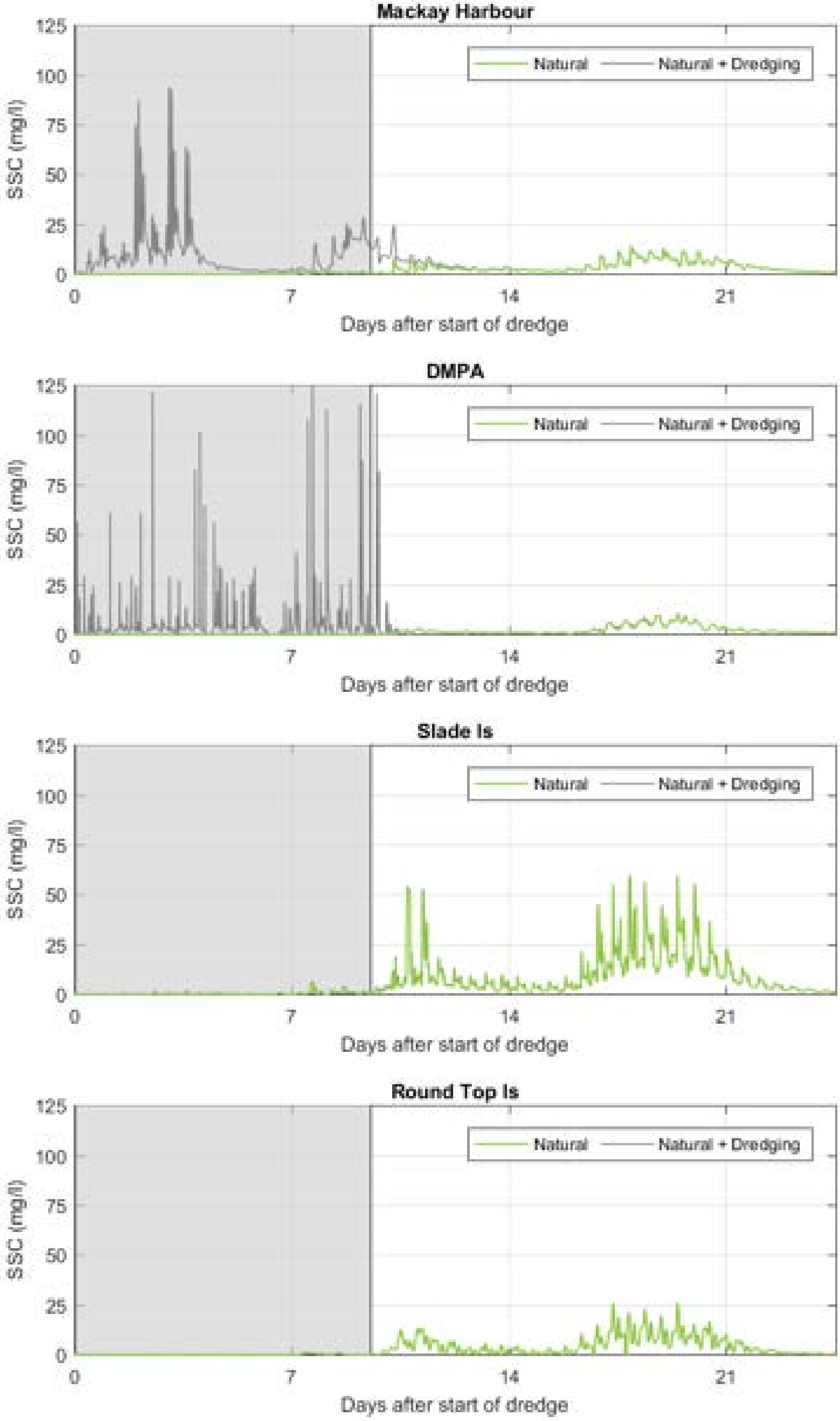

Figure B2. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the energetic dry season. *Note: grey box shows dredge period.*

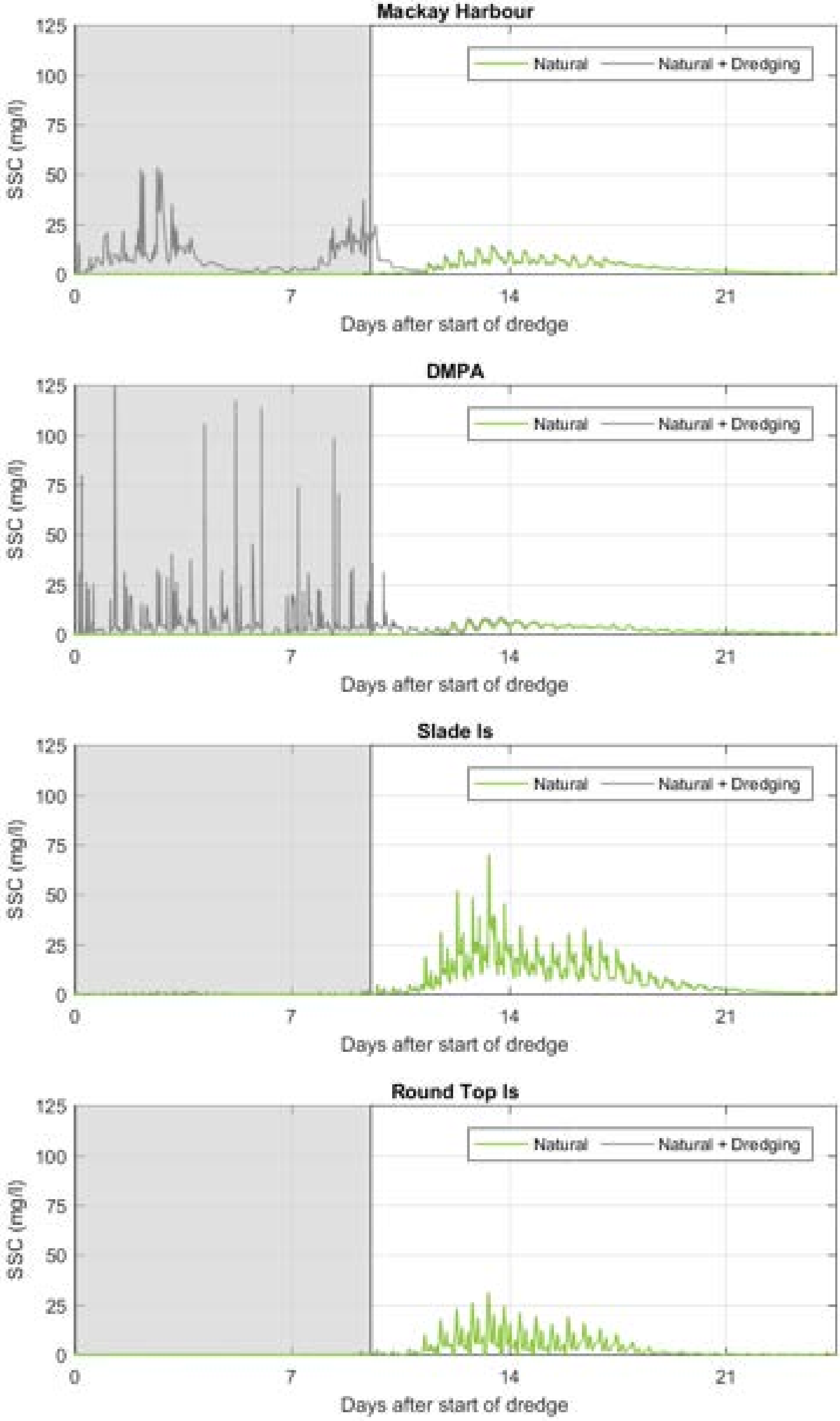

Figure B3. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the ambient wet season. *Note: grey box shows dredge period.*

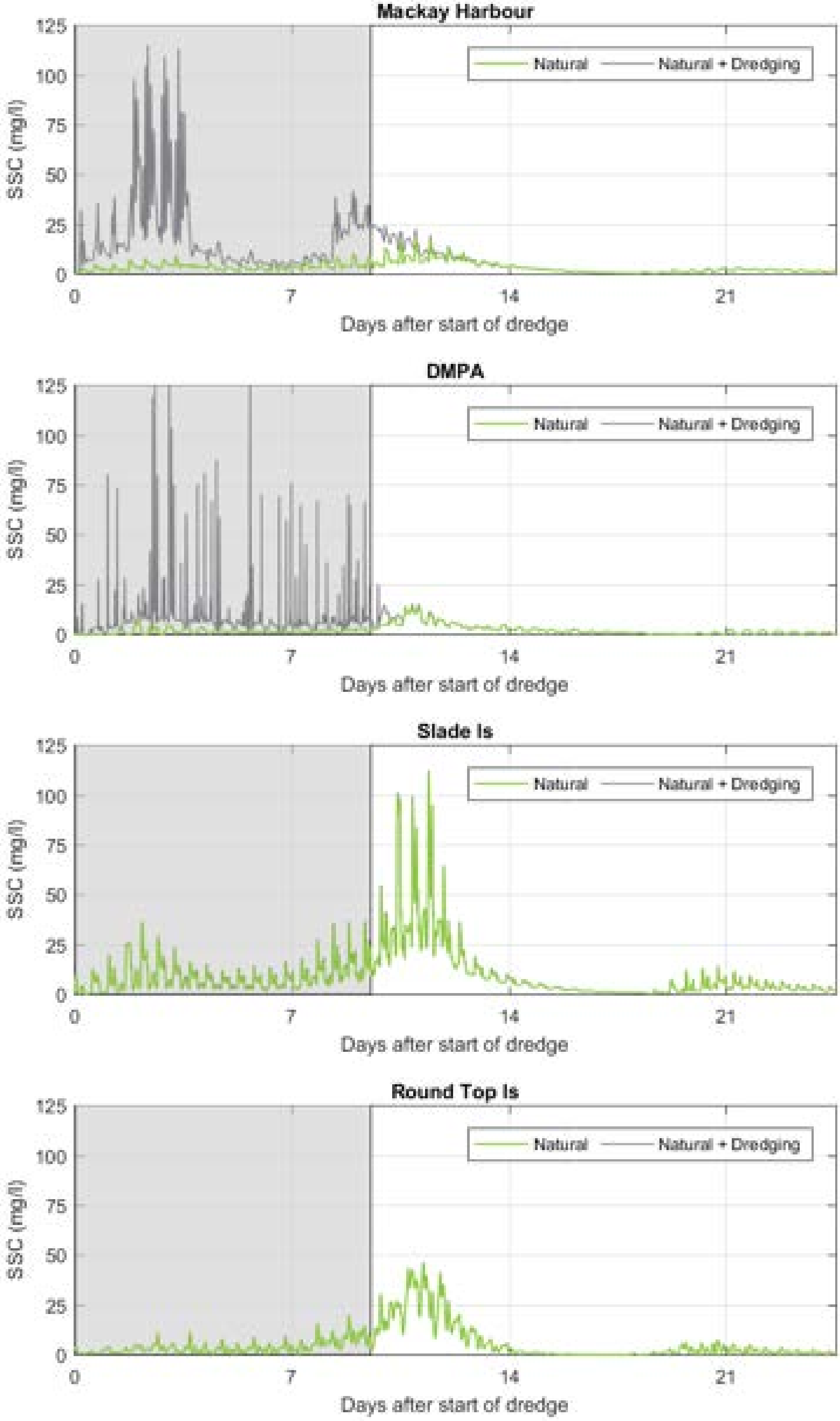

Figure B4. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season. *Note: grey box shows dredge period.*

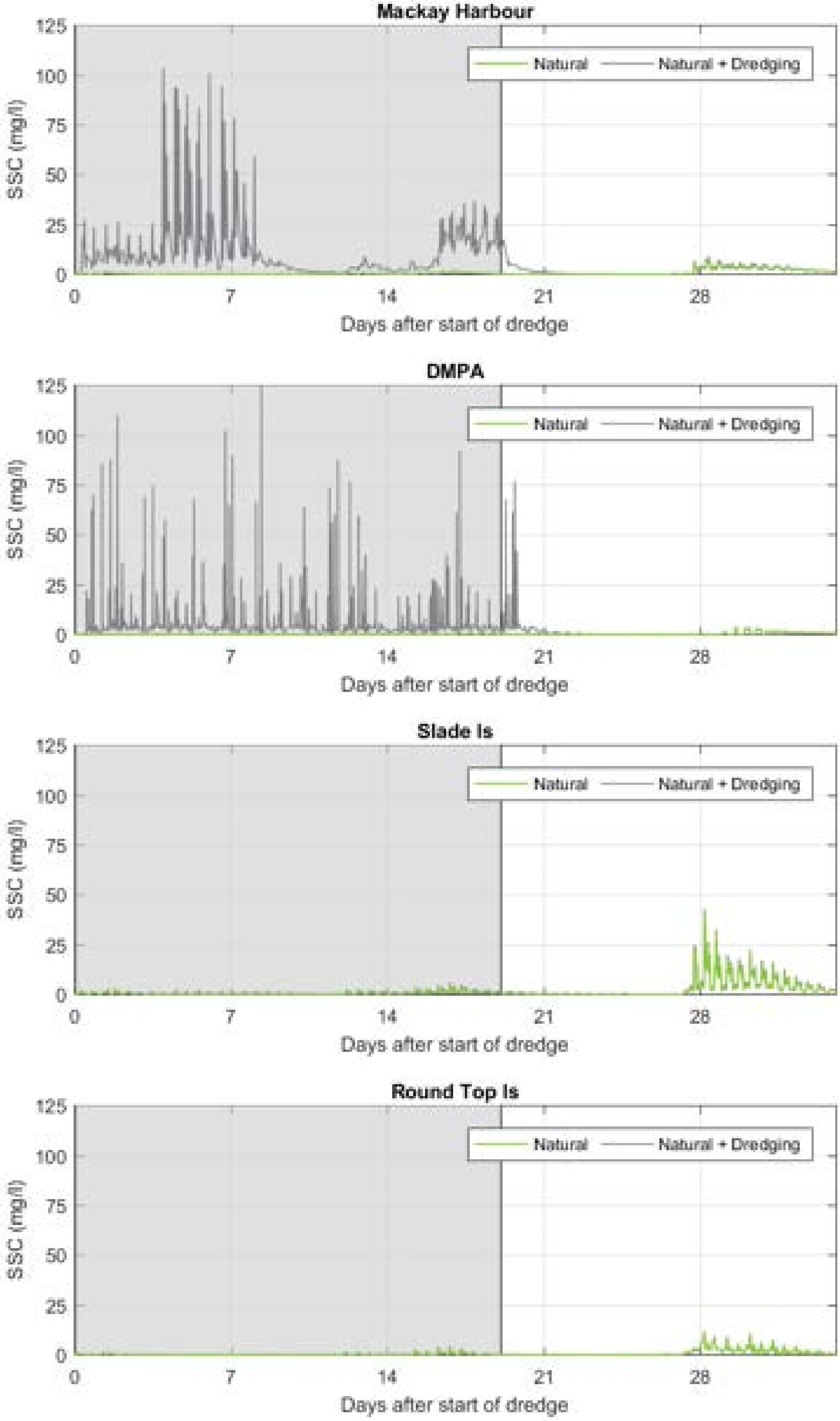

Figure B5. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 250,000 m^3 of sediment in the ambient dry season. *Note: grey box shows dredge period.*

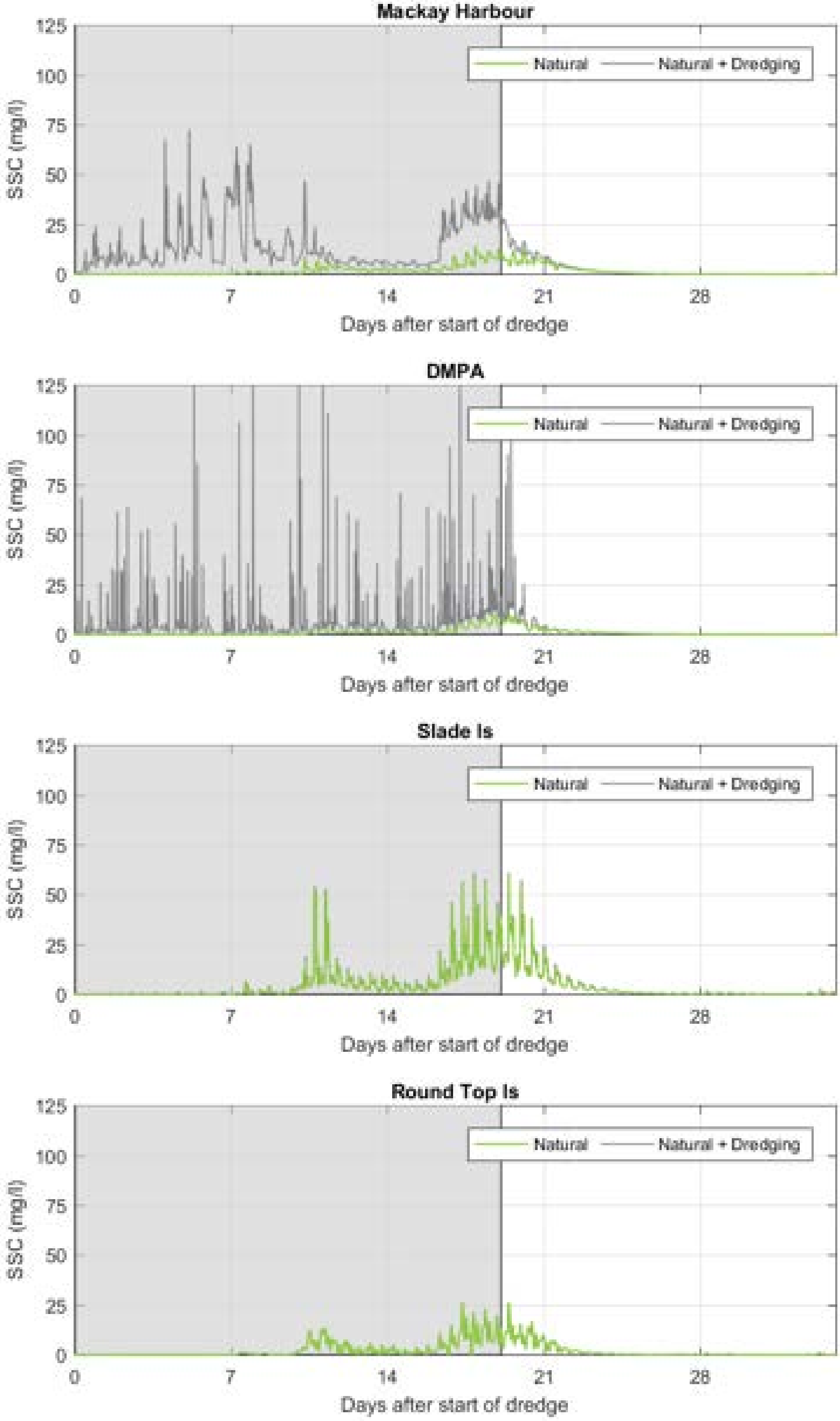

Figure B6. **Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 250,000 m³ of sediment in the energetic dry season.** *Note: grey box shows dredge period.*

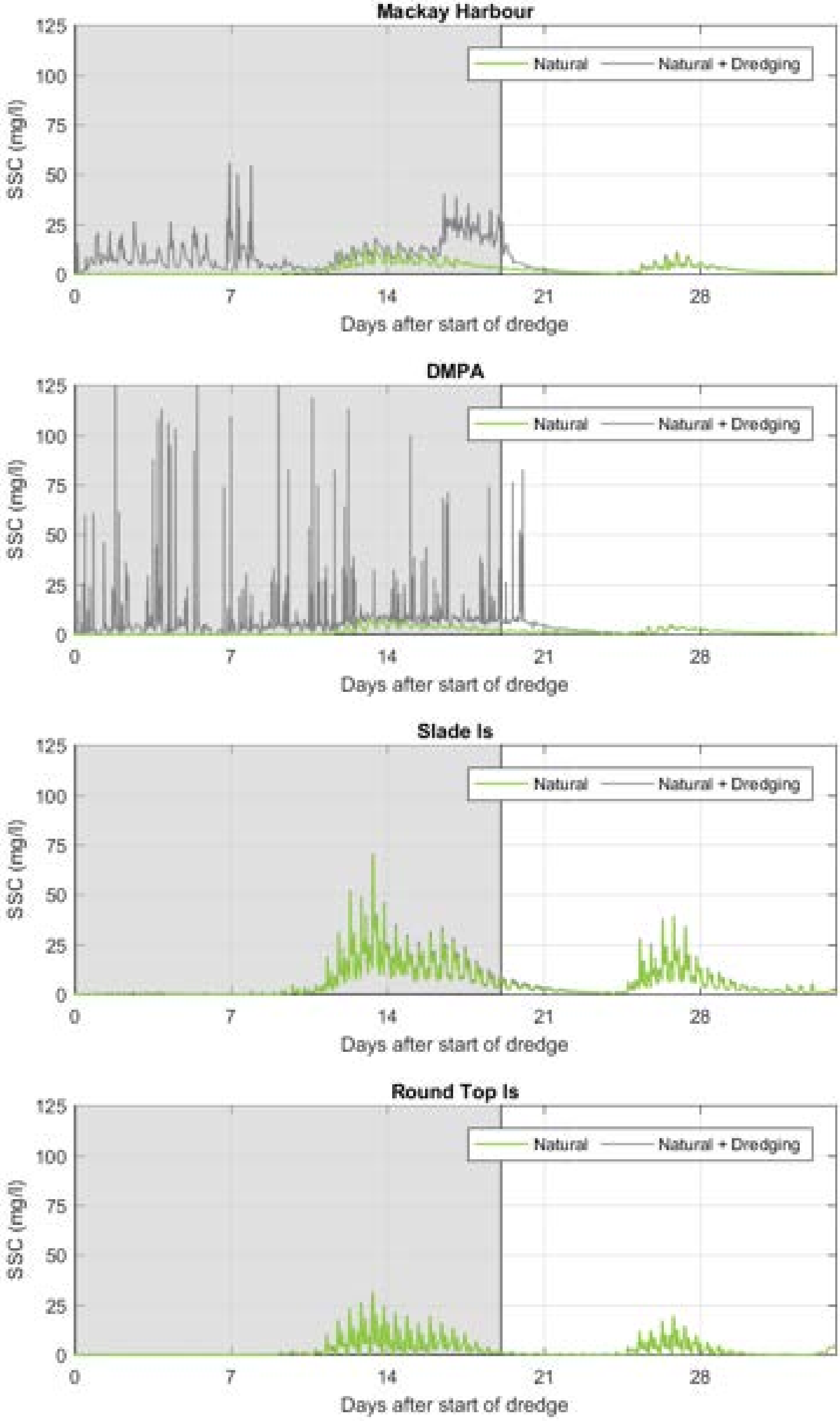

Figure B7. **Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 250,000 m^3 of sediment in the ambient wet season.** *Note: grey box shows dredge period.*

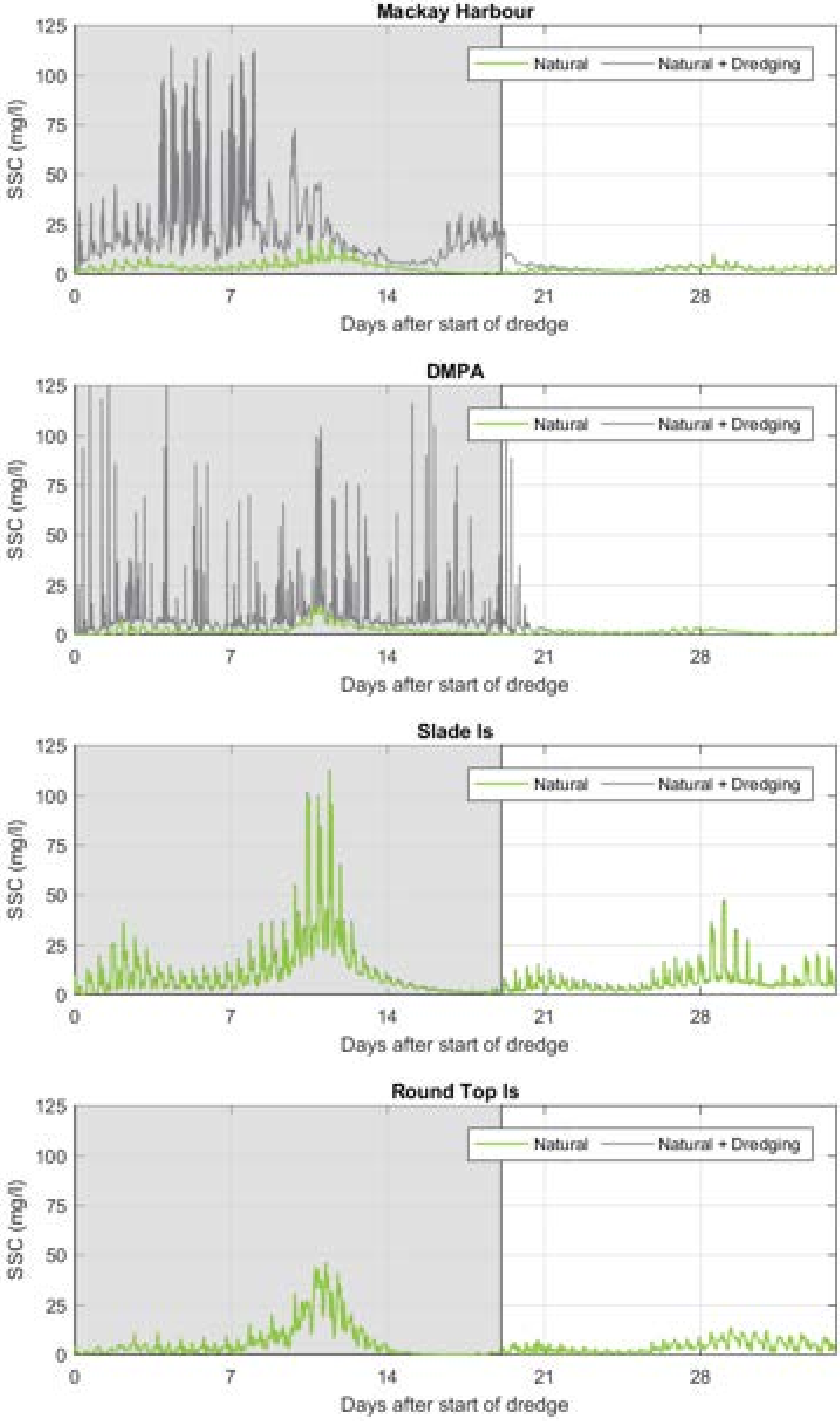

Figure B8. **Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 250,000 m^3 of sediment in the energetic wet season.** *Note: grey box shows dredge period.*

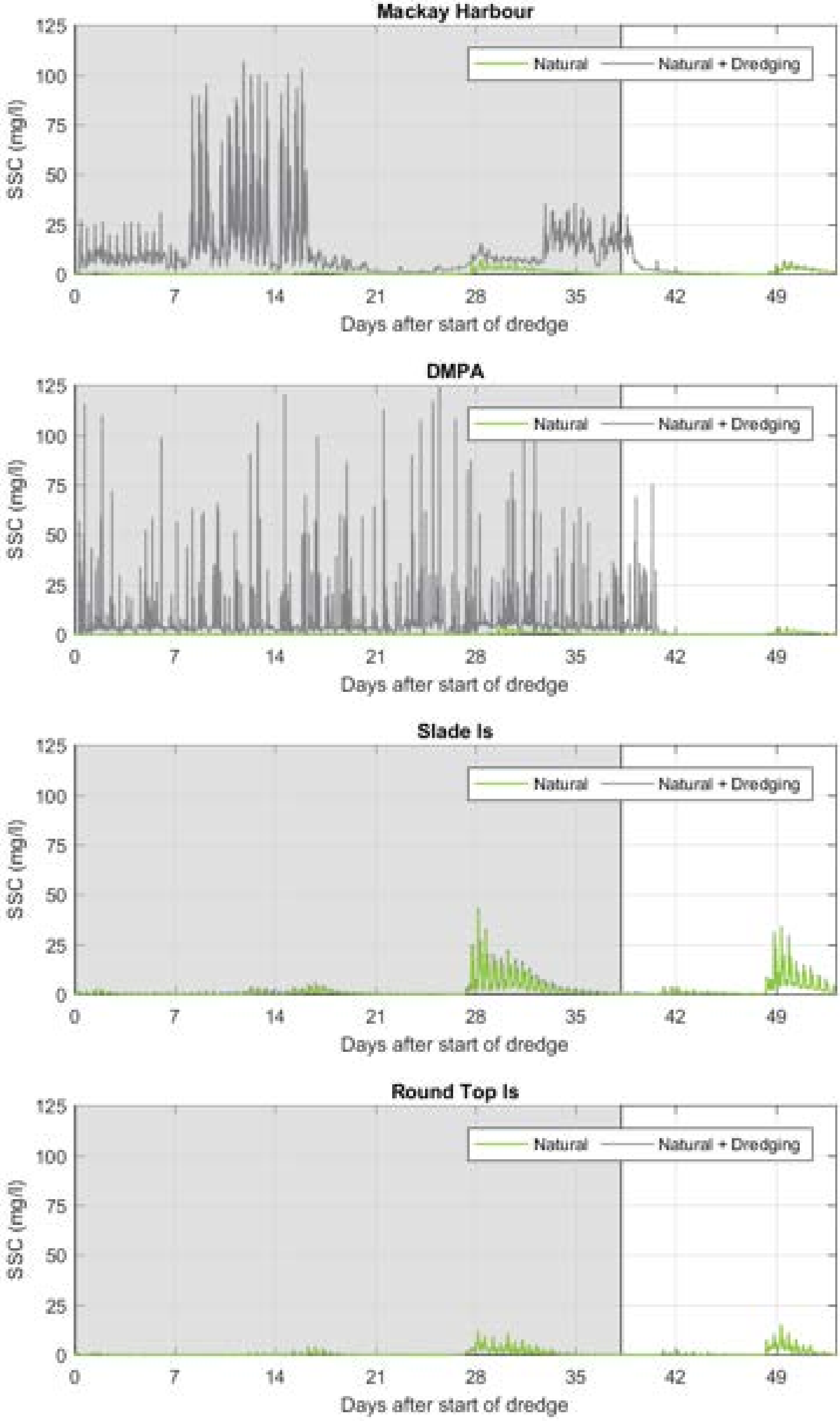

Figure B9. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 500,000 m^3 of sediment in the ambient dry season. *Note: grey box shows dredge period.*

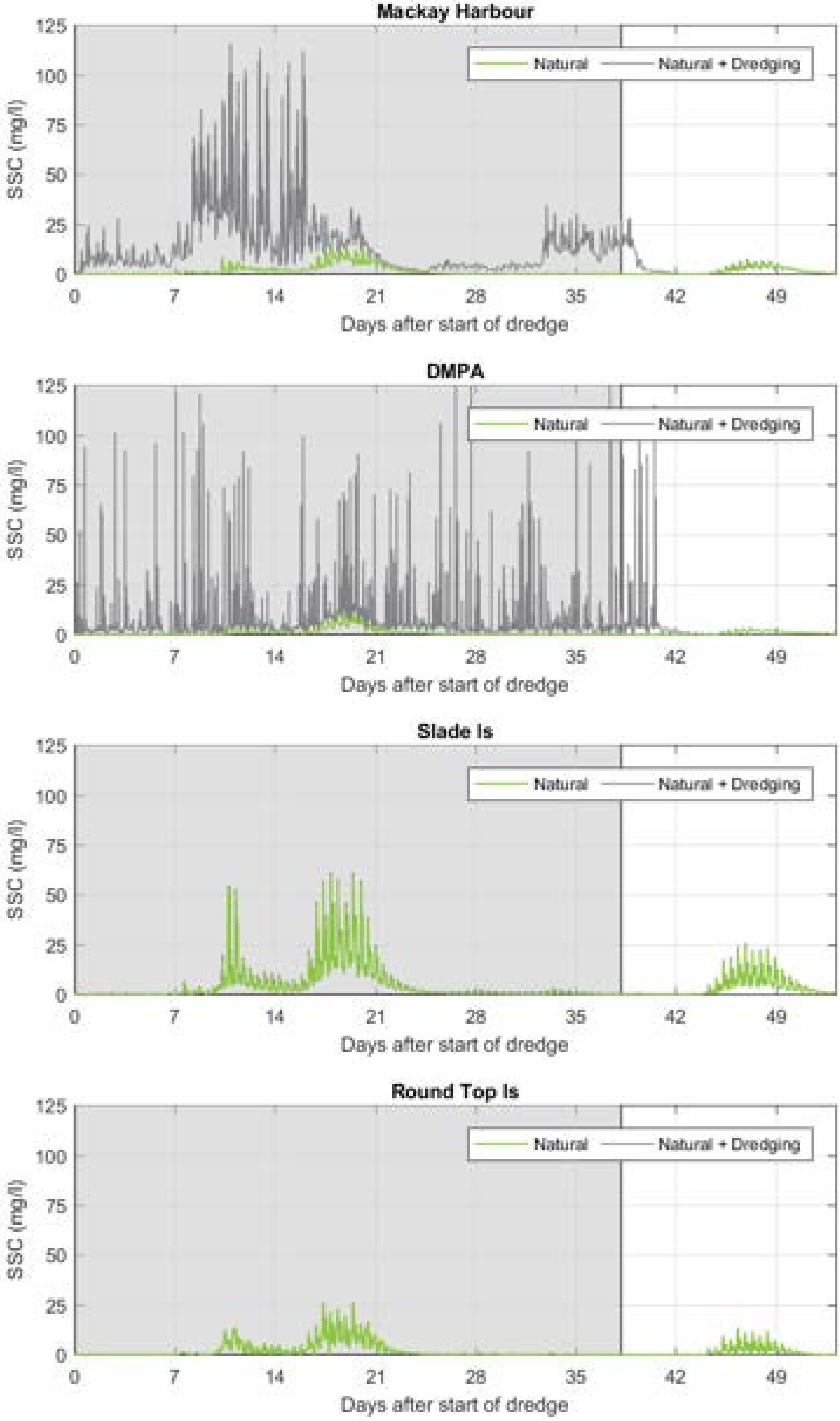

Figure B10. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 500,000 m³ of sediment in the energetic dry season. *Note: grey box shows dredge period.*

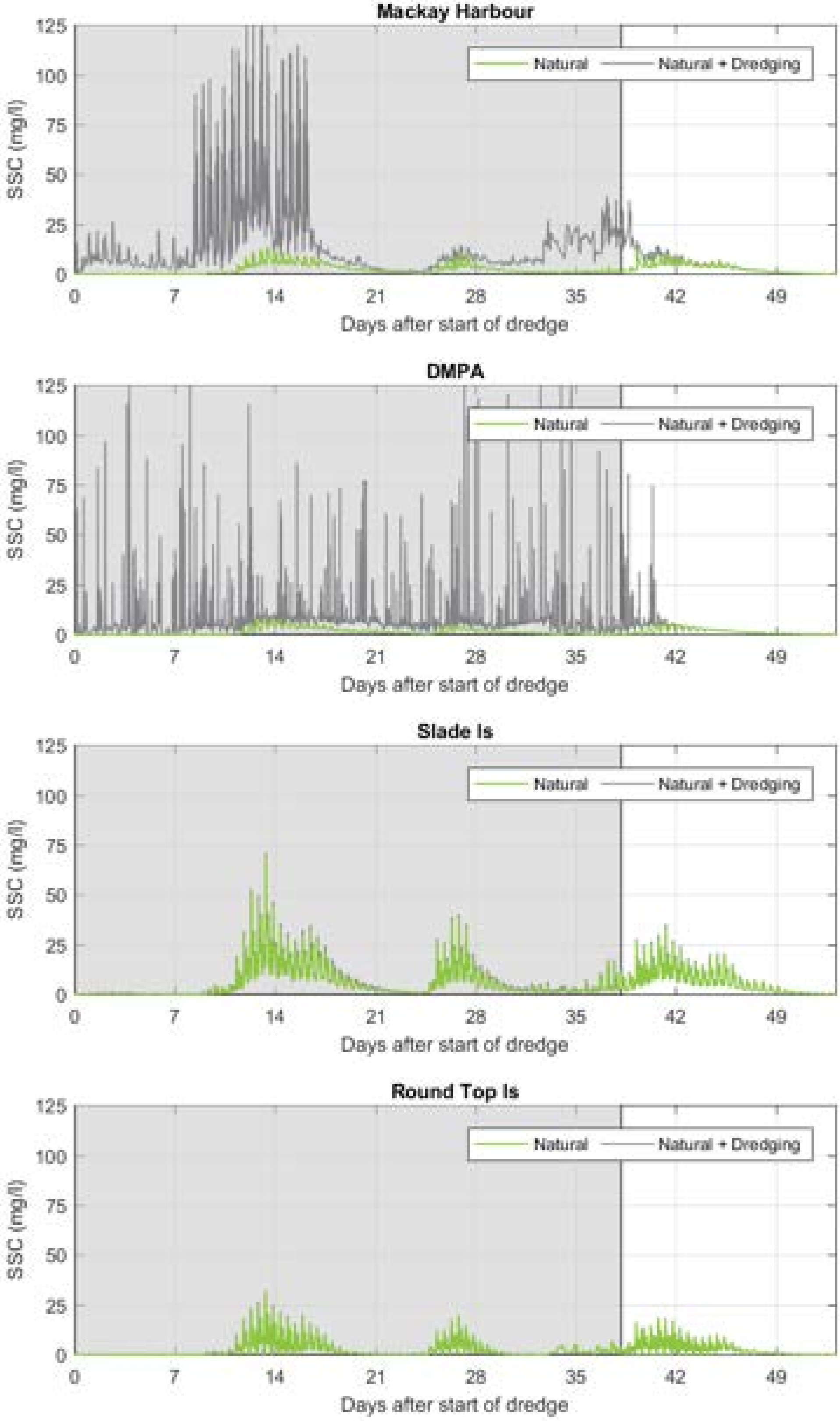

Figure B11. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 500,000 m^3 of sediment in the ambient wet season. *Note: grey box shows dredge period.*

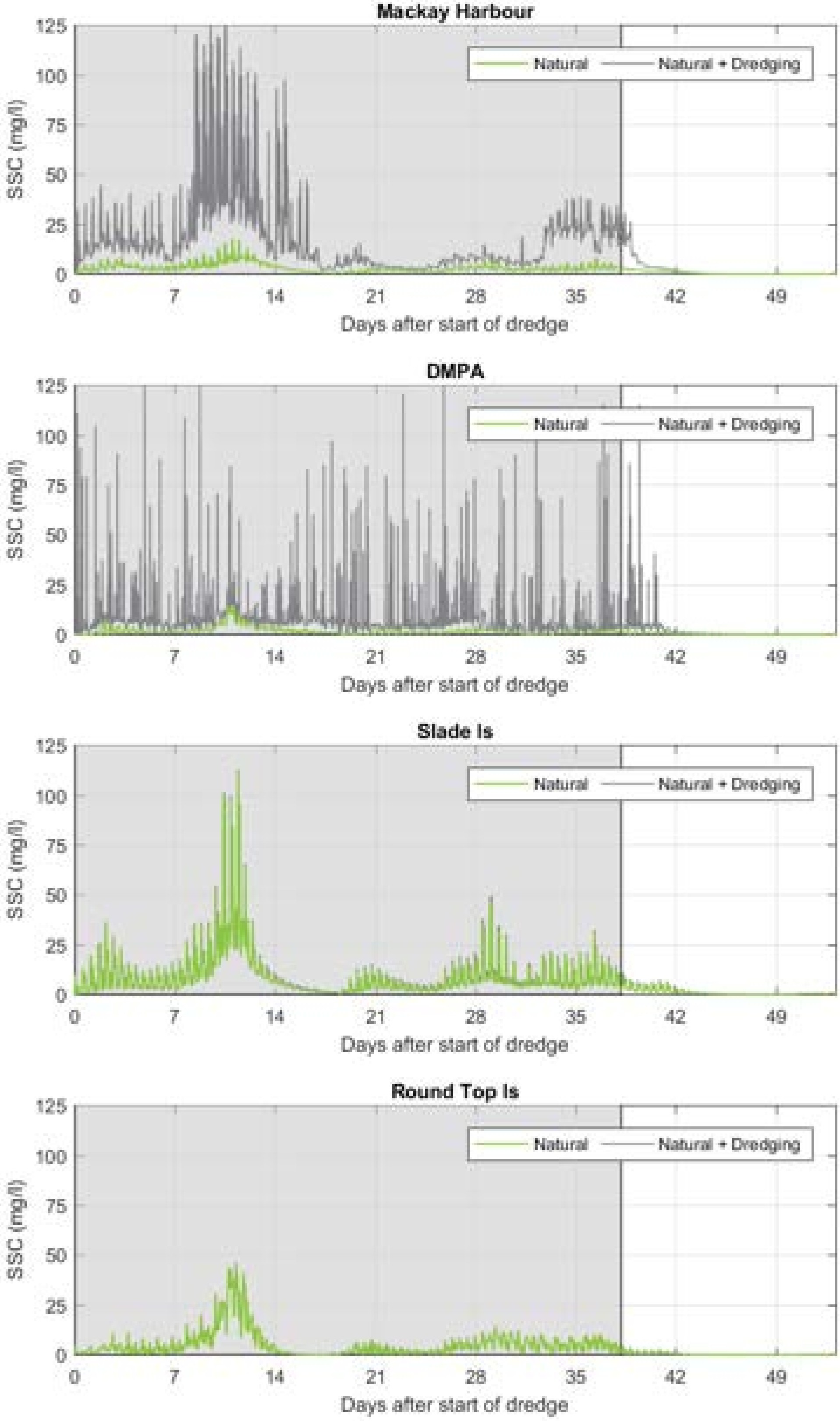

Figure B12. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 500,000 m³ of sediment in the energetic wet season. *Note: grey box shows dredge period.*

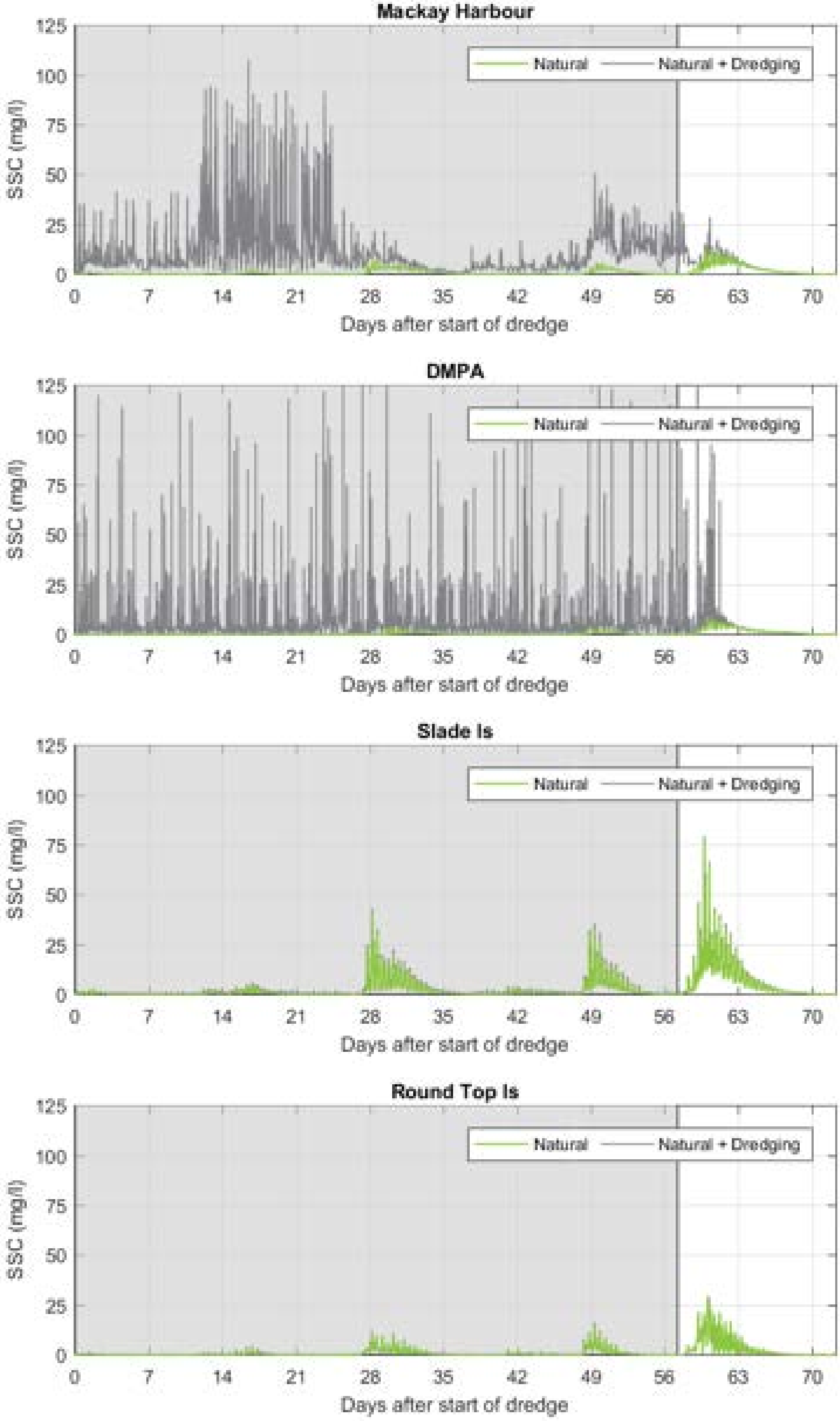

Figure B13. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 750,000 m^3 of sediment in the ambient dry season. *Note: grey box shows dredge period.*

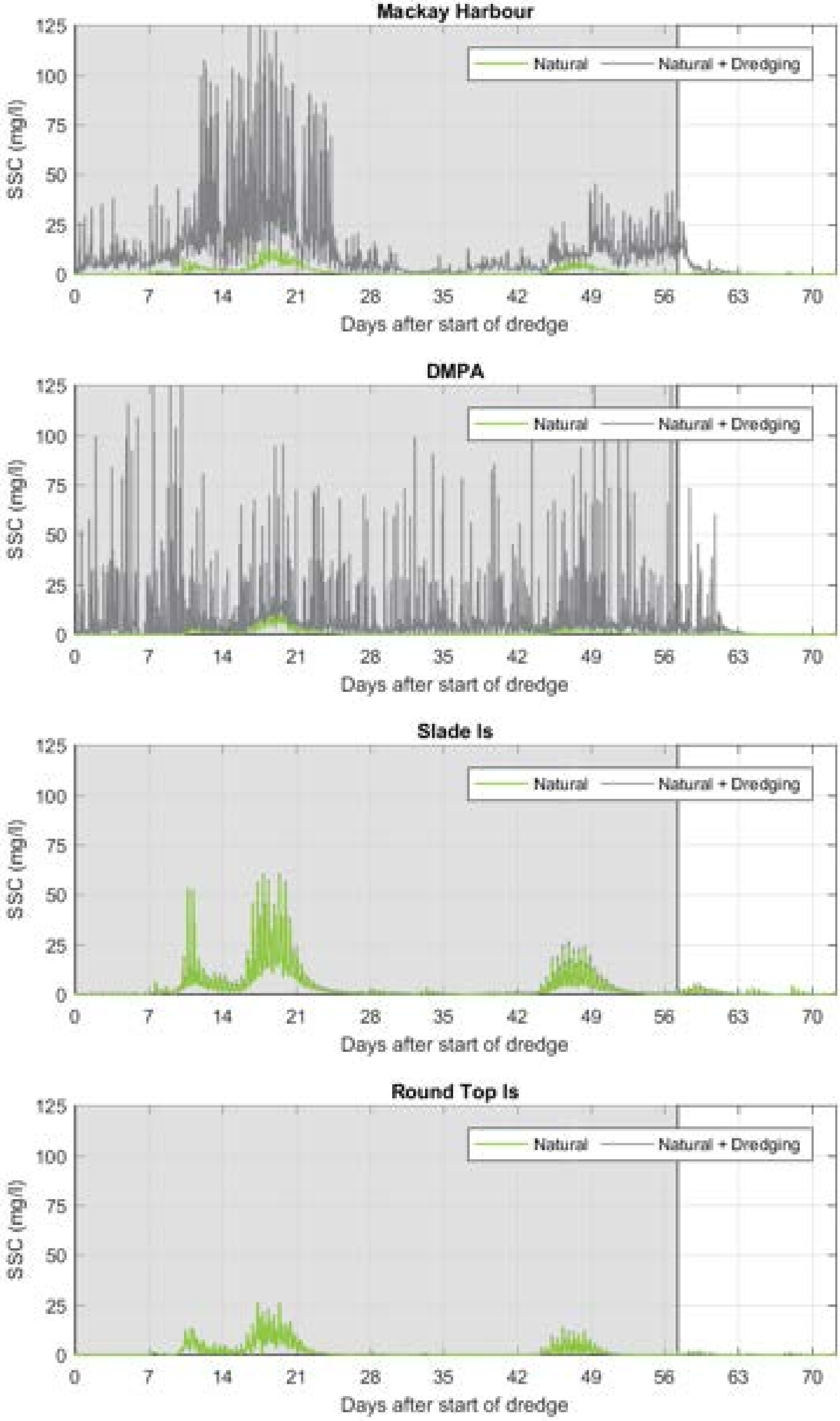

Figure B14. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 750,000 m^3 of sediment in the energetic dry season. *Note: grey box shows dredge period.*

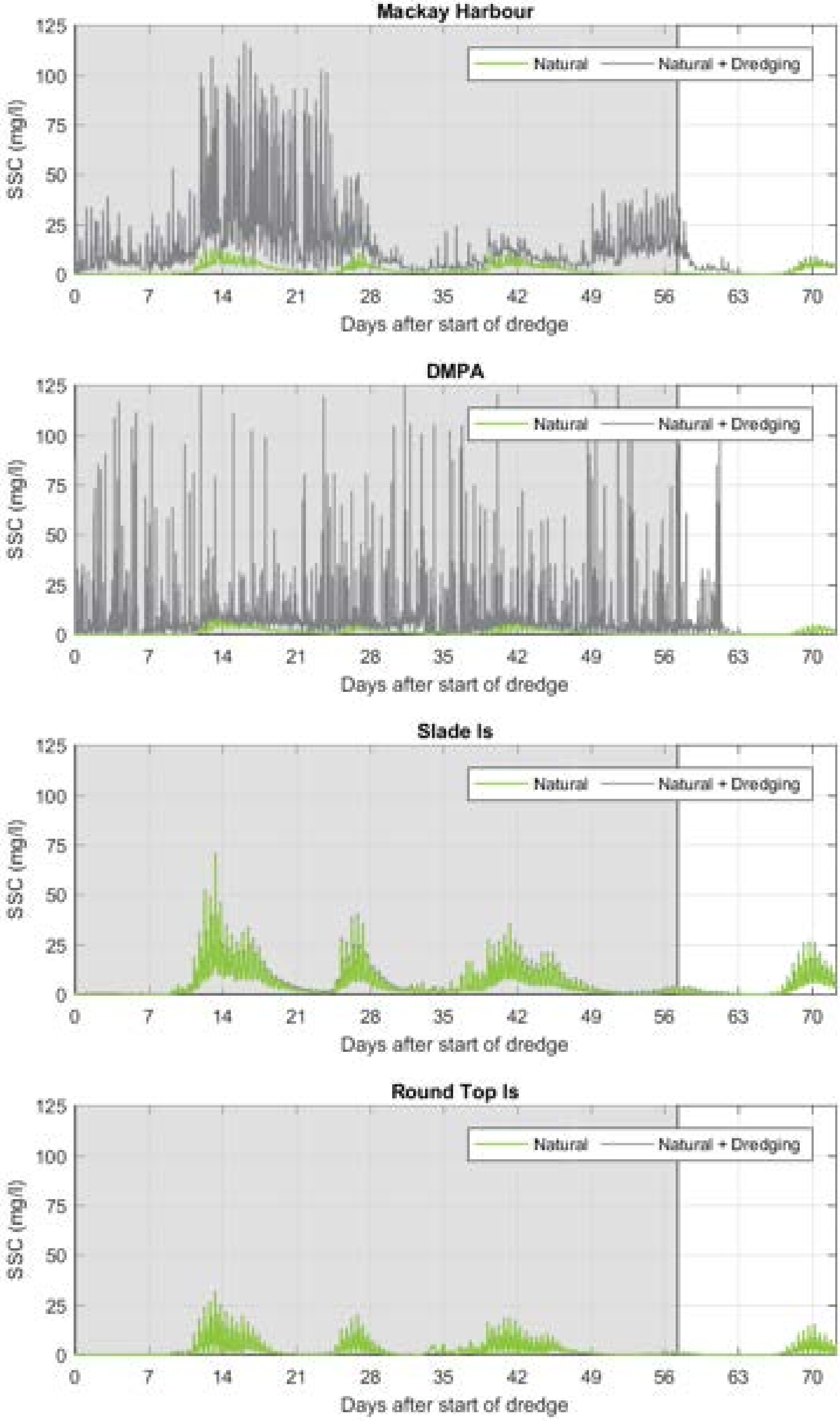

Figure B15. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 750,000 m^3 of sediment in the ambient wet season. *Note: grey box shows dredge period.*

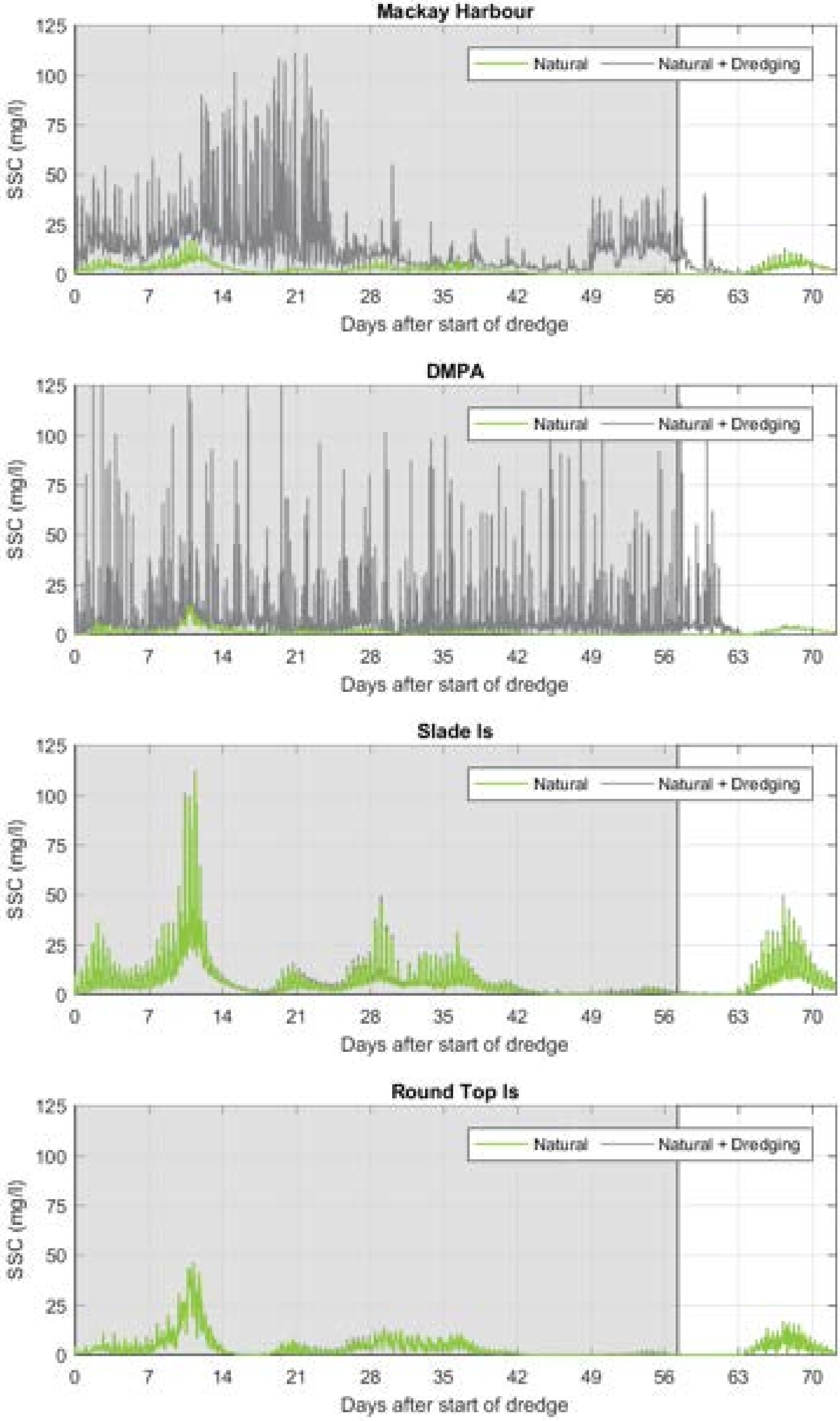

Figure B16. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 750,000 m³ of sediment in the energetic wet season. *Note: grey box shows dredge period.*

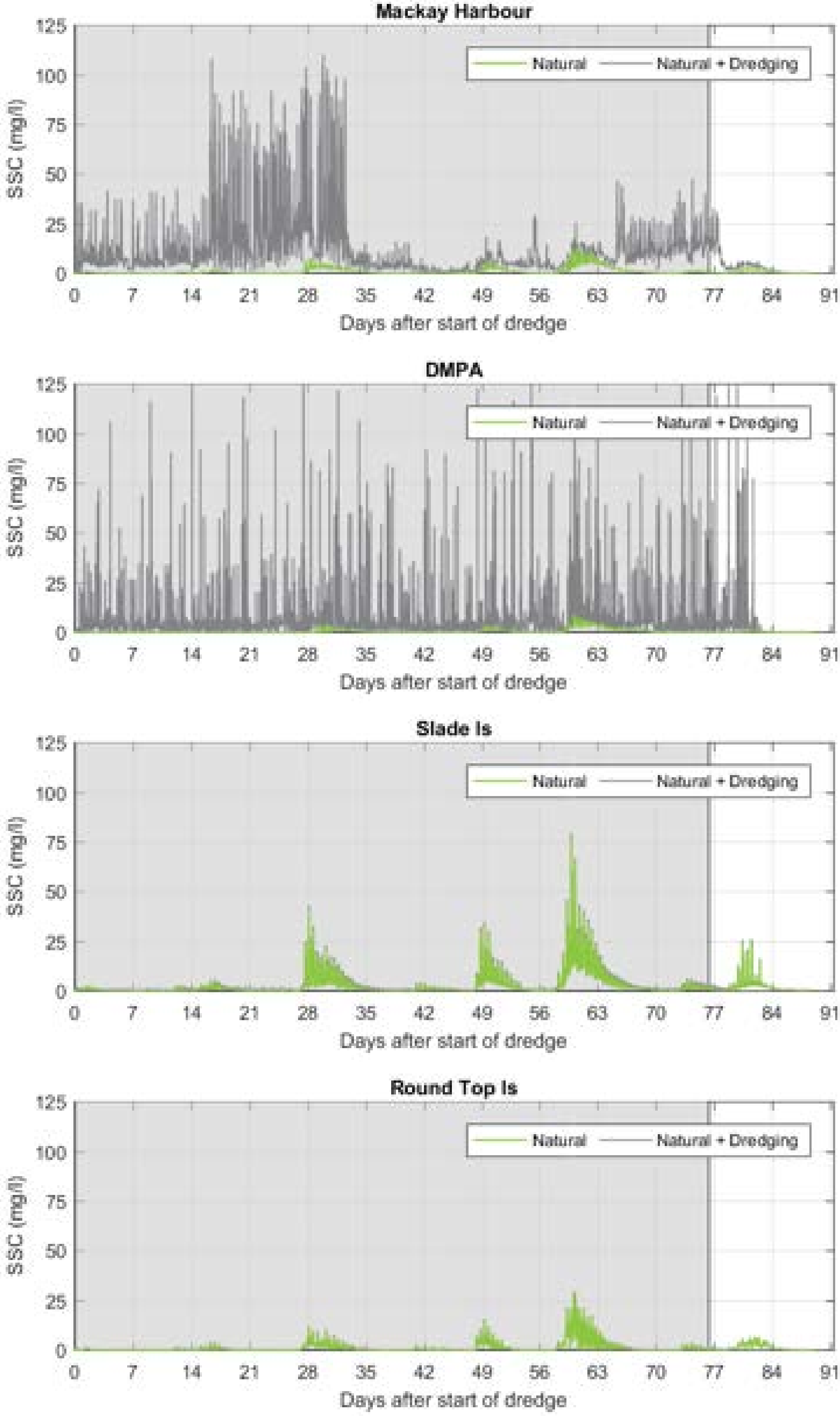

Figure B17. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 1,000,000 m^3 of sediment in the ambient dry season. *Note: grey box shows dredge period.*

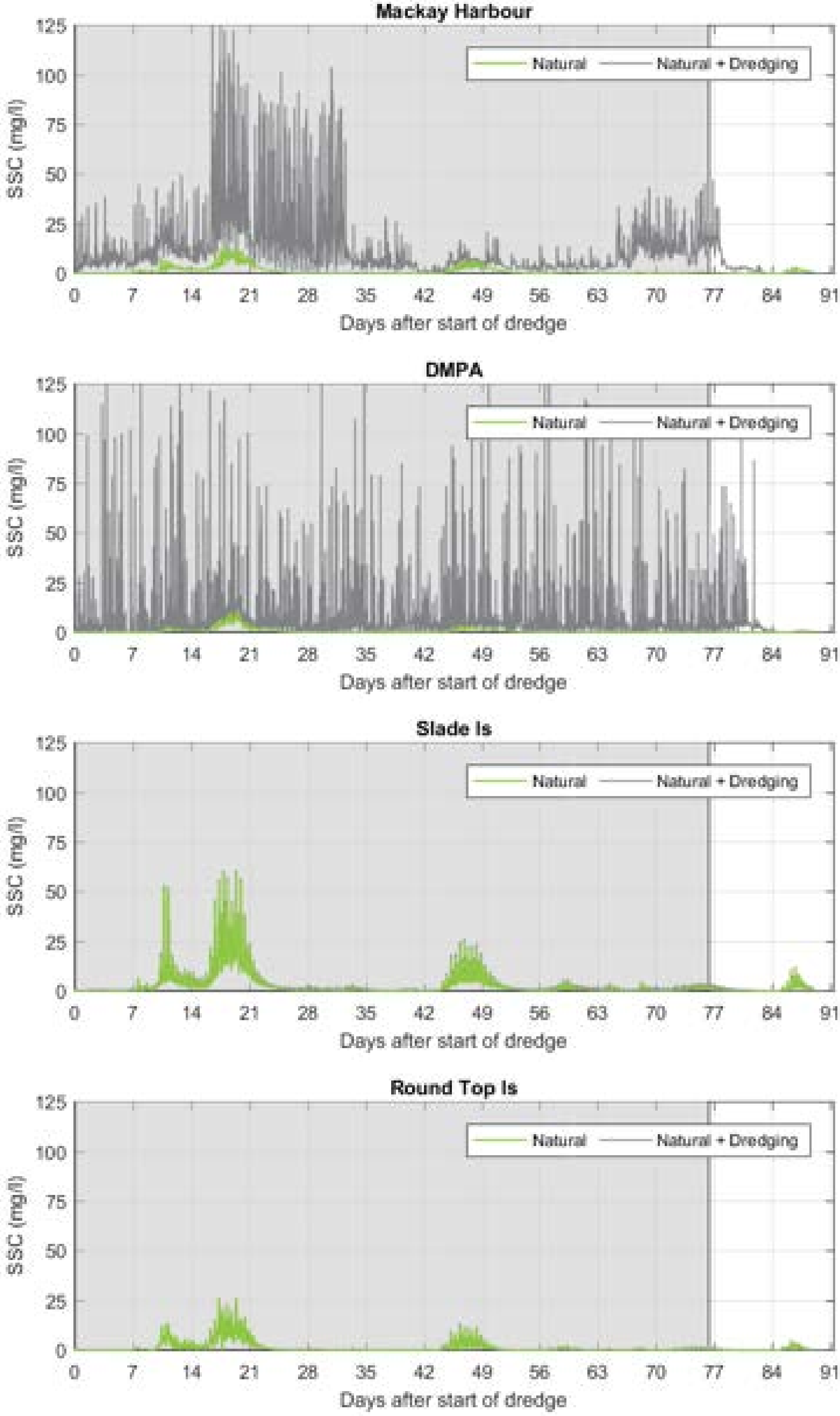

Figure B18. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic dry season. *Note: grey box shows dredge period.*

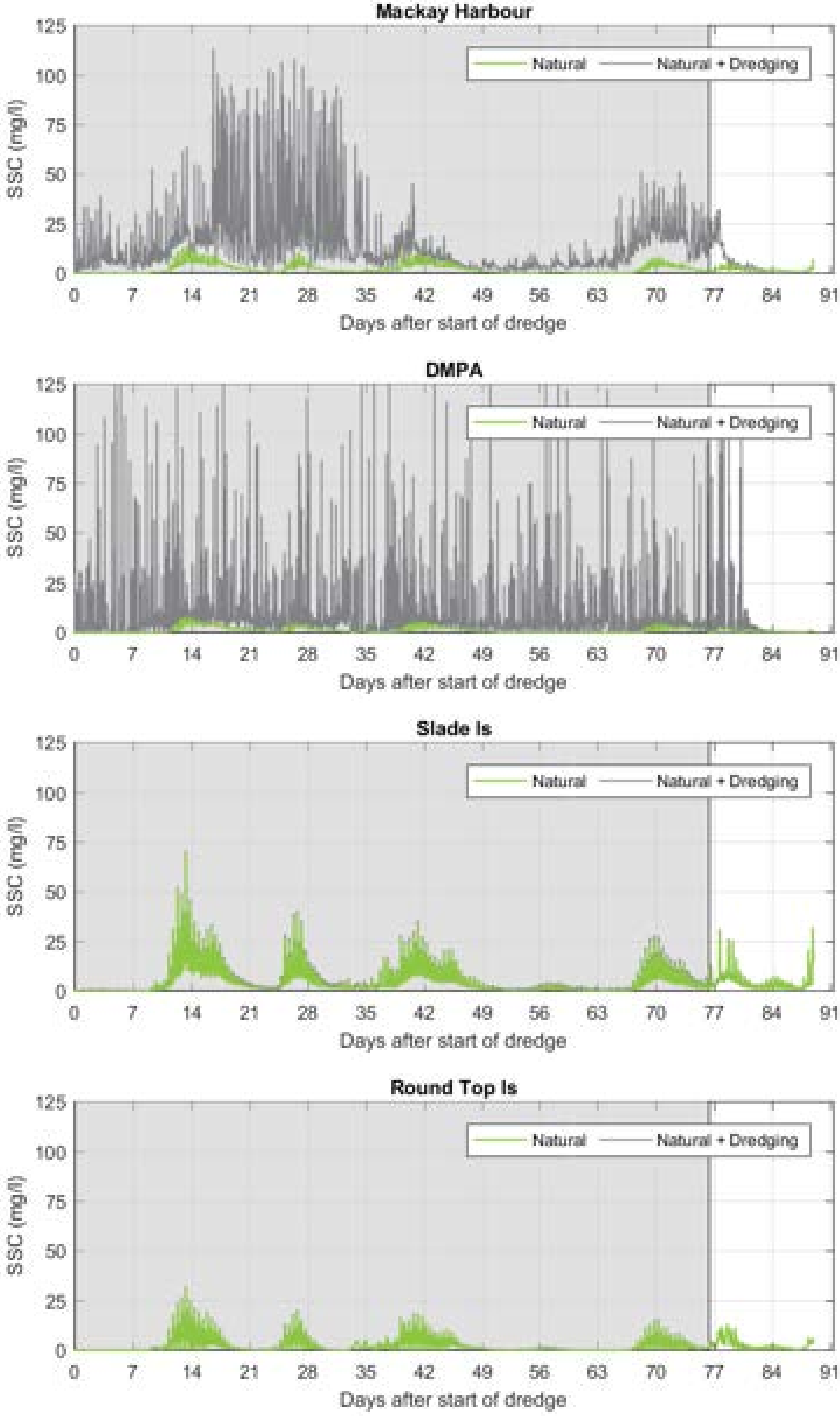

Figure B19. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 1,000,000 m^3 of sediment in the ambient wet season. *Note: grey box shows dredge period.*

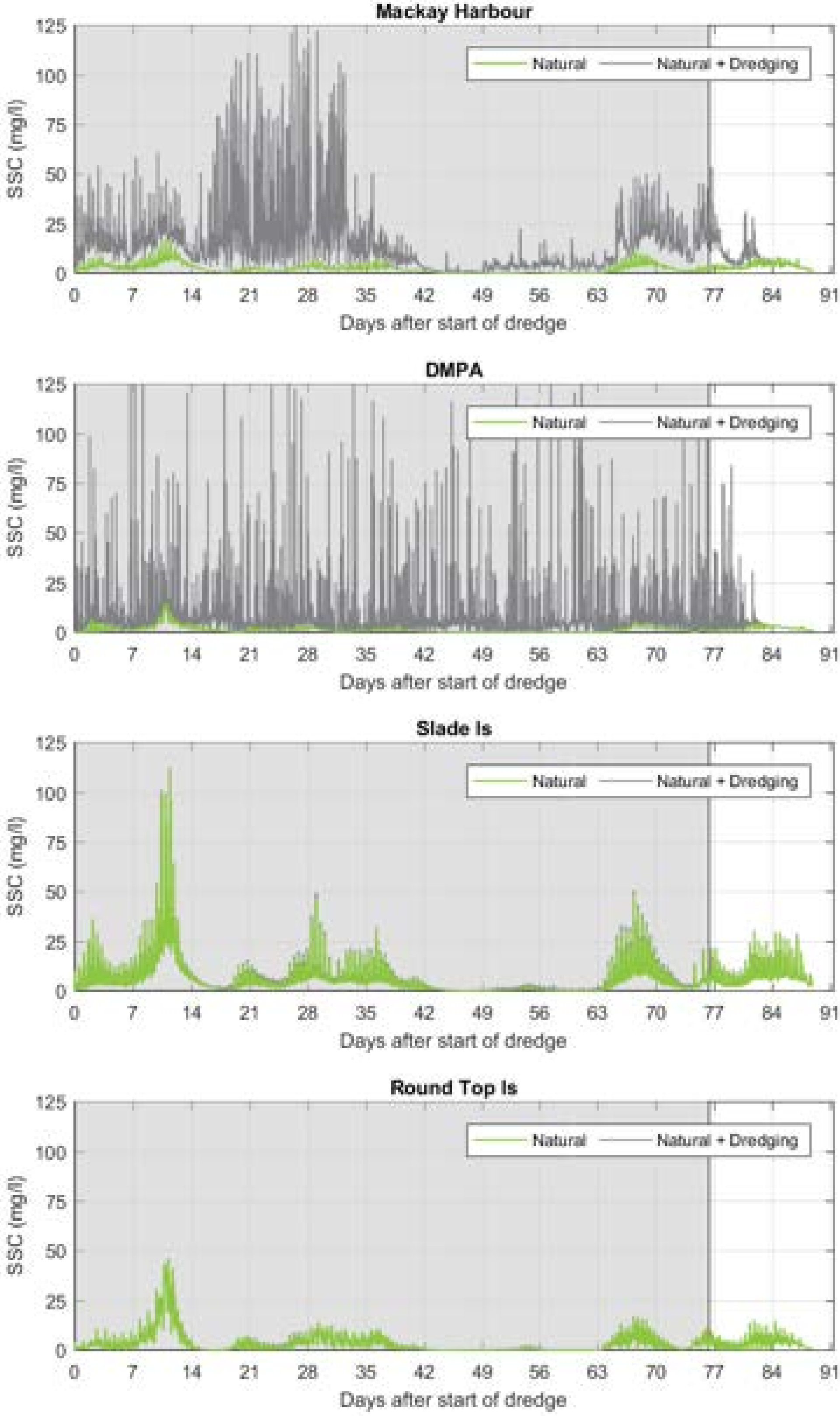

Figure B20. Time series of SSC at Mackay Harbour, Mackay DMPA, Slade Islet and Round Top Island for natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic wet season. *Note: grey box shows dredge period.*

Appendix C – Spatial Deposition Plots

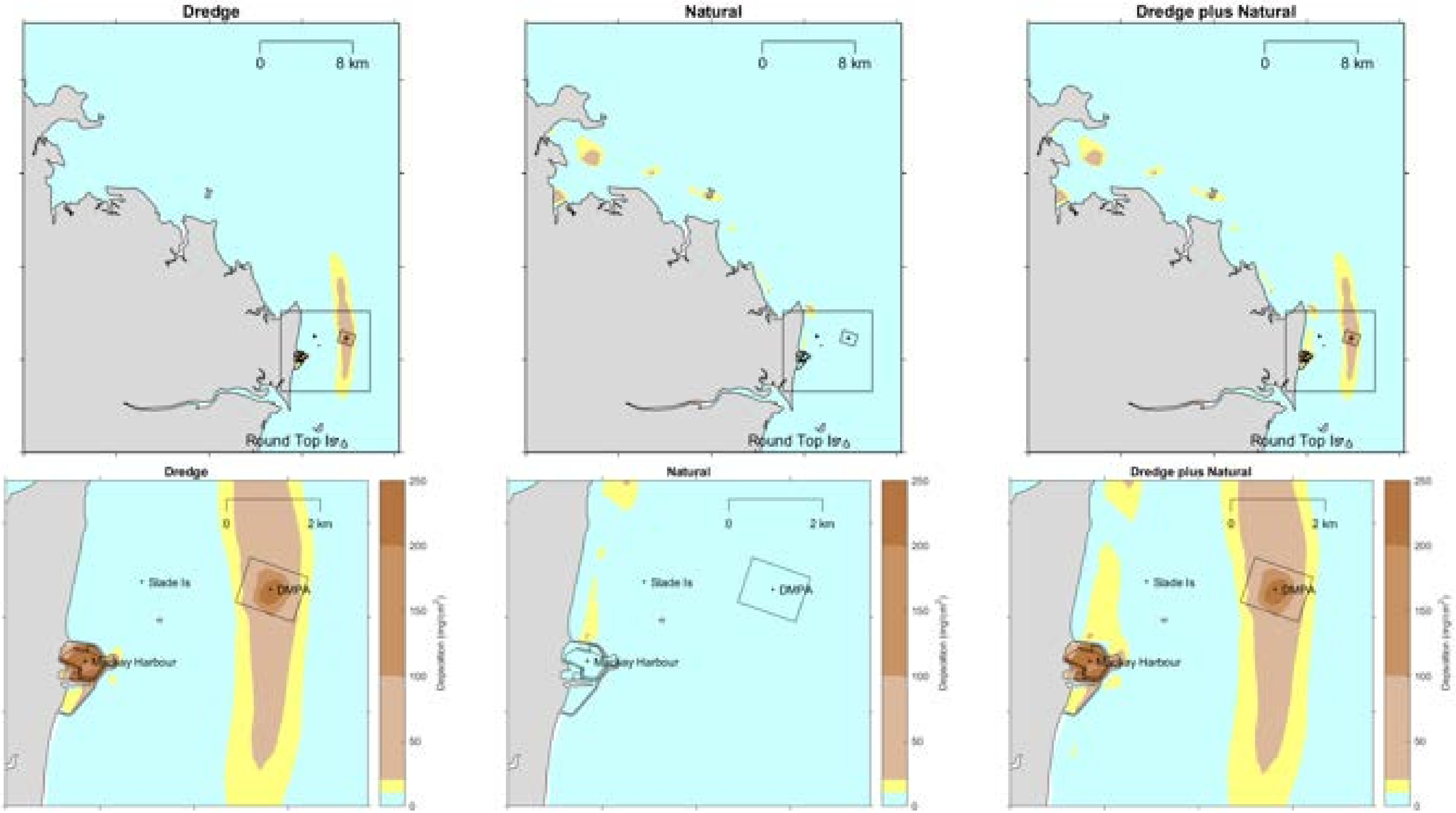

Figure C1. Deposition for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient dry season.

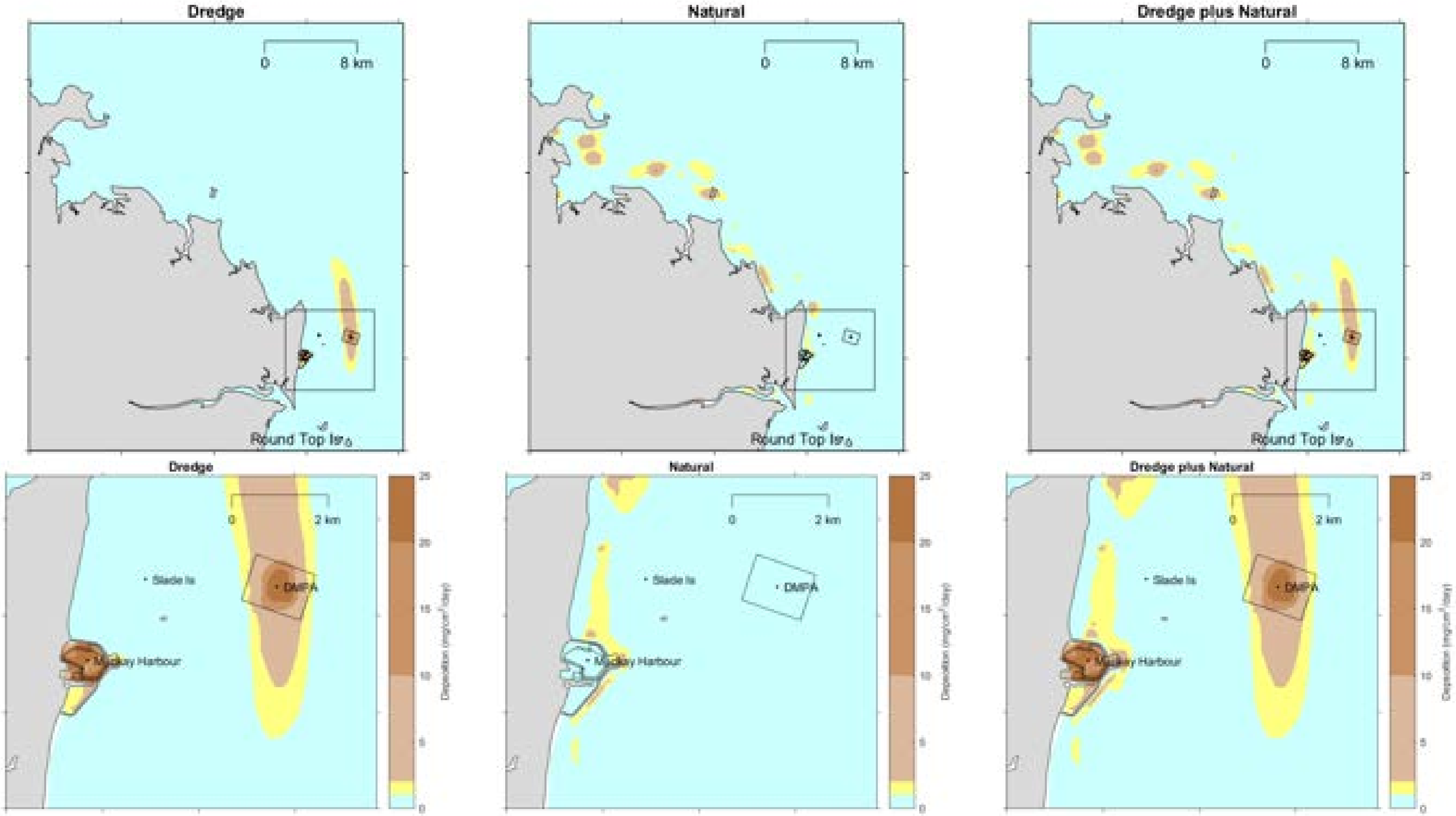

Figure C2. Deposition for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic dry season.

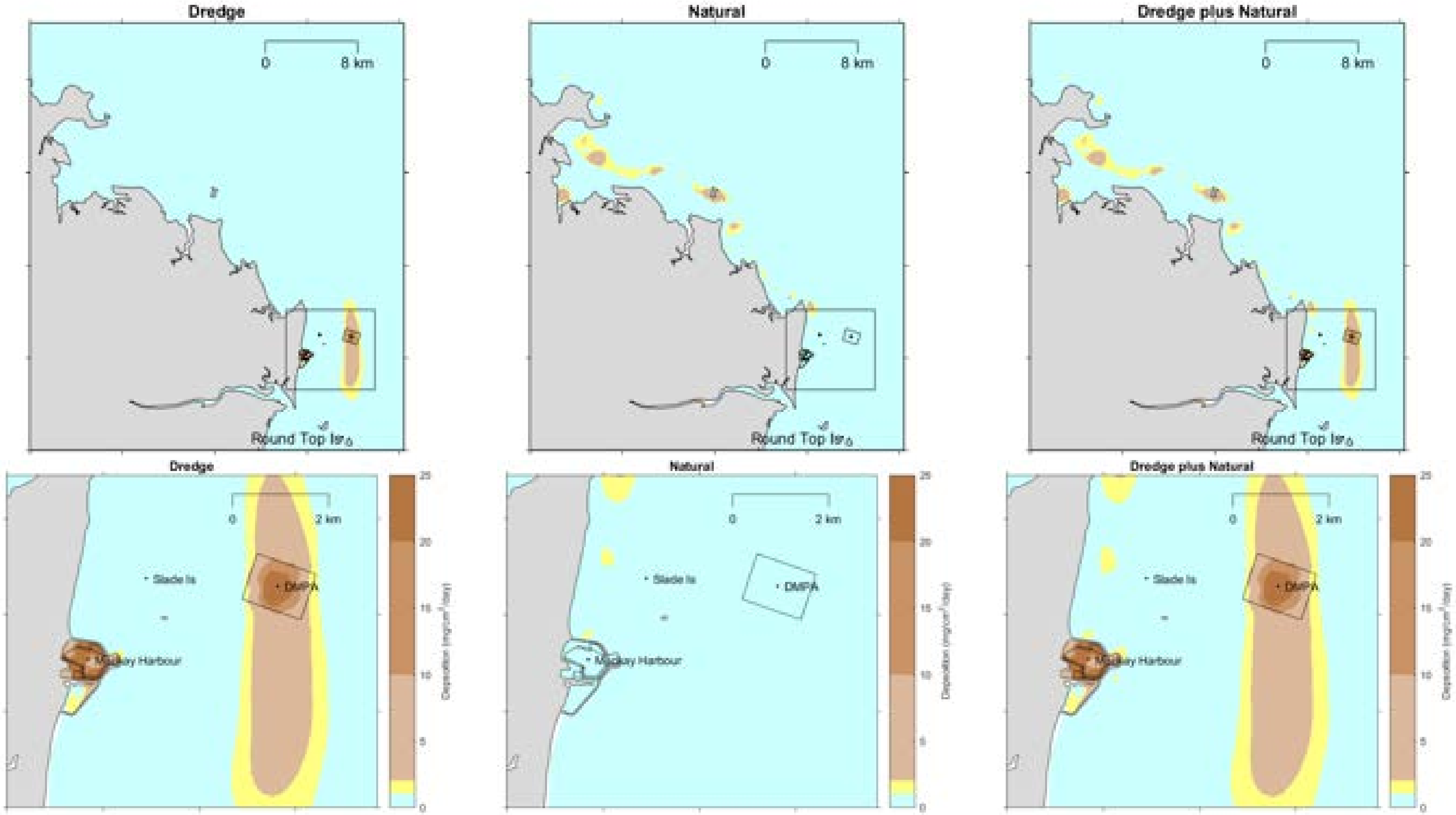

Figure C3. Deposition for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the ambient wet season.

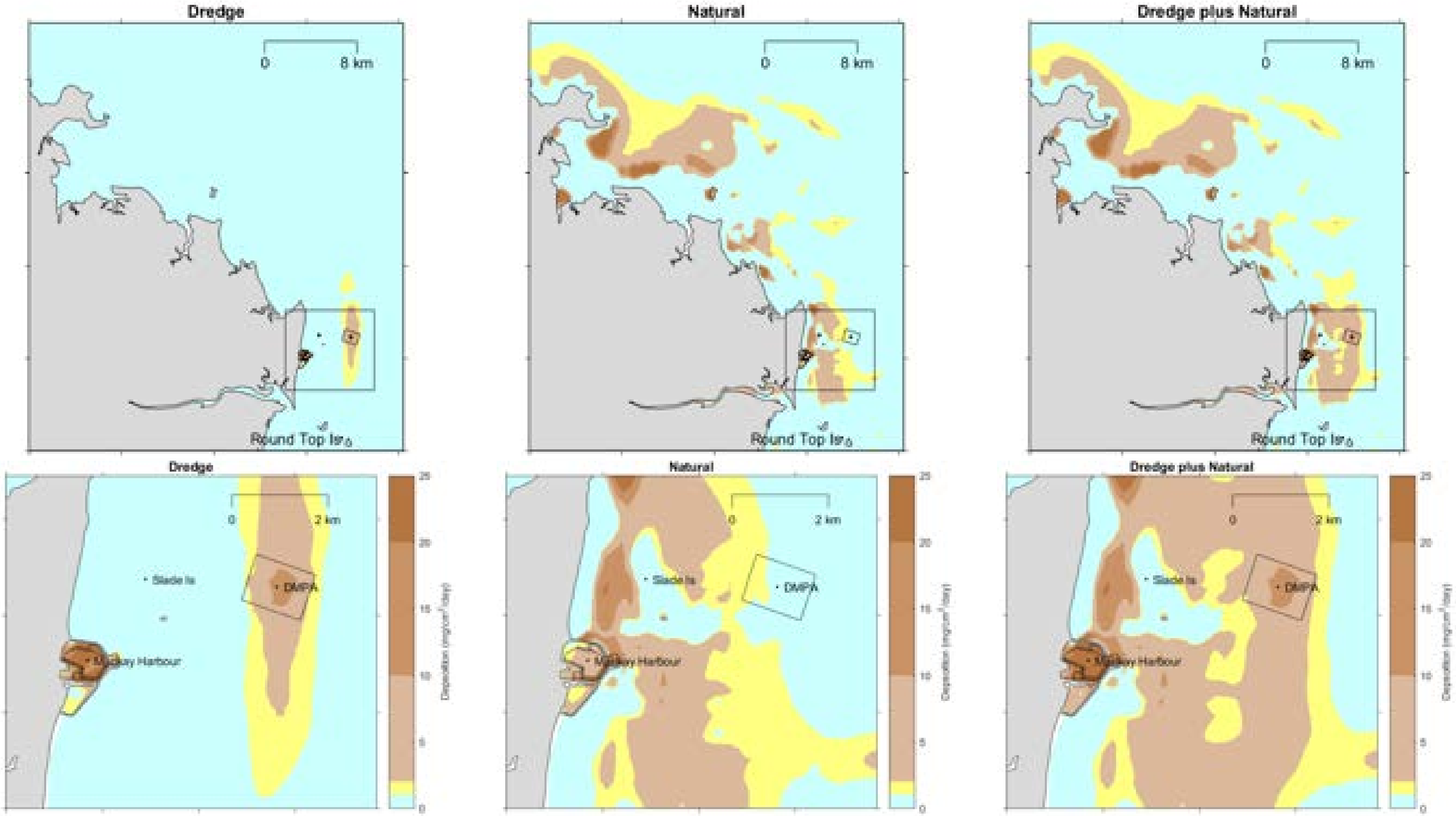

Figure C4. Deposition for dredging, natural and natural plus dredging for 125,000 m^3 of sediment in the energetic wet season.

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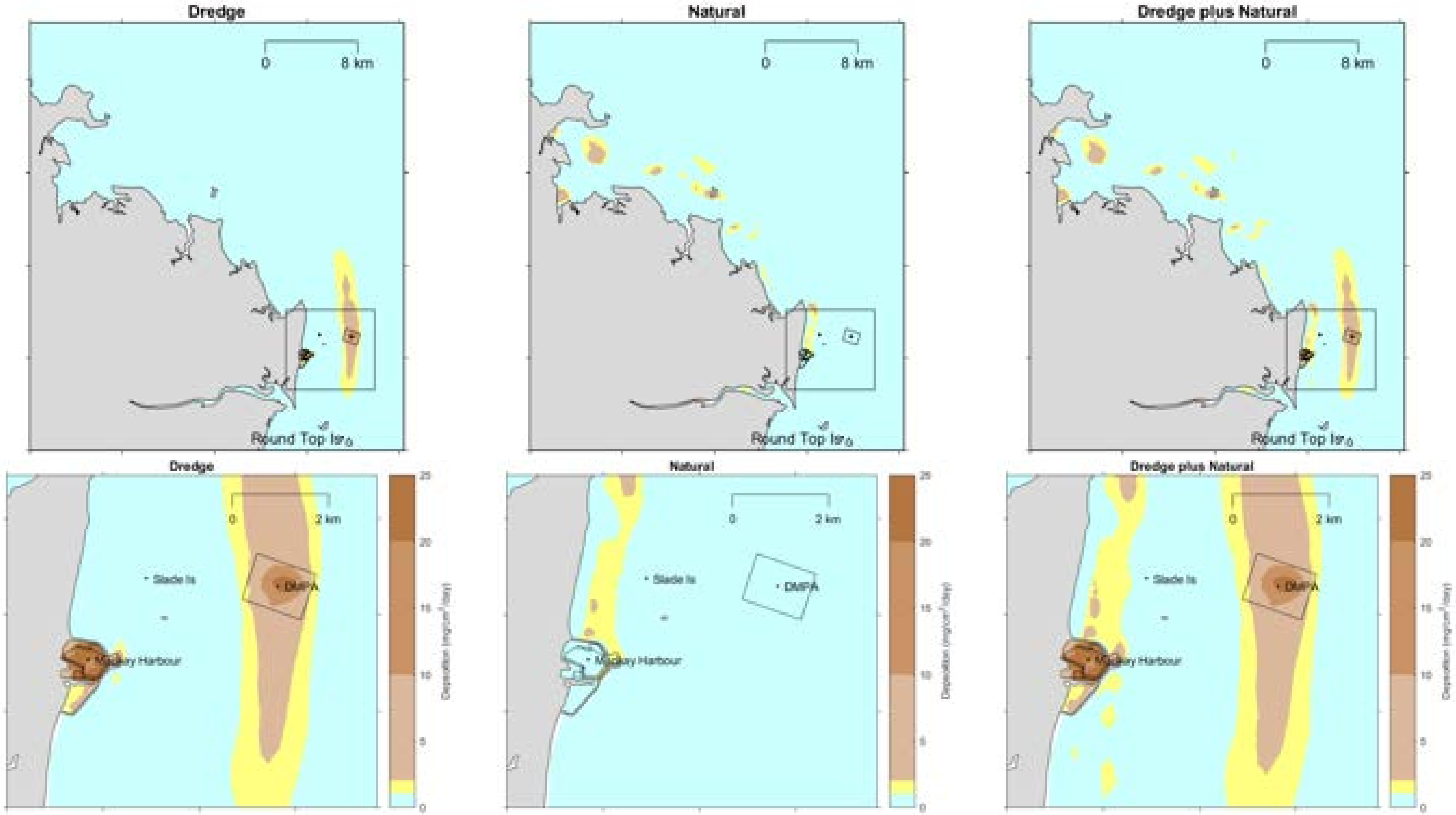

Figure C5. Deposition for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the ambient dry season.

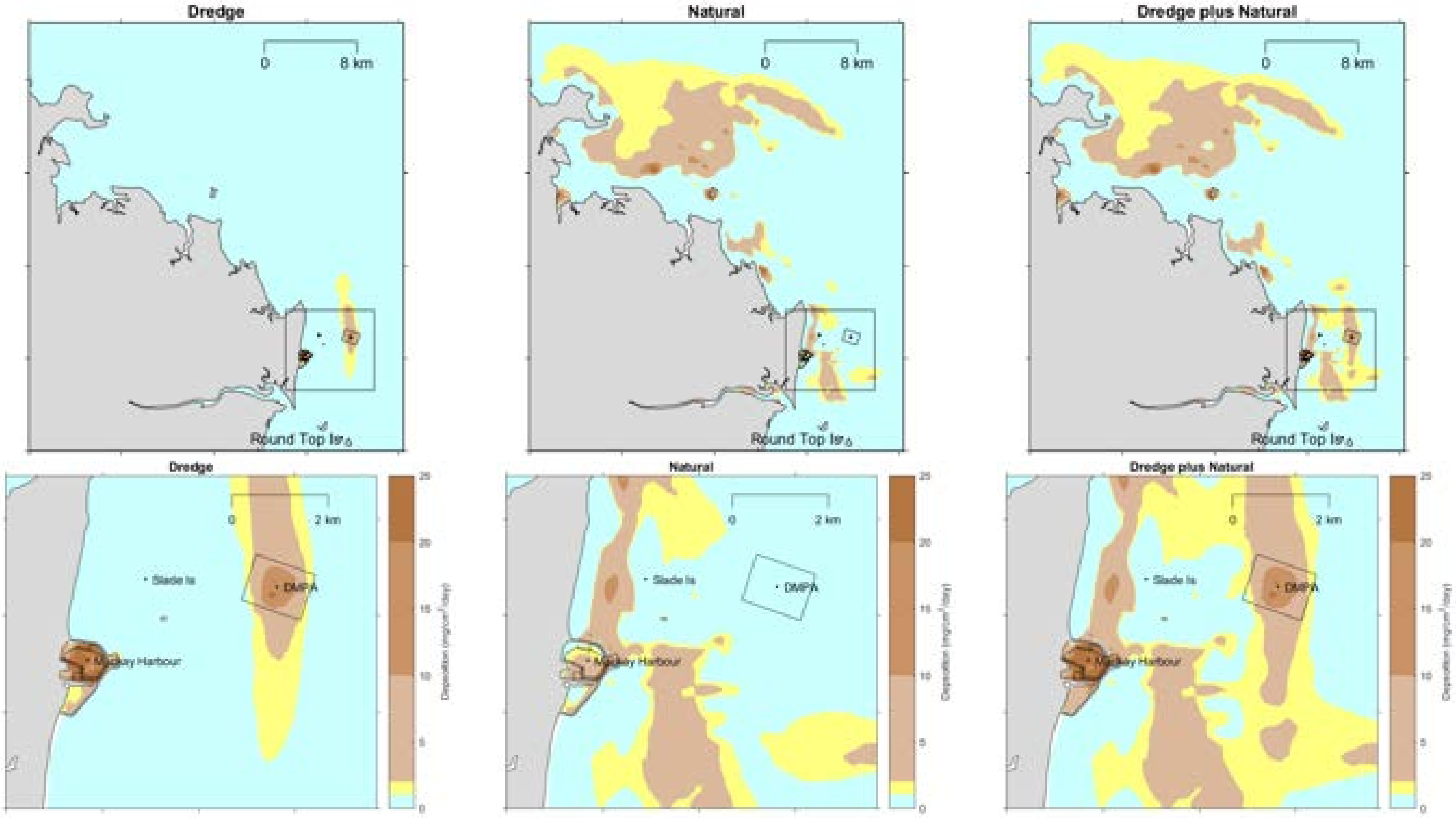

Figure C6. Deposition for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the energetic dry season.

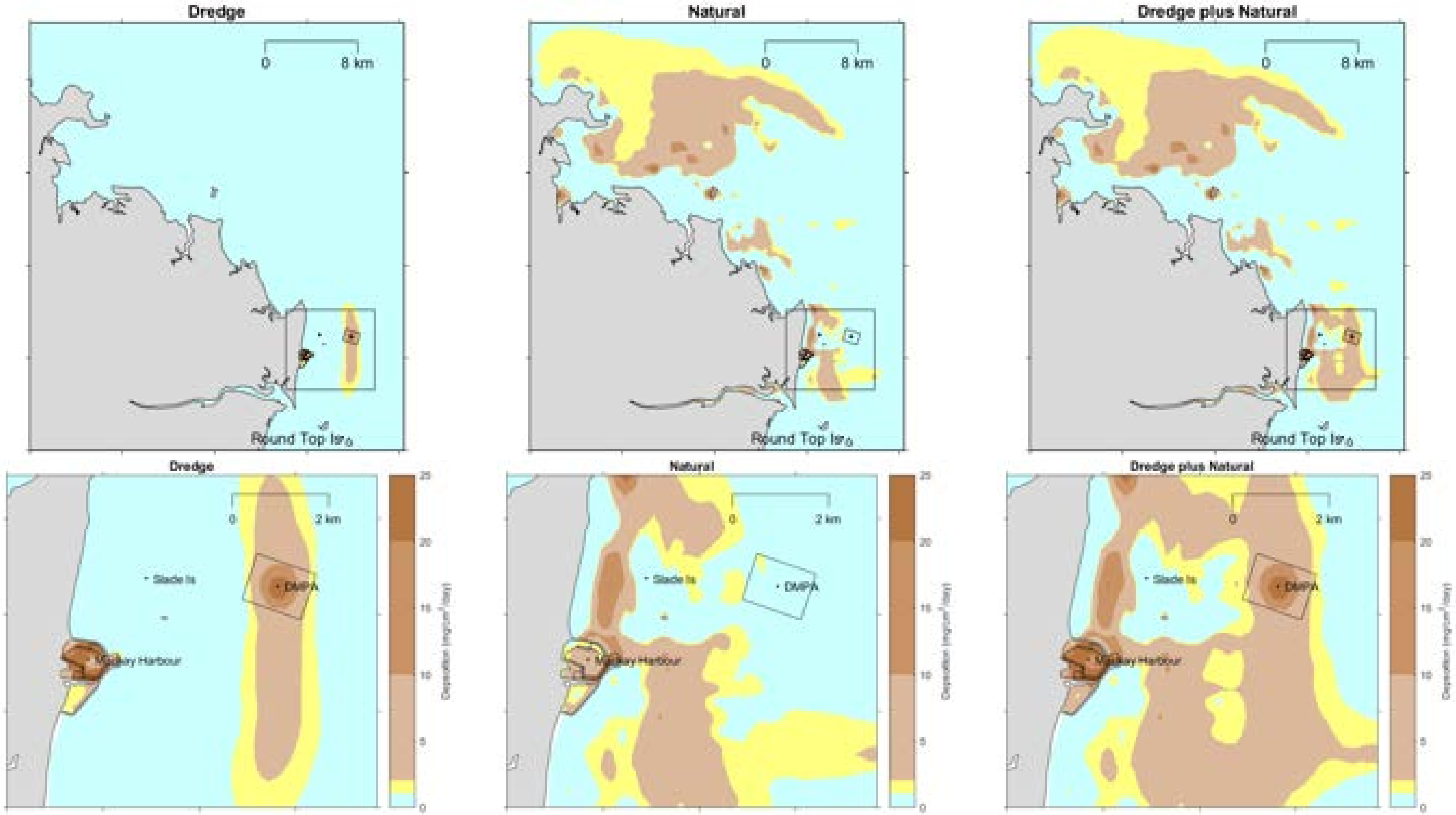

Figure C7. Deposition for dredging, natural and natural plus dredging for 250,000 m^3 of sediment in the ambient wet season.

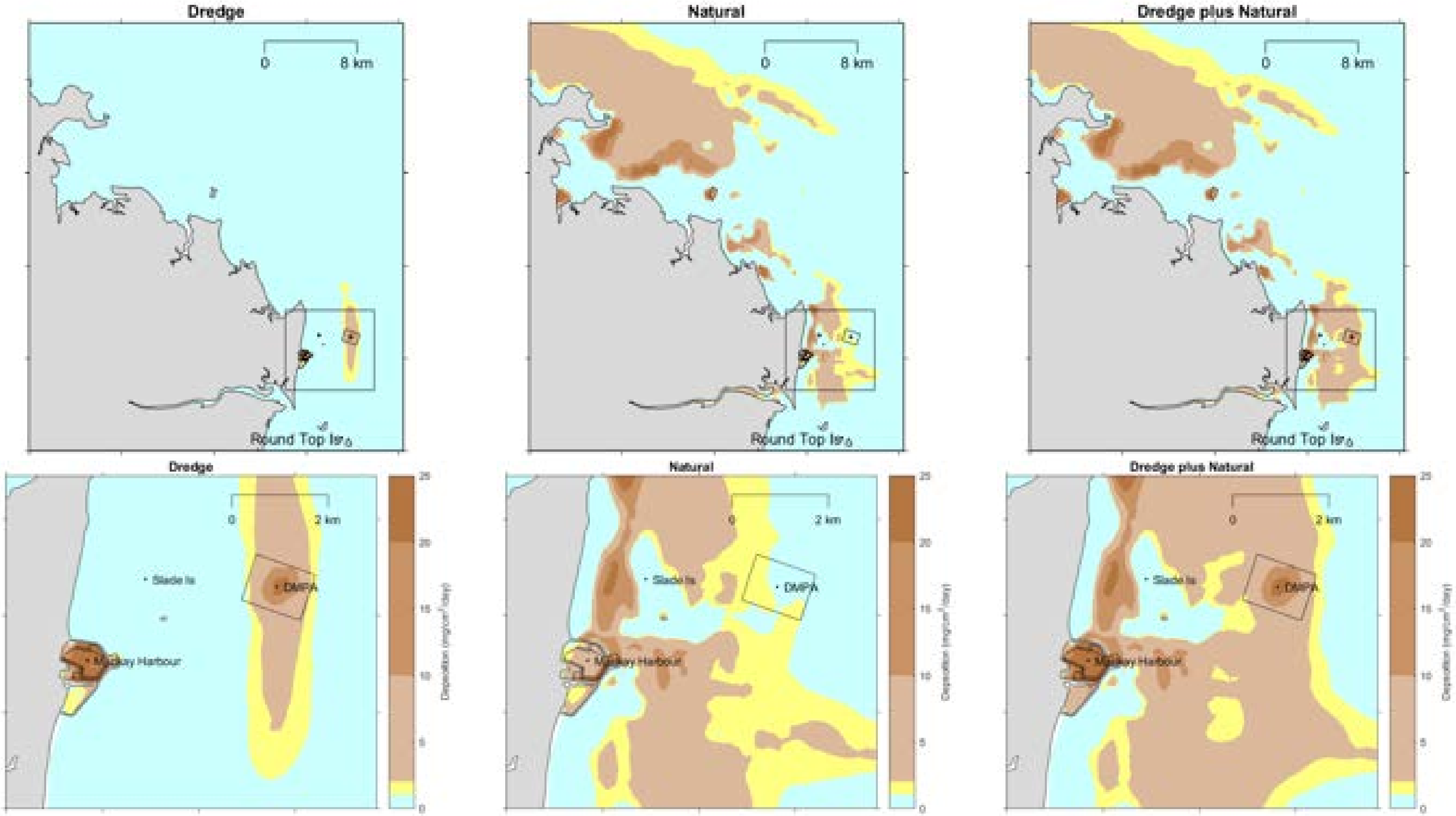

Figure C8. Deposition for dredging, natural and natural plus dredging for 250,000 m³ of sediment in the energetic wet season.

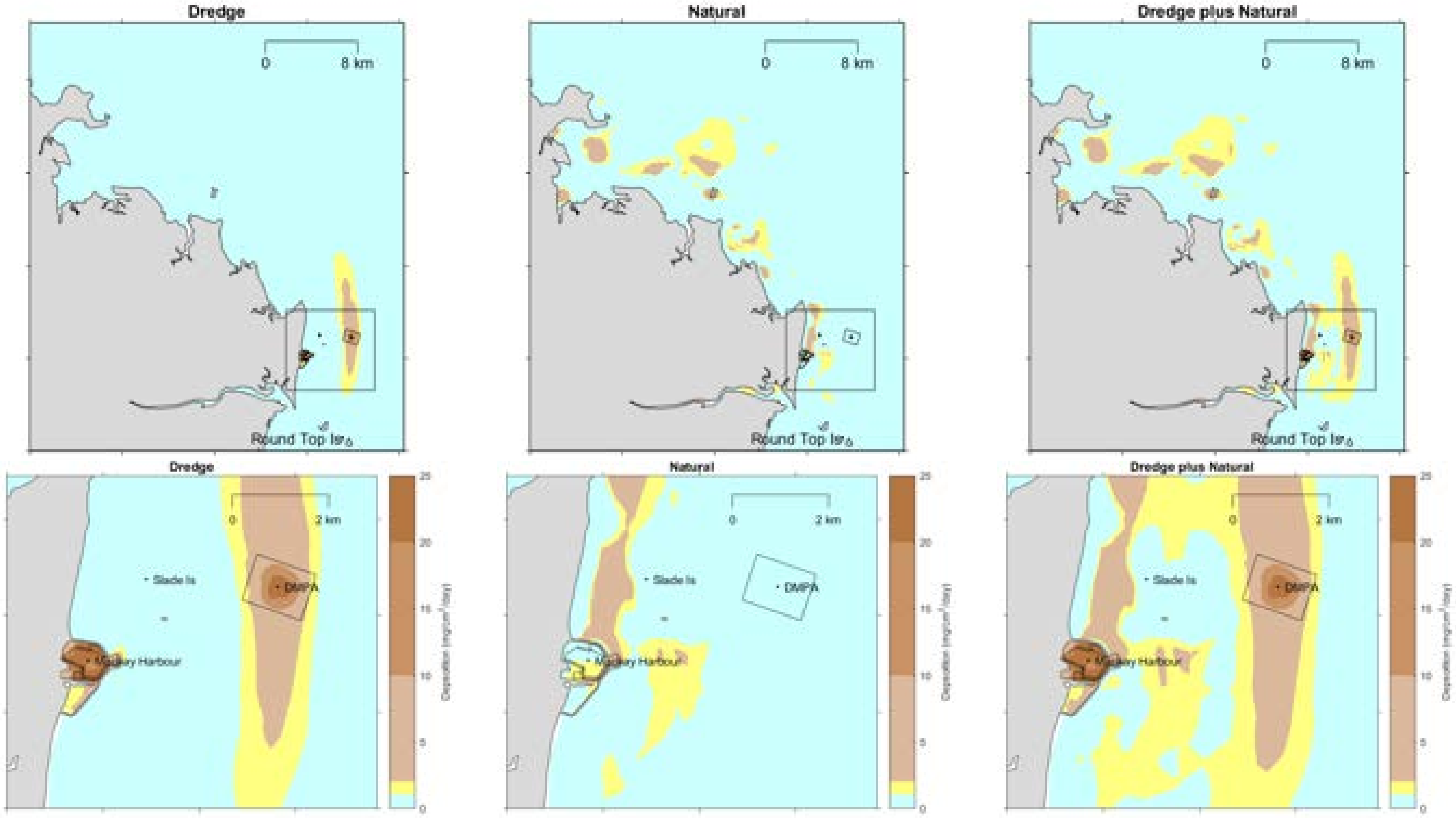

Figure C9. **Deposition for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the ambient dry season.**

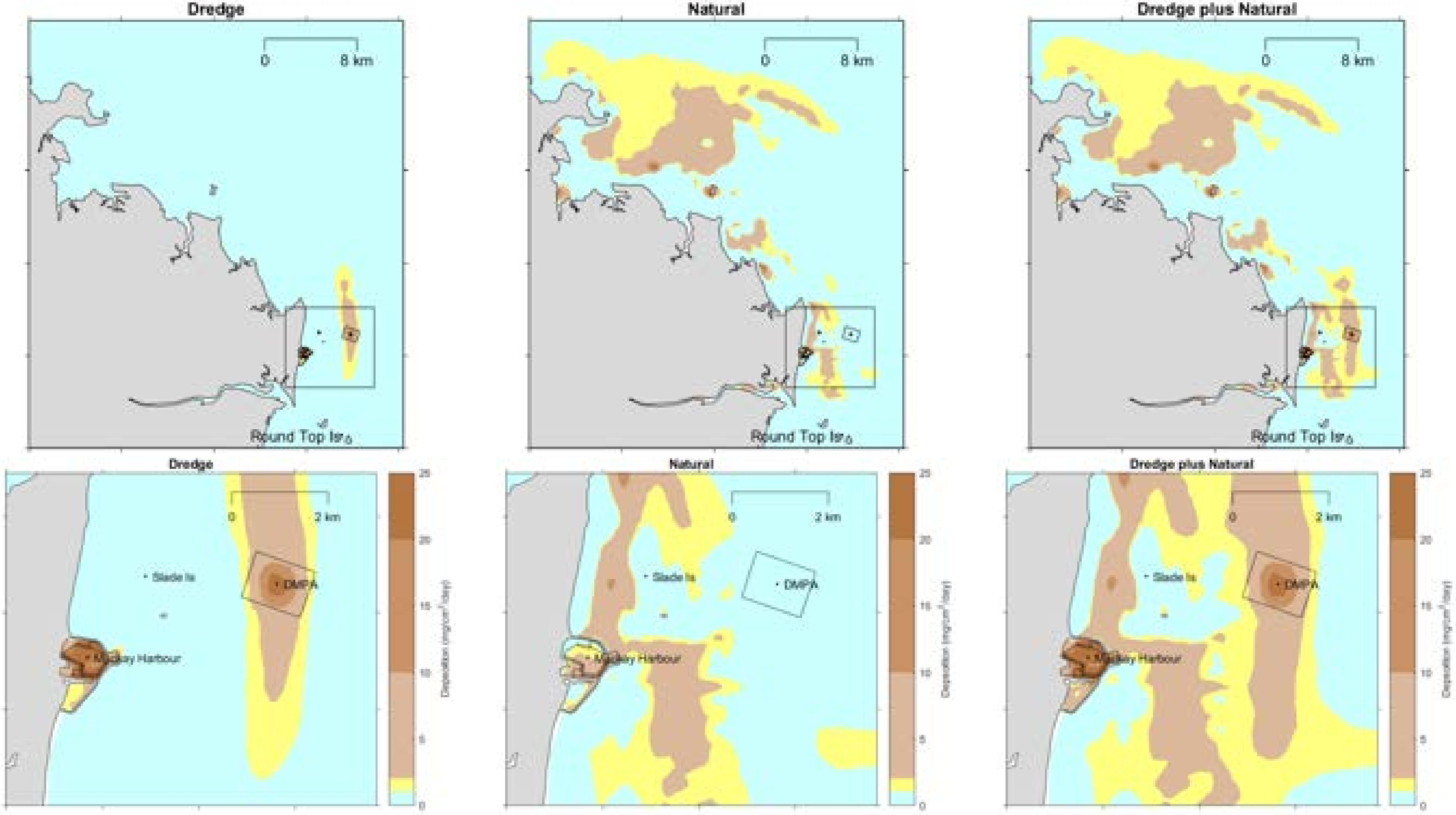

Figure C10. Deposition for dredging, natural and natural plus dredging for 500,000 m³ of sediment in the energetic dry season.

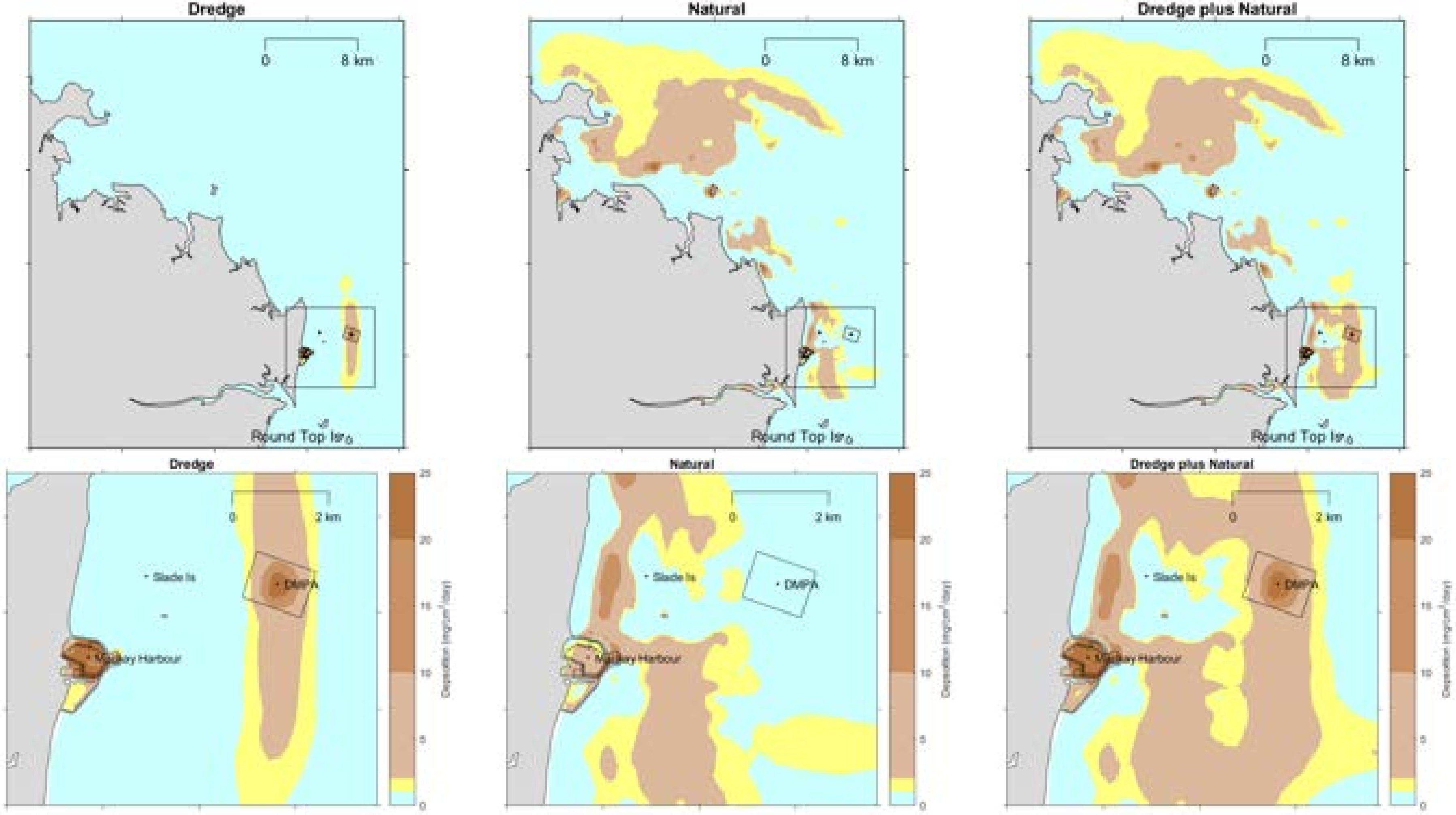

Figure C11. Deposition for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the ambient wet season.

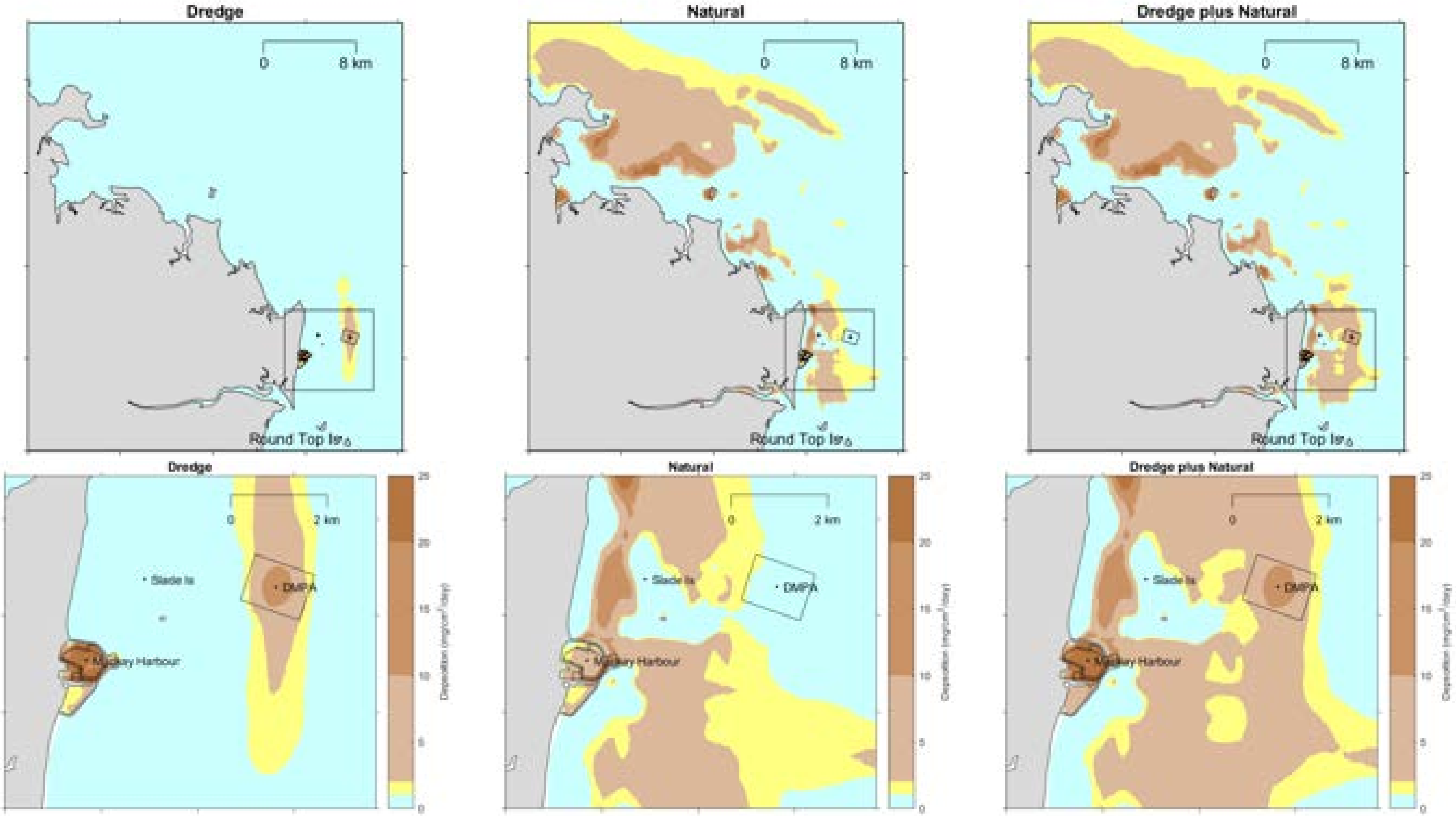

Figure C12. Deposition for dredging, natural and natural plus dredging for 500,000 m^3 of sediment in the energetic wet season.

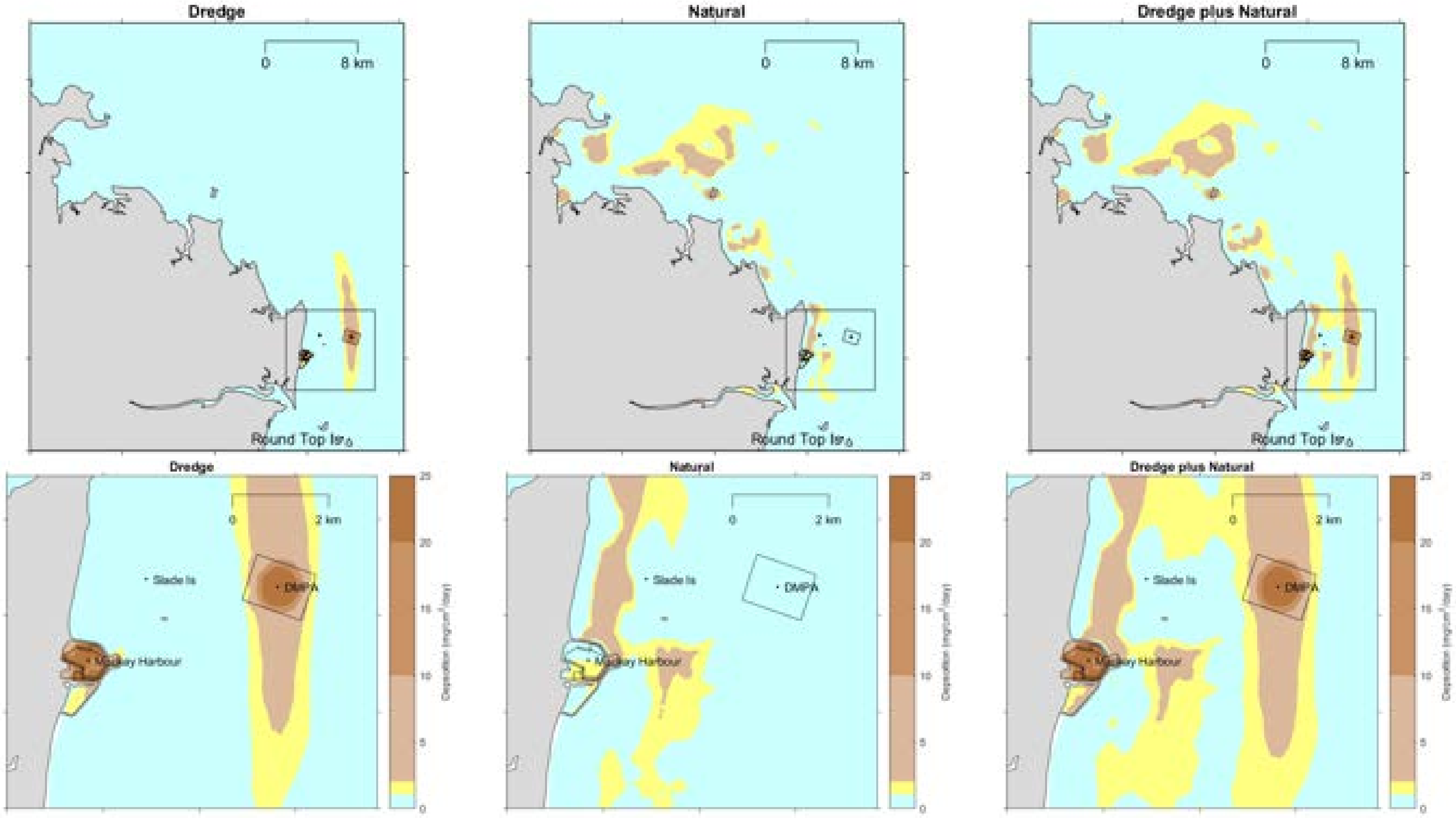

Figure C13. Deposition for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the ambient dry season.

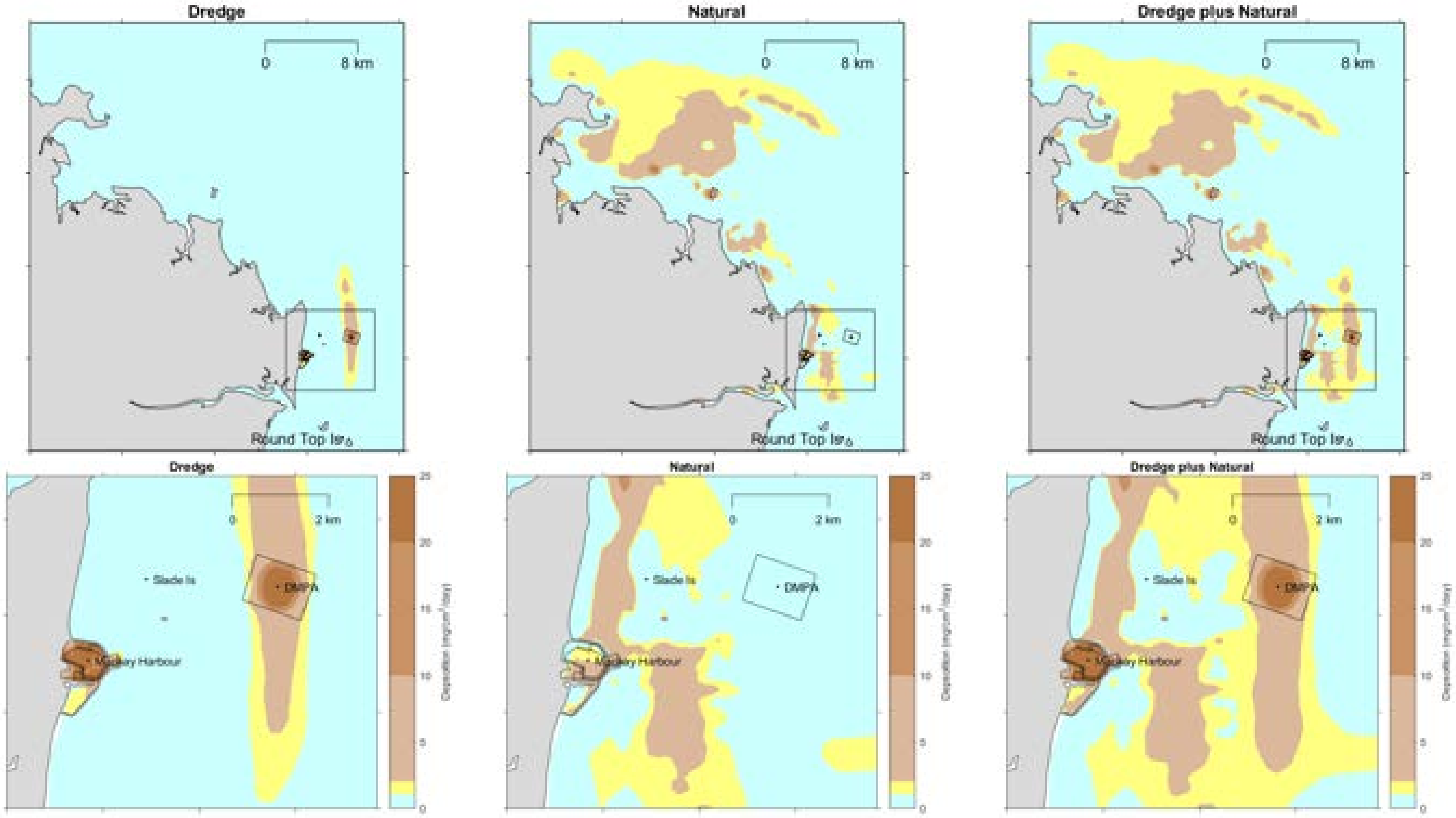

Figure C14. Deposition for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the energetic dry season.

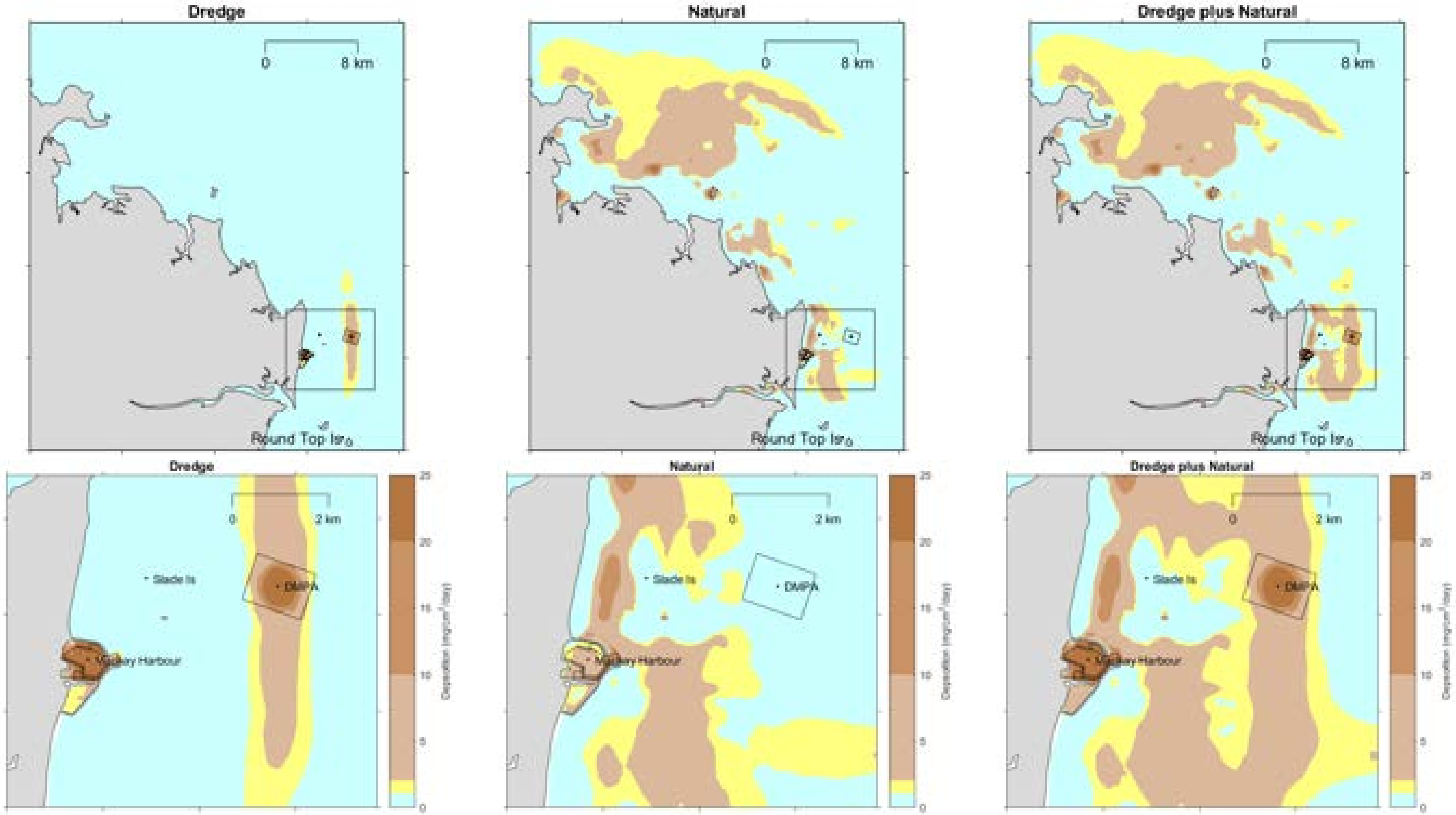

Figure C15. Deposition for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the ambient wet season.

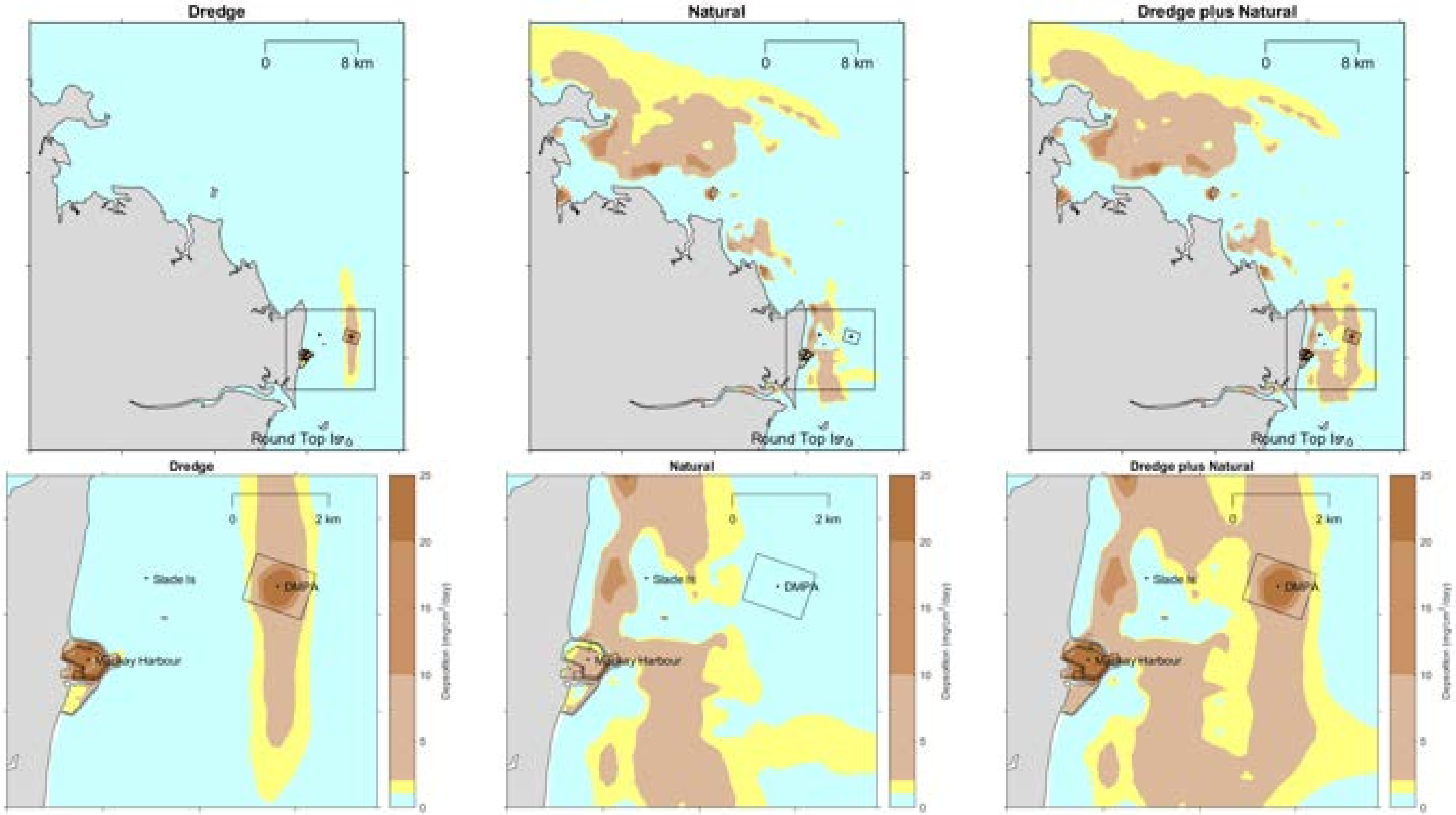

Figure C16. Deposition for dredging, natural and natural plus dredging for 750,000 m^3 of sediment in the energetic wet season.

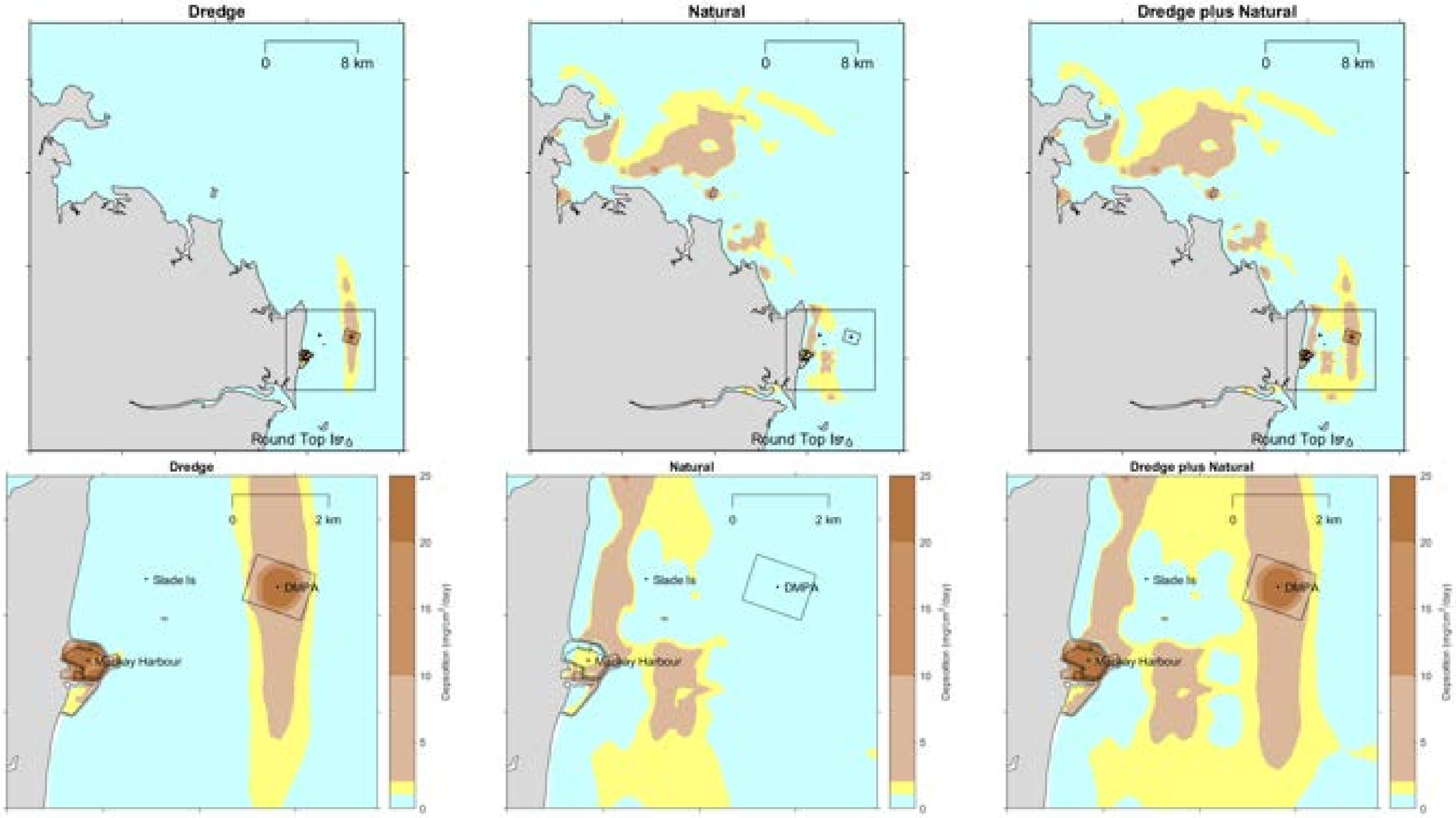

Figure C17. **Deposition for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the ambient dry season.**

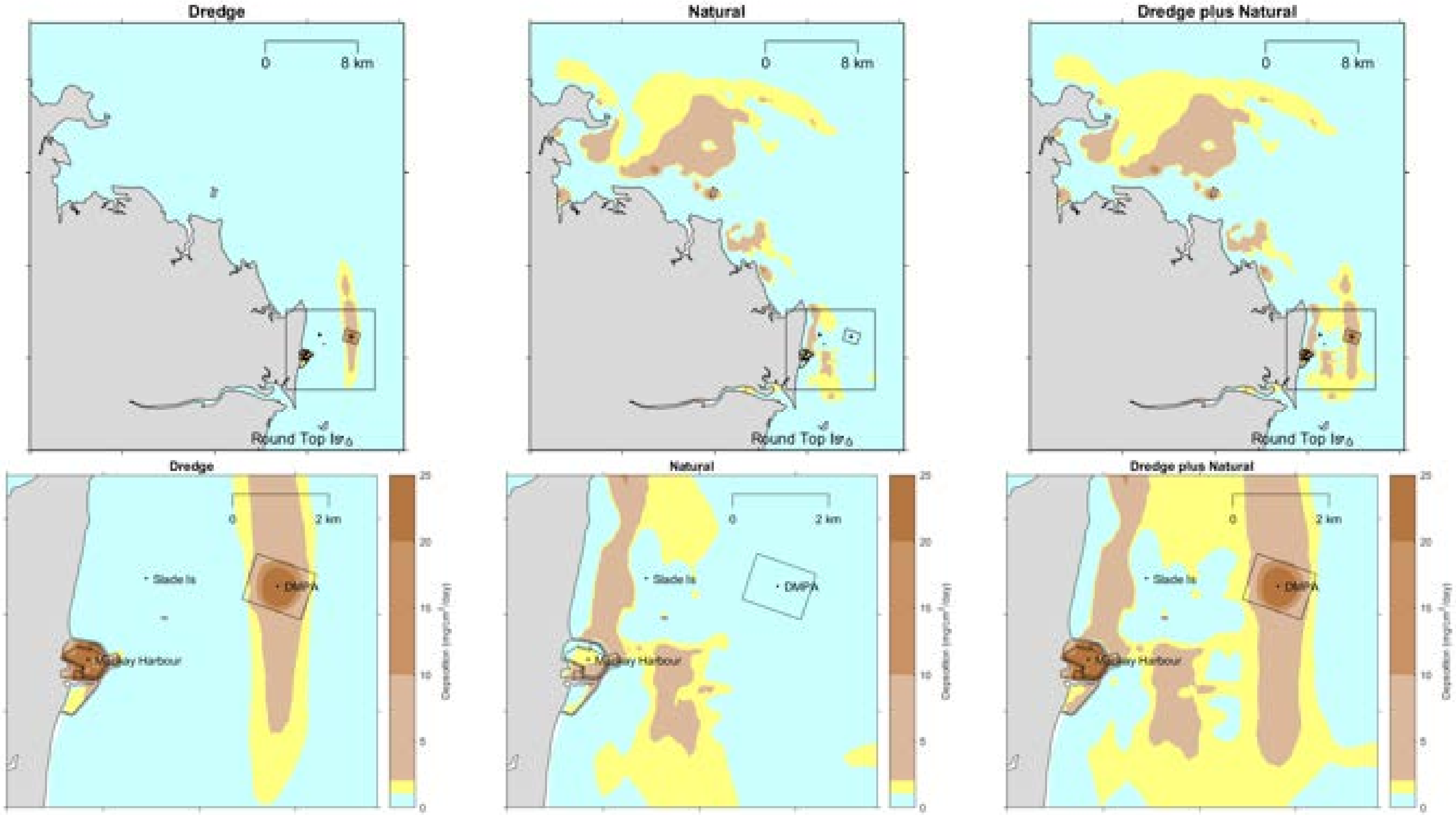

Figure C18. Deposition for dredging, natural and natural plus dredging for 1,000,000 m^3 of sediment in the energetic dry season.

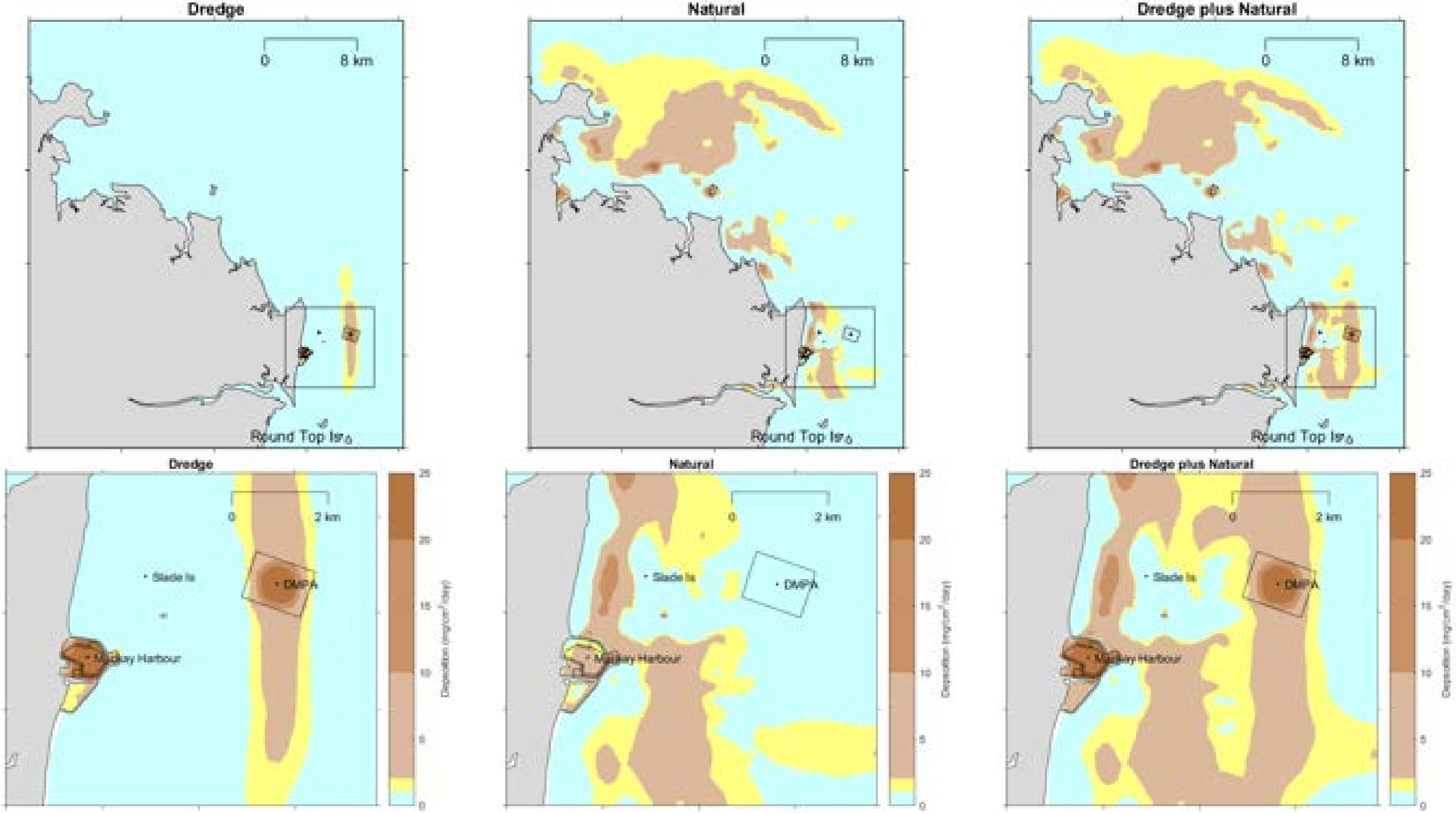

Figure C19. Deposition for dredging, natural and natural plus dredging for 1,000,000 m³ of sediment in the ambient wet season.

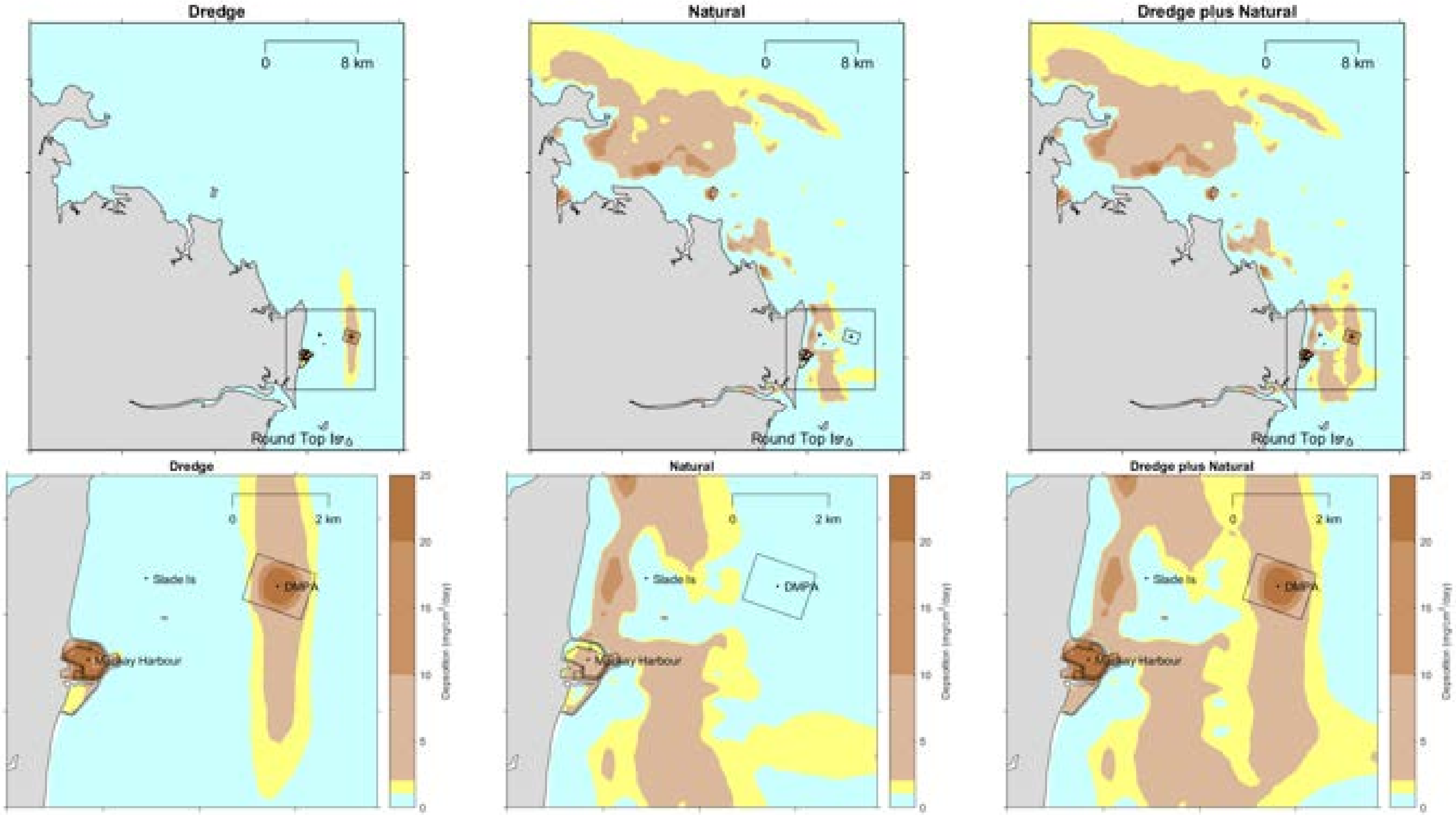

Figure C20. **Deposition for dredging, natural and natural plus dredging for 1,000,000 m³ of sediment in the energetic wet season.**