PORT OF **WEIPA**

APPENDIX E

Dredge plume modelling assessment

Port of Weipa: Sustainable Sediment Management Assessment

Dredge Plume Modelling Assessment

Report No. P022_R05F01

Technical Report
January 2020

PORT & COASTAL
SOLUTIONS

Port of Weipa: Sustainable Sediment Management Assessment

Dredge Plume Modelling Assessment

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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) assessment at the Port of Weipa.

The aim of this study is to undertake an assessment of the effect of dredging for a range of dredge scenarios which could be undertaken as part of the Port of Weipa annual maintenance dredge program. The results need to be contextualised against the natural conditions in the area to better understand the relative contribution of maintenance dredging. To achieve this aim, a numerical model which can simulate hydrodynamic, wave and sediment transport in the Port of Weipa region was developed and applied.

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 26 different maintenance dredging scenarios. These scenarios considered two different metocean conditions which could occur during the dredging program, three different dredge volumes (to account for interannual variations in sedimentation rates) and six different placement options. This approach significantly increases the confidence in the model results presented, providing an indication of the range of effects which could potentially occur. The numerical model was also applied to assess the potential resuspension of material placed at the offshore DMPAs over the long-term (with modelling undertaken for a 7 month period, but with results representative of the annual resuspension for a worst case year).

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

- the natural SSC is generally much higher than the SSC resulting from maintenance dredging. Limited net residual transport of the suspended sediment from maintenance dredging is predicted and as a result the only areas where the increases in SSC from maintenance dredging creates a clear increase in total SSC (natural plus dredging) is at the offshore DMPAs where the natural SSC is low during the dry season and at the beach nourishment site. Natural SSC during the wet season is typically an order of magnitude higher than during the dry season;
- the seagrass sites located within the Inner Harbour (IH1 and IH2) are the sensitive receptors where there is most likely to be an increase in SSC due to maintenance dredging. The relative magnitude and duration of the increase is dependent on the volume dredged, the metocean conditions when the dredging occurs and the placement site;
- the SSC was predicted to remain within natural conditions for the sensitive receptors for all dredge scenarios considered. Only for the worst case dredge volume was the duration above the SSC threshold value for longer than the 90th percentile natural duration (and then only at one sensitive receptor (IH1) and for two options (placement at the Albatross DMPA and Albatross South DMPA with dredging occurring during the energetic dry season));
- the deposition resulting from maintenance dredging is comparably small in spatial extent and low in intensity in comparison to the natural deposition. In most cases it is only possible to clearly distinguish between the natural and natural plus dredging deposition at the dredging and placement locations;
- the highest deposition at IH1 due to maintenance dredging is for the placement of sediment at the land reclamation area, with an equivalent daily rate of up to 1 mg/cm^2/day (which is still below the literature based thresholds for seagrass but does not account for natural deposition which is predicted to be an order of magnitude higher);
- the long term resuspension modelling predicts that sediment placed within all three of the offshore DMPAs modelled will only be resuspended as a result of extreme meteorological

conditions during the wet season (e.g. TCs). For the 2018/2019 wet season modelled, conditions were far more extreme than typical wet season conditions (even for a cyclonic year) and as such the retainment rates from the model of between 35% and 77% present a worst case scenario; and

- the long term resuspension modelling predicted that the deposition of the sediment resuspended from the offshore DMPA sites will be focused in the areas directly adjacent to the sites and that any deposition is not expected to noticeably increase future maintenance dredging volumes.

Overall, the results show that for the typical and cyclonic dredge volumes the three offshore DMPA options and the onshore pond option result in small increases in SSC and deposition and the increases are very small in relation to the natural conditions at the sensitive receptors. The land reclamation and beach nourishment options are predicted to result in higher increases in SSC and deposition for typical dredge volumes, this is due to the beach nourishment assuming unconfined placement and the land reclamation modelling assuming a partial failure of the reclamation liner. As such, the increases in SSC and deposition for both options can be considered to represent a worst case scenario and they could be reduced through additional design considerations or risk mitigation measures. The only time when the modelling predicts that the maintenance dredging could result in a significant increase in the duration of time the SSC thresholds were exceeded was for the worst case dredge volume when a large and small TSHD were working concurrently. Based on this it is recommended that real-time monitoring of turbidity is undertaken for any future maintenance dredge programs which require two dredgers (one of which a large TSHD). Real-time monitoring will allow an adaptive management approach to be adopted during such dredge programs to ensure that the SSC remains within the range of natural variability (ensuring that there is no impact on local receptors).

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 Weipa. The scope of work for the studies being undertaken by PCS are as follows:

- Onshore pond and reclamation assessment: the aim of the study is to assess an onshore pond option and a land reclamation option at the Port of Weipa. As part of the assessment, preliminary concept designs will be developed to allow a comparative analysis between the options and other options being considered as part of the SSM assessments to be undertaken;
- Sediment transport and dredge plume modelling: the aim of the study is to model the transport of suspended sediment released into the marine environment by natural processes and maintenance dredging at the Port of Weipa. The modelling will include a number of offshore and onshore placement sites as well as a range of possible metocean conditions and maintenance dredging volumes;
- Thresholds analysis: the turbidity, deposition and benthic PAR data collected as part of the ambient water quality monitoring at the Port of Weipa 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 at the Port; and
- CO_2 emission calculations: the aim of this study is to undertake calculations to provide an estimate of Greenhouse Gas (GHG) CO_2 equivalent emissions for a number of placement options for the Port of Weipa.

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

1.1. Project Background

NQBP undertakes regular maintenance dredging of the channels and berths at the Port of Weipa to ensure there is sufficient depth for vessels to safely travel to and from the berths. The sediment that has historically been removed by maintenance dredging, has been relocated to an offshore dredge material placement area (DMPA) located in Albatross Bay (Figure 2).

NQBP has current State and Commonwealth approvals to support maintenance dredging and at-sea placement of the dredged sediment at the Port of Weipa. The current 10-year permit was issued in 2010. Since then, the process to obtain new long-term sea dumping permits in Queensland has become more onerous.

A Maintenance Dredging Strategy (MDS) has been developed for the ports that are situated within the Great Barrier Reef World Heritage Area (GBRWHA) (DTMR, 2016). The MDS provides a framework for the sustainable, leading practise management of maintenance dredging (Figure 1). It is a requirement of the MDS that each Port within the GBRWHA develop Long-term Maintenance Dredging Management Plans (LMDMPs). The 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, as well as 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.

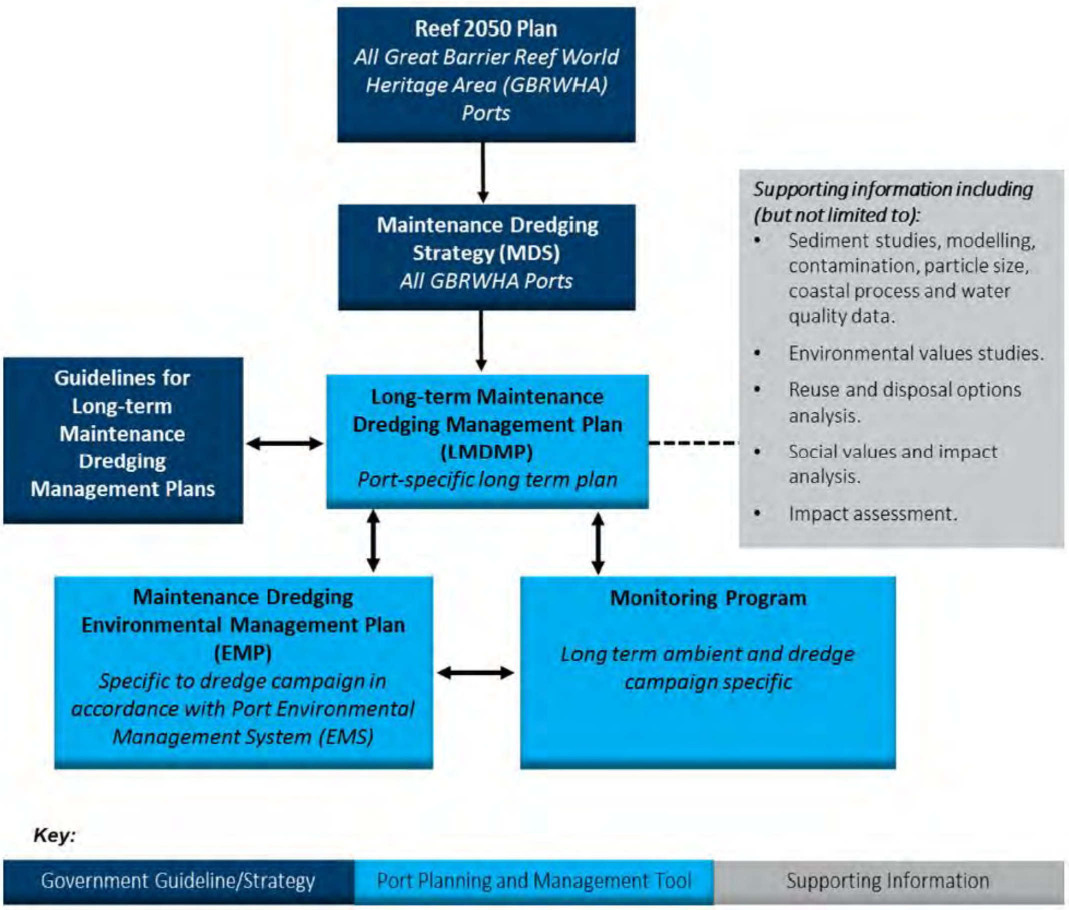


Figure 1. Planning and implementation mechanisms for maintenance dredging of Queensland ports (DTMR, 2018).

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 Weipa as well as the framework developed for the MDS, demonstrating that NQBP have been proactive at developing sound long-term maintenance dredging strategies. The studies included as part of the work currently being undertaken by PCS are aimed at answering the questions posed under point 4. The findings from all these SSM studies will feed into the development of a new LMDMP at the Port of Weipa.

1.2. Port Details

The Port of Weipa is located in the Gulf of Carpentaria, on the north-west coast of the Cape York Peninsula in Northern Queensland. The Port of Weipa is within Albatross Bay, a large embayment, with the wharves and berths located in the Embley River (Figure 2 and Figure 3). The Port of Weipa consists of:

- a main shipping channel in Albatross Bay called South Channel; and
- an Inner Harbour which is within the Embley River and consists of four shipping berths (Lorim Point East and West, Humbug Wharf and Evans Landing) and the Approach and Departure Channels.

The Port has approximately 622 hectares of channels, swing basins and berths where depths are maintained by maintenance dredging. Since 2002 maintenance dredging at the Port has been undertaken annually by the Trailing Suction Hopper Dredger (TSHD) Brisbane, with volumes ranging from approximately 300,000 m^3 to 2,400,000 m^3. The majority of the maintenance dredging requirement at the Port of Weipa is within the mid to outer sections of the South Channel where the sediment is predominantly fine-grained silt and clay. There is also some requirement for annual maintenance dredging within the Inner Harbour and inner area of the South Channel where the sediment has a higher proportion of sand.

The fact that the Port requires annual maintenance dredging indicates that regular natural sediment transport and sedimentation occurs in the region. In addition to the regular sedimentation, it has also been observed that extreme events such as tropical cyclones (TCs) can result in significant increases in the sedimentation and therefore increased maintenance dredging requirements at the Ports. TCs occur in the Gulf of Carpentaria in most years. Based on analysis of historical TCs, it follows that the region is influenced by tropical cyclones on average every other year, although the magnitude of this influence can vary significantly. To reduce the risk of increased sedimentation from a TC resulting in operational or safety issues at the Port, maintenance dredging at the Ports has typically been scheduled immediately after the wet season (when TCs occur).

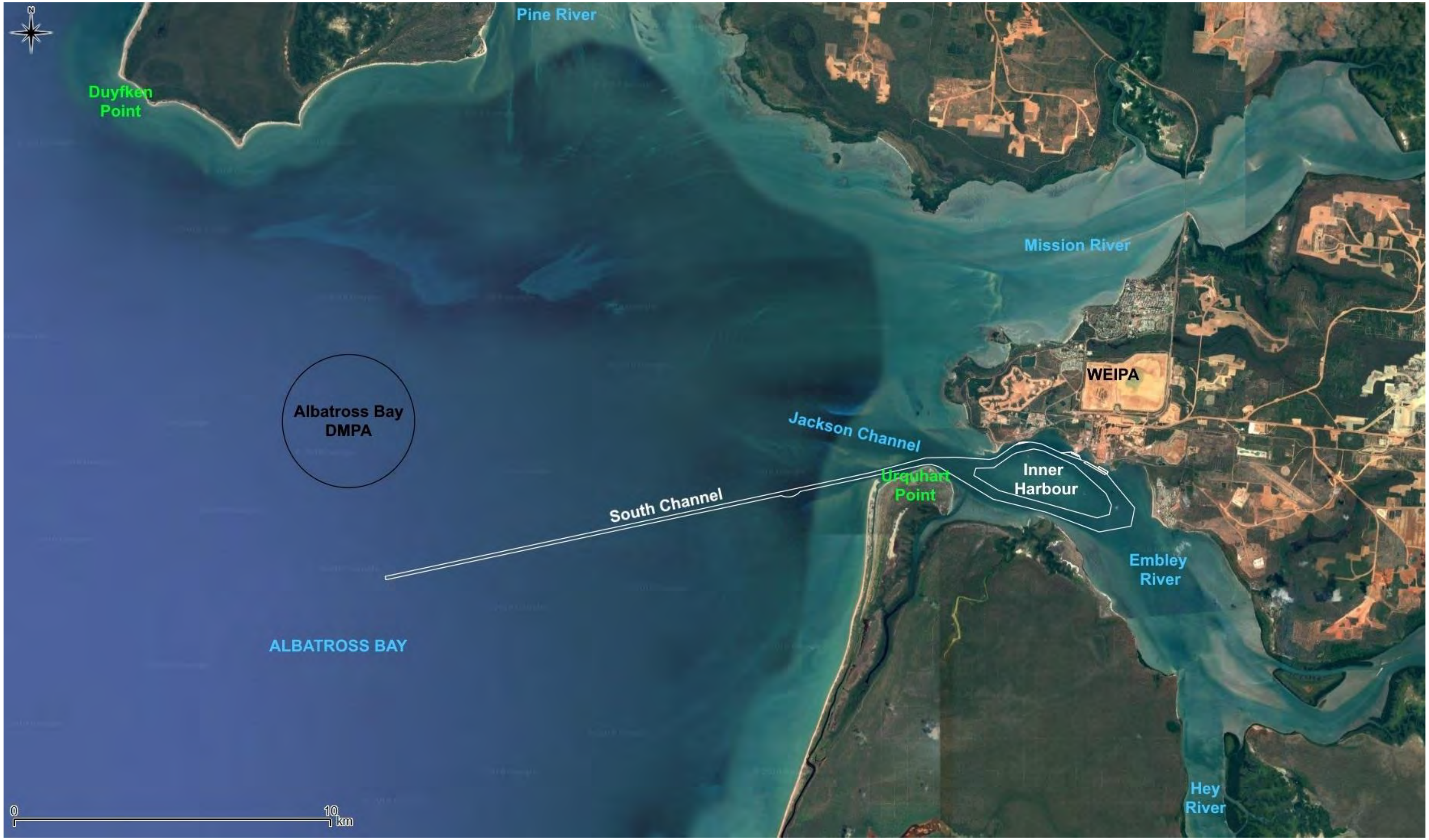


Figure 2. Location of the Port of Weipa.

Figure 3. Close up of the Port of Weipa Inner Harbour area and berths.

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 placement options modelled are discussed in **Section 3**;
- the modelling approach is defined in **Section 4;**
- the model performance is assessed in **Section 5**;
- descriptions of the dredging programs simulated by the model are 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 are adopted throughout:

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

2. Site Conditions

2.1. Introduction

This section provides a summary of the metocean and sediment transport conditions in the Weipa region. It provides an overview of the conditions based on the detailed interpretation provided in PCS (2018a) along with measured data collected in the Weipa region (Figure 5).

2.2. Hydrodynamics

The tidal signal in the Weipa region is predominantly diurnal, with short periods of semi-diurnal tides occurring during the neap tidal phase. A summary of the tidal planes at Weipa (Humbug Point) relative to LAT and Australian Height Datum (AHD) is provided in Table 1, with AHD being 1.752 m above LAT.

Seasonal fluctuations in sea level occur within the Gulf of Carpentaria and these are primarily due to trade winds and forcing from the adjacent Arafura Sea located at the north-western entrance to the Gulf. This can be seen by the elevated predicted water levels at Weipa between November and April (wet season) compared to the levels from May to October (dry season) (Figure 4).

Table 1. Tidal Planes at Weipa.

Tidal Plane	Elevation (m LAT)	Elevation (m AHD)
Highest Astronomical Tide (HAT)	3.38	1.63
Mean High High-Water (MHHW)	2.95	1.20
Mean Low High-Water (MLHW)	2.21	0.46
Mean Sea Level (MSL)	1.83	0.08
Mean High Low-Water (MHLW)	1.46	-0.29
Mean Low Low-Water (MLLW)	0.72	-1.03

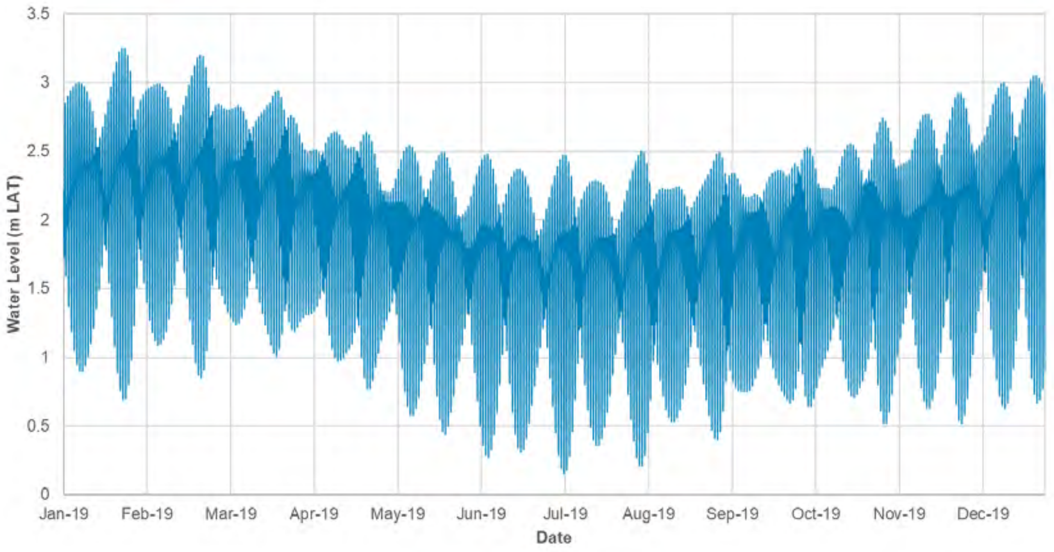


Figure 4. Predicted 2019 water levels for the Port of Weipa (Humbug Point).

Figure 5. Location of measured data in the Weipa region.

Current data have been measured at a number of sites in the Weipa region as part of the ongoing ambient water quality monitoring which is being undertaken by James Cook University (JCU). Current speeds and directions are shown at a site within the Inner Harbour (WQ1) and in Albatross Bay adjacent to the South Channel (WQ2) (Figure 6 and Figure 7). The plots show that there is a clear tidal signal in the current speeds, with higher currents occurring during the larger spring tides and lower currents during the smaller neap tides. The current speed at WQ1 in the Inner Harbour is consistently higher than the current speed at WQ2 in Albatross Bay by between 0.1 and 0.2 m/s. At both locations the highest tidal current speeds occur during the flood stage of the tide, this is due to the small first high water peak which occurs earlier than the second larger peak making the initial flood tide water level curve (before the first high water peak) steeper than the ebb tide water level curve and therefore resulting in higher tidal current speeds.

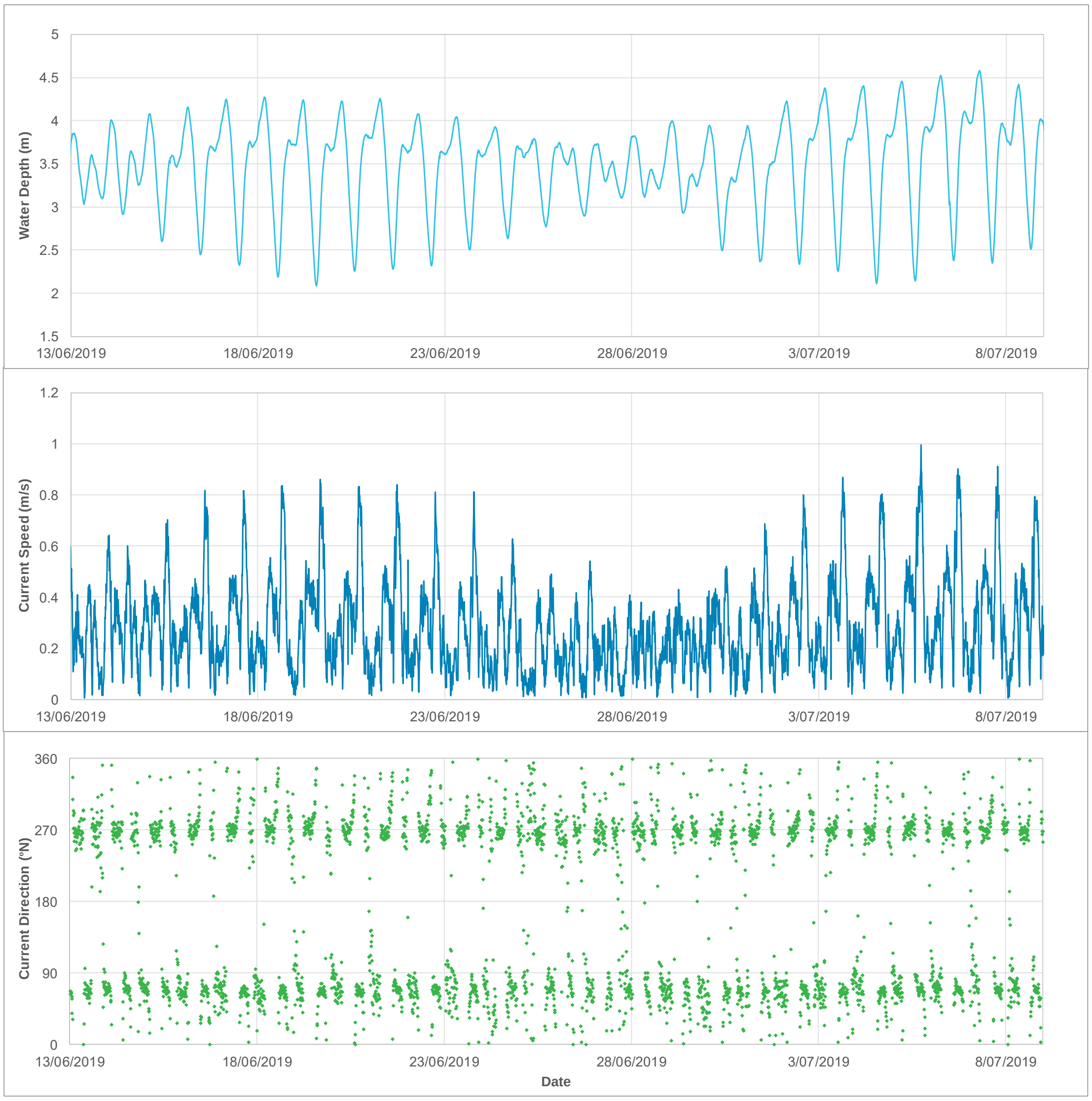


Figure 6. Measured water depth, current speed and direction at WQ1, mid water column.

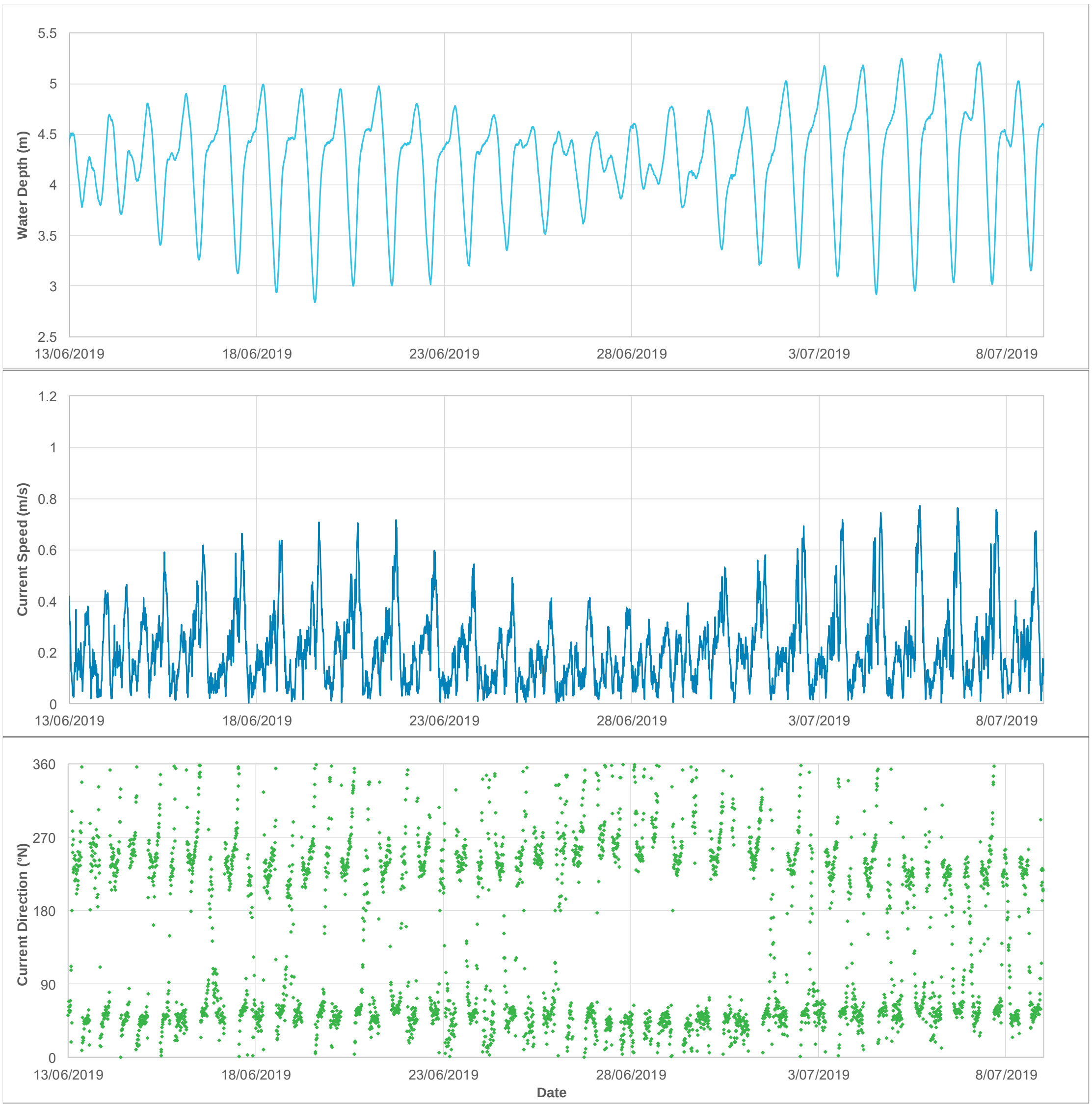


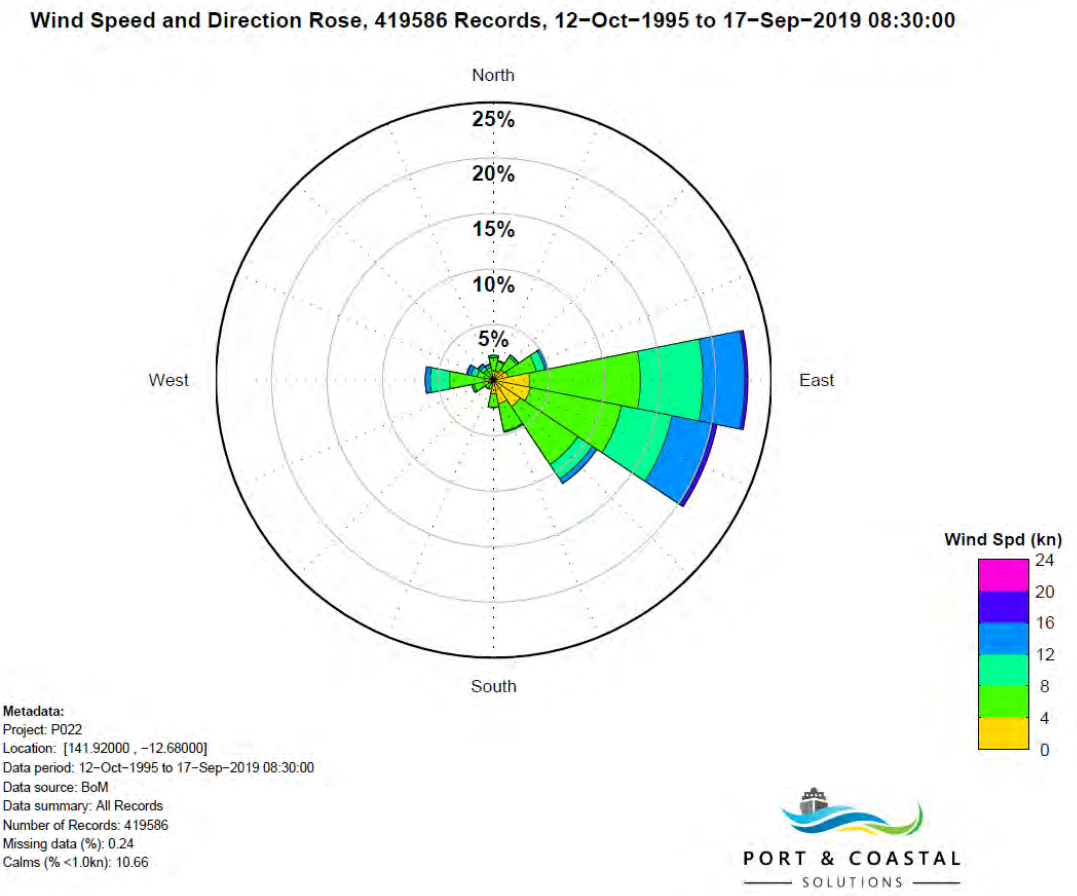
Figure 7. Measured water depth, current speed and direction at WQ2, mid water column.

2.3. Wind and Waves

The Weipa region is dominated by winds from the east to south-east, with approximately 55% of the annual wind recorded from these sectors (Figure 8). Winds from the west occur for 6% of the time, with this direction being the second most frequent sector after the east to south-east sector. The wind conditions also vary seasonally between the wet and dry seasons (Figure 9):

- during the dry season winds from the east to south-east dominate. These conditions generate offshore winds at Weipa which would not result in the local generation of wind waves; and
- during the wet season winds are more variable, with wind directions ranging from the east south-east through north to the west. The most frequent wind directions are from the east and the west, with the strongest winds occurring from the west to north-west. Westerly winds are orientated onshore at Weipa and could therefore result in the local generation of wind waves.

Strong winds or gale force winds in the Weipa region normally only occur during tropical cyclones (TCs). The TC season for the Gulf of Carpentaria is from December through to April. TCs are discussed further in Section 2.6.



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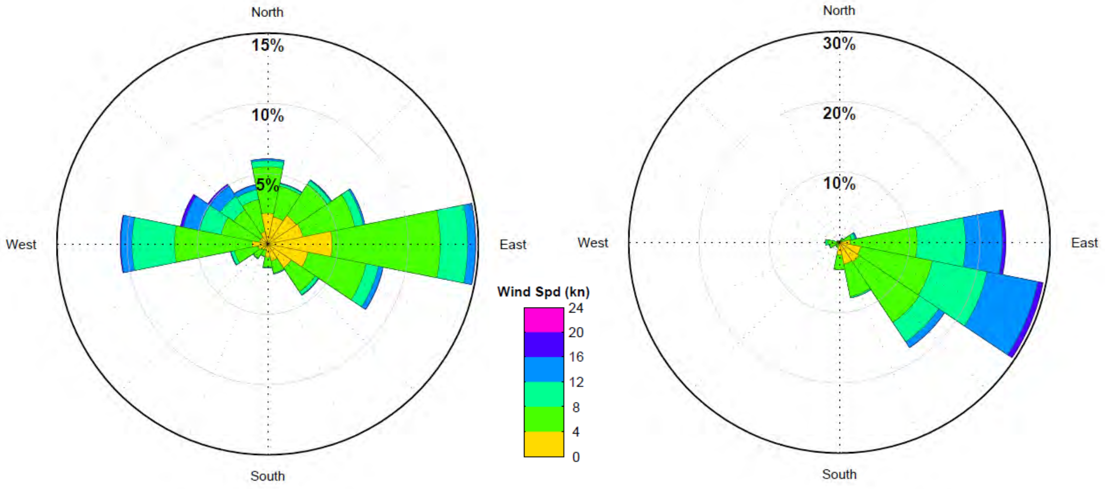
Calms (% <1.0kn): 10.66

Figure 8. Annual wind rose for measured wind data at the BoM Weipa Aero AWS (1995 to 2019.



Peak Wet Season (Dec to Feb) **Peak Dry Season (Jun to Aug)**

Figure 9. Seasonal wind roses of measured wind data at the BoM Weipa Aero AWS (1995 to 2019).

Department of Environment and Science (DES) have been maintaining a directional waverider buoy (WRB) in Albatross Bay measuring wave conditions since 2008. The wave data have been analysed and summary plots of the data are presented in Figure 10 to Figure 13. The wave climate at Weipa is strongly influenced by the local wind conditions. Figure 10 and Figure 12 show that there are three dominant wave directions:

- from the east: the waves are travelling away from the Weipa shoreline and are generated by the dominant east to south-east winds;
- from the west to west north-west: the waves are travelling towards the Weipa shoreline and are generated by the onshore sea breezes and monsoonal and cyclonic winds which occur in the wet season; and
- from the south-west: the waves are travelling toward the Weipa shoreline. Unlike the other two directions the wave direction does not directly correlate to the local wind conditions. The waves are generated further south in the Gulf of Carpentaria, due to the south-easterly winds during the dry season, and the waves then refract into Albatross Bay.

The wave plots show that the wave climate at Weipa is relatively calm, with significant wave heights (H_s) of less than 0.5 m occurring for 80% of the time and with an H_s exceeding 1 m for less than 5% of the time. Wave heights are larger during the wet season compared to the dry season due to the presence of onshore winds, along with the potential for stronger winds from the monsoonal trough and cyclones. During the dry season H_s exceeds 1 m for 1% of the time, while during the wet season, H_s exceeds 1 m for 13% of the time. H_s will typically only exceed 1 m during short duration storm events (tropical lows, monsoons and TCs), which regularly occur in the wet season when the peak H_s is typically greater than 1.5 m. The largest waves are from a westerly direction, with the largest measured H_s of 4.3 m recorded during TC Nora in March 2018.

The wave direction shows a difference between the wet and the dry seasons, with directions during periods with larger wave heights being from between the west to west north-west during the wet season and from the south-west during the dry season. The change in wave direction occurs in April and between October and November and is a result of the clear difference in wind conditions between the two seasons (Figure 9).

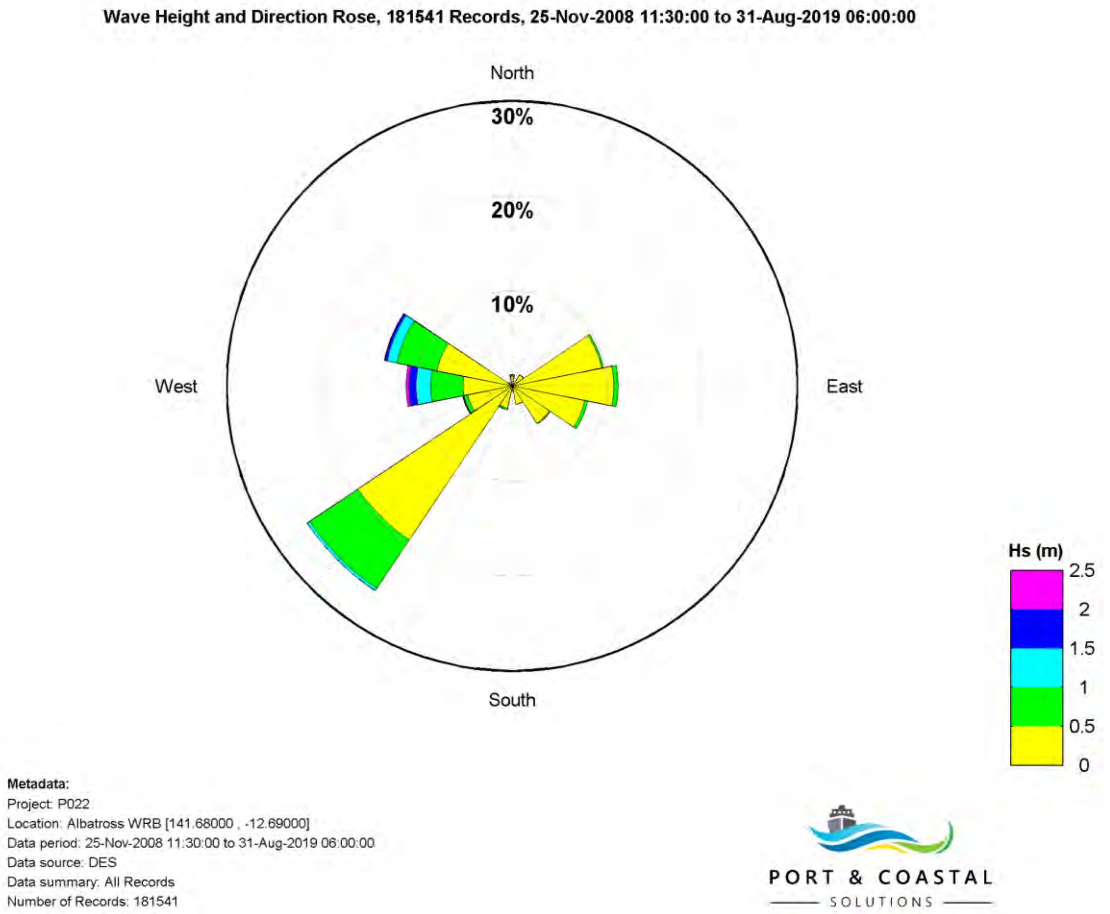
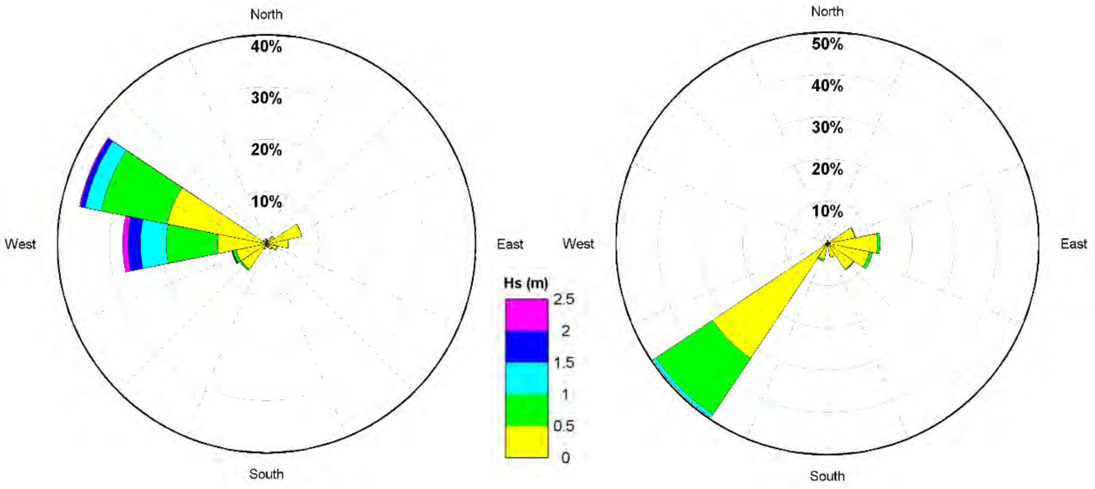


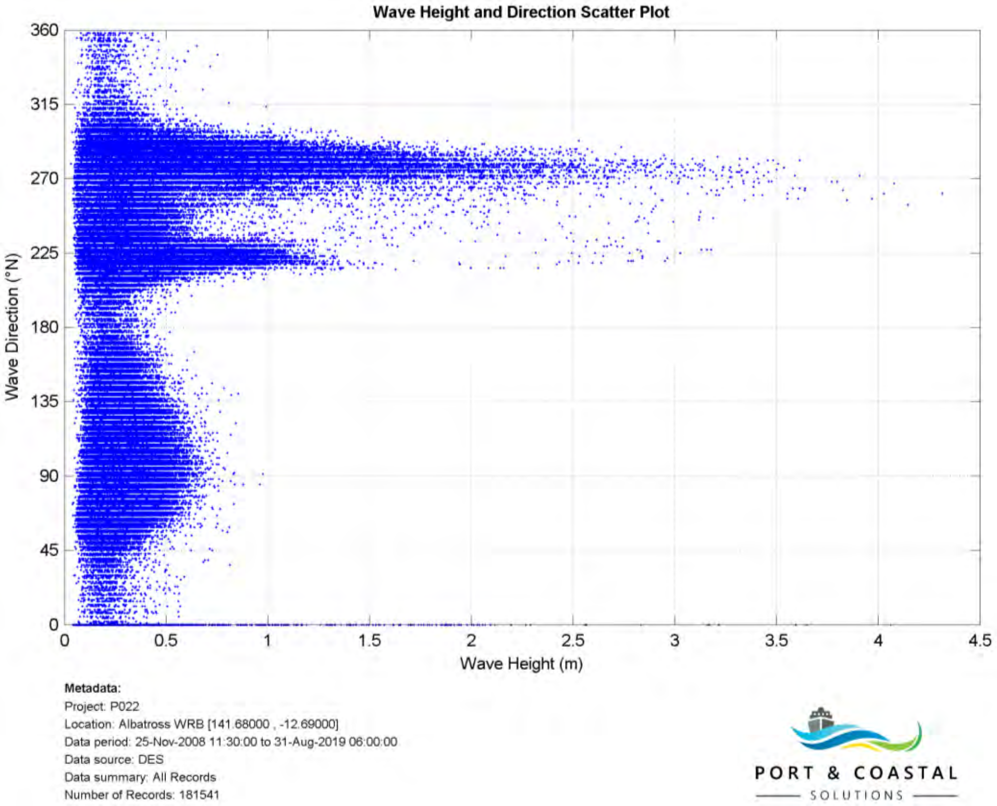
Figure 10. Annual wave rose for measured wave data at the Albatross Bay WRB (2008 to 2019).



Peak Wet Season (Dec to Feb)

Peak Dry Season (Jun to Aug)

Figure 11. Seasonal wave roses of measured wave data at the Albatross Bay WRB (2008 to 2019).



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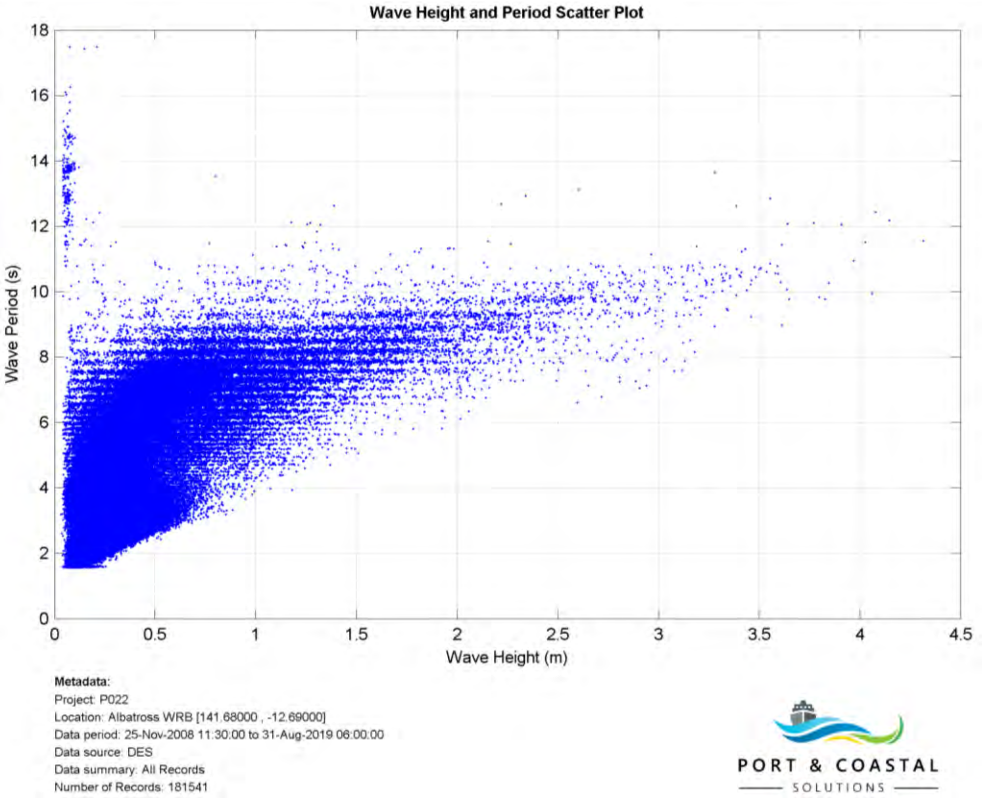
Data source: DES
Data summary: All Records
Number of Records: 181541

Figure 12. Wave height and wave direction scatter plot of measured wave data at the Albatross Bay WRB (2008 to 2019).



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Data period: 25-Nov-2008 11:30:00 to 31-Aug-2019 06:00:00
Data source: DES
Data summary: All Records
Number of Records: 181541

Figure 13. Wave height and peak wave period scatter plot of measured wave data at the Albatross Bay WRB (2008 to 2019).

2.4. Rainfall and River Discharge

The Weipa region has a tropical climate with a distinct monsoonal rainfall trend. Based on measured data (1990 to 2019) at the BoM Weipa Aero Automatic Weather Station (AWS) the average annual rainfall is 1,911 mm. The monthly mean rainfall at the BoM Weipa Aero AWS is shown in Figure 14. The plot shows the following:

- there is a distinct wet season between November and April when over 95% of the annual rainfall occurs with a monthly average of 310 mm; and
- during the dry season from May to October there is very little rainfall with a monthly average of less than 10 mm.

It is important to note that the monsoonal climate is variable and so the start, duration and intensity of rainfall which occurs in the wet season varies between years.

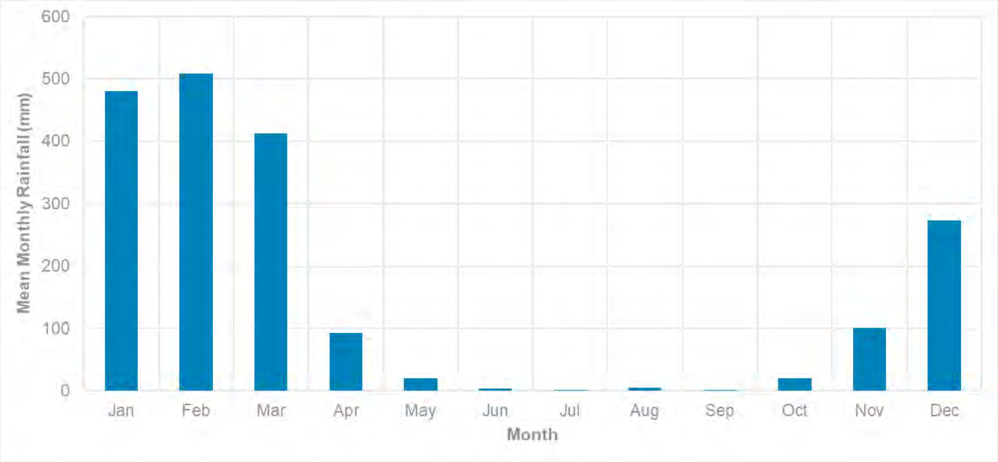


Figure 14. Mean monthly rainfall at the BoM Weipa Aero AWS (data from 1990 to 2019).

There are four relatively small river systems that discharge into Albatross Bay, the Pine to the north, the Mission directly to the north of Weipa and the Embley and Hey Rivers (the Hey River flows into the Embley River) which flow past the Port of Weipa (Figure 2).

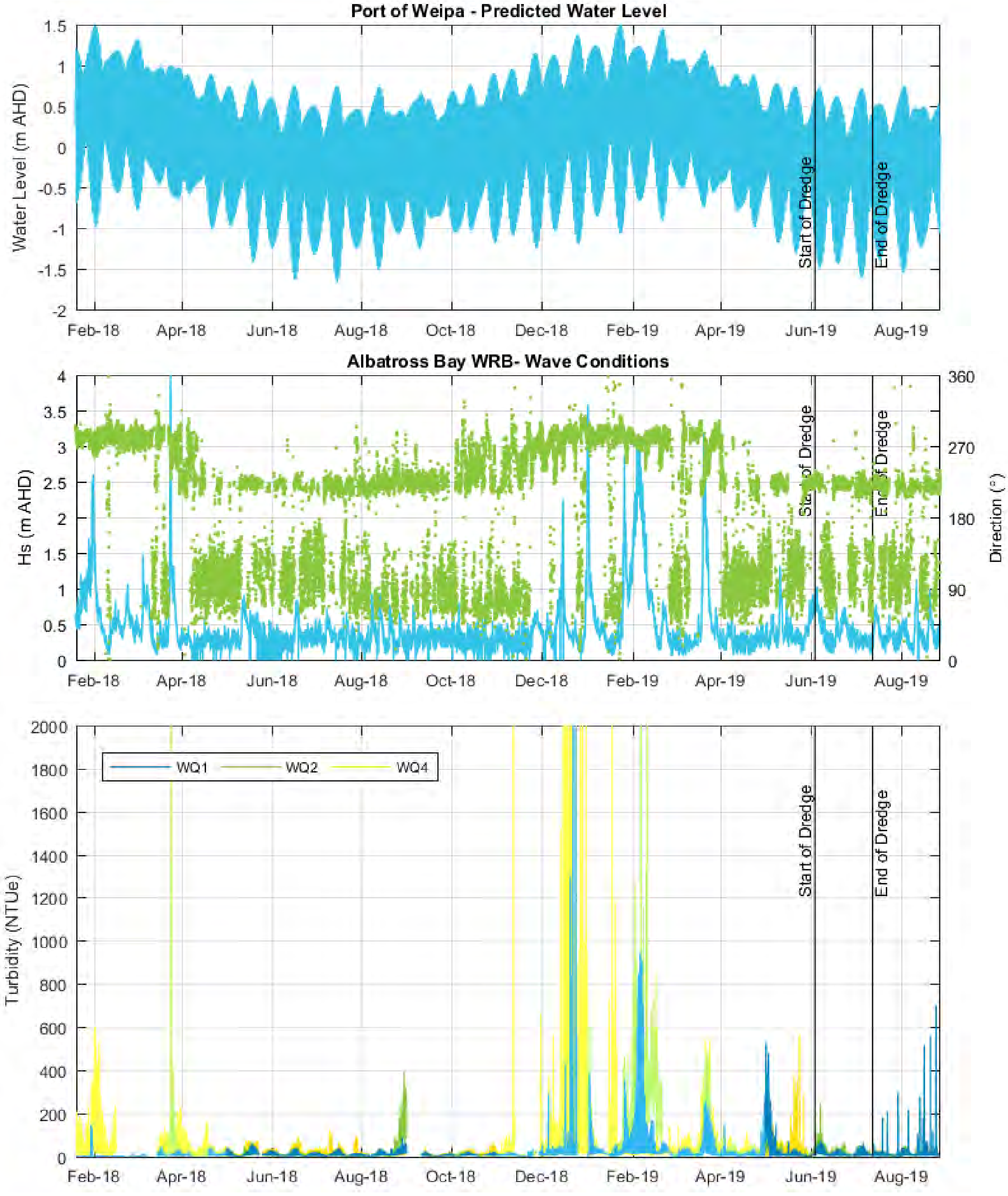
A combined catchment for the Embley and Hey Rivers has been delineated by the DES (2018) with a total catchment area of 1,925 km^2. A combined catchment for the Mission and Pine Rivers has also been delineated with a total area of 2,697 km^2. When these are compared to catchment areas of large rivers in the Gulf of Carpentaria such as the Norman River, which has a catchment area in excess of 50,000 km^2, it is clear that these are relatively small river systems. The size of the catchment areas combined with the relatively flat topography in the area indicates that the discharges from these rivers are likely to be small relative to the tidal discharge and as a result rainfall and river discharge is not expected to be an important process for sediment supply and transport in the Weipa region.

2.5. Sediment Transport

Measured water quality data have been collected at three sites in the Port of Weipa since January 2018 as part of the ongoing ambient water quality monitoring. The data were used to help inform the sediment budget which was developed for the Port (PCS, 2018b). The key findings from the sediment budget were as follows:

- the majority of the sedimentation in the dredged areas of the Port of Weipa has been in the South Channel, with the highest sedimentation being between Beacons SC14 and SC10. Due to the relatively high tidal current speeds in the Inner Harbour area of the Port there has been limited deposition of fine-grained sediment. Sedimentation in the Inner Harbour has primarily been due to Cora Bank encroaching on the channels;

- there is little input of new sediment to the system, with the primary source of sediment which contributes to the increased turbidity in Albatross Bay and at the Port being sediment which is already present on the seabed;
- within Albatross Bay the wave conditions are the dominant process resulting in the natural resuspension of bed sediment and the subsequent increase in turbidity, although during calm wave conditions the tidal currents influence the resuspension and turbidity (higher turbidity during spring tides and lower during neap tides);
- within the Inner Harbour area the natural resuspension is dominated by the tidal currents, although the turbidity is also influenced by the wave conditions in Albatross Bay as suspended sediment from Albatross Bay is transported into the Inner Harbour during the flood tide;
- there is limited net residual transport of sediment within Albatross Bay, with suspended sediment tending to be circulated around the bay rather than being exported from it; and
- within Albatross Bay and the adjacent estuaries there is estimated to be in the order of 30 Mm^3 of existing sediment on the seabed resuspended during a typical year and 40 Mm^3 during a cyclonic year (a year with a single cyclone). The majority of this sediment is transported around Albatross Bay with a small percentage of what is transported backwards and forwards past the South Channel being deposited within the channel (estimated to be in the order of 2 to 3% of the gross transport across the channel). Measured turbidity data are shown in Figure 15 for a site in Albatross Bay (WQ2) and two sites in the Inner Harbour (WQ1 and WQ4) along with the water level and wave conditions. The plots highlight how the turbidity varies due to the wave conditions and how the calmer wave conditions over the dry season result in a significant reduction in turbidity and a switch from it being controlled by the wave conditions to it being controlled by the tidal conditions.



Note: for turbidity, data for the wet season is shown as lighter colour and data for the dry season as darker colour.

Figure 15. Predicted water level (top), measured waves (middle) and benthic turbidity data (bottom) at the Port of Weipa.

2.6. Tropical Cyclones

Tropical Cyclones regularly form in the Gulf of Carpentaria during the wet season and have the potential to result in strong to gale force winds and large wave heights in the Weipa region. Between 1969 and 2019 a total of 25 TCs have passed within 100 km of the Port of Weipa, with three of these being over the 2018/19 wet season (as well as a prolonged tropical low).

The largest measured significant wave heights at the DSITI WRB in Albatross Bay occurred during TC Nora with a maximum H_s of 4.3 m, while the largest measured H_{max} of 6.7 m occurred during TC Oswald. Measured time series data of the wave conditions during TC Nora from the Albatross Bay WRB are shown in Figure 16. The plot shows that during TC Nora the H_s remained above 1.5 m for a 1 day and the peak wave period during TC Nora was between 10 and 14 s. The wave direction during the peak of the event was from the west. The strong winds and large waves from TCs have the potential to result in substantial resuspension and the resultant transport of sediment from the seabed both within Albatross Bay and in the adjacent areas of the Gulf of Carpentaria. The importance of TCs to sediment transport and sedimentation in Albatross Bay is highlighted by the fact that over 2 Mm^3 of sedimentation occurred in the South Channel during the 2018/19 wet season. This period had three tropical cyclones and a prolonged tropical low and shows that as a result there was very high turbidity through much of the 2018/19 wet season. This sedimentation volume is more than double the sedimentation during any previous years since the South Channel was enlarged in 2006 (PCS, 2019a).

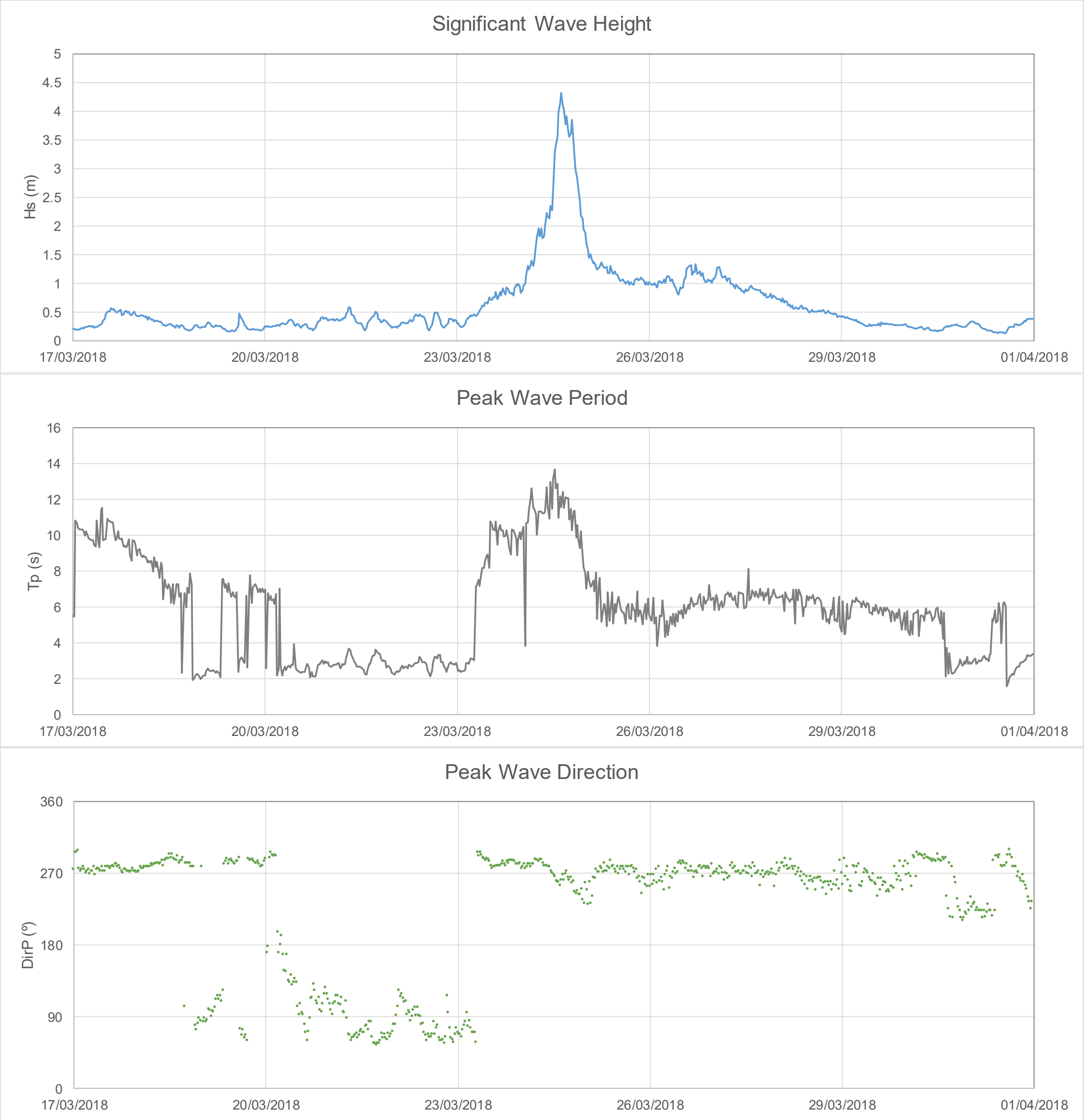


Figure 16. Measured wave conditions at the Albatross Bay DSITI WRB during TC Nora.

3. Placement Scenarios

3.1. Introduction

As part of this assessment a number of different placement options are being considered as well as a range of possible maintenance dredging volumes. This section provides details of the placement scenarios which are being considered.

3.2. Dredging Volumes

Detailed bathymetric analysis has been undertaken at the Port of Weipa to better understand the natural sedimentation that has occurred in the dredged areas of the Port since 2003 (PCS, 2018a & 2019a). The analysis found that the annual sedimentation was highly variable depending on the wave conditions which occurred during the wet season, with the occurrence of TCs in the region being a key driver for larger waves and increased sedimentation. As noted in Section 2.5, the analysis also found that the majority of the sedimentation occurred in the South Channel, with limited sedimentation occurring in the Inner Harbour. Based on the previous bathymetric analysis, sedimentation volumes were defined for the Port of Weipa to represent a range of years with different sedimentation:

- Typical Year: the annual sedimentation for a typical year is approximately 400,000 m^3. This represents a year with average wave conditions and no TCs;
- Cyclonic Year: the annual sedimentation for a year with a TC is approximately 800,000 m^3. This represents a year with above average wave conditions due to the occurrence of a single TC which directly impact the Weipa region; and
- Worst Case Year: the annual sedimentation for a year with multiple TCs is approximately 2,500,000 m^3. This represents a year with worst case wave conditions due to the occurrence of multiple TCs and tropical lows which directly impact the Weipa region.

These sedimentation volumes have been adopted as the maintenance dredging volumes required to maintain depths in the dredged areas of the Port of Weipa for this assessment. All of the offshore placement options have been modelled for each of these volumes. The onshore option has been modelled for the typical year and the cyclonic year as the onshore pond is too small for the volume associated with the worst case year. The reclamation and beach nourishment options have only been undertaken for the typical year as the options only assume that a portion of the dredge volume is used and this amount would not significantly vary between the different sedimentation years.

3.3. Sediment Composition

Sediment sampling and characterisation have periodically been undertaken by NQBP at the Port of Weipa to ensure the sediments remain suitable for placement at sea at the approved Albatross Bay DMPA. Data from the two most recent sampling programs undertaken in 2018 (Advisian, 2018) and 2013 (PaCE, 2013) have been used to inform the sediment characterisation in the areas where regular sedimentation occur. The sediment characterisation can be separated between the South Channel and the Inner Harbour region:

- South Channel: the majority of the annual sedimentation in the Port of Weipa occurs in the South Channel, with most of this being seaward of Beacon SC14 (Figure 17). The sediment which is deposited in this area ranges from 75% silt and clay to almost 100% silt and clay, with an average composition of approximately 90% silt and clay and 10% sand; and
- Inner Harbour: approximately 10% of the sedimentation volume is within the Inner Harbour during a typical year, with the percentage reducing for the cyclonic and worst case years (as the majority of the additional sedimentation occurs in the South Channel). When the sediment sampling locations in the Inner Harbour are compared to the historic bathymetric changes (see PCS (2018a)) it can be seen that most of the samples are not

located in areas where regular sedimentation occurs. As a result, the overall results suggest that on average more than 70% of the sediment in the Approach and Departure Channels and berths is sand sized. However, samples from locations where regular sedimentation has occurred have been predominantly silt and clay with between 75% and >90% of the sediment being composed of silt and clay sized sediment. Based on this, a conservative assumption has been adopted for the modelling (in terms of the potential release of fine-grained sediment while dredging), whereby all the sediment dredged from the Inner Harbour has been assumed to be 90% silt and clay and 10% sand. This assumption will ensure that any potential release of suspended silt and clay sized sediment from the dredging activity within the Inner Harbour is not underestimated.

3.4. Option 1: Albatross DMPA

This option assumes that all of the dredged sediment is placed offshore at the Albatross Bay DMPA.

Due to recent limitations associated with the depth of the existing Albatross Bay DMPA as part of the 2019 maintenance dredging program[1], the DMPA location has been assumed to have been moved 2 km to the west for this assessment. This means that the eastern half of the DMPA overlaps the western half of the existing DMPA.

The Albatross DMPA is shown in Figure 17. It has depths of 10-11 m (below LAT) and its centre is located 6 km to the north north-west of channel marker SC2.

3.5. Option 2: Albatross West DMPA

This option assumes that all of the dredged sediment is placed offshore at a new Albatross Bay DMPA located 10.5 km to the west of the existing DMPA. The new Albatross West DMPA has been moved so that it is located in deeper water and as such would not have any depth limitations for a larger TSHD.

The Albatross West DMPA is shown in Figure 17. It has depths of 12-14 m (below LAT) and its centre is located 12.5 km to the west north-west of channel marker SC2.

3.6. Option 3: Albatross South DMPA

This option assumes that all of the dredged sediment is placed offshore at a new Albatross Bay DMPA located 11 km to the south of the existing DMPA. The new Albatross South DMPA has been moved so that it is located in deeper water, and as such would not have any depth limitations for a larger TSHD, but is still located relatively close to the seaward end of the South Channel.

The Albatross South DMPA is shown in Figure 17. It has depths of 12-14 m (below LAT) and its centre is located 6.5 km to the south-west of channel marker SC2.

3.7. Option 4: Onshore Pond

This option assumes that all of the dredged sediment from the typical and cyclonic years is pumped to an onshore pond. As such, for this option there would not be any offshore placement of the dredged sediment with the only release of sediment to be included in the modelling being from the dredging activity and the tailwater discharge from the pond (assumed to be located adjacent to the Evans Landing wharf).

The onshore pond proposed for this modelling assessment is located approximately 1 km to the north of the Evans Landing wharf (Figure 18). A 135 hectare onshore pond could be located at this site, with estimates suggesting that the pond could contain approximately

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[1] the fully laden draft of the large trailing suction hopper dredger (TSHD) used for the program meant that it could only place sediment in the south-western quarter of the DMPA.

1.8 Mm^3 of dredged sediment (PCS, 2019b). Therefore, the pond is not large enough to contain all the sediment from a worst case year and so this scenario has not been modelled.

3.8. Option 5: Evans Landing Reclamation

This option assumes that the sediment dredged from the Inner Harbour and inner South Channel (100,000 m^3 for the typical year) is pumped into the reclamation, with the remaining sediment from the South Channel being placed at the Albatross DMPA.

The reclamation proposed for this modelling assessment is located at Evans Landing, with the reclamation being 5.5. hectares in size (Figure 18). The total capacity of the reclamation has been estimated to be 440,000 m^3, and as such the reclamation would be gradually filled with sediment from the Inner Harbour and inner South Channel over multiple years (PCS, 2019b).

3.9. Option 6: Beach Nourishment

This option assumes that the sediment dredged from the Inner Harbour and inner South Channel (100,000 m^3 for the typical year) is pumped to a beach nourishment site. The remaining sediment from the South Channel is assumed to be placed at the Albatross DMPA.

The proposed beach nourishment site for this modelling assessment is located to the west of Gonbung Point (Figure 19). The area is relatively shallow (depths of 0 to 1 m below LAT) and represents an environment with a mix of sand and fine-grained (silt and clay) sediment. It is unknown what capacity of sediment could actually be placed at the site but for this assessment a conservative assumption that all sediment from the Inner Harbour and inner South Channel could be placed at the site was adopted.

Figure 17. Location of the Albatross Bay offshore placement sites.

Figure 18. Locations of onshore pond and land reclamation for Port of Weipa.

Figure 19. Location of the beach nourishment site.

4. Modelling Approach

4.1. Introduction

The approach adopted for the modelling has been developed to ensure that it complies with the guidelines provided by the Great Barrier Reef Marine Park Authority (GBRMPA) (GBRMPA, 2012). Although the Port of Weipa is not located within the Great Barrier Reef Marine Park (GBRMP), the GBRMPA modelling guidelines were adopted to ensure the modelling met the highest international standards of best practise and therefore give additional confidence in the results.

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

4.2. 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 adopted 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 to be represented in the model.

The MIKE modules allow a flexible mesh (FM) to be adopted which allows the spatial resolution of the model mesh to be varied throughout the model domain. Adopting 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 while a lower mesh resolution can be adopted in offshore areas and areas away from any areas of interest.

4.3. Model Configuration

HD, SW and MT models for the Weipa region were developed as part of the SSM Project Sediment Budget assessment (PCS, 2018b). These models were adopted for this assessment with further refinements being made based on the additional calibration and validation data available.

4.3.1. Mesh

The extent of the model domain has been kept the same as the domain adopted for the previous SSM modelling (PCS, 2018b). The extent had been carefully selected taking into consideration the location of both Ports and the physical processes within the study area. The extent of the domain adopted also allows the same domain to be used for the HD, SW and MT models.

The model domain covered all of Albatross Bay and approximately 80 km of shoreline to the north (to Port Musgrave) and south (to Love River). The domain extended offshore to approximately the -50 m LAT depth contour, resulting in the northern boundary being 73 km in length and the southern boundary 90 km in length. The domain extent, boundary position and length of each boundary are shown in Figure 20.

The spatial discretisation of MIKE's flexible mesh enabled the model mesh resolution to be varied within the model domain, with higher resolution in areas of interest, such as around the Ports of Weipa, at the various DMPA locations and at other tailwater release locations, and lower resolution in offshore areas. This approach assists with optimising the model simulation times without compromising on representing important physical processes within key study areas. Plots of the mesh configuration are shown in Figure 21 and Figure 22 for the Albatross Bay region and the Inner Harbour at Weipa.

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 (i.e. each layer represents 20% of the water column) included in the model.

Figure 20. Domain extent, boundary locations and boundary lengths (PCS, 2018b).

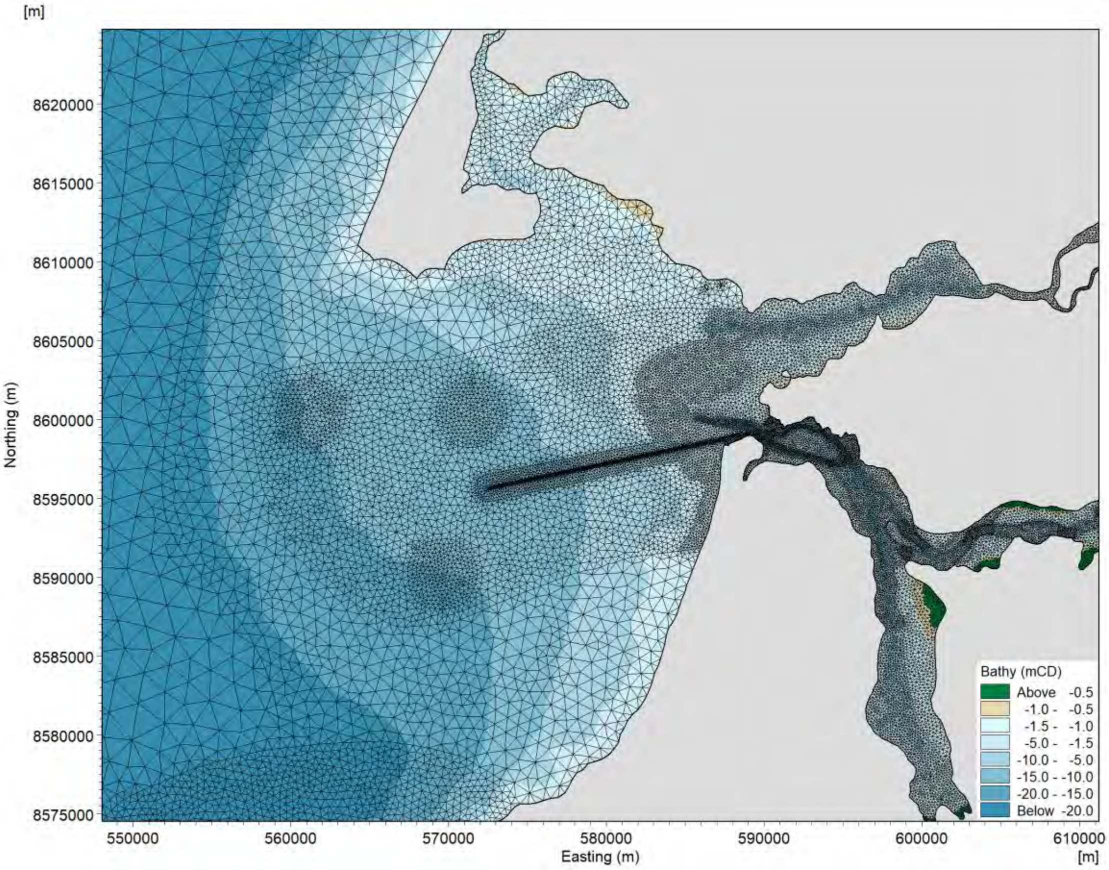

Figure 21. Mesh configuration for the Albatross Bay region.

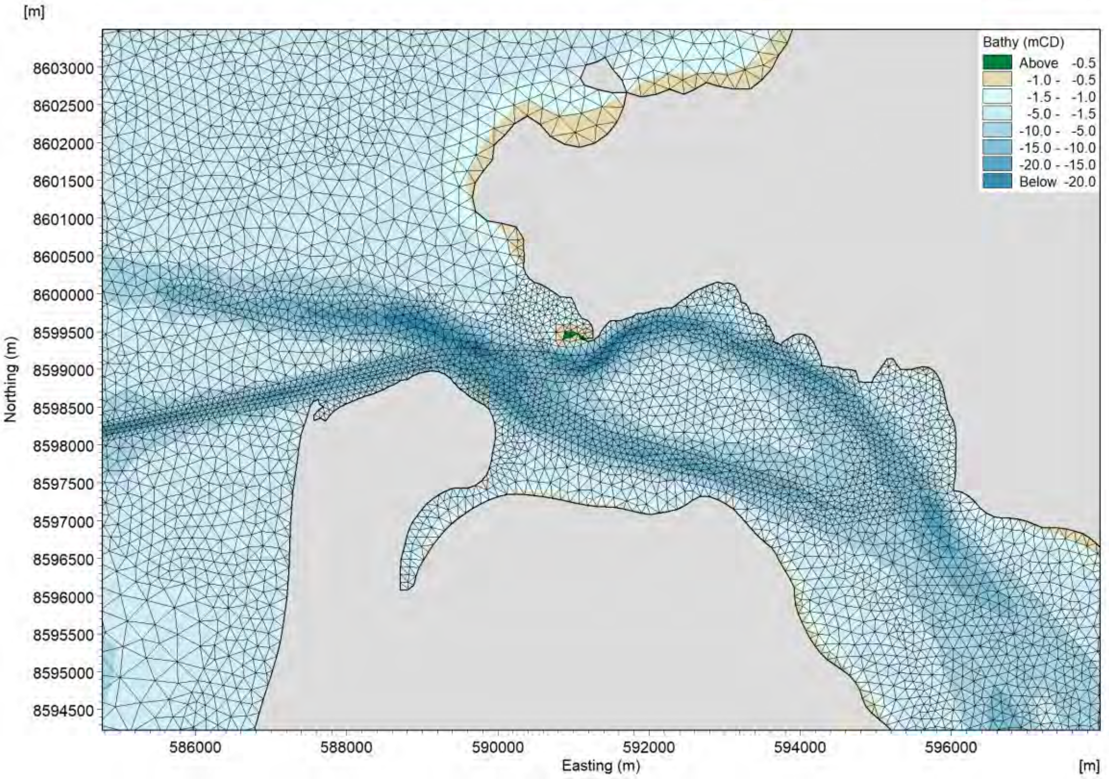

Figure 22. Mesh configuration for the Inner Harbour region.

4.3.2. Bathymetry

The model bathymetry of the model domain has been kept the same as the bathymetry adopted for the previous SSM modelling. The bathymetry includes a selection of data including recent survey data at the Port of Weipa obtained from NQBP, chart data from the Australian Hydrographic Office (AHO) and, where data gaps existed, water depths were inferred from aerial imagery (PCS, 2018b).

An overview of the interpolated soundings covering the extent of the model domain is shown in Figure 23 and for the Port of Weipa region in Figure 24.

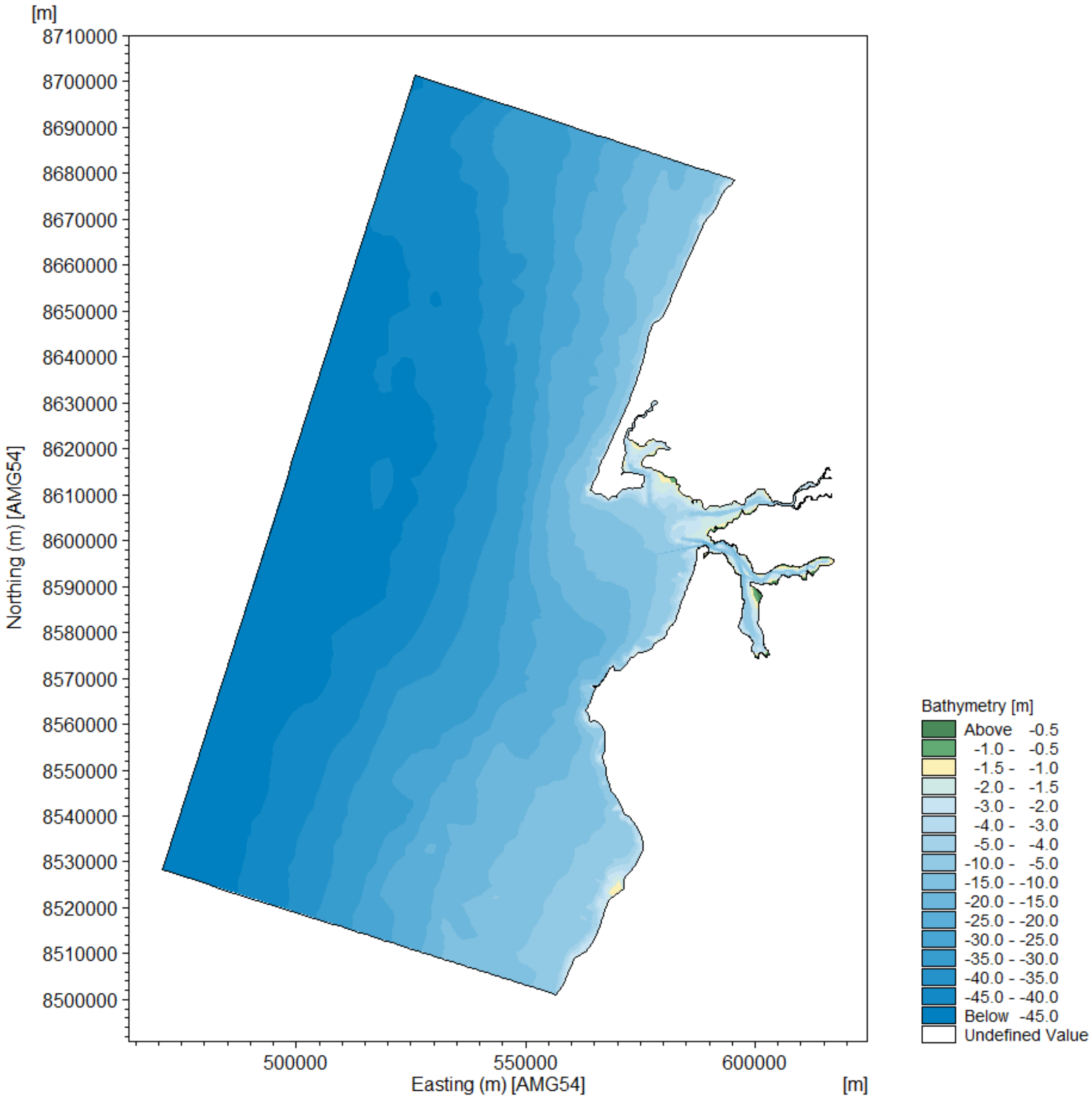

Figure 23. Model bathymetry within the model domain (PCS, 2018b).

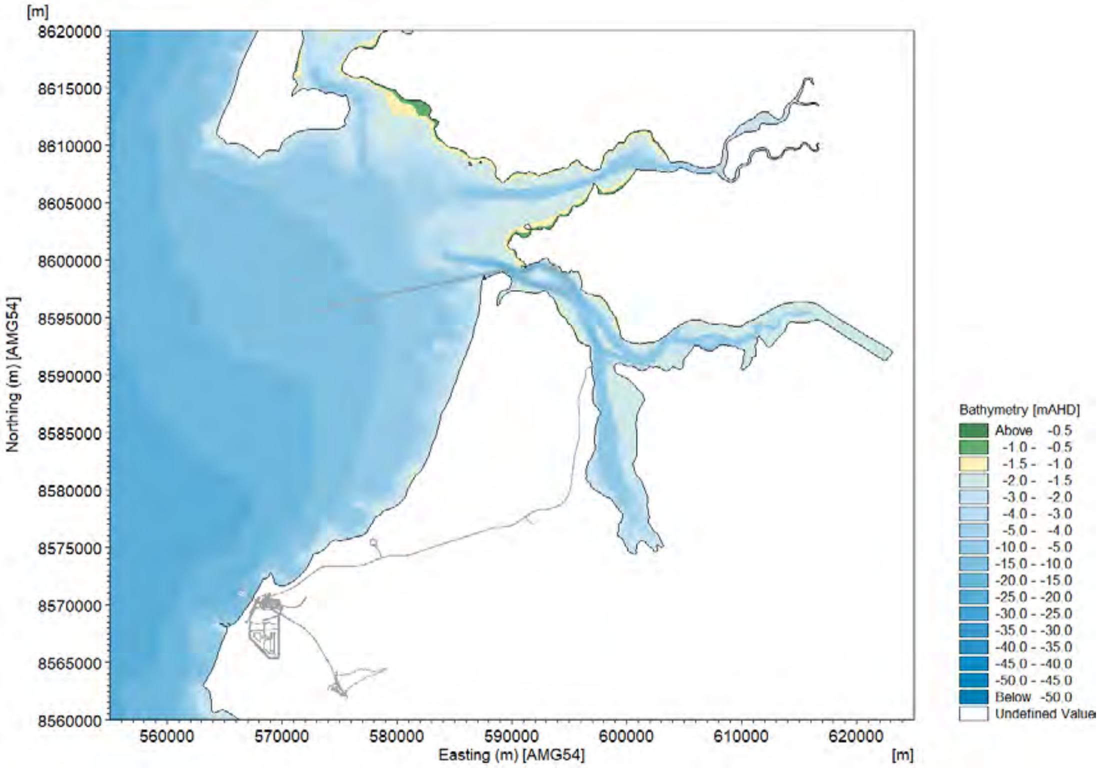

Figure 24. Model bathymetry within the study area (PCS, 2018b).

4.3.3. Boundary Conditions

Details of the boundary conditions adopted to drive the HD and SW models are provided in the following sections. The boundary conditions were kept consistent with those adopted for the previous SSM modelling, although it was necessary to generate new boundaries to undertake modelling for the second half of 2018 and 2019. The approach used to generate these new boundaries was consistent with that used for the previous SSM modelling.

4.3.3.1. Hydrodynamic Model

The model has three tidal boundaries (north, west and south). The boundary conditions were generated using the TPXO 8 Global Inverse Tide Model. TPXO is a series of fully-global models of ocean tides, which best-fits, in a least-squares sense, the Laplace Tidal Equations and measured altimetry data.

Spatially varying water levels have been used to drive all three of the tidal boundaries for the model to account for variations in water level slope, between the nearshore and offshore, and over the length of the offshore boundary.

4.3.3.2. Spectral Wave Model

The boundary conditions for the SW model were derived from the measured Albatross Bay WRB data. In addition to the wave boundary conditions, local winds were also included in the model to ensure any locally generated waves were represented in the model (these are particularly important during the dry season when south to south-easterly winds dominate). Local measured winds from the Bureau of Meteorology Weipa Airport weather station (Weipa Aero) were included in the model to allow for the generation of any local wind waves within the estuaries, Albatross Bay and further offshore.

4.4. Natural Sediment Transport

As part of the previous modelling undertaken to inform the Port of Weipa sediment budget, a natural sediment transport model was setup and calibrated/validated against measured SSC data. This model has been further improved for this assessment, with an additional 12 months of measured SSC data available to calibrate the model.

The model was setup so that the only sediment present in the model at the start of the simulation was on the seabed, to allow the model to naturally resuspend sediment based on the metocean conditions. There was no additional input of suspended sediment applied at the model boundaries, which meant 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 three separate sediment types which are expected to represent the majority of sediment which is regularly resuspended: (i) medium to coarse silt, (ii) very fine to medium silt and (iii) clay.

The model was also setup to include the process of flocculation, whereby the cohesive properties of the sediment 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 sediments is dependent on the SSC, with larger flocs and higher settling velocities occurring with higher SSC.

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, the final critical erosion threshold which was adopted was 0.5 N/m^2.

4.5. Dredging Simulations

As part of the GBRMPA Modelling Guidelines it is required that the modelling represents the ambient conditions at the time of year in which dredging occurs (GBRMPA, 2012). Maintenance dredging at the Port of Weipa is undertaken during the dry season. This is due to the majority of the wet season having increased ambient wind and wave conditions compared to the dry season as well as the risk of TCs during the majority of the wet season. Typically, the metocean conditions during the transition period between the wet and dry seasons (end of March to April) are relatively calm meaning that maintenance dredging could be undertaken anytime from the end of March to the end of October.

Analysis of the wave conditions measured at the Albatross Bay WRB shows that although there has been significant variability in wave height over different wet season years, the wave conditions over the dry season years have been fairly consistent (Figure 25). Based on this consistency along with measured water quality data only being available to calibrate/validate the natural sediment transport model in 2018 and 2019 and the wave conditions being slightly more energetic in 2019 compared to 2018, the 2019 dry season was selected for the dredge plume modelling.

The measured wind and wave conditions at the Albatross Bay WRB were analysed in more detail from the end of the March to August 2019 to determine how variable the metocean conditions are over this period. Based on the analysis an ambient dry season period was selected from the end of March to the end of May and an energetic dry season period was selected from the end of May to the end of July 2019 (Figure 26). For the ambient dry season period the H_s is less than 0.5 m for the majority of the period, while for the energetic dry season period the H_s is more than 0.5 m for almost half of the period. All of the dredge placement options and the natural sediment transport will be modelled for these two periods. For the dredge placement options the dredging will commence one day after the start of the simulation to allow the model to warm up.

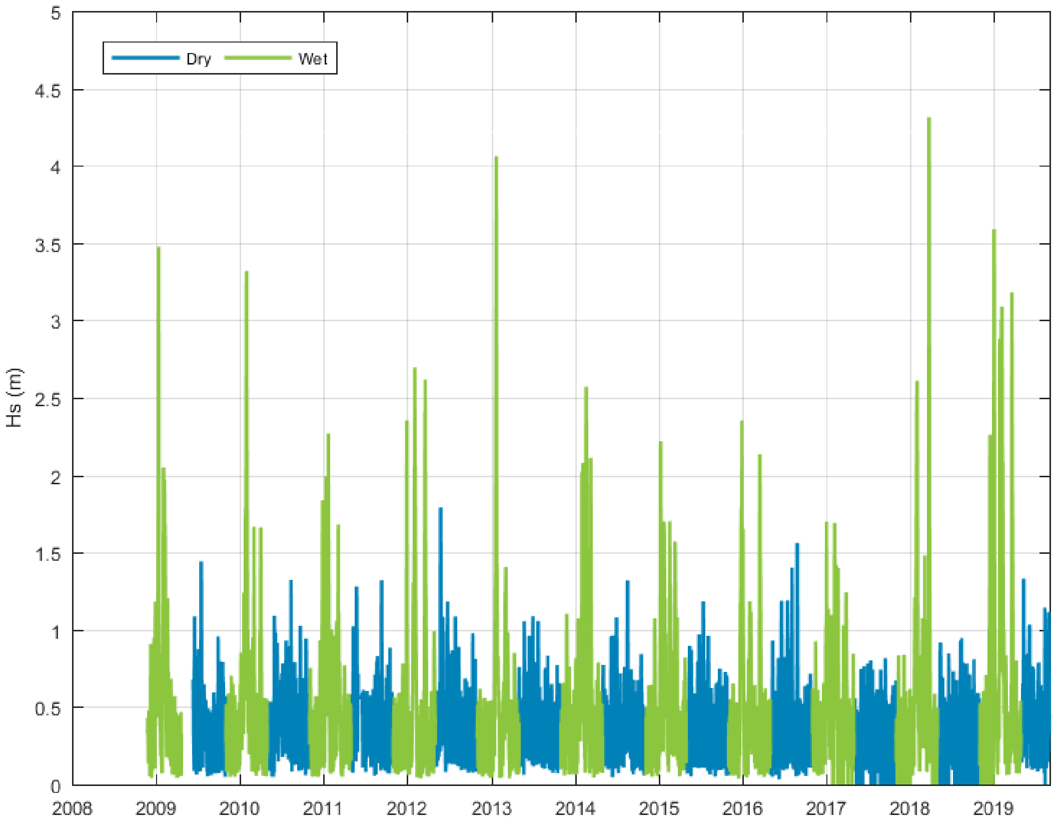

Figure 25. Wet and dry season measured H_s at the Albatross Bay WRB from 2009 to 2019.

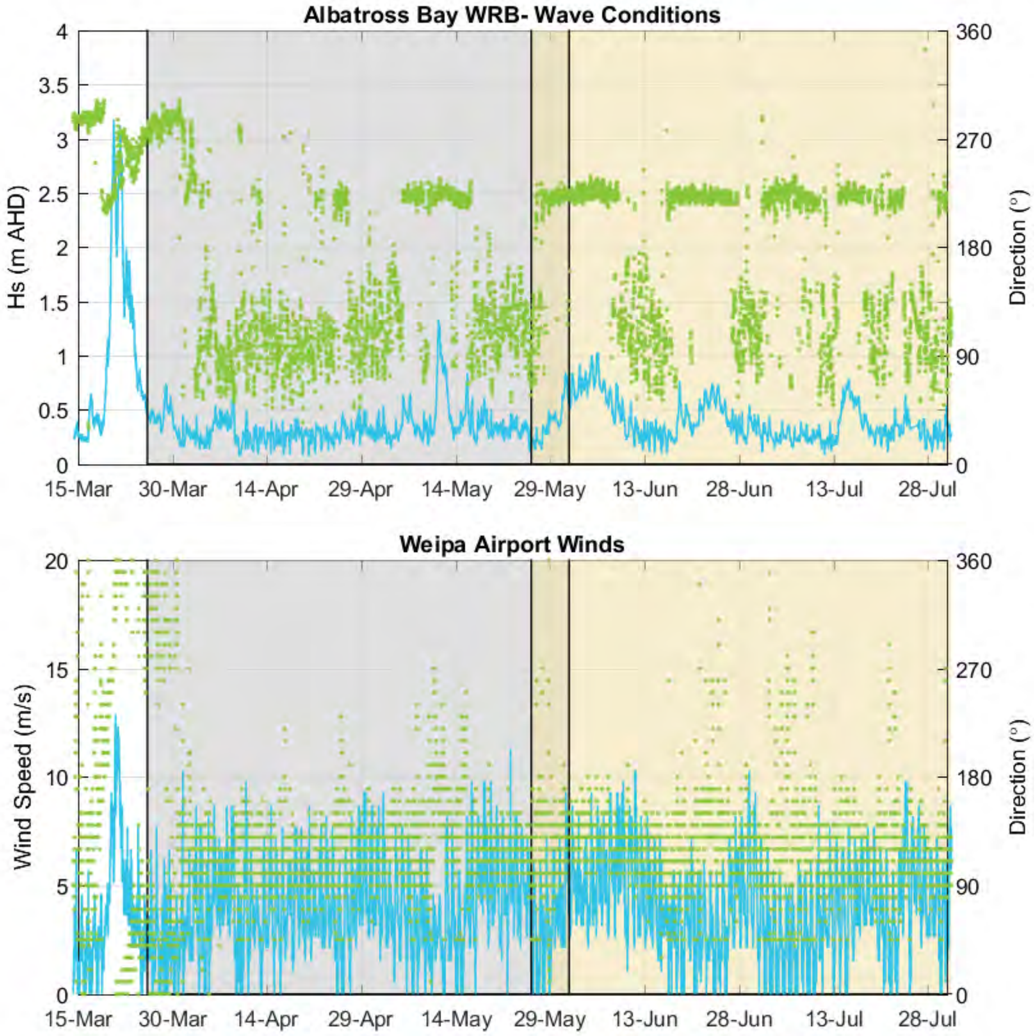

Figure 26. Wave and wind conditions during the two dredge simulation periods.

4.6. Long-term Resuspension Simulations

The GBRMPA Modelling Guidelines specify that the modelling should represent the resuspension associated with different weather conditions that occur after dumping and initial settlement (GBRMPA, 2012). Given the depth of the offshore placement options being considered in this assessment (ranging from 10 to 14 m below LAT) and the seasonality of the wave conditions, resuspension of sediment from the offshore placement sites is most likely to occur during the wet season when larger waves occur. Data from the Albatross Bay WRB has been analysed to calculate the duration of time the H_s has exceeded 2 m and 3 m for each year[2] (Figure 27). It is during these larger wave events when widespread resuspension would be expected throughout much of Albatross Bay and when resuspension from the offshore placement sites could occur. To represent the worst case resuspension scenario, the 2018/19 period has been selected for the simulations as the wave conditions were significantly larger. The model was run for a 7 month period to represent the 2018/19 wet season and the start of the 2019 dry season. The models were setup to represent the volume of sediment that would have been placed following a worst case sedimentation year (2.5 Mm^3), assuming that the sediment was evenly placed over the entire placement site and

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[2] a year is from the start of April one year to the end of March the following year to make sure the whole wet season is included in a single year.

the dry density of the sediment was 300 kg/m^3 (medium consolidated sediment) giving 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).

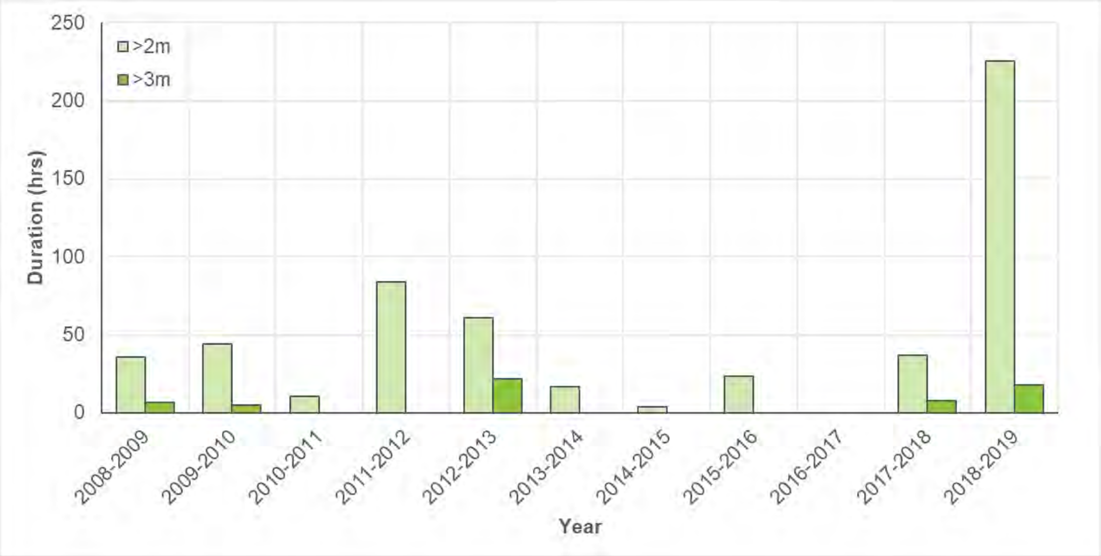

Figure 27. Summary of wave conditions from 2008 to 2019 (each year from 1st April to 31st March).

5. Model Calibration and Validation

5.1. Introduction

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.

5.2. 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 combined coastal and estuarine waters such as around the Port of Weipa, the following performance criteria have been defined and can be expressed in percentage terms as:

- Modelled water levels (WL) should be within 15 – 20% of the tidal range over a spring neap tidal cycle, or within ± 0.1 – 0.3 m;
- Timing of high water (HW) and low water (LW) should be within 15 – 25 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, or within ± 0.2 m/s; and
- Modelled peak flow directions at PE and PF should be within 10 – 15 degrees 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 15-25 minutes.

These statistics consider the model performance throughout the full tidal period and not just at the time of peaks. This can be particularly relevant in areas where the tidal signal departs significantly from the typical sinusoidal shape, such as occurs in the Weipa region.

These standards provide a good basis for assessing model performance, but experience has shown that sometimes 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 wave models we have undertaken a qualitative comparison between measured and modelled wave height, wave period and wave direction. In addition, a correlation between modelled and measured wave heights has also been undertaken.

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. 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 & 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'.

5.3. Hydrodynamic Model

To ensure that the hydrodynamic model accurately represents the natural conditions within the Weipa region, predicted and measured water levels and currents (speed and direction) have been compared against modelled predictions. The location of available data (referred to as calibration data) are shown in Figure 5.

Based on the available data and the selected model dredging simulation periods (see Section 4.5), modelled water levels and currents have been compared with the calibration data for the following periods:

- calibration period: a 14.5 day spring-neap cycle between 14 April 2019 and 28 April 2019, when conditions are characteristic of ambient dry season conditions; and
- validation period: a 14.5 day spring-neap cycle between 15 June 2019 and 29 June 2019, when conditions are characteristic of energetic dry season conditions.

5.3.1. Water Levels

Long term predicted water level data are available at Humbug Point within the Port of Weipa. Additionally, pressure readings from Acoustic Doppler Current Profilers (ADCP's) deployed by James Cook University (JCU) at sites WQ1 and WQ2 have been converted to water levels for comparison with the model.

Time series of predicted/measured and modelled water levels at Humbug Point, WQ1 and WQ2 are shown in Figure 28 to Figure 30. The comparison is shown for the four month period for which the hydrodynamics have been simulated, with the first two months selected to characterise ambient dry season conditions and the last two months selected to characterise more energetic dry season conditions. Subplots are included to show the water level comparison for the calibration and validation periods in more detail. The plots demonstrate the complexity of the tidal signature in the Weipa region with alternating periods of semi-diurnal (two per day) and diurnal (one per day) tides, with the former typically occurring during neap tides and the latter occurring during spring tides.

The time series plots demonstrate that overall, the model replicates the predicted/measured variations in water levels that occur in the region, capturing the magnitude and timing of peak (HW and LW) levels as well as the complex shape of the tidal curve. For both the calibration and the validation periods the model has a slight tendency to over-predict the HW and LW levels on some tides. There are also some small differences in the timing of the tide, although there does not appear to be a consistent lag or lead in the modelled tides across all sites and periods.

To further assess the level of calibration achieved (and to ensure that the model performs within the calibration standards set out in Section 5.2), a statistical analysis was undertaken to quantify the difference in elevation and timing between the modelled and measured water levels. The results of the statistical analysis are presented in Table 2. The guideline standards are achieved for all statistics, for all three sites during both the calibration and validation periods with only one exception; the HW phasing at WQ2 during the validation period indicates that HW in the model is 40 minutes earlier than measured (note that the HW phase differences at the other two sites are ± 2 minutes). This is due to subtle differences in the shape of the modelled and measured tidal curves during the validation period. The particular tidal shape in this region is subject to subtle variations with shifts between diurnal and semi-diurnal tides occurring both temporally and spatially, these variations are driven by complex interactions between tidal harmonics and resonant and frictional effects as the tide propagates through the Gulf of Carpentaria.

Despite the HW phasing difference at HW during the validation period, the modelled water levels are considered to provide a good representation of the tide at WQ2 with the overall phasing of the tide agreeing to within 19 minutes (which is within the guideline standard). Further, the model provides a good representation of the tide at Humbug Point and WQ1, with all statistics falling within the guideline standards at these locations, providing confidence that the modelled tides in the Port of Weipa region are suitably replicated.

Table 2. Statistics for comparison of modelled and measured water levels during the ambient and energetic dry season run periods.

Site	WL difference (m)			WL difference (%)		Phase difference (minutes)		
	HW	LW	RMS	HW	LW	HW	LW	All
Dry Season, ambient (calibration period)								
Humbug Point	0.04	0.04	0.10	3	3	6	-13	-12
WQ1	0.02	0.02	0.11	2	2	14	-4	-1
WQ2	0.05	0.01	0.10	5	1	-11	-23	-22
Dry Season, energetic (validation period)								
Humbug Point	0.11	0.04	0.13	13	5	2	12	-1
WQ1	0.09	0.02	0.13	10	2	-2	21	7
WQ2	0.08	0	0.12	9	0	**-39**	3	-19

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

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

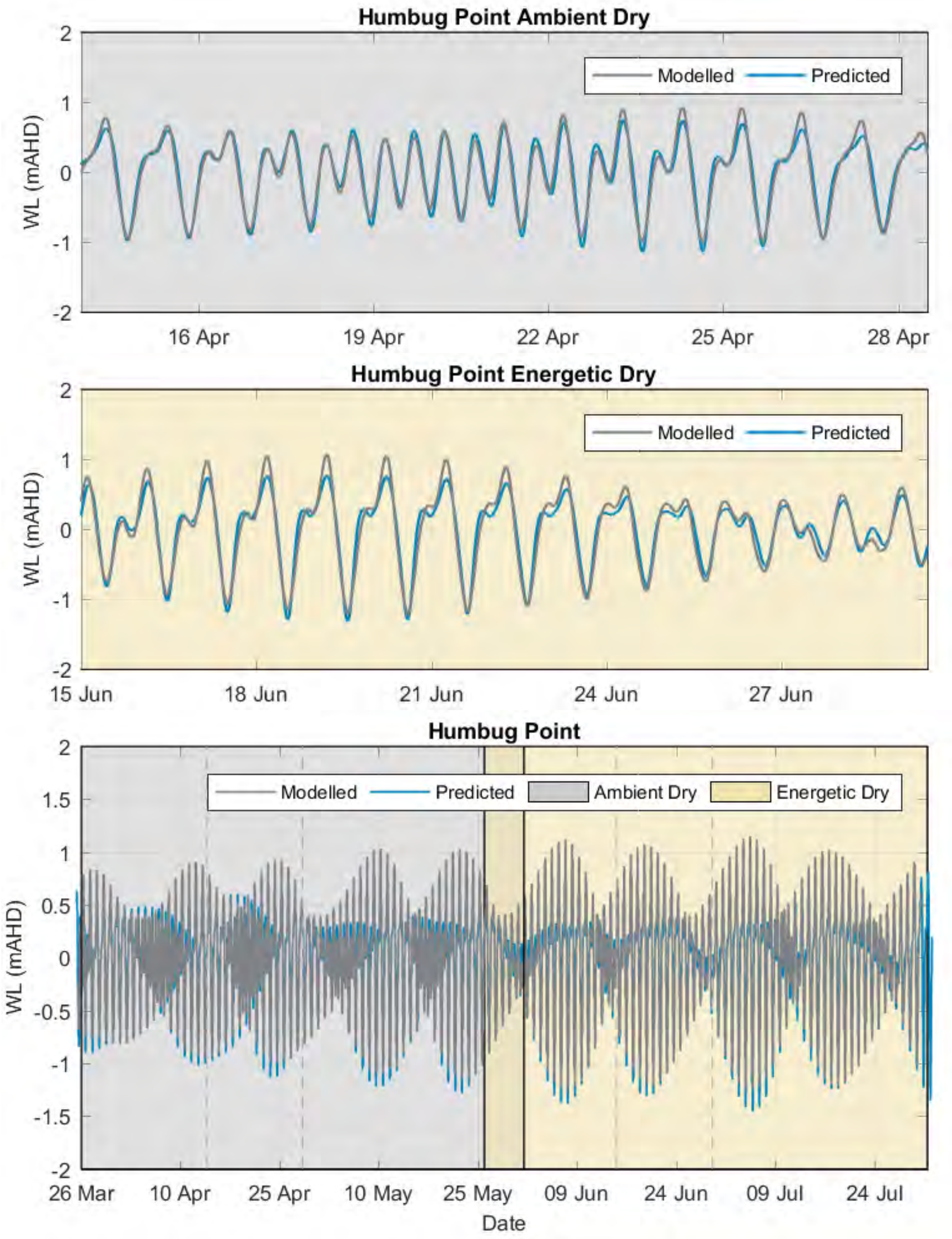

Figure 28. Comparison of modelled and measured water levels at Humbug Point during the ambient and energetic dry season run periods.

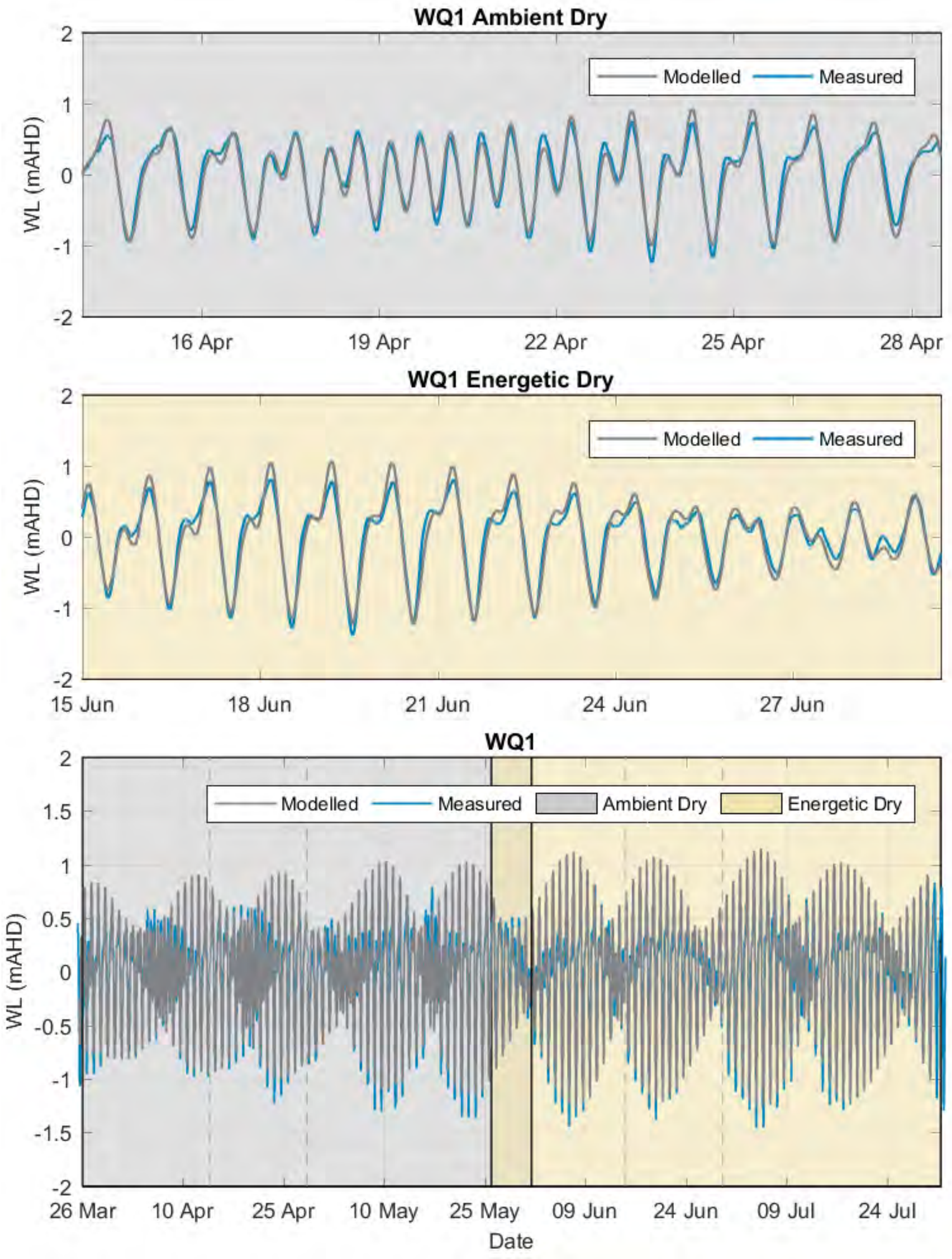

Figure 29. Comparison of modelled and measured water levels at WQ1 during the ambient and energetic dry season run periods.

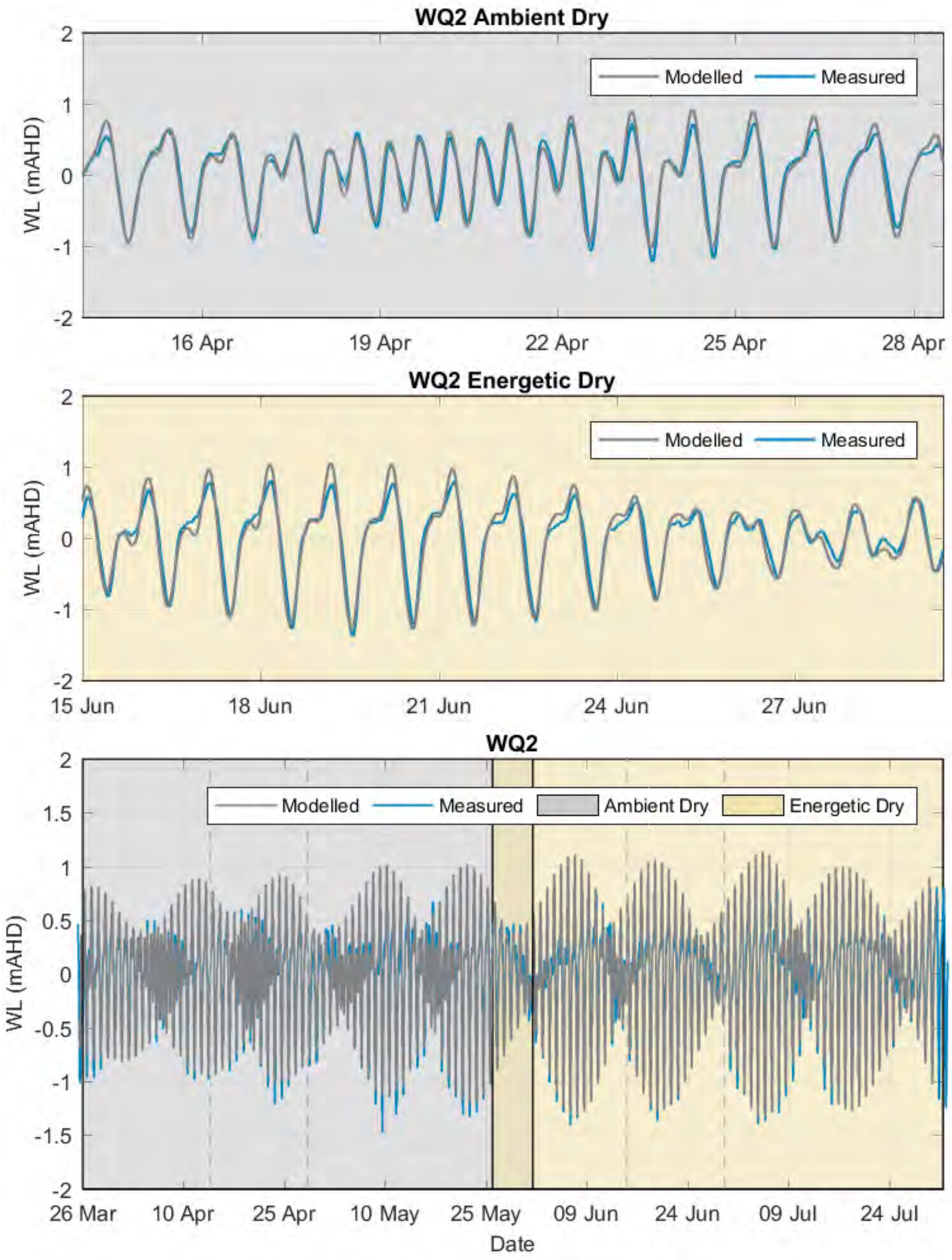

Figure 30. Comparison of modelled and measured water levels at WQ2 during the ambient and energetic dry season run periods.

5.3.2. Currents

Measured current data have been collected at discrete bins throughout the water column using ADCPs deployed at WQ1 and WQ2. Data from a layer near the bed and at approximately mid depth were extracted and used to calibrate the current speed and direction in the model.

Time series plots of the measured and modelled near bed and mid-depth current speed and direction at the ADCPs are shown in Figure 31 to Figure 34. As for the water levels, currents are shown for the four month duration of the model simulation and also for the calibration and validation periods to show the comparison in more detail. Typically, due to the larger tidal range on spring tides, spring tidal currents are faster than neap tidal currents. However, in the Weipa region the variations in current speed throughout the spring-neap period are more complex and neap tide currents can sometimes be comparable and even higher than spring tide currents. This is because the current speed is controlled by the rate of change in water level, which due to the tendency for semi-diurnal tides during periods of neap tides and diurnal tides during periods of spring tides can be steeper during neap tides than during spring tides. The model does a reasonable job of replicating the measured variations in current speeds that occur over the spring-neap calibration and validation periods.

During the calibration and validation period at both WQ1 and WQ2, the fastest mid depth currents typically occur on the flood tide with peaks of 0.75 m/s to 1 m/s at WQ1 and peaks of around 0.5 m/s at WQ2. Ebb currents, particularly at WQ2 are slower, being less than 0.25 m/s. The model captures this flood-ebb difference although it is slightly less pronounced than measured.

To further assess the level of calibration achieved (and to ensure that the model performs within the calibration standards set out in Section 5.2), a statistical analysis was undertaken to quantify the difference in magnitude and phasing between the modelled and measured current speeds and directions. The results of the statistical analysis are presented in Table 3 for near bed currents and in Table 4 for mid-depth currents.

For the most part the guideline standards are achieved, with modelled current speeds agreeing to within 0.2 m/s (and 20 %) and with phasing to within 25 minutes at both sites and during both periods. The modelled current speeds also generally agree with the measured direction to within the guideline standard of 10-15 degrees. The only statistics lying outside of the guideline standards are the percentage speed difference for the near bed ebb current speed at WQ2 during the validation period and the mid depth peak ebb direction difference, also at WQ2 during the validation period. While the current speed difference in percentage terms is slightly above the guideline standard for near bed currents at WQ2 during the validation period, the difference in measured and modelled peak current in absolute terms is only 0.08 m/s and the large percentage difference is an artefact of the low measured near bed ebb flows. The directional differences at WQ2, which are also just outside the guideline standards are also an artefact of the low current speeds at this site resulting in variable current directions.

Table 3. Statistics for comparison of modelled and measured near bed currents during the ambient and energetic dry season run periods.

Site	Speed difference (m/s)			Speed difference (%)		Direction difference (°)		Phase difference (minutes)
	PF	PE	RMS	PF	PE	PF	PE	All
Dry Season, ambient (calibration period)								
WQ1	-0.09	-0.13	0.13	-9	-21	8	-2	12
WQ2	-0.06	0.04	0.08	-9	10	12	1	21
Dry Season, energetic (validation period)								
WQ1	0	0	0.12	0	0	3	0	20
WQ2	-0.02	0.08	0.11	-4	**25**	8	-6	25

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

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

Table 4. Statistics for comparison of modelled and measured mid depth currents during the ambient and energetic dry season run periods.

Site	Speed difference (m/s)			Speed difference (%)		Direction difference (°)		Phase difference (minutes)
	PF	PE	RMS	PF	PE	PF	PE	All
Dry Season, ambient (calibration period)								
WQ1	0.03	-0.11	0.18	3	-15	9	-10	-5
WQ2	-0.02	0.08	0.12	-3	14	15	0	16
Dry Season, energetic (validation period)								
WQ1	0.10	0.02	0.20	10	3	15	-11	16
WQ2	0.03	0.08	0.15	4	16	12	**-17**	19

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

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

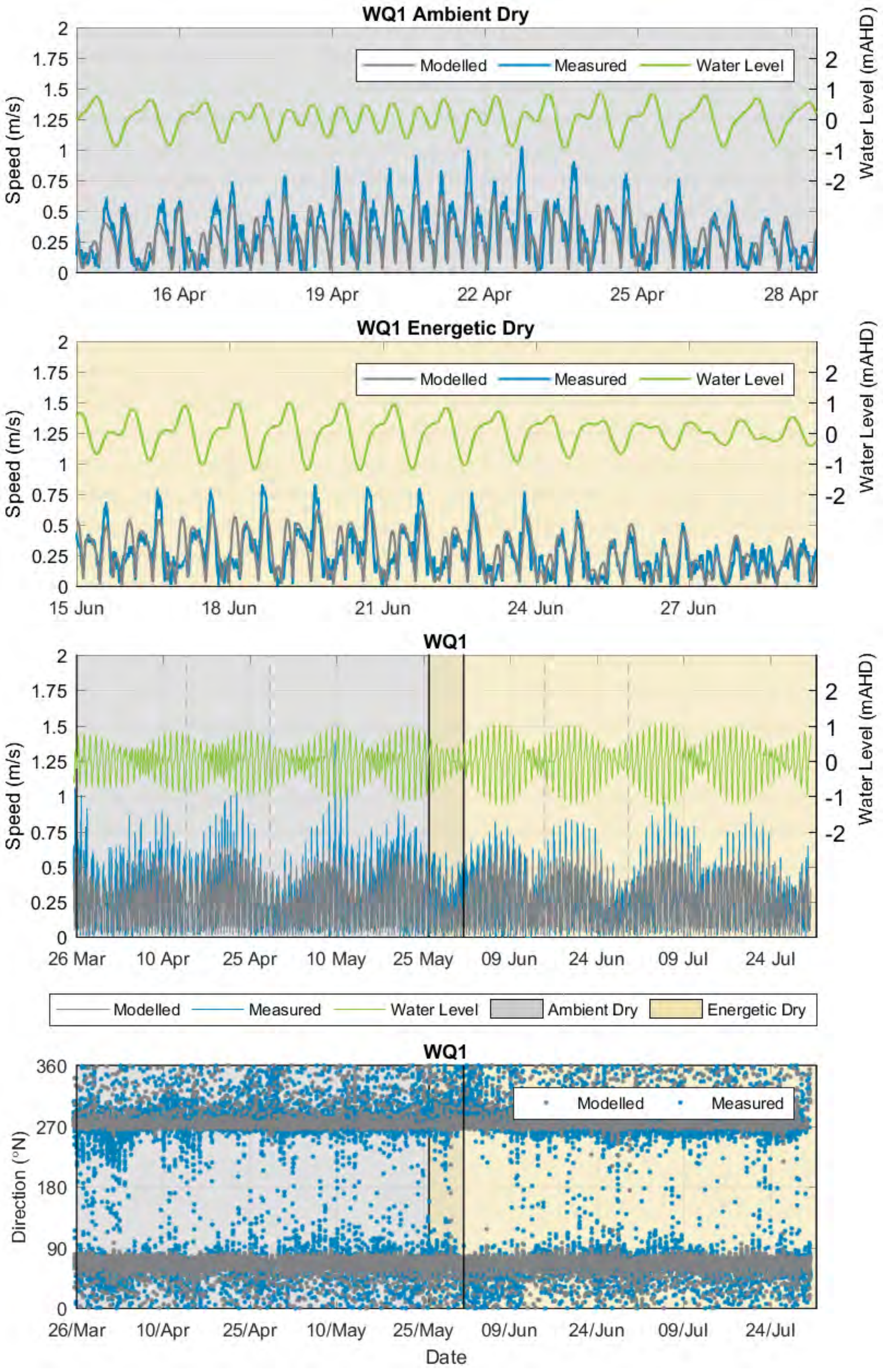

Figure 31. Comparison of modelled and measured near bed currents at WQ1 during the ambient and energetic dry season run periods.

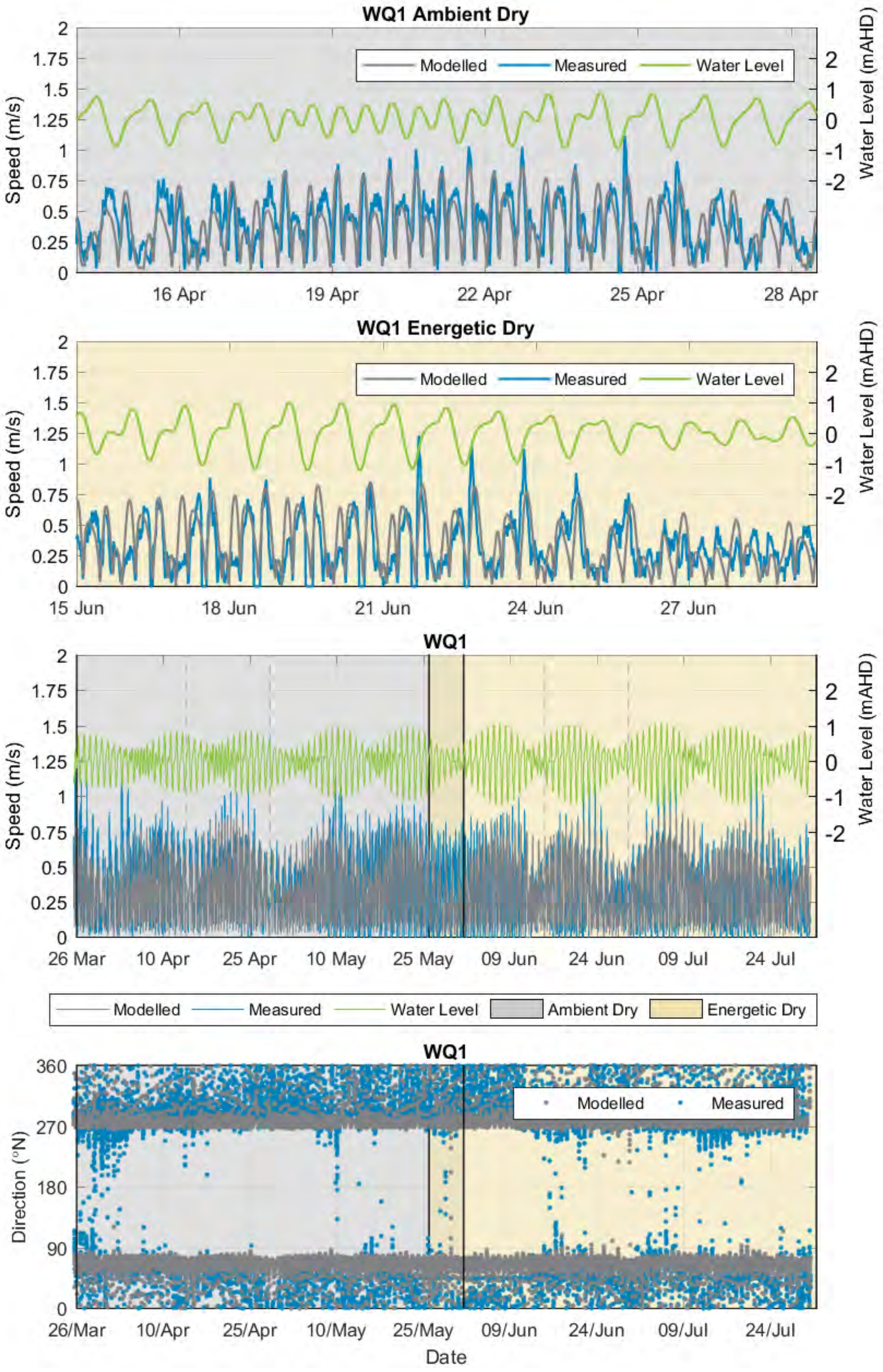

Figure 32. Comparison of modelled and measured mid depth currents at WQ1 during the ambient and energetic dry season run periods.

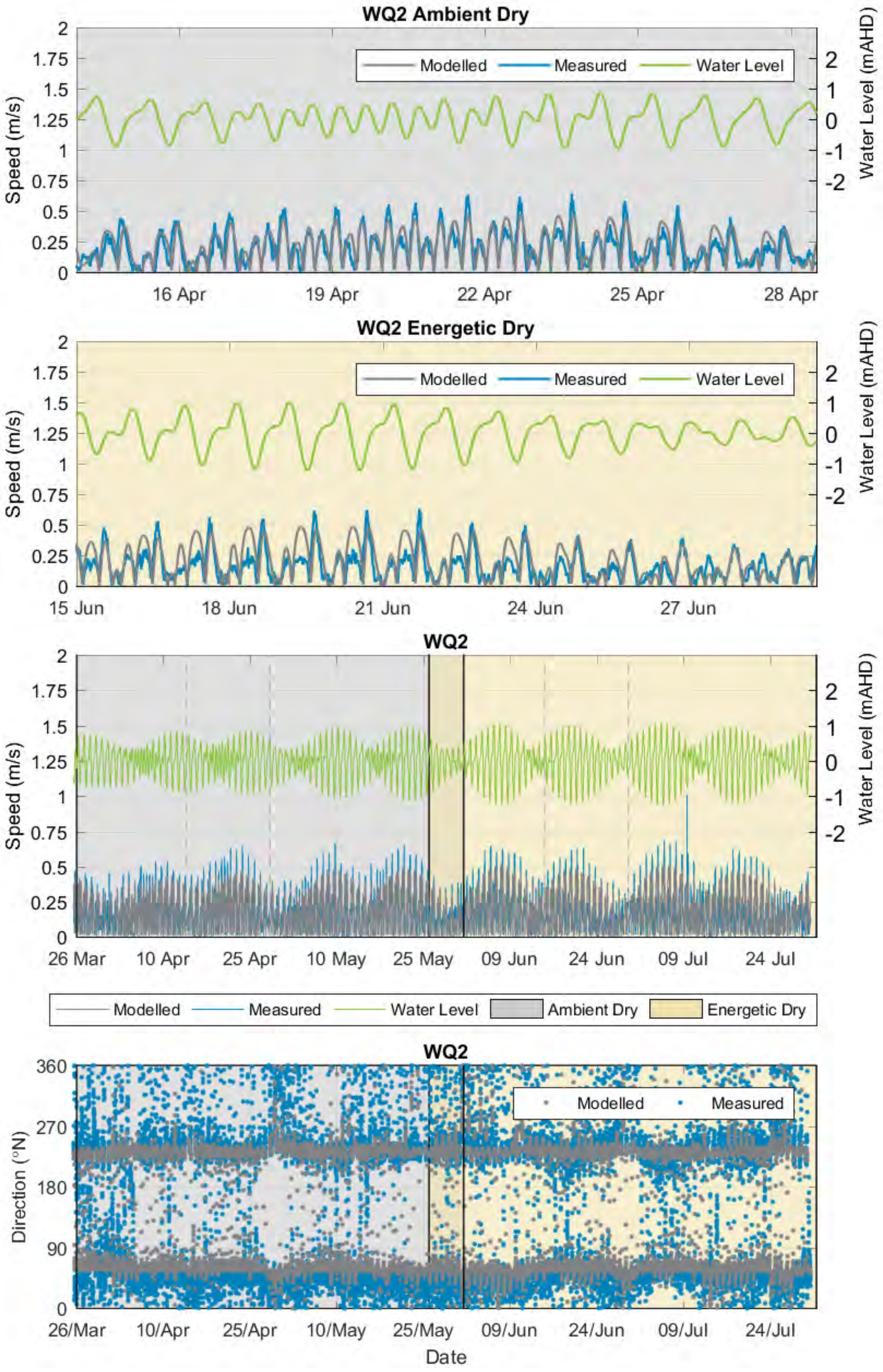

Figure 33. Comparison of modelled and measured near bed currents at WQ2 during the ambient and energetic dry season run periods.

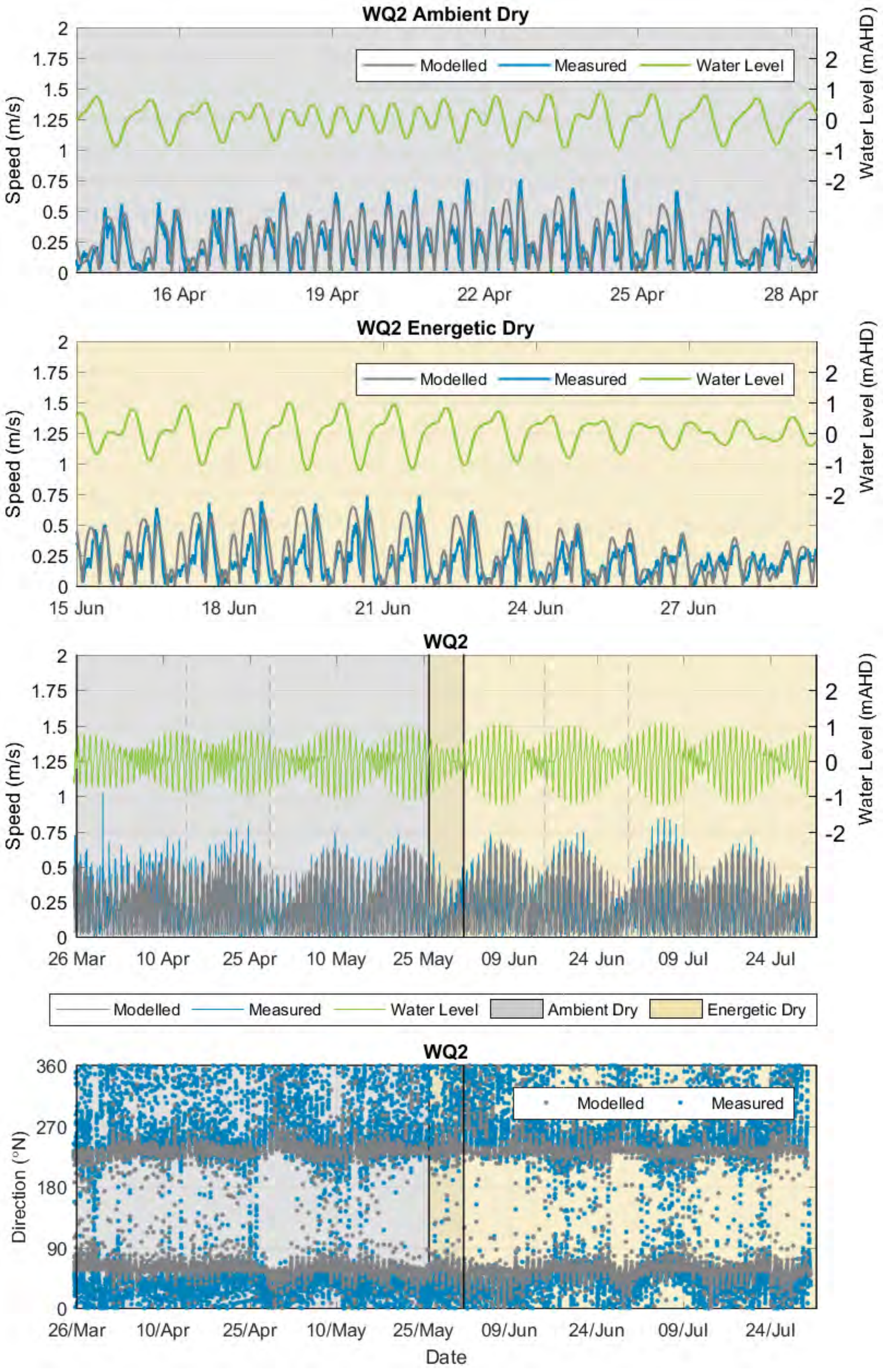

Figure 34. Comparison of modelled and measured mid depth currents at WQ2 during the ambient and energetic dry season run periods.

5.4. Waves

The wave model was set up to replicate the wave conditions at the Albatross Bay Waverider Buoy (WRB) between January and July 2019. This period was selected to cover both typical conditions that could occur during maintenance dredge programs (i.e. during ambient and energetic dry season periods, see Section 4.5) and more extreme conditions during the wet season. Time series plots of H_s, peak wave period (T_p) and mean wave direction are shown over the four month dry season period considered for the hydrodynamic model performance (late March to late July 2019) in Figure 35 and over an extended period between January and July 2019 to include the 2018/2019 wet season period in Figure 36. The plots show that the model provides a good representation of the measured wave height, period and direction at the WRB site throughout the model simulation period. The model performs well during both typical conditions occurring in the dry season and during the more extreme conditions occurring in the wet season (such as the prolonged Tropical Low in late January 2019 to mid February 2019 and TC Trevor in late March 2019).

A quantitative assessment of the model calibration at the WRB site is provided in Table 5, with percentile statistics presented for both measured and modelled H_s over the full model run period and also for ambient and energetic dry season periods. The statistics confirm that the modelled waves agree well with the measured data (to within 0.1 m). The correlation between the modelled and measured waves is also shown as a scatter plot in Figure 12 and the correlation coefficient (r^2) is provided in Table 6. All plots and statistics presented confirm that the model accurately represents the wave conditions at the Albatross Bay WRB.

Table 5. Statistics for comparison of modelled and measured H_s during the model simulation period.

Percentile	Jan to July 2019		Ambient Dry Season		Energetic Dry Season	
	Modelled H_s (m)	Measured H_s (m)	Modelled H_s (m)	Measured H_s (m)	Modelled H_s (m)	Measured H_s (m)
99th	2.69	2.67	0.92	0.98	0.91	0.91
95th	1.73	1.79	0.63	0.63	0.78	0.75
90th	1.01	1.05	0.51	0.49	0.70	0.69
80th	0.67	0.67	0.44	0.42	0.59	0.58
50th	0.36	0.35	0.31	0.31	0.38	0.35
20th	0.19	0.23	0.17	0.23	0.23	0.24
10th	0.13	0.19	0.12	0.19	0.15	0.20
5th	0.08	0.15	0.08	0.16	0.08	0.18

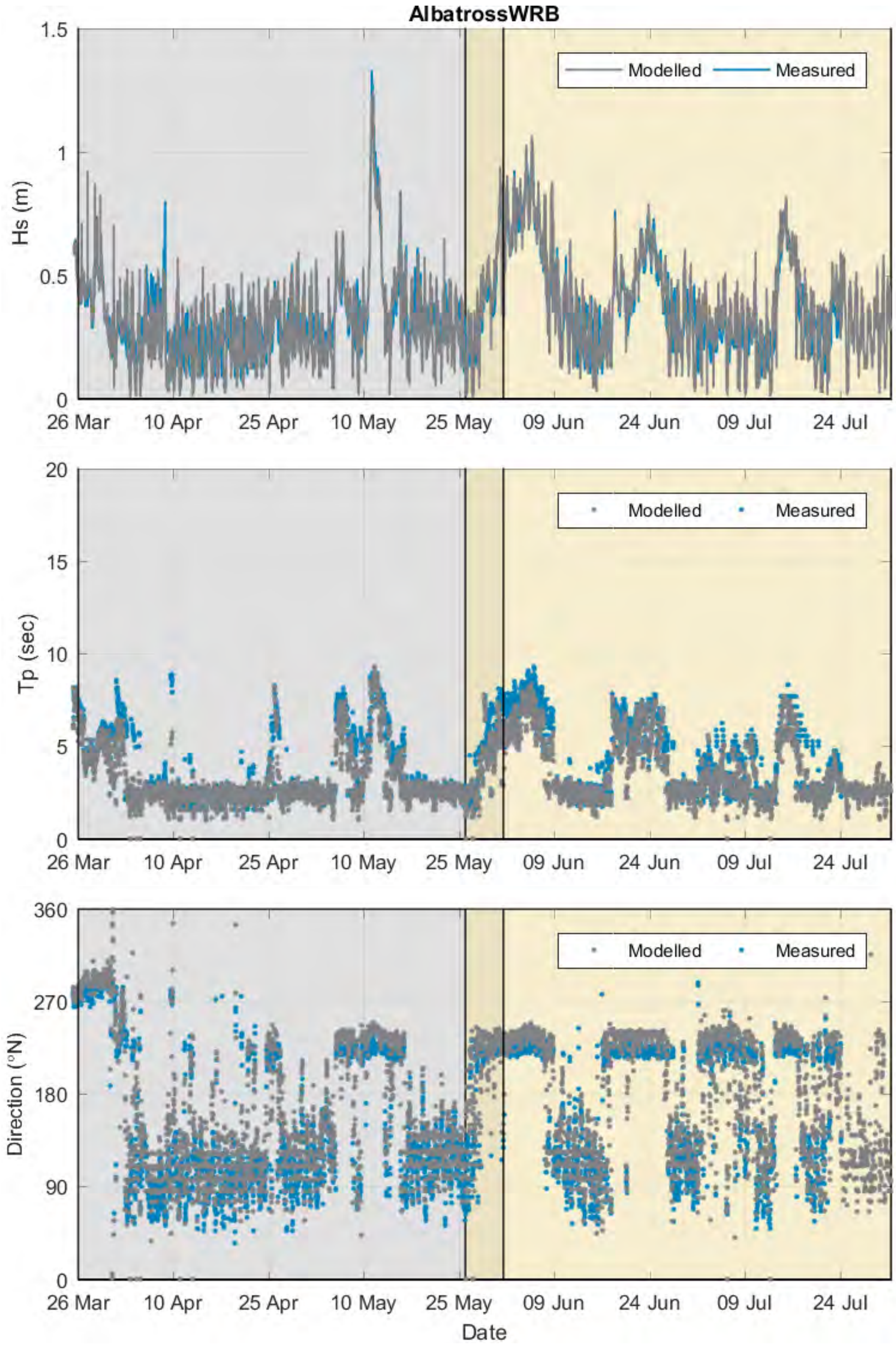

Figure 35. Comparison of modelled and measured waves at the Albatross Bay WRB during the ambient and energetic dry season run periods, showing significant wave height (upper), peak period (middle) and peak direction (lower).

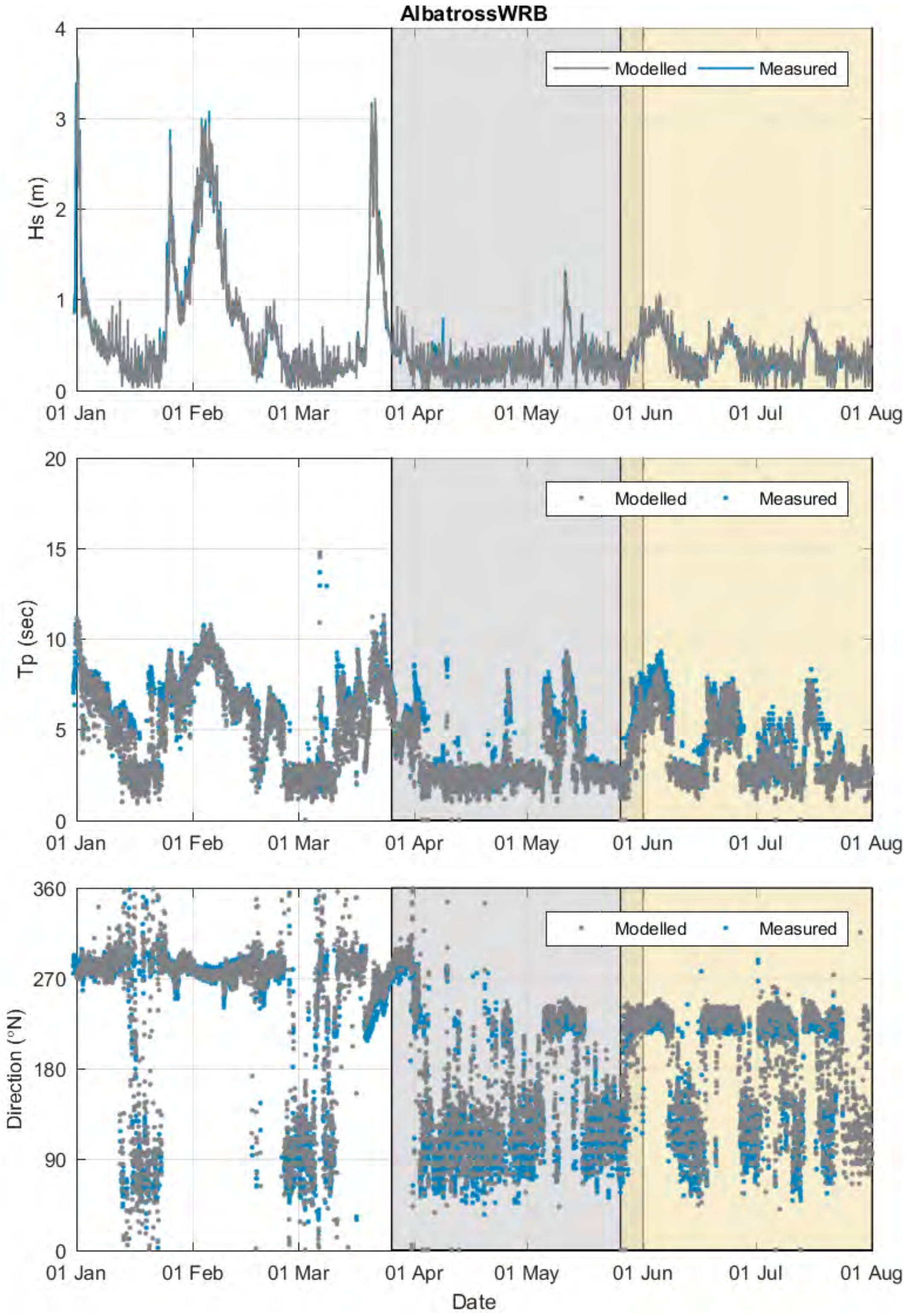

Figure 36. Comparison of modelled and measured waves at the Albatross Bay WRB during the 2018/2019 wet season, showing significant wave height (upper), peak period (middle) and peak direction (lower).

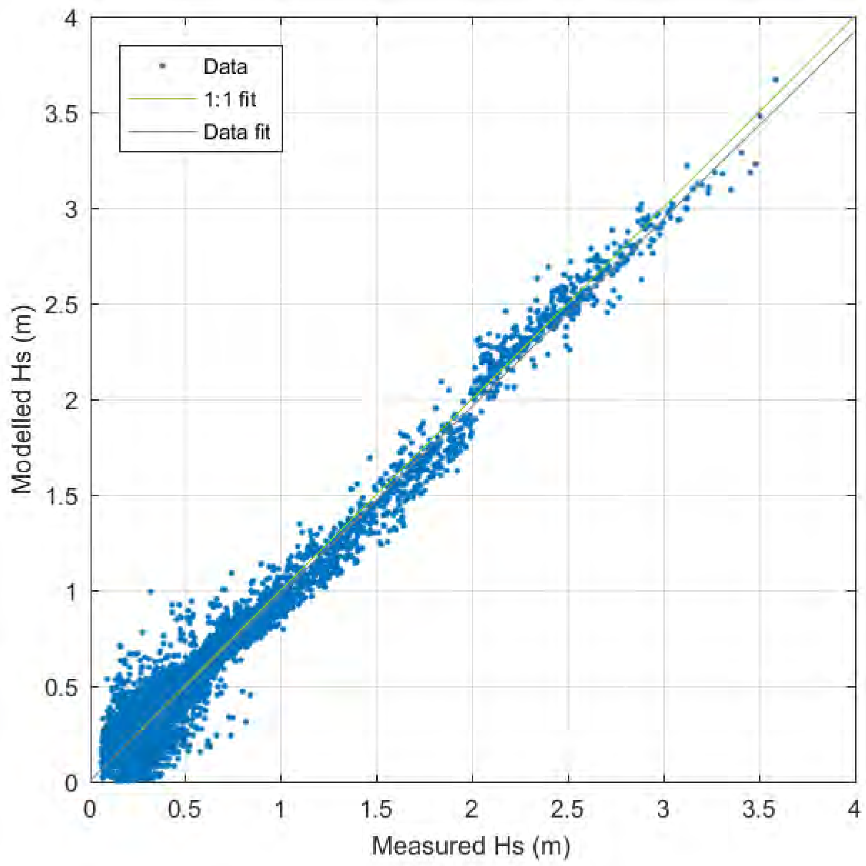

Figure 37. Comparison of modelled and measured H_s at the Albatross Bay WRB with best fit lines.

Table 6. Correlation coefficient between modelled and measured H_s.

Jan to July 2019	Ambient Dry Season	Energetic Dry Season
0.96	0.64	0.76

5.5. Sediment Transport

To ensure that the sediment transport model accurately represents the natural conditions within the Weipa region, measured turbidity readings obtained by JCU at WQ1, WQ2 and WQ4 have been converted to SSC and then compared against modelled SSC. The location of available data (referred to as calibration data) are shown in Figure 5.

Based on the available data, the selected model dredging simulation periods (see Section 4.5) and the selected model long-term resuspension simulation periods (see Section 4.6), modelled SSC have been compared against the calibration data for the following periods:

- calibration period: a two month period between late March 2019 and late May 2019, when conditions are characteristic of ambient dry season conditions;
- validation period: a two month period between late May 2019 and late July 2019, when conditions are characteristic of energetic dry season conditions; and
- further validation period: a two month period between 1 February 2019 and 1 April 2019, characteristic of extreme conditions. During this period a prolonged Tropical Low and a TC (TC Trevor) influenced the region. Data returns at the monitoring sites were low during this period due to the extreme wave conditions and very high SSC.

Time series plots of the measured and modelled SSC at sites WQ1, WQ2 and WQ4 are provided in Figure 38 to Figure 40. As for the hydrodynamics, plots show variations in SSC over the four month duration of the model simulation (encompassing the calibration and validation periods) and also over a spring-neap cycle within the ambient and energetic dry season periods to allow for more detailed visual assessment of the model performance. In addition, the modelled and measured SSC during the wet season period are also shown. During the dry season periods, the SSC at both WQ1 and WQ2 is dominated by a tidal signal, with SSC elevated during periods of faster tidal flows. During the wet season periods tidal variations are still apparent, however superimposed on this are periods with elevated SSC which coincide with higher wave activity (see Figure 12).

The measured SSC was elevated for a ten day period at the start of May 2019, most notable at WQ1, but also apparent at WQ2. This period of elevated SSC did not coincide with periods of enhanced wave activity, nor did the model predict any equivalent increase in SSC at this time. Following a service visit to the instruments on the 10 May 2019, SSC at both WQ1 and WQ2 returned to more normal levels. This suggests that this short period of enhanced SSC was most likely a result of biofouling of the instruments.

SSC data collected at WQ4 exhibit very high peaks, particularly after the relocation of the instrument in May 2019. PCS (2019c & 2019e) found that these peaks at WQ4 were not correlated with either metocean conditions, or data collected at other nearby instruments and as such the data collected at WQ4 after this period is considered to be either representative of very localised conditions or to be erroneous. This has been considered when calibrating the model to replicate SSC (i.e. the model was not tuned to represent the high peaks in SSC at WQ4).

The model suitably replicates the temporal trends in the SSC data during both dry season and wet season conditions, capturing the timing and intensity of peaks. This provides confidence that the model is representing the effect of the key physical processes (tidal currents and waves) on SSC. While some of the short period ‘spikes’ captured by the data are not replicated by the model it is important to remember that the model shows the SSC averaged over the water column and over a grid cell, while the instruments measure near bed variations at a discrete location.

The CF has been calculated for the model run period and the results are given in Table 7. At all three sites the CF is significantly lower than one, providing a statistical confirmation that the modelled SSC is in ‘very good’ agreement with observations (see Section 5.2).

Table 7. OSPAR cost function summary at the three monitoring sites.

Site	Dry season CF
WQ1	0.33
WQ2	0.54
WQ4	0.28

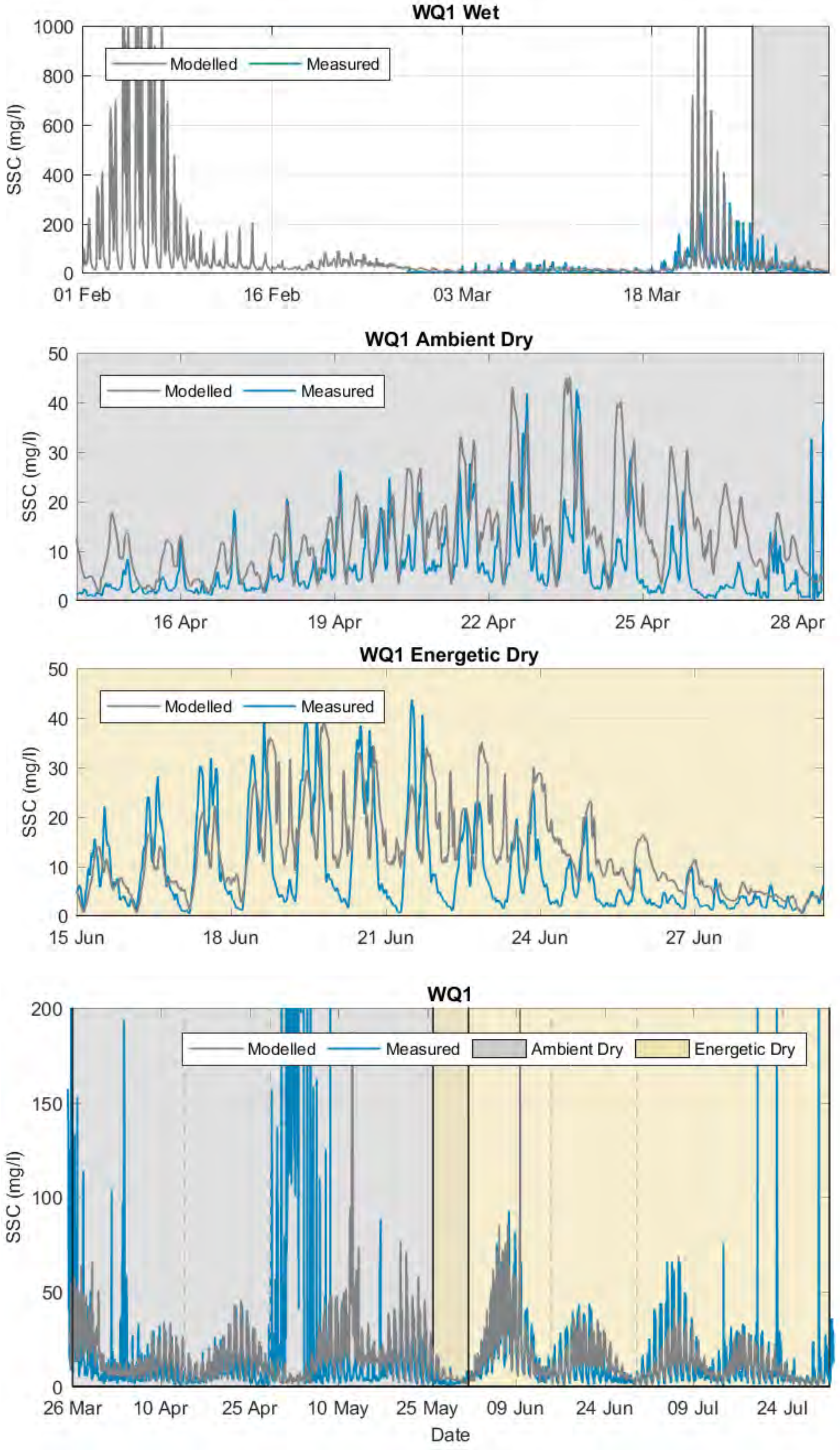

Figure 38. Comparison of modelled and measured SSC at WQ1 during the ambient and energetic dry season run periods.

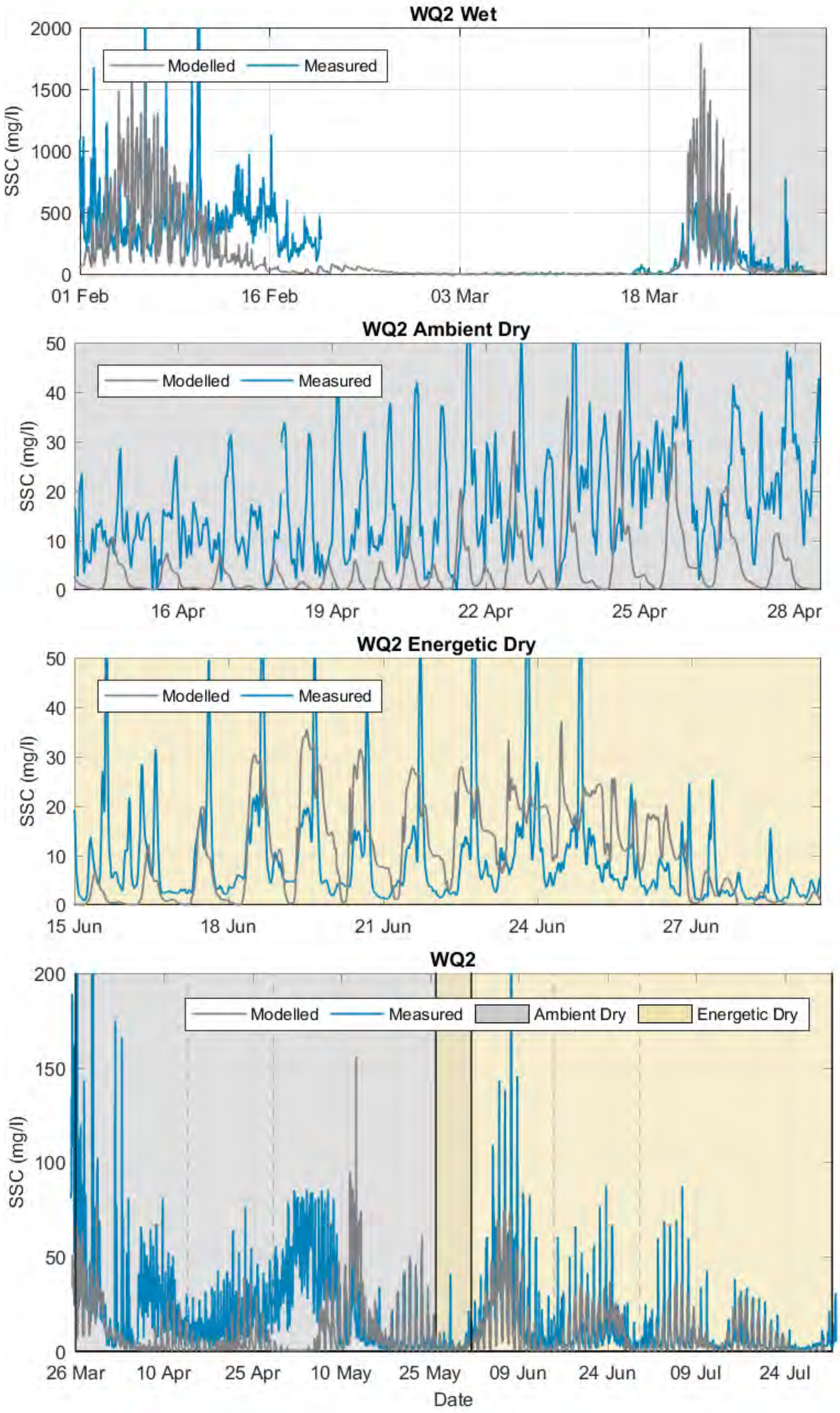

Figure 39. Comparison of modelled and measured SSC at WQ2 during the ambient and energetic dry season run periods.

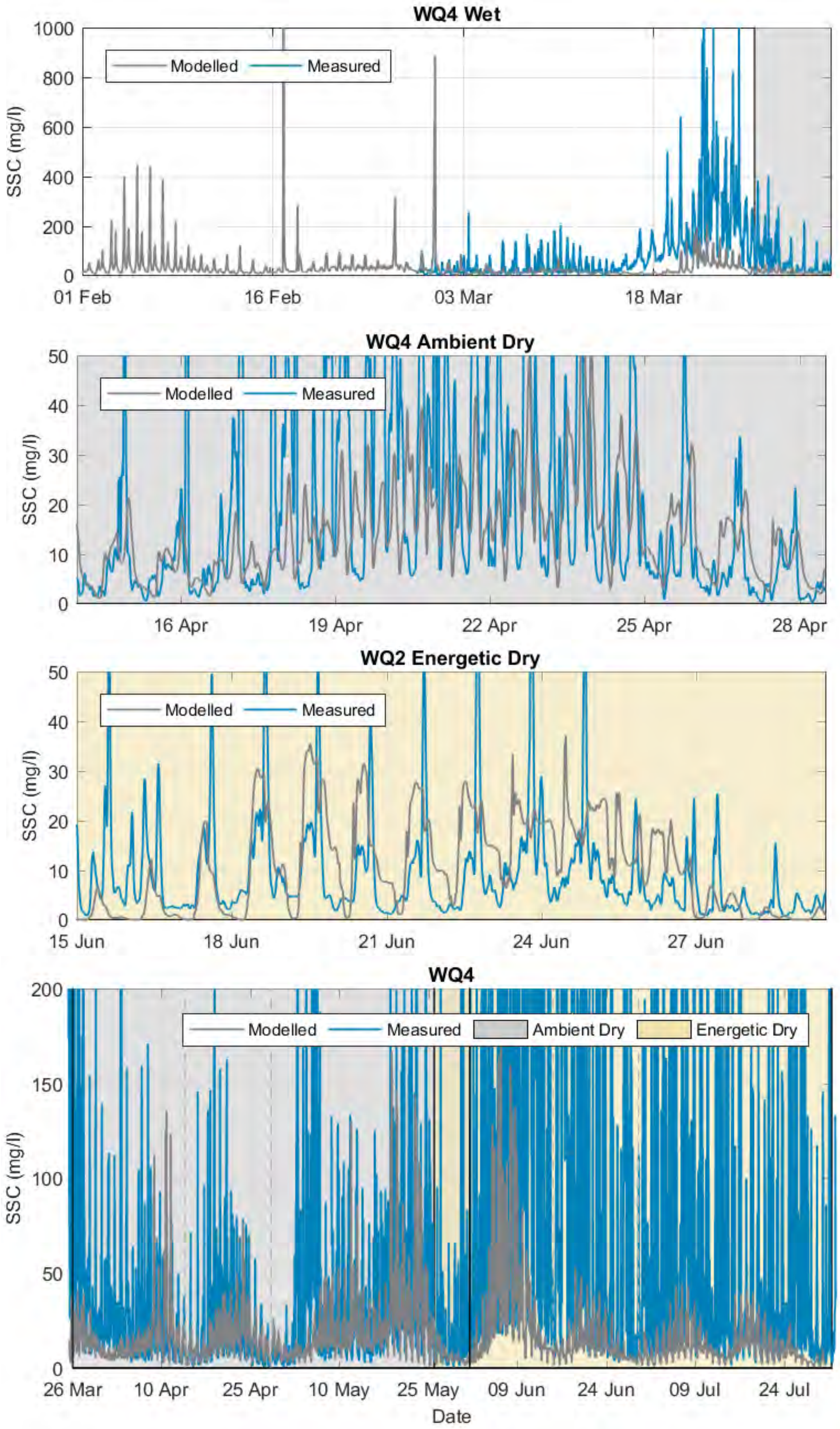

Figure 40. Comparison of modelled and measured SSC at WQ4 during the ambient and energetic dry season run periods.

5.6. Dredge Plume

The dredge plume model was calibrated against satellite imagery and near bed turbidity data at the water quality monitoring sites for the duration of the 2019 maintenance dredge program. Full details on the dredge plume model calibration are provided by PCS (2019d). Key findings of the calibration were as follows:

- the initial configuration of the dredge plume model, which adopted dredge source terms in the upper range of those noted in the literature, was found to result in an overestimation of the SSC due to the dredging. As part of the calibration process the dredge source terms were reduced and model parameters adjusted so that the increase in SSC due to the maintenance dredging was more realistic. The final calibrated dredge source terms adopted were in the lower range of those noted in the literature for the dredging activity and around the average for the dredge material placement; and
- following calibration of the dredge plume model, comparison between the modelled SSC and the measured turbidity/SSC data (both in-situ logger data and satellite derived turbidity maps) showed that the model is providing a good representation of both the natural SSC and the SSC due to the maintenance dredging. This provides confidence that the Port of Weipa numerical models can be used to assess the SSC resulting from future maintenance dredging programs.

An example map plot comparing the modelled natural SSC and dredge related SSC with satellite derived turbidity data is provided in Figure 41.

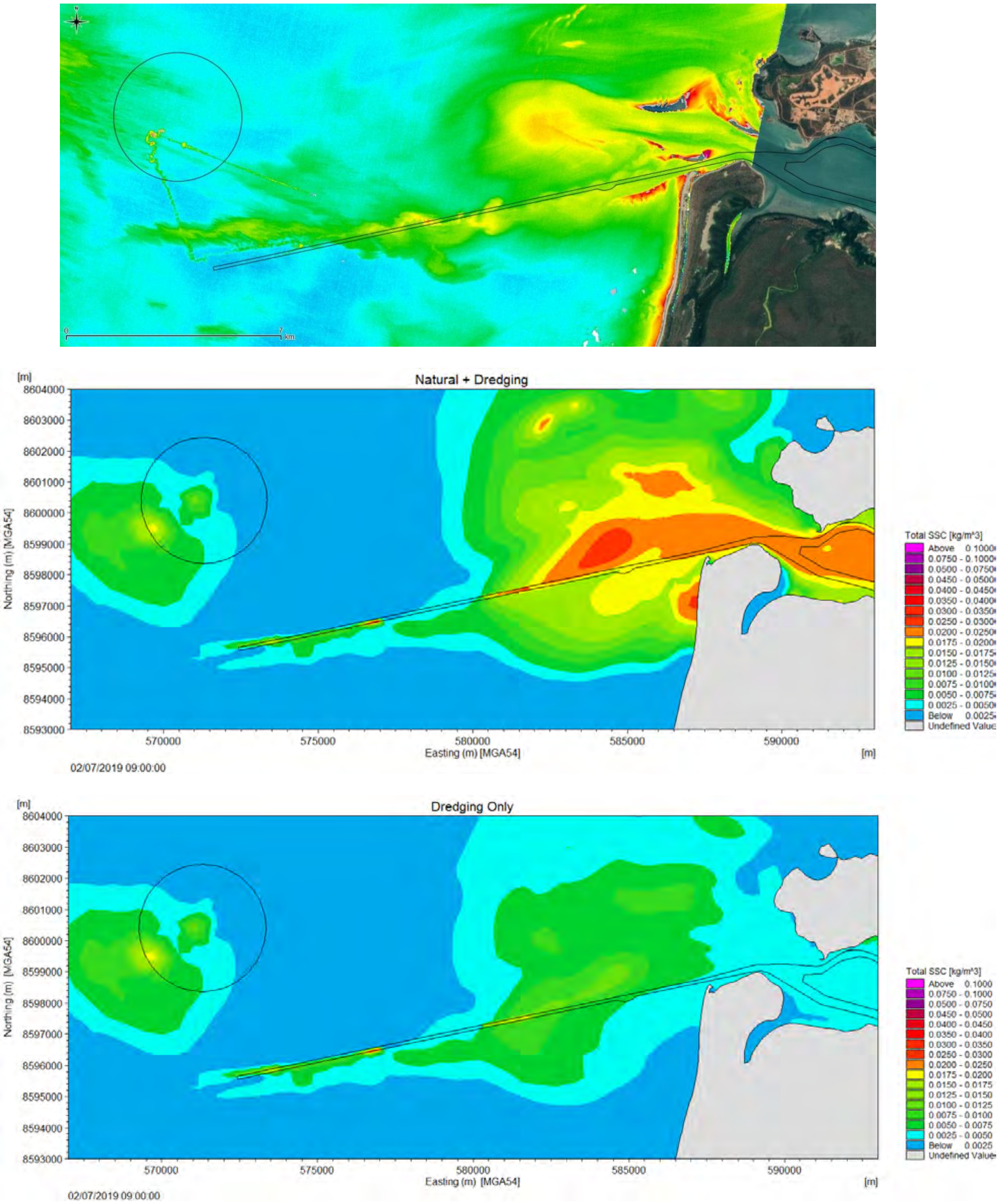

Figure 41. Comparison of turbidity from satellite imagery and modelled SCC for natural + dredging and dredging only scenarios on the 2nd July 2019 09:00.

6. Dredging Description

6.1. Overview

As discussed in Sections 3 and 4, this assessment is considering the following:

- six dredge material placement options including three offshore options, one onshore option and two beneficial reuse options with both onshore and offshore placement;
- three annual dredge volumes to represent the maintenance dredging required following typical, cyclonic and worst case sedimentation years;
- two dry season periods of just over two months each to model the resultant plume from the dredging and placement activities during ambient and energetic dry season conditions; and
- a seven month period over the 2018/19 wet season and the start of the 2019 dry season to model the long-term resuspension and transport of sediment placed at the offshore DMPAs. The 2018/19 wet season was selected as this was the most energetic year in terms of wave conditions since the Albatross Bay WRB was installed.

This section provides details of the proposed dredging activity associated with the options and how the dredging has been conceptualised within the numerical model.

6.2. Dredger

Maintenance dredging at the Port of Weipa has generally been undertaken by a Trailing Suction Hopper Dredger (TSHD) as it is the most suitable type of dredger 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.

Over the last 20 years the majority of the maintenance dredging at the Queensland Ports has been undertaken by the TSHD Brisbane. This dredger 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 Weipa. 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 associated with the typical and cyclonic years, herein this dredger will be called the ‘Small TSHD’. For the worst case year the dredge volume is too large for a vessel of this size to undertake the dredging on its own in a realistic timeframe (it would take approximately 5 months) and so it has been assumed that a larger TSHD would also be used (i.e. two TSHDs would be working together for the worst case years). For the larger dredger the vessel specifications have been assumed to be similar to the TSHD Oranje which was used alongside the TSHD Brisbane to remove 2.4 Mm^3 during the Port of Weipa 2019 maintenance dredging program (PCS, 2019c), herein this dredger will be called the ‘Large TSHD’. Vessel specifications for the two dredgers are shown in Table 8. Based on the dry season metocean conditions and the vessel weather restrictions it is unlikely that either dredger would have any weather downtime when dredging at the Port of Weipa during the dry season.

During previous maintenance dredging programs at the Port of Weipa, dredging within the Inner Harbour has been limited to the ebb stage of the tide to reduce the risk of any suspended sediment being transported upstream of the Port. For the modelling undertaken as part of this assessment a conservative assumption that dredging can occur at any stage of the tide in the Inner Harbour at Weipa has been adopted to help better understand the worst case plume extent within the Inner Harbour region.

Table 8. Vessel specifications for the TSHD dredgers assumed for this assessment.

Specifications	Small TSHD (TSHD Brisbane)	Large TSHD (TSHD Oranje)
Length Overall (m)	84	156
Beam (m)	16	28
Draft – Fully Laden (m)	6.3	12.0
Hopper Capacity (m^3)	2,900	16,000
Vessel Average Speed (kts)	12	15

6.3. 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 2019 maintenance dredging program. Based on this the following assumptions were made:

- for both dredgers 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;
- both dredgers take 10 minutes to place their load at any of the offshore DMPAs;
- it will take two hours for the small TSHD to pump a full hopper load out for all three of the onshore placement options (Options 4 to 6). This includes the time pumping the sediment as well as the time for mooring and coupling/decoupling to the pipeline; and
- both dredgers have an average operational downtime of 10% to allow for crew changes and bunkering.

Based on the assumptions detailed above the average dredge cycle times were defined for the different options and the two dredgers. An overview of the dredge cycle times for the offshore DMPA options, assuming dredging from the middle of the South Channel, are provided in Table 9. The table shows very similar dredge cycle times for the Albatross DMPA and Albatross South DMPA options, but with the Albatross West DMPA having a longer cycle time of approximately 40 minutes due to the increased distance to and from the DMPA.

Table 9. Dredge cycle times for the small/medium TSHD the three offshore placement options.

Details	Albatross DMPA	Albatross West DMPA	Albatross South DMPA
Dredging – No Overflow	20 min	20 min	20 min
Dredging – Overflow	40 min	40 min	40 min
Sailing Laden	35 min	55 min	36 min
Placement	10 min	10 min	10 min
Sailing Unladen	30 min	50 min	31 min
Average Dredge Cycle	**135 min (2.25 hrs)[1]**	**175 min (2.92 hrs)[1]**	**137 min (2.28 hrs)[1]**

[1]the cycle time for the large TSHD would be approximately 18 minutes less for the Albatross DMPA and Albatross South DMPA and 30 minutes less for the Albatross West DMPA. This is due to the increased sailing speed of the large TSHD compared to the small TSHD.

An overview of the dredge cycle times for the onshore placement options, assuming dredging from the middle of the South Channel and the eastern end of the Departure Channel and then pumping out adjacent to Evans Landing, are provided in Table 10. The table shows that the dredge cycle is on average 40 minutes longer when sediment from the South Channel is being pumped ashore from Evans Landing (this only occurs for Option 4, the onshore pond) compared to when sediment from the Inner Harbour is being pumped ashore.

Table 10. Dredge cycle times for pumping sediment onshore at Evans Landing from the South Channel and Inner Harbour.

Details	Sediment from South Channel	Sediment from Inner Harbour
Dredging – No Overflow	20 min	20 min
Dredging – Overflow	40 min	40 min
Sailing Laden	35 min	15 min
Pumping Onshore	120 min	120 min
Sailing Unladen	30 min	10 min
Average Dredge Cycle	**245 min (4.1 hrs)**	**205 min (3.4 hrs)**

Based on the dredge cycle times detailed in Table 9 and Table 10, the total duration of the dredging for the options being modelled are detailed in Table 11.

Table 11. Total dredge duration for the placement options modelled.

Option	Typical Year	Cyclonic Year	Worst Case Year[1]
1) Albatross DMPA	23.9 days	47.8 days	33.1 days
2) Albatross West DMPA	32.2 days	64.4 days	41.0 days
3) Albatross South DMPA	25.4 days	50.9 days	34.5 days
4) Onshore Pond	46.0 days	92.1 days[2]	N/A
5) Reclamation	28.4 days	N/A	N/A
6) Beach Nourishment	28.4 days	N/A	N/A

[1] the offshore placement for the worst case years assume both the small and large TSHD working concurrently making the duration significantly shorter than the cyclonic year which only assumes the small TSHD.

[2] the onshore pond option for the cyclonic year is longer than the 66 day model simulation period and as such only the first 66 days of the dredging has been represented. However, this is expected to give a realistic representation of the SSC over the entire period.

6.3.1. Source Terms: Dredging and Offshore Placement

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 & 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 assumed for the two dredgers as part of this assessment. The source terms adopted for the small and large TSHDs have been taken from the source terms which were defined as part of the dredge plume model validation for the Port of Weipa 2019 maintenance dredging program (PCS, 2019d). For the validation the source terms for the small TSHD were based on previously validated source terms which had been adopted for previous modelling of the TSHD Brisbane (BMT, 2017; RHDHV, 2018). The source terms for the large TSHD were calibrated as part of the assessment, and this resulted in lower source terms than the small TSHD for the overflow and offshore placement activities. Previous studies have observed that TSHDs with a larger hopper can be more efficient, in terms of the release of sediment into the passive plume during overflow, than smaller TSHDs and so applying lower source terms for the mass of sediment released into the passive plume from the overflow of sediment for the large TSHD is considered realistic (Kemps & Masini, 2017).

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	Small TSHD	Large TSHD
Draghead and Propeller Wash	<5%	2%	2%
Overflow	5-15%	7.5%	5%
Offshore Placement	0-15%	7.5%	7.5%

6.3.2. Source Terms: Onshore Placement

The onshore placement options (Options 4 to 6) also require a source term to be included to represent any fine-grained sediment released as part of the onshore placement. Details of the source terms applied for the three options are provided below:

- Option 4 - Onshore Pond: the modelling includes source terms from the dredging activity associated with the small TSHD (see previous section) and a tailwater discharge to drain excess water and any sediment remaining in suspension from the onshore pond. The tailwater discharge adopted has been located adjacent to the Evans Landing wharf. A constant flow rate for the tailwater was calculated to be 0.93 m^3/s and it was conservatively assumed that the SSC of the water discharged would be a constant 50 mg/l (the SSC would likely be lower than this for the majority of the time);

- Option 5 – Evans Landing Reclamation: the modelling includes source terms from the dredging activity associated with the small TSHD (see previous section) along with a conservative assumption of a partial failure in the reclamation liner resulting in a constant release of 1,000 mg/l during the dredging at the north-eastern corner of the reclamation. This approach is in line with the previous reclamation modelling undertaken as part of the Port of Hay Point SSM Project (RHDHV, 2016). However, it is important to note that the partial failure scenario modelled represents a conservative assumption to highlight the potential risk of the option to the sensitive receptors as opposed to the likely impacts of the option (which are what the other two options show); and

- Option 6 – Beach Nourishment: the modelling includes source terms from the dredging activity associated with the small TSHD (see previous section) along with a constant source of fine-grained sediment over the period when sediment would be pumped to the area (8.5 day duration). The source term has been calculated based on the assumption that only sandy sediment would be placed at this location (90% sand, 10% silt and clay) and that of the mass of silt and clay placed 10% of it would remain in suspension and be available for transport.

7. Results

7.1. Introduction

The results from each of the dredge plume model simulations are presented in the following sections in the form of:

- spatial maps of percentile values of the predicted increase in SSC due to maintenance dredging and in relation to the natural SSC, considering the 20th, 80th and 95th percentiles (Section 7.2 and Appendix A);
- tabulated percentile values of the predicted increase in SSC at sensitive receptors, considering the 20th, 80th and 95th percentiles (Section 7.2);
- time series plots of the natural and natural plus dredging SSC during the dredging program at sensitive receptors (Section 7.2 and Appendix B);
- tabulated durations of threshold exceedance at sensitive receptors (Section 7.2.1); and
- spatial maps of the mass of sediment deposited during the dredging program due to dredging, natural sedimentation and natural plus dredging (Section 0 and Appendix C).

The results from the assessment of the long-term resuspension of material deposited at the offshore DMPAs are presented in Section 7.4 in the form of;

- time series plots of sediment volume within the DMPAs;
- tabulated volumes of sediment retained in the DMPAs at the end of the model simulation period;
- spatial maps of sediment deposition at the end of the model simulations;
- time series plots of sediment volume within the Port of Weipa dredge areas; and
- tabulated volumes of sediment within the Port of Weipa dredge areas at the end of the model simulation.

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

- AB1: closest area of extensive seagrass meadows to the South Channel in Albatross Bay (based on GHD (2019));
- AB2: closest rocky reef to the South Channel in Albatross Bay (based on GHD (2019));
- IH1: nearest area of seagrass to the location of the tailwater discharge/reclamation failure and close to the Evans Landing and Humbug wharves and the Departure Channel (and area which is regularly surveyed by JCU (McKenna & Rasheed, 2019)); and
- IH2: area of widespread seagrass on the southern bank of the Embley River which is regularly surveyed by JCU and located to the south-east of the Approach Channel (McKenna & Rasheed, 2019).

7.2. Suspended Sediment Concentration

The SSC results from the model simulations are relevant to assessing ecological impacts, primarily as a result of the effect of enhanced SSC on reducing benthic Photosynthetically Active Radiation (PAR).

A full set of spatial statistical maps showing percentile values of the precited increase in SSC due to each of the dredge plume modelling simulations are provided in Appendix A. The increase in SSC is shown along with the modelled natural SSC for context. Selected plots are duplicated here to provide an overview of the results and to demonstrate the effect of the metocean conditions, dredge volumes and various placement options 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 entire dredge program. The percentile plots show the value which the SSC is below for a given percentage of time during the dredge campaign. For example, the 80th percentile plot shows the value that the SSC is below for 80% of the time over the duration of the dredge program.

Plots are presented for the following;

- spatial maps of the 80th and 95th percentile SSC for the ambient dry season in Figure 42 and Figure 43 and for the energetic dry season in Figure 44 and Figure 45 for a typical dredge volume, with placement at the Albatross DMPA;
- spatial maps of the 95th percentile SSC for the ambient dry season period, with placement at the Albatross DMPA, for a typical dredge volume (400,000 m^3), a cyclonic dredge volume (800,000 m^3) and a worst-case dredge volume (2.5 million m^3), in Figure 43, Figure 46 and Figure 47, respectively;
- spatial maps of the 95th percentile SSC for the ambient dry season period, for a typical dredge volume and for placement at Albatross DMPA, Albatross West DMPA and Albatross South DMPA in Figure 43, Figure 48 and Figure 49, respectively. The results from the typical dredge volumes are presented to facilitate comparison of results across all the different offshore placement options; and
- spatial maps of the 95th percentile SSC for the ambient dry season period, for a typical dredge volume and for placement at the onshore pond, the reclamation site and for beach nourishment in Figure 50 to Figure 52.

To provide quantification of the effect of the dredge on the SSC, percentile values of the increase in SSC at the sensitive receptor sites due to maintenance dredging activity for each of the dredge plume modelling simulations are presented in Table 13 to Table 18. Time series plots of the SSC at the sensitive receptors are also provided for each dredge plume modelling simulation in Appendix B. As with the map plots, selected time series plots are also duplicated here (Figure 53 to Figure 55).

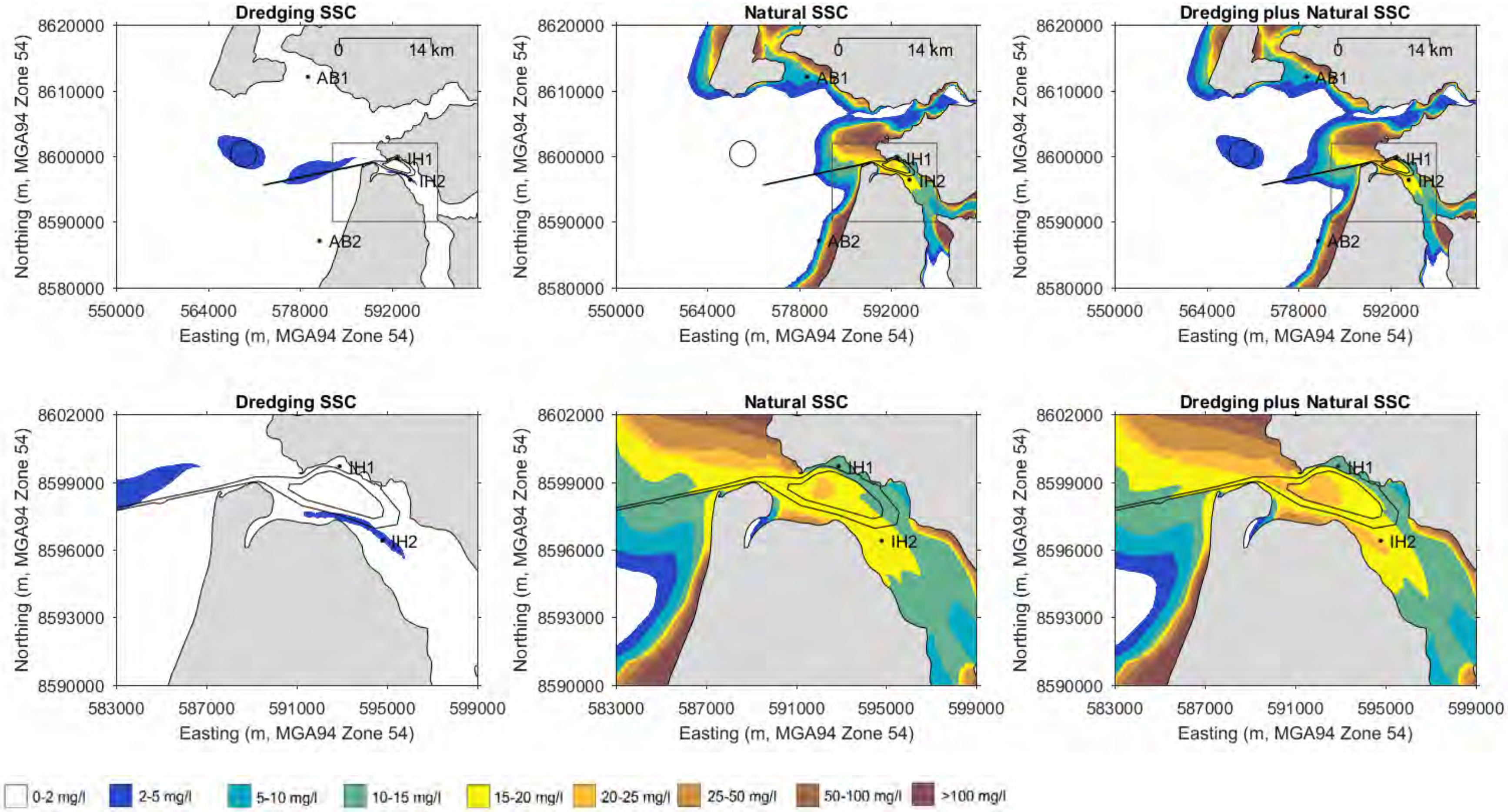

Figure 42. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

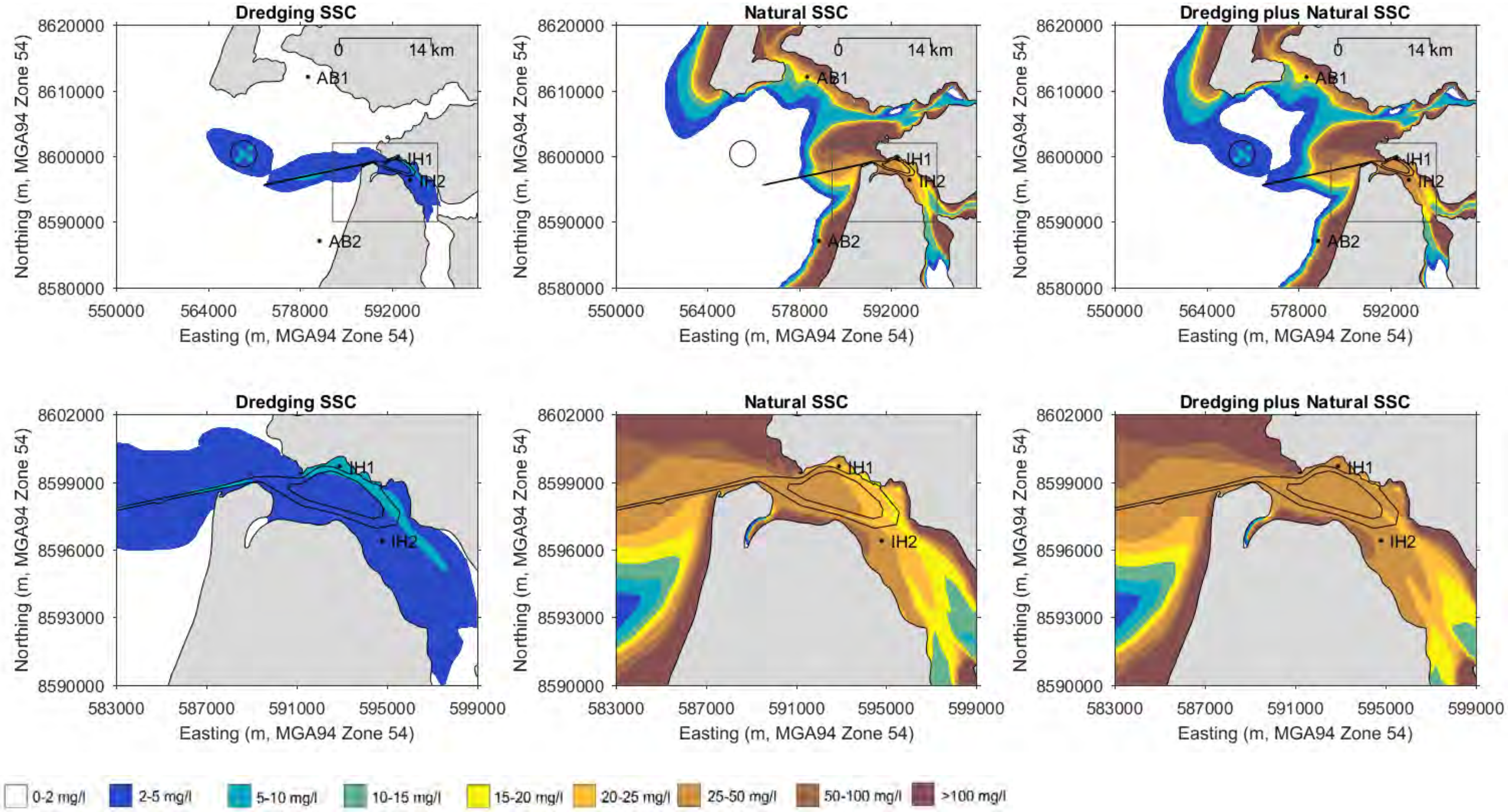

Figure 43. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

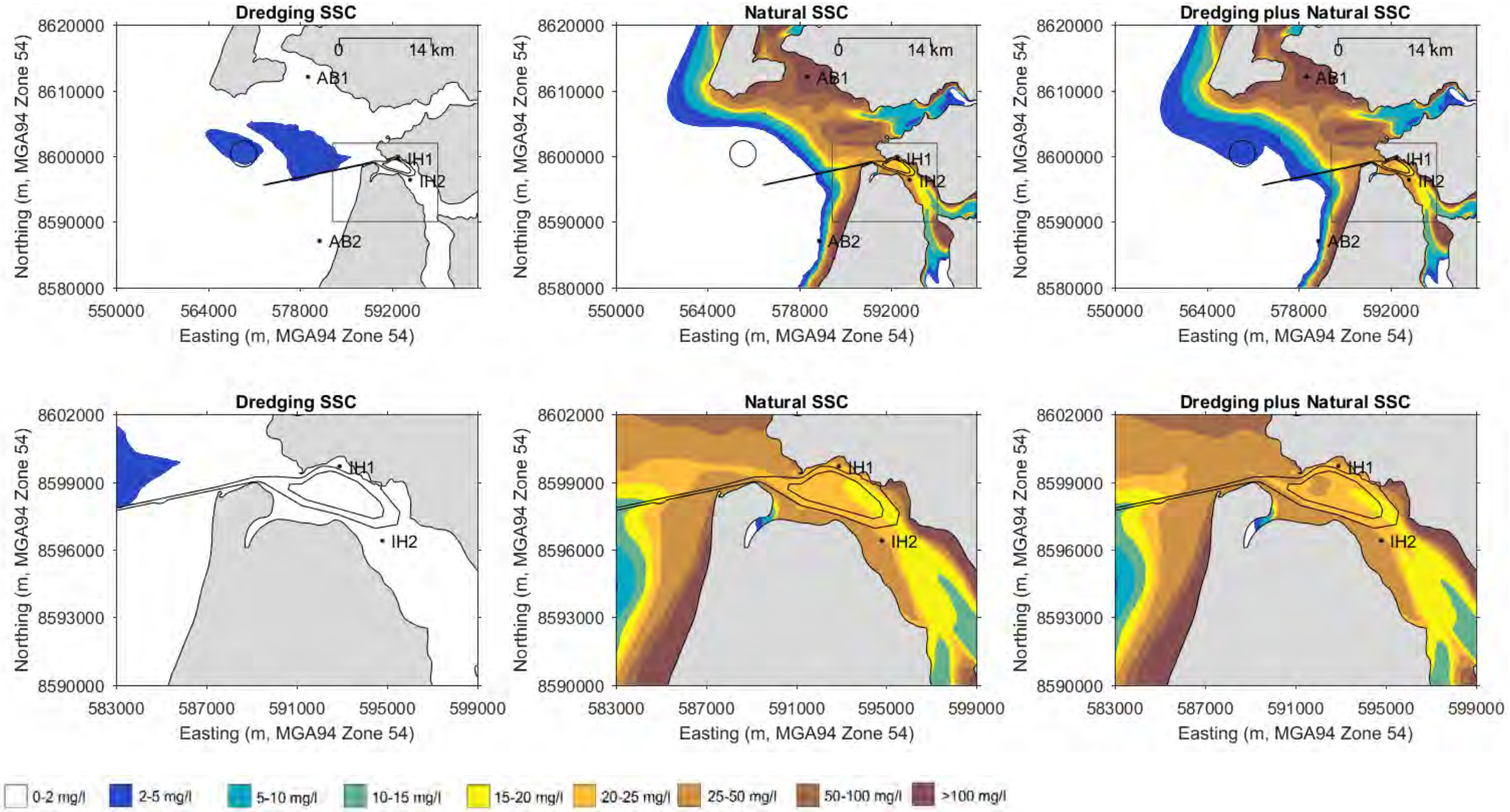

Figure 44. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

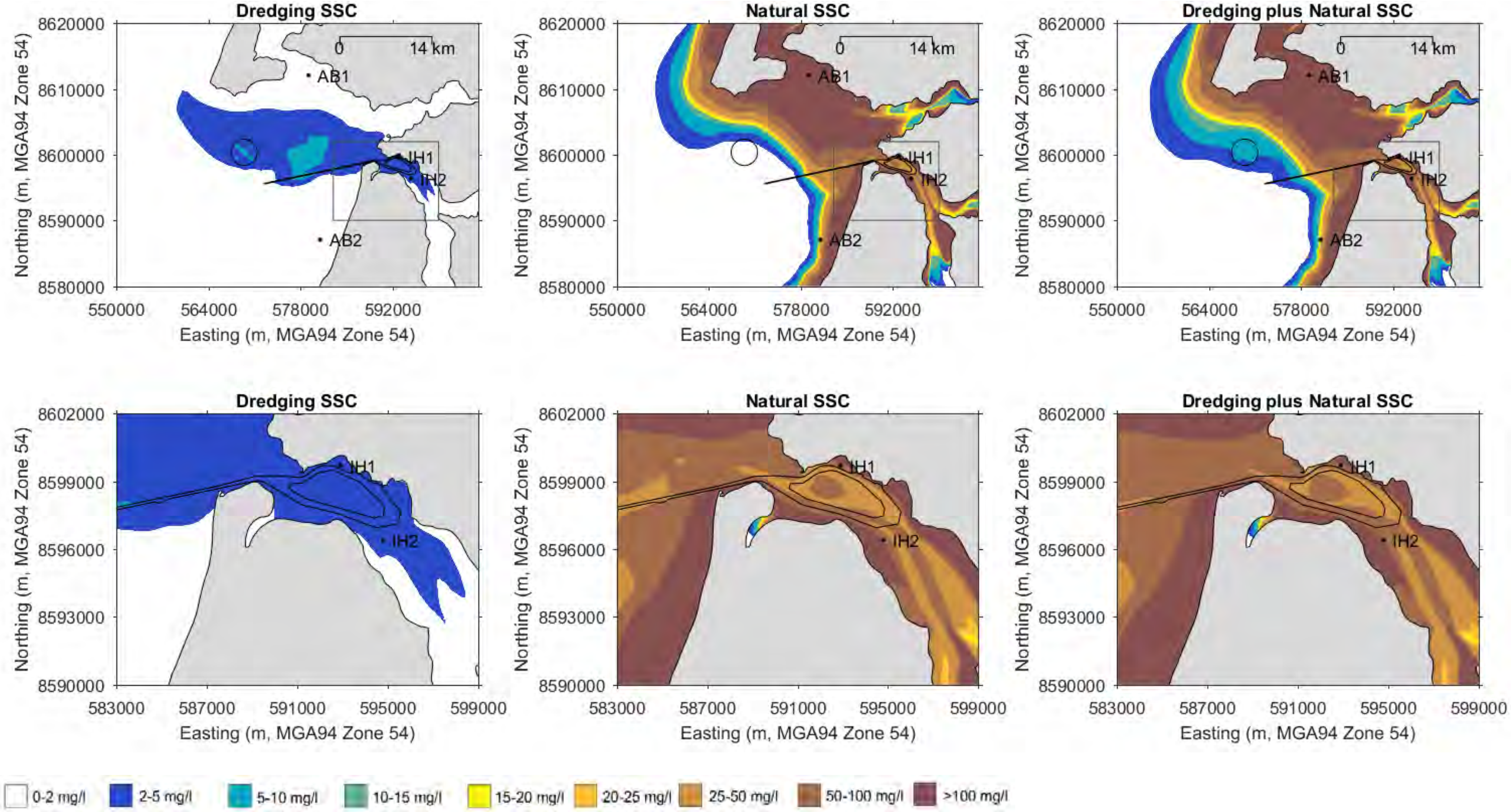

Figure 45. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

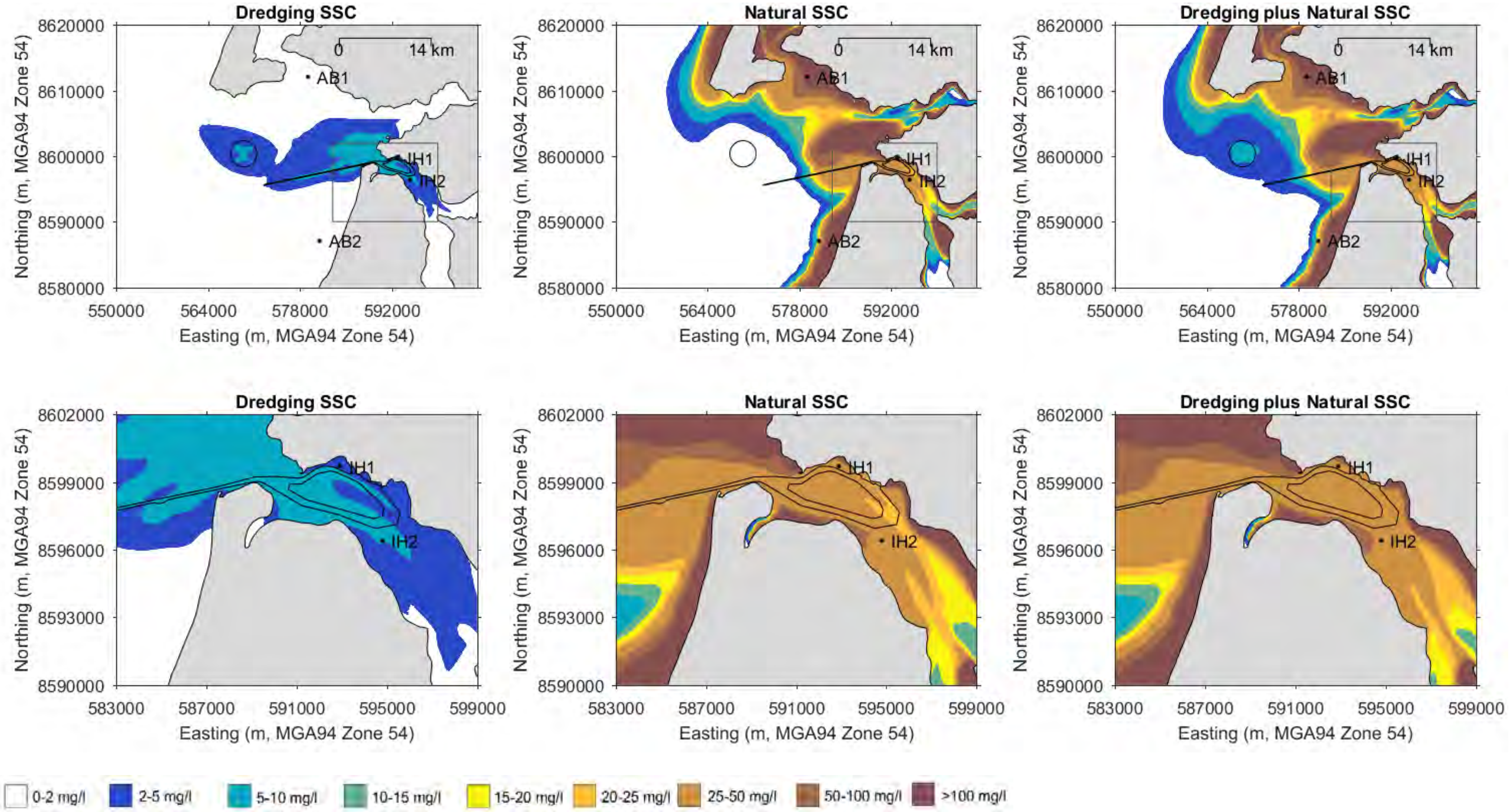

Figure 46. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross DMPA in the ambient dry season.

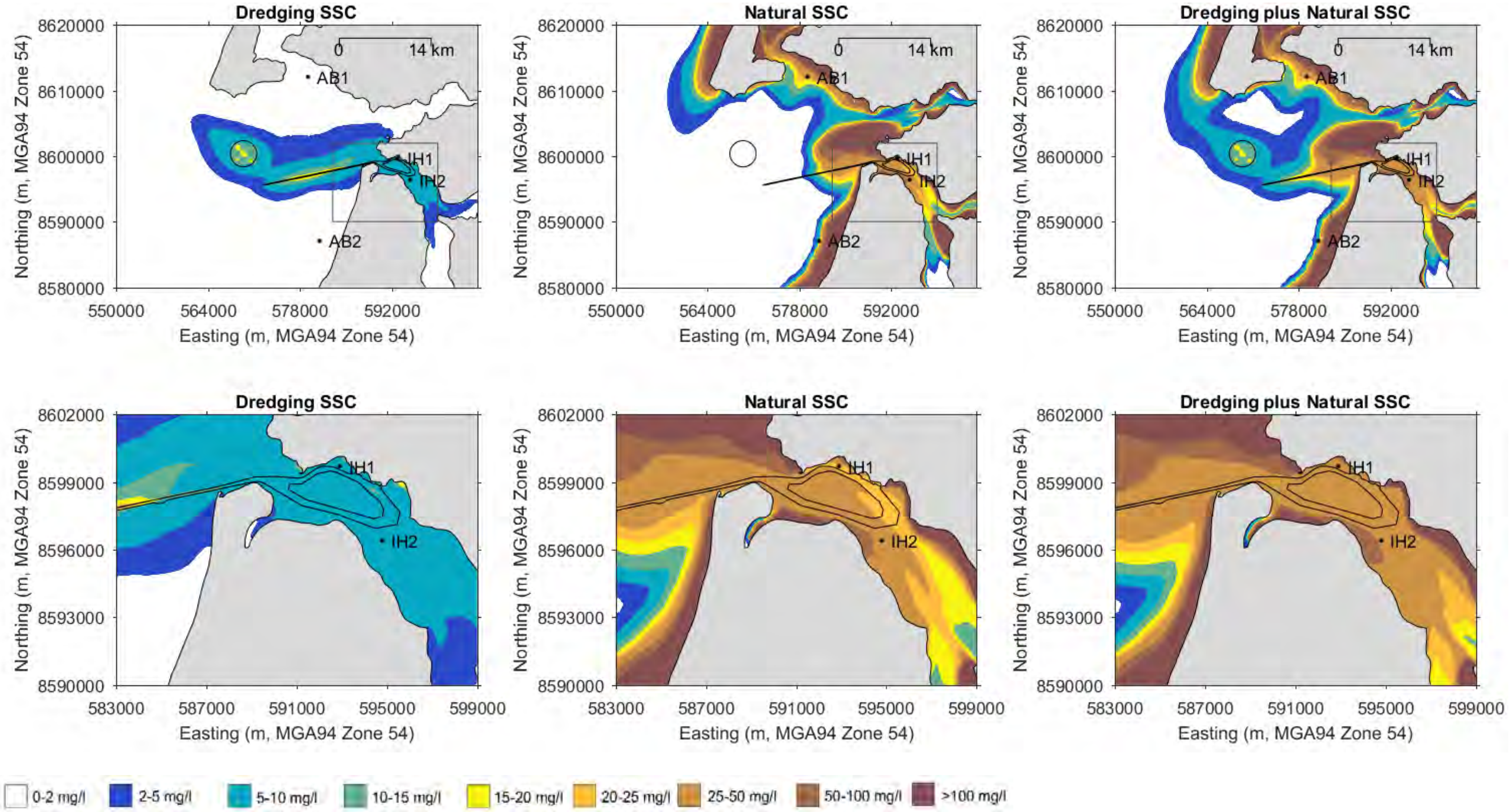

Figure 47. 95th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross DMPA in the ambient dry season.

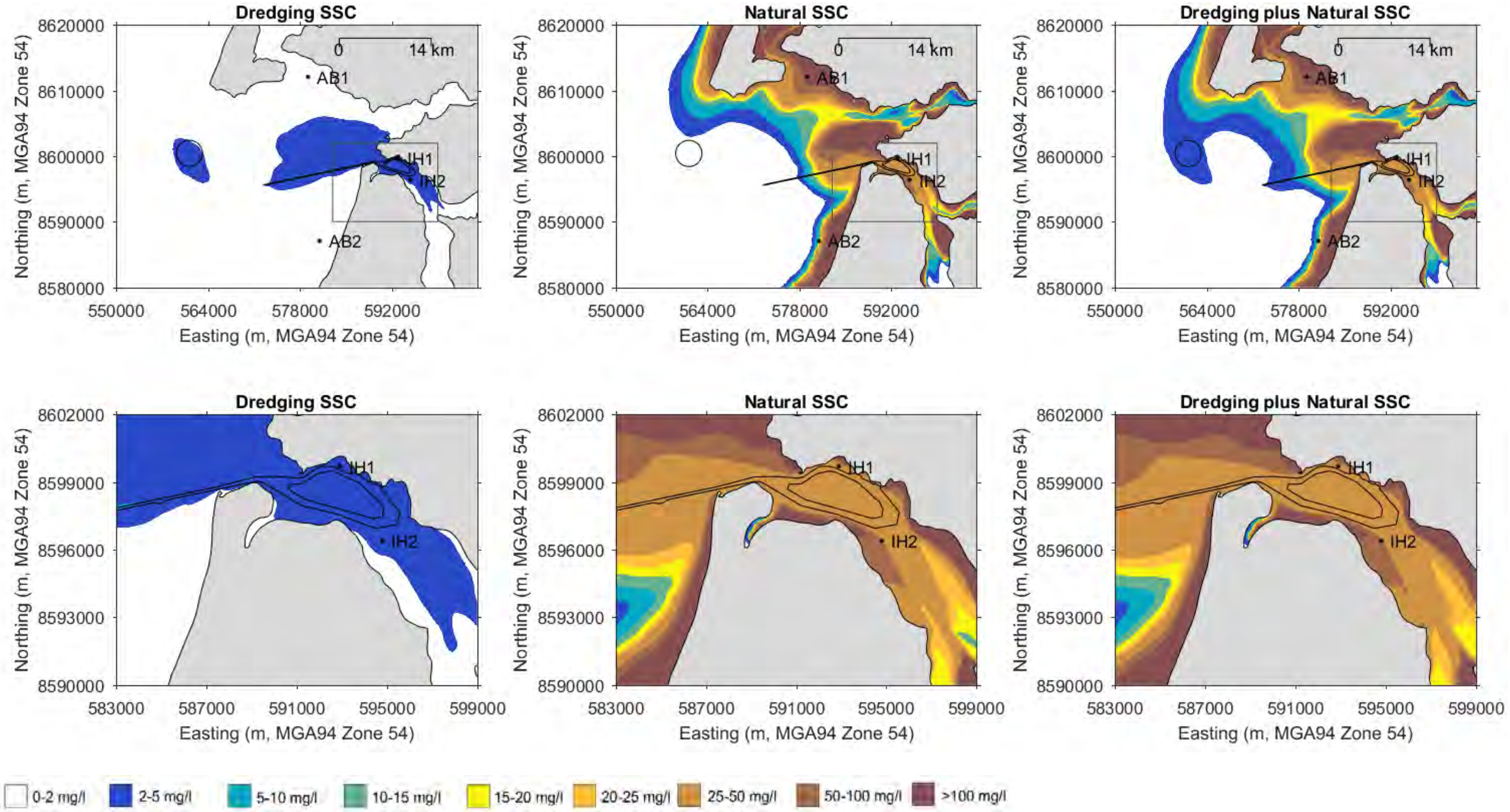

Figure 48. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

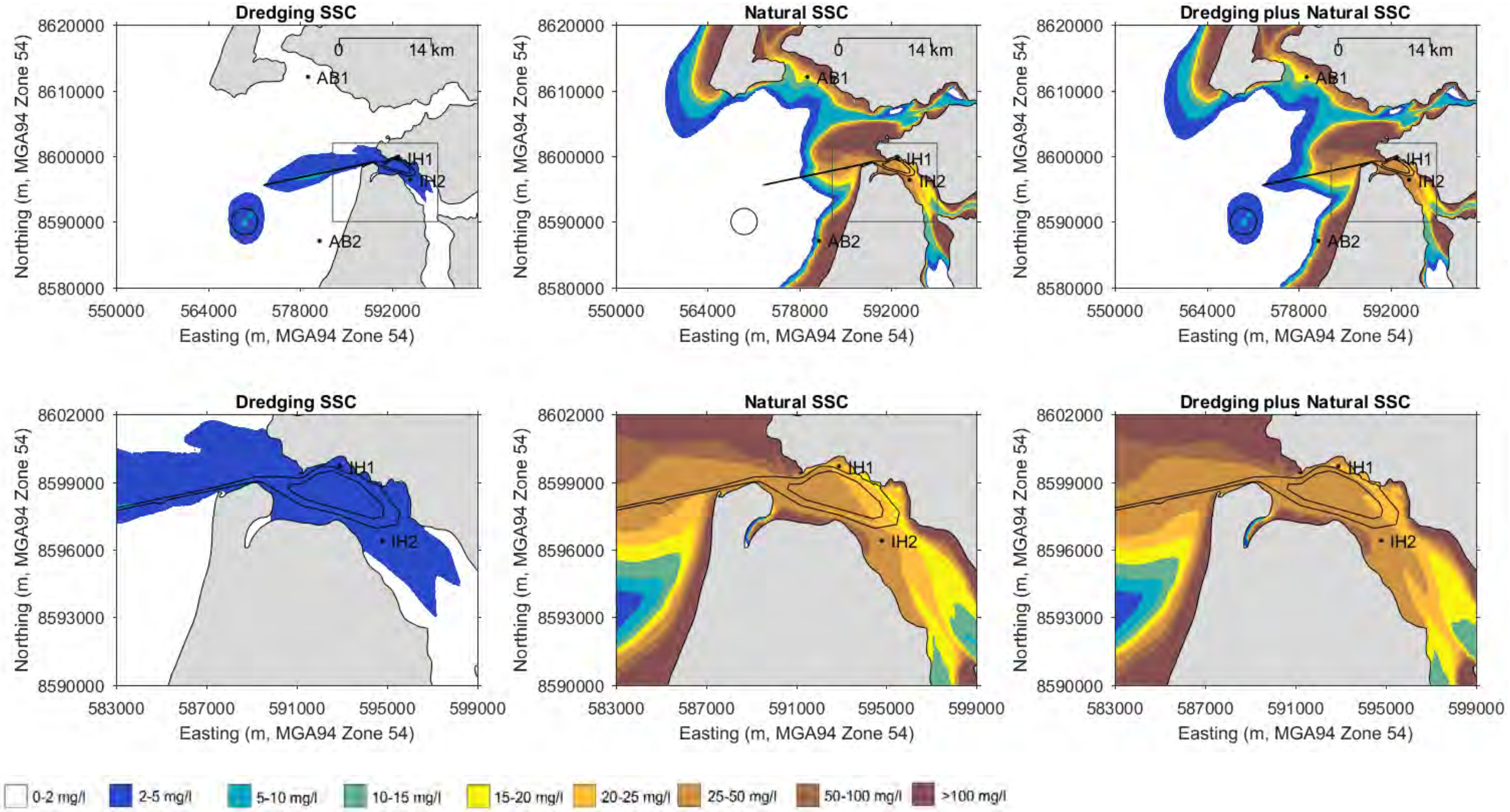

Figure 49. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

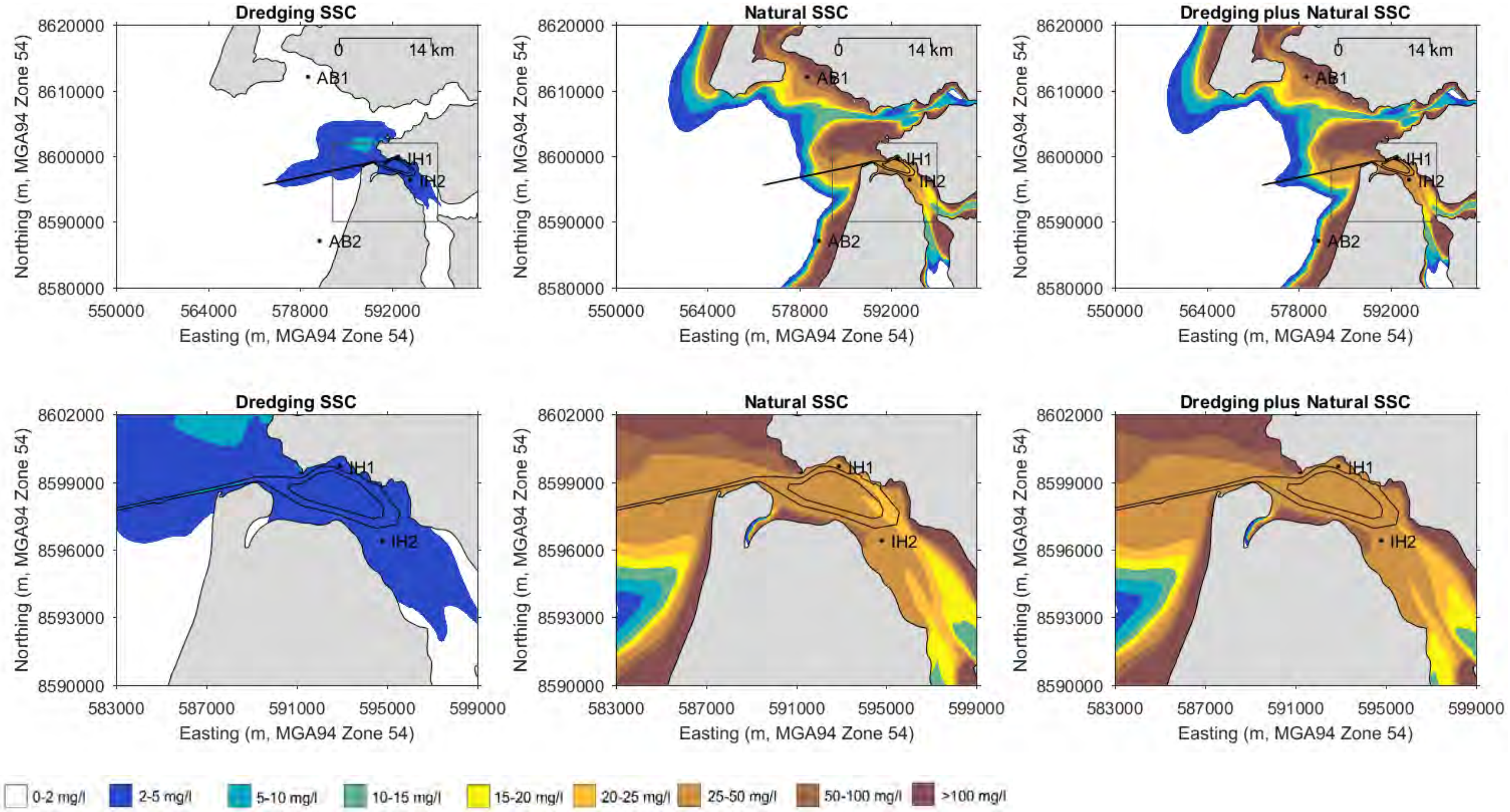

Figure 50. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

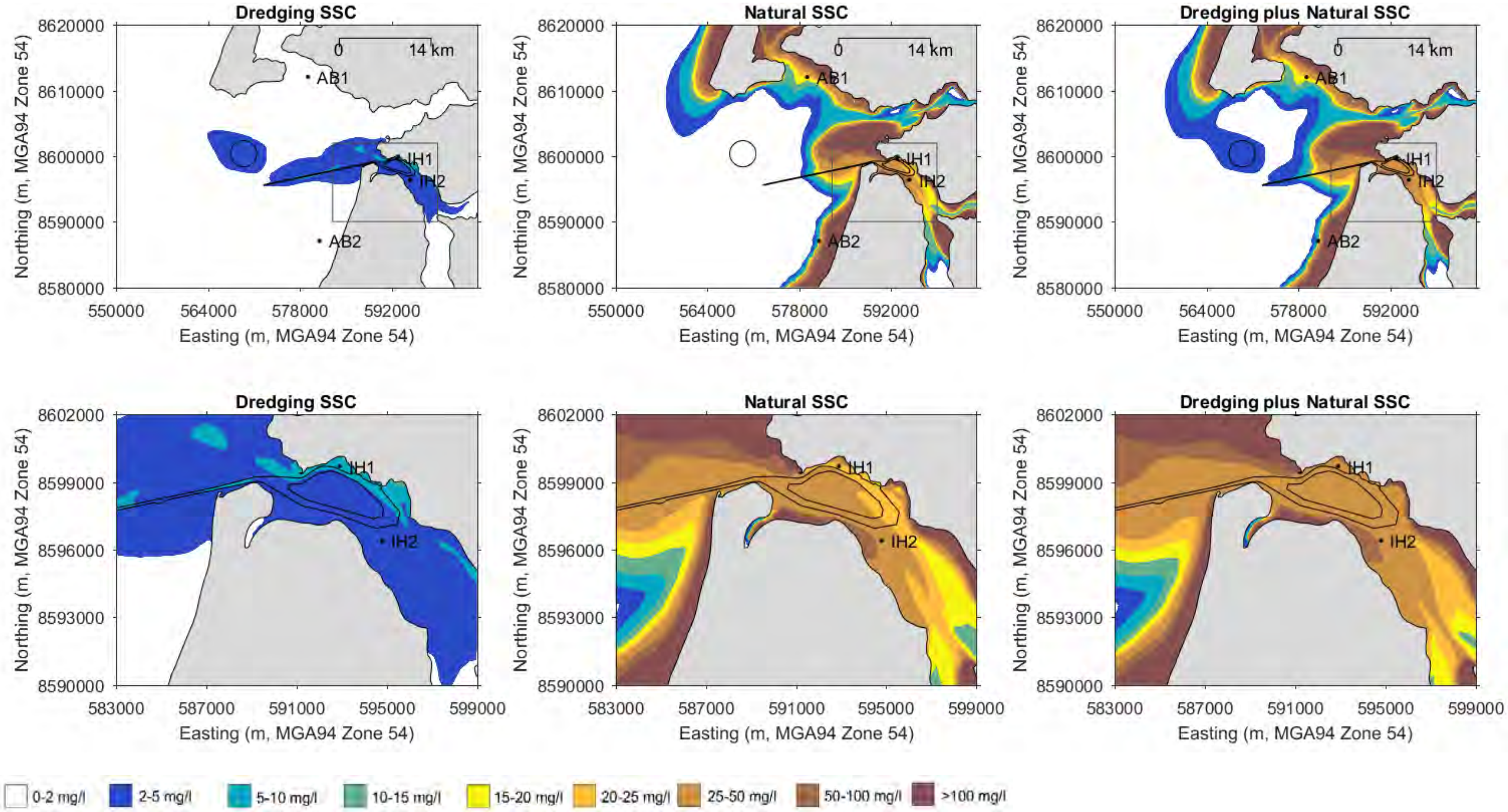

Figure 51. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the ambient dry season.

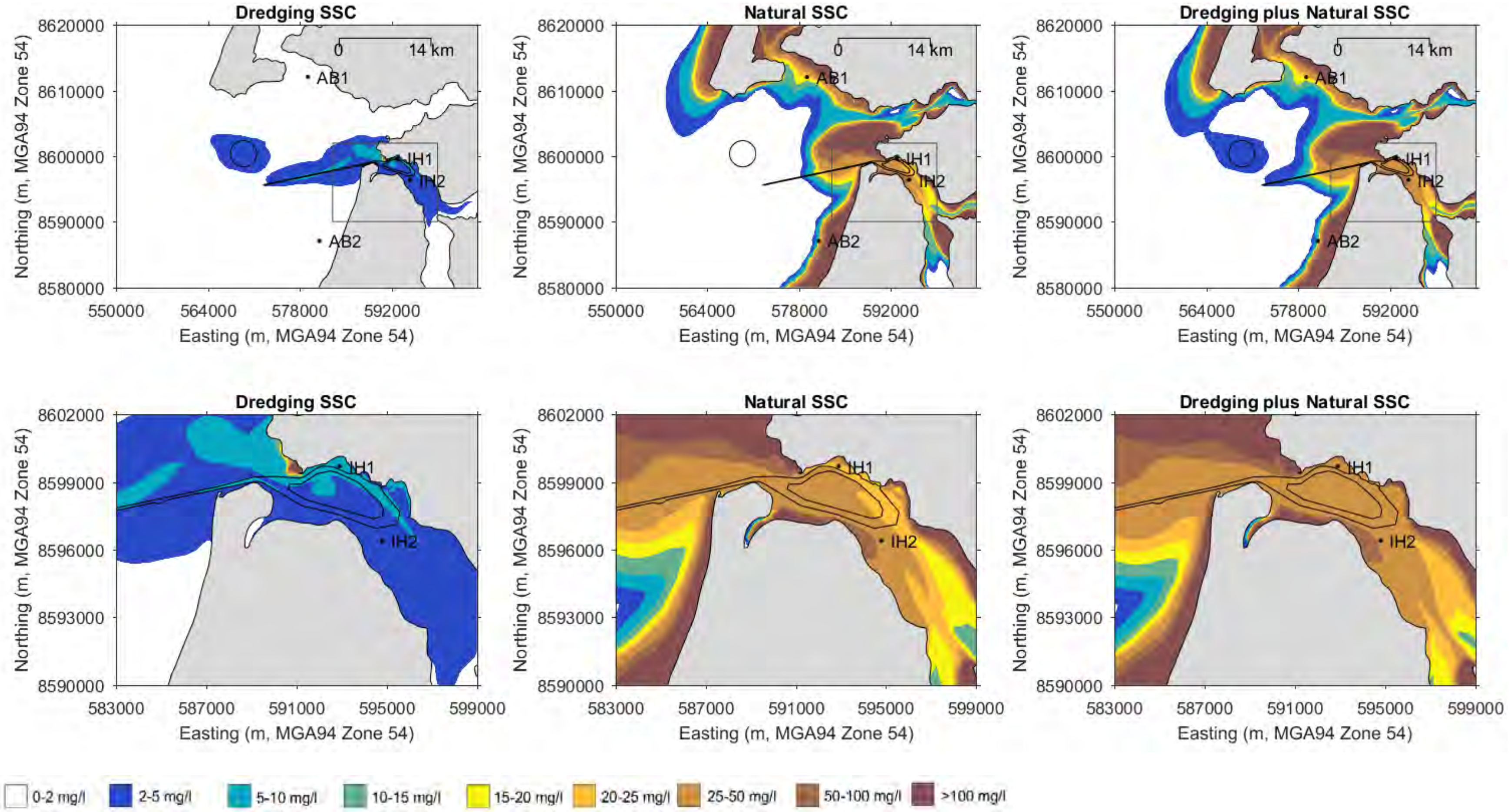

Figure 52. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the ambient dry season.

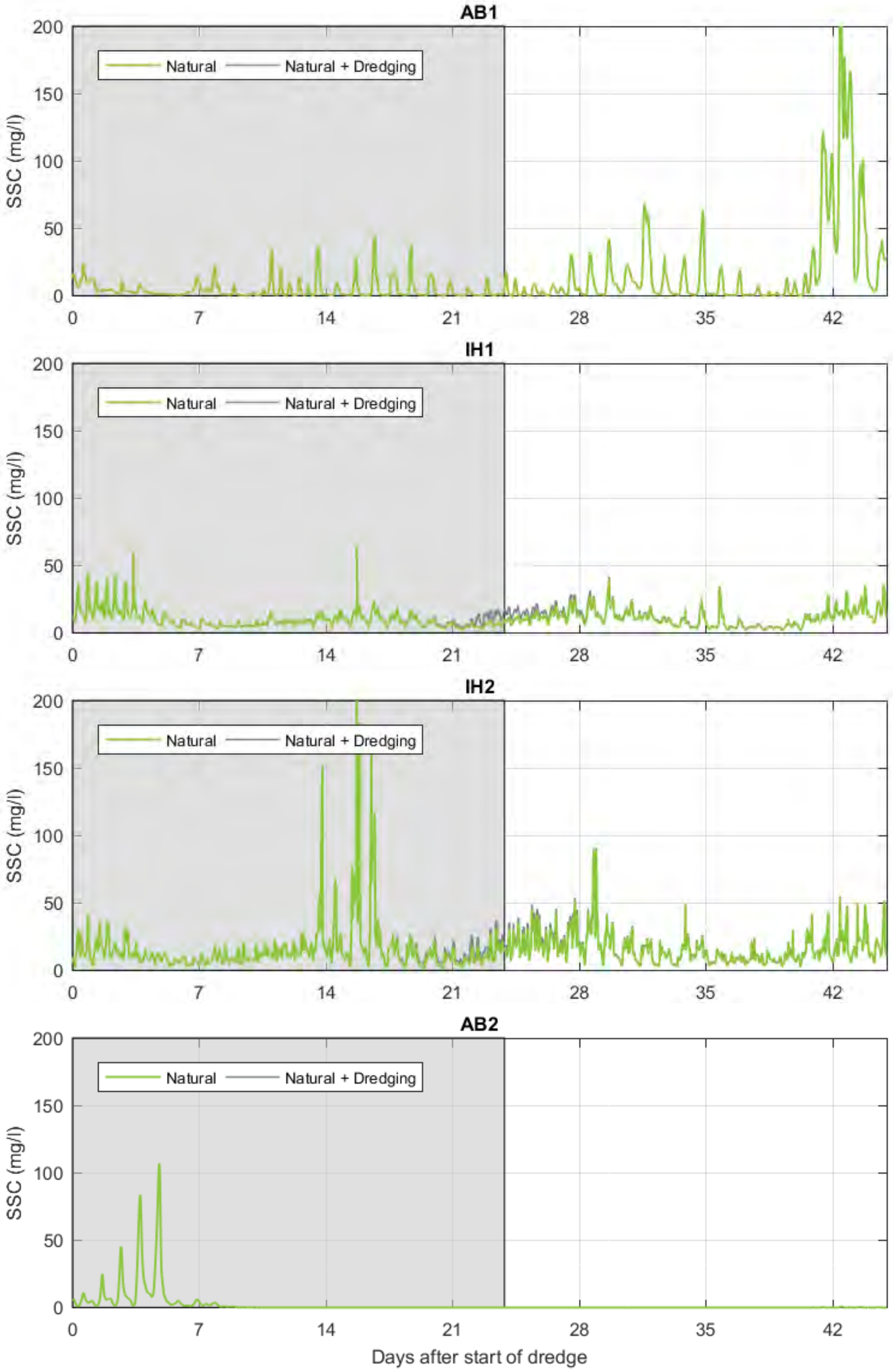

Figure 53. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

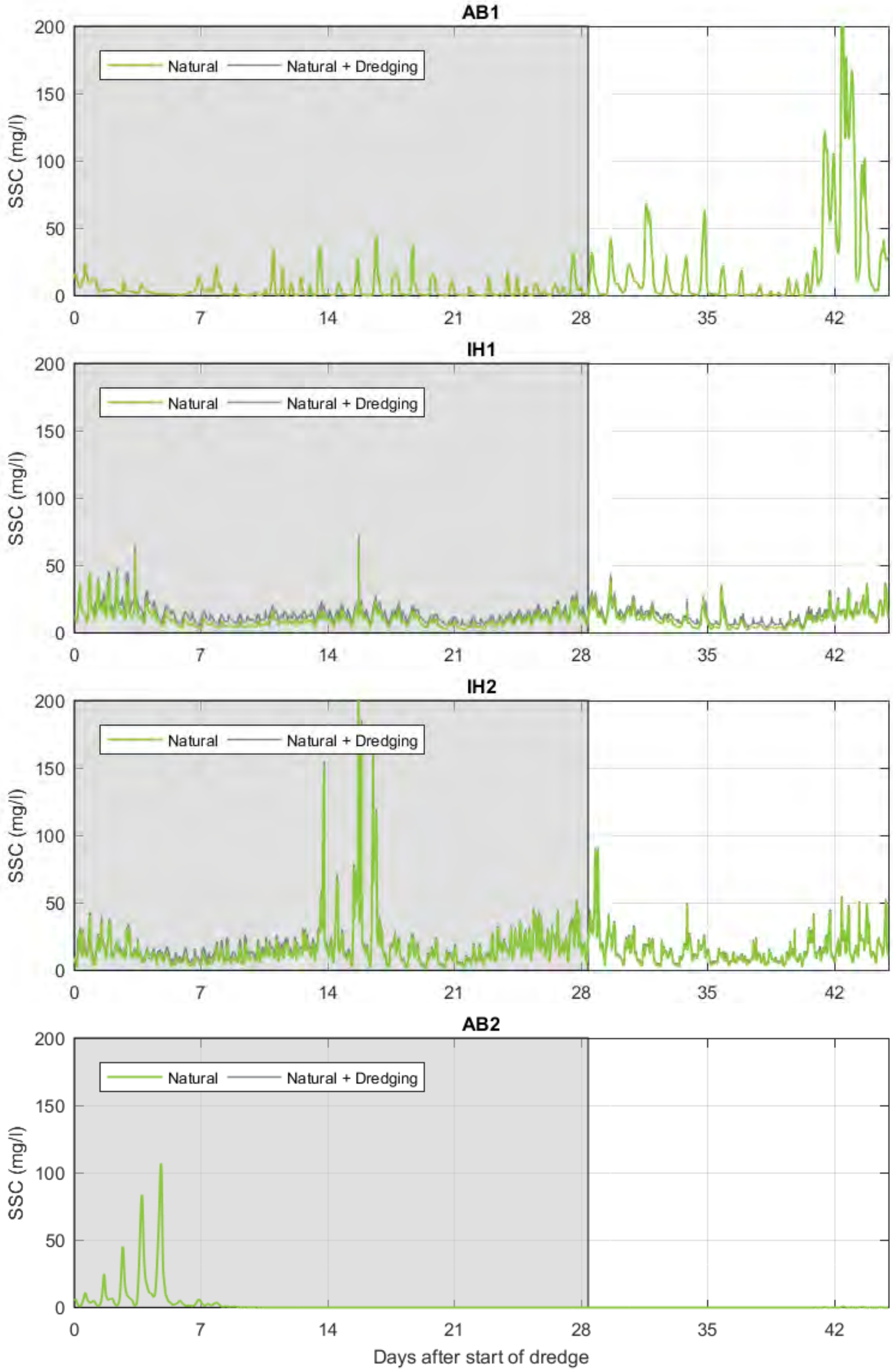

Figure 54. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the ambient dry season.

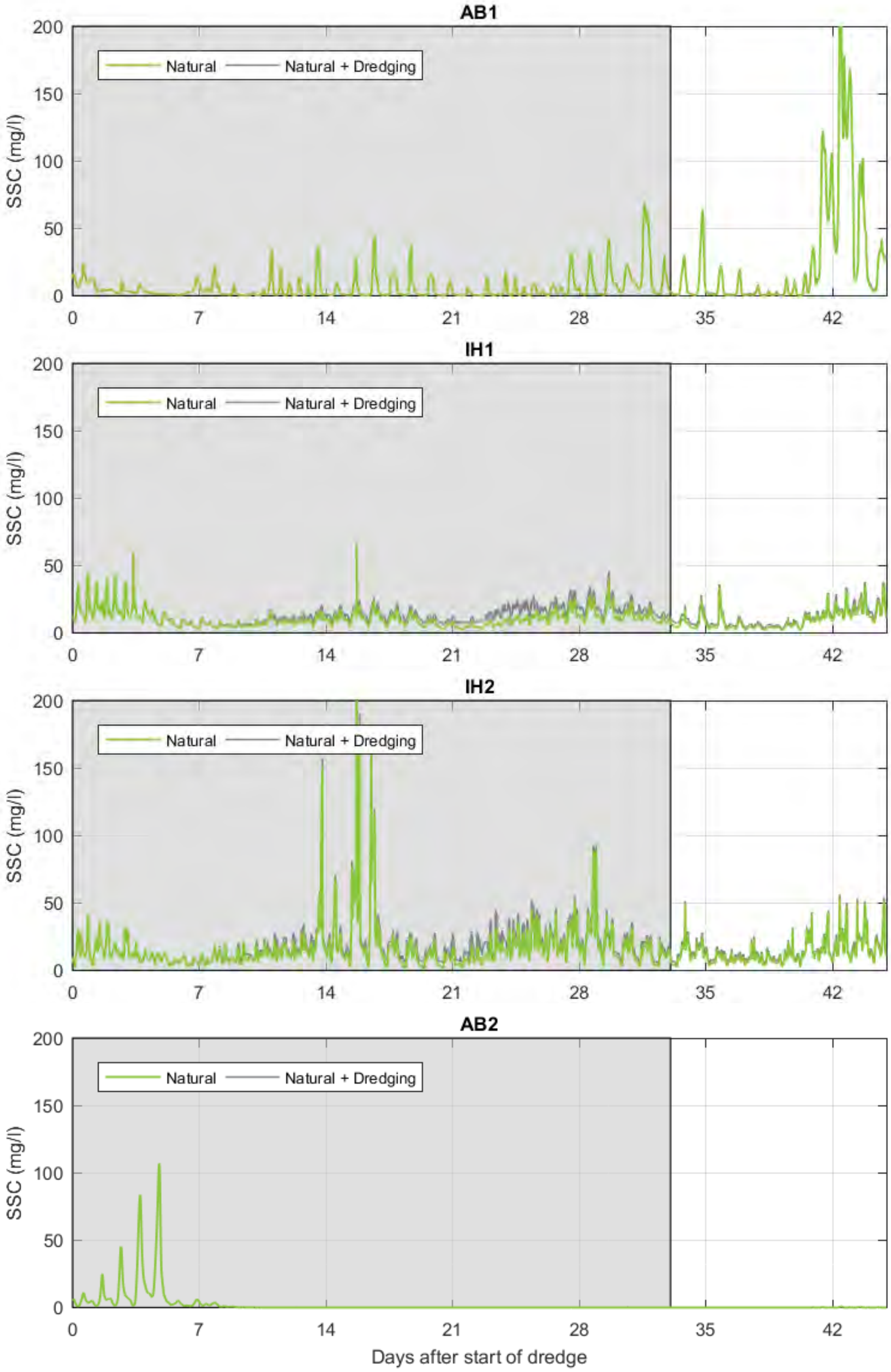

Figure 55. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

Table 13. SSC percentile results at sensitive receptors for the dredge plume modelling simulations with a typical dredge volume, undertaken during the ambient dry season period.

Placement	SSC percentile (mg/l)											
	AB1			AB2			IH1			IH2		
	20th	80th	95th	20th	80th	95th	20th	80th	95th	20th	80th	95th
Albatross DMPA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5.8	0.0	2.0	4.5
Albatross West DMPA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	4.2	0.0	1.4	3.5
Albatross South DMPA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	3.4	0.0	1.0	2.4
Onshore Pond	0.0	0.2	0.3	0.0	0.0	0.0	0.1	1.2	4.1	0.0	1.2	4.0
Reclamation	0.0	0.1	0.1	0.0	0.0	0.0	2.9	5.0	7.0	1.4	3.2	4.2
Beach Nourishment	0.0	0.0	0.1	0.0	0.0	0.0	1.8	3.7	6.0	1.3	3.3	4.4

Table 14. SSC percentile results at sensitive receptors for the dredge plume modelling simulations with a typical dredge volume, undertaken during the energetic dry season period.

Placement	SSC percentile (mg/l)											
	AB1			AB2			IH1			IH2		
	20th	80th	95th	20th	80th	95th	20th	80th	95th	20th	80th	95th
Albatross DMPA	0.0	0.1	0.2	0.0	0.0	0.0	0.0	1.1	2.6	0.0	0.6	2.3
Albatross West DMPA	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.6	3.4	0.0	1.2	2.2
Albatross South DMPA	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.9	2.9	0.0	0.6	2.3
Onshore Pond	0.0	0.2	0.3	0.0	0.0	0.0	0.1	0.7	2.5	0.0	0.9	1.7
Reclamation	0.0	0.8	1.0	0.0	0.0	0.0	1.3	5.2	7.1	0.6	2.3	4.8
Beach Nourishment	0.0	1.3	1.7	0.0	0.0	0.0	1.4	4.4	6.0	1.2	3.0	5.2

Table 15. SSC percentile results at sensitive receptors for the dredge plume modelling simulations with a cyclonic dredge volume, undertaken during the ambient dry season period.

Placement	SSC percentile (mg/l)											
	AB1			AB2			IH1			IH2		
	20th	80th	95th	20th	80th	95th	20th	80th	95th	20th	80th	95th
Albatross DMPA	0.0	0.3	0.4	0.0	0.0	0.0	0.0	1.8	4.7	0.0	1.8	5.0
Albatross West DMPA	0.0	0.7	0.9	0.0	0.0	0.0	0.0	1.5	3.3	0.0	1.1	2.2
Albatross South DMPA	0.0	0.3	0.7	0.0	0.0	0.0	0.0	1.6	4.4	0.0	1.2	3.2
Onshore Pond	0.0	0.4	0.7	0.0	0.0	0.0	0.1	0.9	1.6	0.0	0.5	0.9

Table 16. SSC percentile results at sensitive receptors for the dredge plume modelling simulations with a cyclonic dredge volume, undertaken during the energetic dry season period.

Placement	SSC percentile (mg/l)											
	AB1			AB2			IH1			IH2		
	20th	80th	95th	20th	80th	95th	20th	80th	95th	20th	80th	95th
Albatross DMPA	0.0	0.4	0.5	0.0	0.0	0.0	0.0	1.2	5.1	0.0	1.9	3.4
Albatross West DMPA	0.0	0.6	0.8	0.0	0.0	0.0	0.0	1.2	4.2	0.0	1.5	2.7
Albatross South DMPA	0.0	0.5	0.6	0.0	0.0	0.0	0.0	1.1	4.4	0.0	1.6	3.3
Onshore Pond	0.0	0.2	0.5	0.0	0.0	0.0	0.1	0.4	0.6	0.0	0.3	0.4

Table 17. SSC percentile results at sensitive receptors for the dredge plume modelling simulations with a worst case dredge volume, undertaken during the ambient dry season period.

Placement	SSC percentile (mg/l)											
	AB1			AB2			IH1			IH2		
	20th	80th	95th	20th	80th	95th	20th	80th	95th	20th	80th	95th
Albatross DMPA	0.0	0.1	0.4	0.0	0.0	0.0	0.2	5.2	7.4	0.1	4.5	7.6
Albatross West DMPA	0.0	0.3	0.8	0.0	0.0	0.0	0.3	4.9	5.7	0.1	4.1	6.1
Albatross South DMPA	0.0	0.2	0.5	0.0	0.0	0.0	0.4	5.3	6.6	0.1	4.1	5.8

Table 18. SSC percentile results at sensitive receptors for the dredge plume modelling simulations with a worst case dredge volume, undertaken during the energetic dry season period.

Placement	SSC percentile (mg/l)											
	AB1			AB2			IH1			IH2		
	20th	80th	95th	20th	80th	95th	20th	80th	95th	20th	80th	95th
Albatross DMPA	0.1	3.6	5.7	0.0	0.0	0.0	0.1	4.8	9.9	0.0	2.0	2.6
Albatross West DMPA	0.1	1.7	2.3	0.0	0.0	0.0	0.2	4.0	6.8	0.0	2.3	3.3
Albatross South DMPA	0.0	1.9	2.8	0.0	0.0	0.0	0.1	6.8	10.2	0.0	5.1	6.5

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

- the sediment released in suspension during the dredging and material placement activity results in small areas of increased SSC for relatively short durations;
- there is limited net residual transport of the suspended sediment from maintenance dredging with the dredge plume area predicted to typically extend roughly east-west along the dredge channel and into the Embley River;
- for the typical dredge volume, the 20th percentile SSC (the SSC which is exceeded for 80% of the time over the duration of the dredging program) is less than 2 mg/l everywhere, for all placement options modelled, except for the placement in the land

reclamation site. For this placement option there is a small area in the Inner Harbour (including at sensitive receptor IH1) where the 20th percentile SSC is between 2 and 5 mg/l when the dredge is undertaken during the ambient dry season;

- for the typical dredge volume, the 80th percentile SSC (the SSC which is only exceeded for 20% of the time over the duration of the dredging program) is generally only above 2 mg/l (and remains less than 5 mg/l) over small areas centred on the placement site, the South Channel and within the Inner Harbour (for example Figure 42). The exceptions to this are for placement at the land reclamation and for beach nourishment, which result in slightly more extensive areas of enhanced SSC;
- for the typical dredge volume, the 95th percentile SSC (the SSC which is only exceeded for 5% of the time over the duration of the dredging program) is around 5-10 mg/l, but again this only occurs over small areas within and around the placement site, the South Channel and the Inner Harbour for almost all placement options (for example Figure 43). The only exception to this is for the beach nourishment option, where localised increases in the 95th percentile SSC exceed 100 mg/l adjacent to the beach nourishment location at Gonbung Point (see Figure 52);
- any increases in SSC associated with dredging are short-lived, with much smaller areas and intensity for the 80th percentile compared to the 95th percentile;
- comparison of the effect of the dredge on SSC during the ambient and energetic dry seasons (Figure 42 and Figure 44 for the 80th percentile and Figure 43 and Figure 45 for the 95th percentile) indicates only slight differences in the intensity and extent of increase. Outside of the Inner Harbour region, the SSC is slightly higher when dredging is undertaken in the energetic dry season. Conversely, within the Inner Harbour increases in SSC are generally slightly higher when dredging occurs during the ambient dry season due to the calmer wave conditions resulting in reduced dispersion of suspended sediment in Albatross Bay which in turn results in higher SSCs due to the dredging being transported into the Inner Harbour from Albatross Bay during the flood stage of the tide. At the sensitive receptor sites the 95th percentile is 5.8 mg/l or less for the ambient dry season conditions, while for the energetic dry season conditions this is reduced to 3 mg/l or less (Table 13 and Table 14);
- as expected, for the worst-case dredge volumes when two dredgers are working concurrently, the area of increased SSC and the intensity of these increases are enhanced relative to the typical dredge volume. The 95th percentile for the worst-case dredge volume is more than 20 mg/l outside of the Inner Harbour but for the most part remains less than 10 mg/l within the Inner Harbour (except for very localised areas on the intertidal). These predicted increases in SSC for the worst-case volumes are primarily due to the increased sediment release rates associated with the use of a larger dredger (which has been assumed to only be required for worst-case dredge volumes);
- of the three offshore sediment placement options, the existing Albatross DMPA site results in the highest 95th percentile values (of 5 to 10 mg/l) within the Inner Harbour area for the typical dredge volume. At the sensitive receptor IH1 the 95th percentile SSC is 5.8 mg/l, 4.2 mg/l and 3.4 mg/l for placement at Albatross DMPA, Albatross West DMPA and Albatross South DMPA, respectively;
- of all sediment placement options considered for the typical dredge volume, the land reclamation results in the highest 95th percentile SSC at sensitive receptor IH1 (7.0 mg/l and 7.1 mg/l for typical dredge volumes with dredging occurring during the ambient and energetic dry season periods, respectively);
- of all sediment placement options, the beach nourishment option results in the highest 95th percentile values (of 1.7 mg/l for a typical dredge volume) at the sensitive receptor AB1;
- for larger dredge volumes (cyclonic and worst-case), the 95th percentile increase in SSC at AB1 is less than 1 mg/l for all placement options and dredge volumes when dredging

occurs during the ambient dry season. However, when the dredge occurs during the energetic dry season, the 95th percentile increases in SSC at AB1 are higher, being 5.7 mg/l, 2.3 mg/l and 2.8 mg/l for the worst case dredge volume and placement at Albatross DMPA, Albatross West DMPA and Albatross South DMPA, respectively;

- for the worst-case dredge volume, the largest increase in the 95th percentile SSC is at IH1, where the increase is 10.2 mg/l for placement at Albatross South DMPA when dredging occurs during the energetic dry season;
- the increases in 95th percentile SSC at both IH1 and IH2 are below 11 mg/l at all sensitive receptors and for all dredge scenarios modelled. For context the 50th percentile SSC at WQ1 and WQ4 (which are taken to be representative of conditions at IH1 and IH2) are 5 mg/l and 8 mg/l respectively. The natural plus dredging SSC is therefore expected to remain below the intensity threshold of 22 mg/l and 30 mg/l at IH1 and IH2, respectively for the majority of the time. This is discussed further in Section 7.2.1; and
- SSC is not increased at AB2 by any of the dredge plume model simulations for any of the percentiles considered.

Comparing the percentile and time series plots of the natural SSC to the natural plus dredging SSC provides context to the relative influence of the increase in SSC from the maintenance dredging on the marine environment. It is worth noting that the natural SSC varies between the dredge scenarios due to differences in the period of time over which the percentiles are calculated (selected to be consistent with the dredge period, which varies between scenarios).

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 at the placement site, where the natural SSC is low;
- the natural SSC is higher during the energetic dry season than during the ambient dry season (compare Figure 42 and Figure 44), with 95th percentile SSC of 15 to 25 mg/l in the Inner Harbour. 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. Note that variations in SSC during the wet season are much larger than those which occur between the different dry season conditions; the wet season 90th percentile SSC at WQ1 is approximately double the dry season 90th percentile (PCS, 2019e); and
- at the sensitive receptors the increases in SSC due to dredging are typically also associated with an increase in natural SSC. This is because the increases are the result of natural resuspension of bed sediment (both natural and deposited sediment from dredging) mainly resulting from tidal currents (see Figure 53 to Figure 55);

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

7.2.1. Sensitive Receptor Threshold Exceedance

The plume modelling results presented in Section 7.2 indicate that maintenance dredging at the Port of Weipa is not expected to increase SSC at the closest rocky reef (AB2). Seagrass beds (present at AB1, IH1 and IH2) are therefore the primary sensitive receptor located in the area surrounding the Port of Weipa where dredging could potentially result in changes to the water quality. The results from the plume modelling have shown that IH1 and IH2 are the sensitive receptors where an increase in SSC is most likely to occur during maintenance dredge programs.

PCS (2019e) reviewed existing literature on seagrass beds and analysed data from the water quality monitoring undertaken by JCU to propose suitable thresholds to consider during maintenance dredging activities. The adoption of percentile SSC values 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 90th percentile turbidity was adopted as a turbidity intensity threshold. As the proposed 90th percentile turbidity/SSC threshold is on average only naturally exceeded for 10% of the time, it 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. The 90th percentile SSC (and equivalent value as measured in Nephelometric Turbidity Unit equivalent – NTUe) at each of the long-term water quality monitoring stations is provided in Table 19.

Table 19. 90th percentile SSC during the dry season at the water quality monitoring stations.

Site	90th Percentile turbidity for the dry season	
	NTUe	SSC (mg/l)
WQ1	17	22
WQ2	15	20
WQ4	18	31

Since no data were collected at the exact locations of the sensitive receptors, for this assessment the thresholds defined at WQ1 are considered applicable to IH1, the thresholds defined at WQ2 are considered applicable to AB1 and AB2 (although it is important to note that both sites are located closer to the shoreline and therefore could potentially experience higher natural SSC than at WQ2) and the thresholds defined at WQ4 are considered applicable to IH2.

The analysis proposed that the total duration that the SSC intensity threshold is naturally exceeded over the dredge duration could be monitored during the dredge program and potentially used to inform adaptive management (when required). The 90th percentile total duration and the maximum total duration of exceedance at the sensitive receptors over periods equivalent to the simulated maintenance dredge programs are provided in Table 20. These durations are calculated using data collected at the water quality monitoring sites WQ1, WQ2 and WQ4 by JCU. These durations can be applied to the model results to determine when any increase in SSC due to maintenance dredging has resulted in the intensity and duration thresholds being exceeded at the sensitive receptors.

Table 20. Threshold duration applicable at the sensitive receptors for the dredge duration periods (calculated from the water quality monitoring data collected by JCU).

Dredge Period (days)	Duration of natural exceedance (hours) over defined period							
	90th percentile				Maximum			
	AB1	AB2	IH1	IH2	AB1	AB2	IH1	IH2
24	206	206	109	128	247	247	142	179
25	210	210	112	130	247	247	142	179
28	224	224	116	142	248	248	142	179
32	233	233	125	167	251	251	142	194
33	234	234	126	174	267	267	144	196
34	234	234	126	179	273	273	149	205
41	239	239	142	198	273	273	156	248
46	240	240	144	203	276	276	157	258
48	240	240	147	210	285	285	161	270
51	240	240	156	218	295	295	173	296
64	273	273	167	274	302	302	193	351
92	306	306	206	392	336	336	225	413

The natural and natural plus dredging exceedance of the intensity thresholds has been quantified at each sensitive receptor and for each dredge plume simulation and the results are presented in Table 21 to Table 26. Exceedance calculations are very sensitive to the natural exceedance and the models ability to accurately replicate the higher SSC and it was found that the natural SSC at AB1 predicted by the model was consistently higher than the maximum exceedance hours shown at AB1 in Table 20. To reduce the sensitivity of the results presented to this, the exceedance durations presented in the table for the natural conditions are taken to be 10% of the dredge duration (the statistical definition for exceedance of the 90th percentile). The dredge exceedance durations are the increase in exceedance duration due to the increased SSC from the dredging plus the natural exceedance value. This method is provides a more robust representation of the effect of the dredge on the potential for enhancing the SSC above the defined thresholds.

The tabulated values show:

- for typical and cyclonic dredge volumes and all placement options, the dredging results in either a very short duration increase, or no increase in exceedance duration at AB1 and AB2;
- for typical and cyclonic dredge volumes and offshore placement, the dredging results in a small increase in exceedance duration at IH1 and IH2 of 9 hours or less;
- for typical dredge volumes and the placement of material onshore, the dredging results in a larger increase in exceedance duration at IH1 and IH2. This increase is up to 42 hours at IH1 for the land reclamation option, however the duration remains below the 90th percentile duration;
- for worst case dredge volumes, the dredging results in a short increase in exceedance duration (up to 7 hours) at AB1 and no increase in exceedance duration at AB2; and
- for worst case dredge volumes, the increase in exceedance duration is largest (56 and 58 hours) during the energetic dry season period at IH1 for placement at Albatross DMPA and Albatross South DMPA. The total exceedance durations (135 and 141 hours) exceed the 90th percentile natural duration over the dredge period (126 hours), but remains less than the maximum natural duration over the dredge period (144 and 149 hours). These are the only scenarios modelled where the total exceedance duration is longer than the 90th percentile natural duration.

Table 21. Exceedance of the intensity thresholds at sensitive receptors for the dredge plume modelling simulations with a typical dredge volume, undertaken during the ambient dry season period.

Placement	Dredge duration (days)	Exceedance (hours)							
		Natural				Natural plus dredging			
		AB1	AB2	IH1	IH2	AB1	AB2	IH1	IH2
Albatross DMPA	24	57	57	57	57	57	57	61	58
Albatross West DMPA	32	77	77	77	77	77	77	80	83
Albatross South DMPA	25	61	61	61	61	61	61	64	62
Onshore Pond	46	110	110	110	110	110	110	119	118
Reclamation	28	68	68	68	68	68	68	110	76
Beach Nourishment	28	68	68	68	68	68	68	95	77

Table 22. Exceedance of the intensity thresholds at sensitive receptors for the dredge plume modelling simulations with a typical dredge volume, undertaken during the energetic dry season period.

Placement	Dredge duration (days)	Exceedance (hours)							
		Natural				Natural plus dredging			
		AB1	AB2	IH1	IH2	AB1	AB2	IH1	IH2
Albatross DMPA	24	57	57	57	57	57	57	60	58
Albatross West DMPA	32	77	77	77	77	77	77	79	81
Albatross South DMPA	25	61	61	61	61	61	61	64	62
Onshore Pond	46	110	110	110	110	110	110	116	114
Reclamation	28	68	68	68	68	70	68	103	74
Beach Nourishment	28	68	68	68	68	71	68	106	76

Table 23. Exceedance of the intensity thresholds at sensitive receptors for the dredge plume modelling simulations with a cyclonic dredge volume, undertaken during the ambient dry season period.

Placement	Dredge duration (days)	Exceedance (hours)							
		Natural				Natural plus dredging			
		AB1	AB2	IH1	IH2	AB1	AB2	IH1	IH2
Albatross DMPA	48	115	115	115	115	115	115	124	124
Albatross West DMPA	64	155	155	155	155	156	155	158	159
Albatross South DMPA	51	122	122	122	122	122	122	127	126
Onshore Pond	92	221	221	221	221	222	221	225	223

Table 24. Exceedance of the intensity thresholds at sensitive receptors for the dredge plume modelling simulations with a cyclonic dredge volume, undertaken during the energetic dry season period.

Placement	Dredge duration (days)	Exceedance (hours)							
		Natural				Natural plus dredging			
		AB1	AB2	IH1	IH2	AB1	AB2	IH1	IH2
Albatross DMPA	48	115	115	115	115	115	115	120	122
Albatross West DMPA	64	155	155	155	155	156	155	157	159
Albatross South DMPA	51	122	122	122	122	122	122	126	127
Onshore Pond	92	221	221	221	221	221	221	223	222

Table 25. Exceedance of the intensity thresholds at sensitive receptors for the dredge plume modelling simulations with a worst case dredge volume, undertaken during the ambient dry season period.

Placement	Dredge duration (days)	Exceedance (hours)							
		Natural				Natural plus dredging			
		AB1	AB2	IH1	IH2	AB1	AB2	IH1	IH2
Albatross DMPA	33	79	79	79	79	80	79	122	99
Albatross West DMPA	41	98	98	98	98	99	98	119	115
Albatross South DMPA	34	83	83	83	83	83	83	111	99

Table 26. Exceedance of the intensity thresholds at sensitive receptors for the dredge plume modelling simulations with a worst case dredge volume, undertaken during the energetic dry season period.

Placement	Dredge duration (days)	Exceedance (hours)							
		Natural				Natural plus dredging			
		AB1	AB2	IH1	IH2	AB1	AB2	IH1	IH2
Albatross DMPA	33	79	79	79	79	86	79	**135**	84
Albatross West DMPA	41	98	98	98	98	100	98	133	106
Albatross South DMPA	34	83	83	83	83	84	83	**141**	102

*Note: values in **blue** are above the 90th percentile natural duration exceedance.*

7.3. Deposition

The sediment deposition results from the model simulations are relevant for assessing ecological impacts to seagrasses. For context, literature values for seagrass tolerance to deposition rates were found to be of the order of 1.6 to 8 mg/cm^2/day (PCS, 2019e). However, analysis by PCS (2019e) of the JCU measured data indicated that natural sedimentation rates at the monitoring locations were significantly higher than this, with median values in the range of 13 to 20 mg/cm^2/day during the dry season and with a 95th percentile value an order of magnitude higher. 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);
- differences in the location of the instrument (on the subtidal) and the seagrass (on the adjacent intertidal); and
- potentially a greater tolerance of the seagrass at the Port of Weipa to sediment deposition rates than the literature values suggest.

Due to the limitations with collecting accurate deposition data, PCS (2019e) recommended against using deposition data for adaptive management purposes and no attempt was made to define more applicable thresholds at the Port of Weipa. 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 seagrasses.

The mass of sediment on the seabed at the end of the dredging program is presented as spatial maps for the dredging, natural and natural plus dredging cases. Note that values at the end of the dredging program represent sedimentation over a 24 to 67 day period so that 38.4 mg/cm^2 to 107.2 mg/cm^2 would be equivalent to 1.6 mg/cm^2/day. The spatial maps clearly show the spatial distribution and magnitude of the deposition which has occurred naturally and due to maintenance dredging.

The following plots are shown;

- spatial maps of the deposition at the end of the dredging program for the ambient dry season and for the energetic dry season for a typical dredge volume, with placement at the Albatross DMPA (Figure 56 and Figure 57);
- spatial maps of the deposition at the end of the dredging program for the ambient dry season period, with placement at the Albatross DMPA, for a typical dredge volume (400,000 m^3), a cyclonic dredge volume (800,000 m^3) and a worst-case dredge volume (2.5 million m^3), in Figure 56, Figure 58 and Figure 59, respectively;

- spatial maps of the deposition at the end of the dredging program for the ambient dry season period, for a typical dredge volume and for placement at Albatross DMPA, Albatross West DMPA and Albatross South DMPA in Figure 56, Figure 60 and Figure 61, respectively. Results are shown for a typical dredge volume for ease of comparison of results across all placement options modelled; and
- spatial maps of the deposition at the end of the dredging program for the ambient dry season period, for a typical dredge volume and for placement at the onshore pond, the land reclamation area and for beach nourishment in Figure 62 to Figure 64.

For reference, the following values can be used to approximately represent deposition thickness:

- 20 mg/cm^2 = 0.7 mm;
- 100 mg/cm^2 = 3 mm; and
- 200 mg/cm^2 = 6.7 mm.

The plots show:

- the majority of the deposition due to the dredging and material placement activity occurs at the dredging locations (particularly in and adjacent to the South Channel) and within and adjacent to the offshore DMPAs;
- deposition is slightly higher when the dredging occurs during the ambient dry season compared to when it occurs during the energetic dry season;
- as expected, the deposition increases as the dredge volume increases, with the worst case (2,500,000 m^3) results showing significantly more deposition than the typical (400,000 m^3) dredge volume results;
- the deposition resulting from the dredging activity is predicted to be less than 10 mg/cm^2 in the areas at and immediately adjacent to the sensitive receptors AB1, AB2 and IH2 for all dredge simulations modelled;
- the deposition from dredging is predicted to be more than 10 mg/cm^2 at sensitive receptor IH1 for the land reclamation and the beach nourishment placement options and for the worst-case dredge volumes for all the offshore DMPAs. The deposition at IH1 is typically less than 20 mg/cm^2 (around 0.7 mm depth) for these options, except for the placement at the land reclamation area when dredging occurs during the ambient dry season. Deposition at the end of the dredging program for this dredge scenario is around 28 mg/cm^2 which is equivalent to a rate over the 28 day dredge period of 1 mg/cm^2/day. This remains below the thresholds defined for seagrasses in the literature but does not account for the naturally occurring deposition;
- the naturally occurring deposition is spatially variable with discrete deposition areas along the coastlines to the north and south of the Port of Weipa, as well as within parts of the South Channel and the Embley River;
- the natural deposition at sensitive receptor IH1 is above the thresholds defined in the literature (being in the order of 12 mg/cm^2/day);
- when the deposition due to maintenance dredging is compared to the natural deposition (which is typically around 100 mg/cm^2 in areas where deposition occurs) it is evident that deposition from the dredging is comparably small, with only limited spatial extent and intensity; and
- comparison of the natural and natural plus dredging plots clearly show that it is only the deposition at the dredging and offshore DMPA locations which can be visibly observed over the natural deposition which occurred over the dredge duration.

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

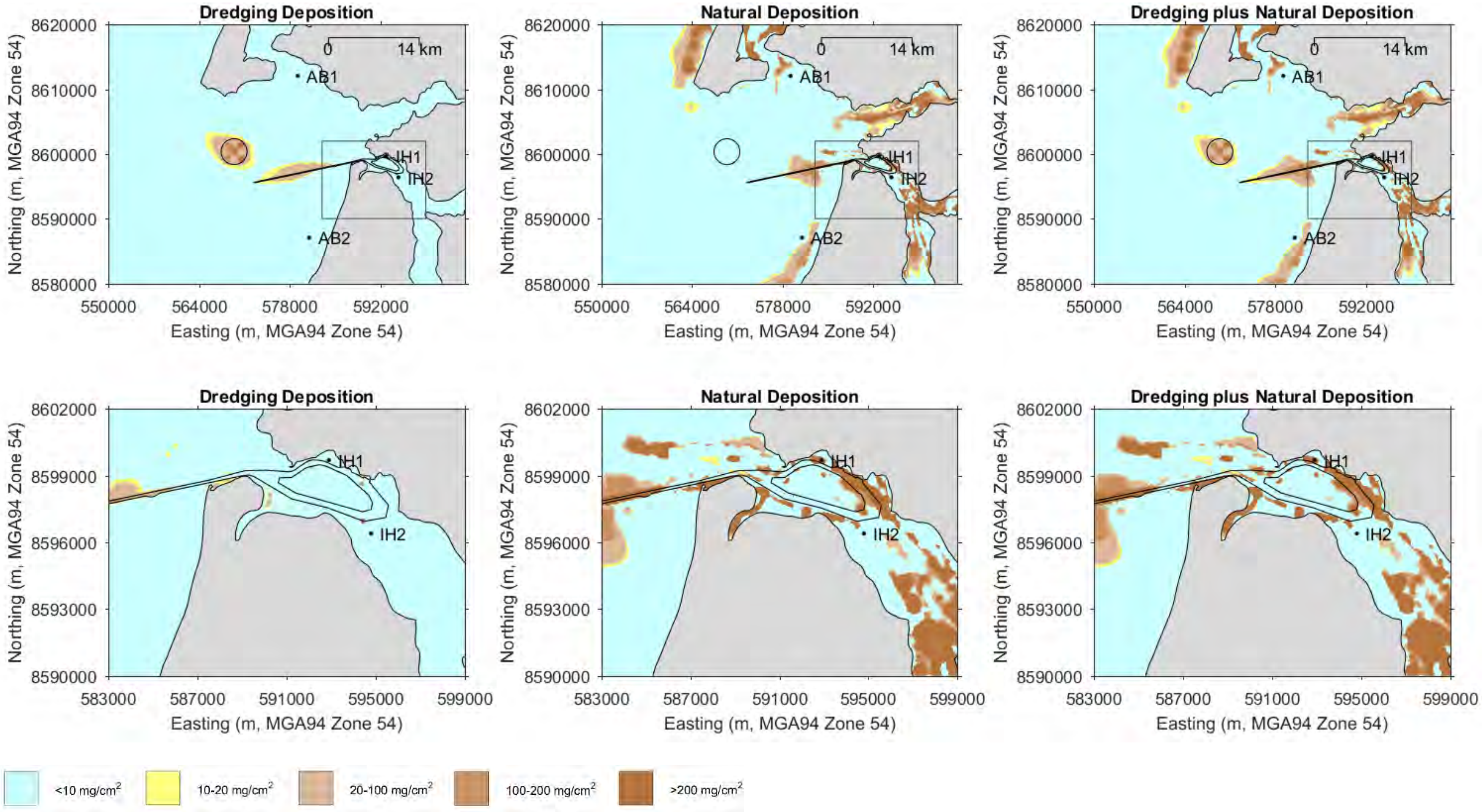

Figure 56. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

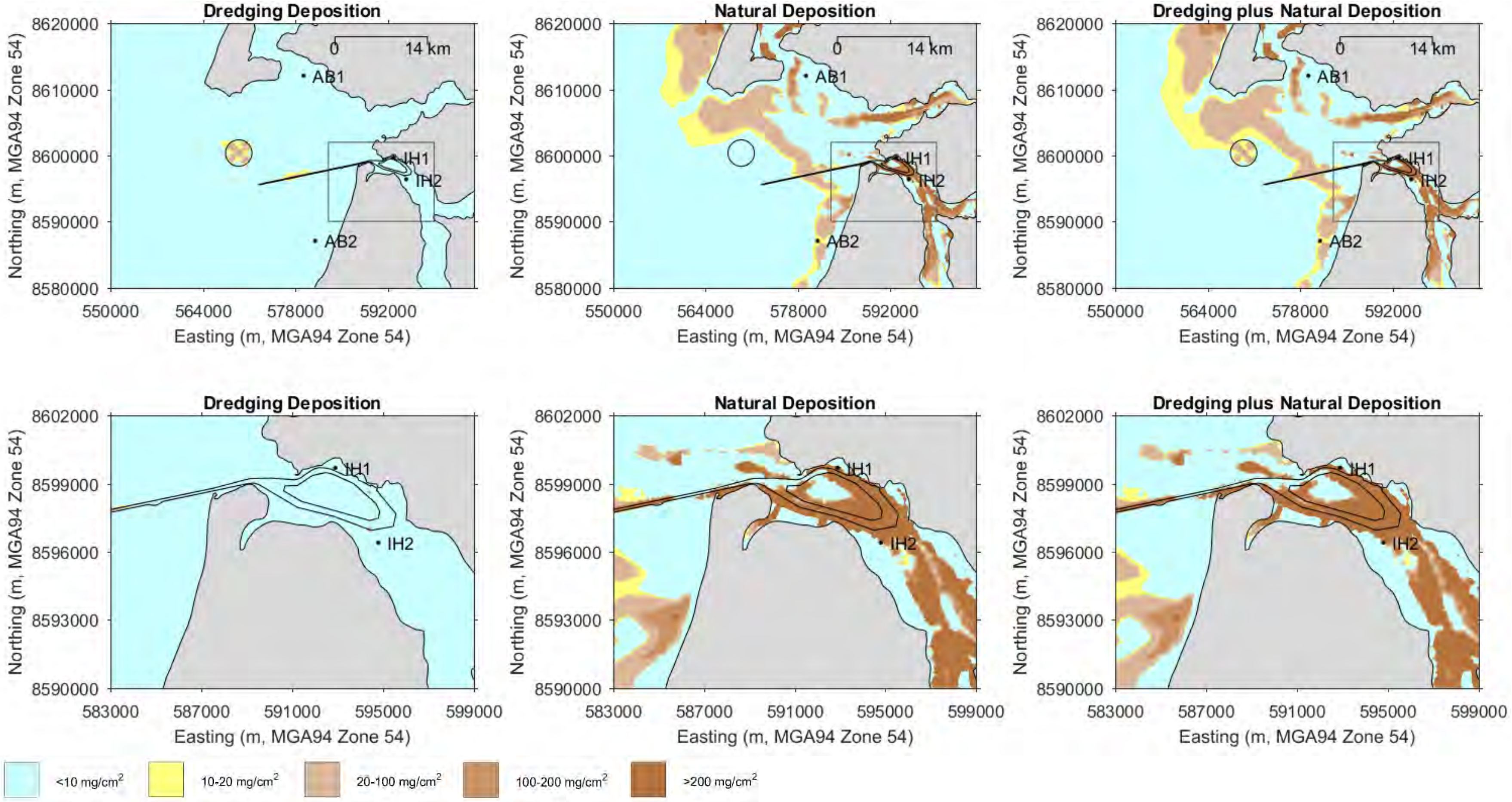

Figure 57. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

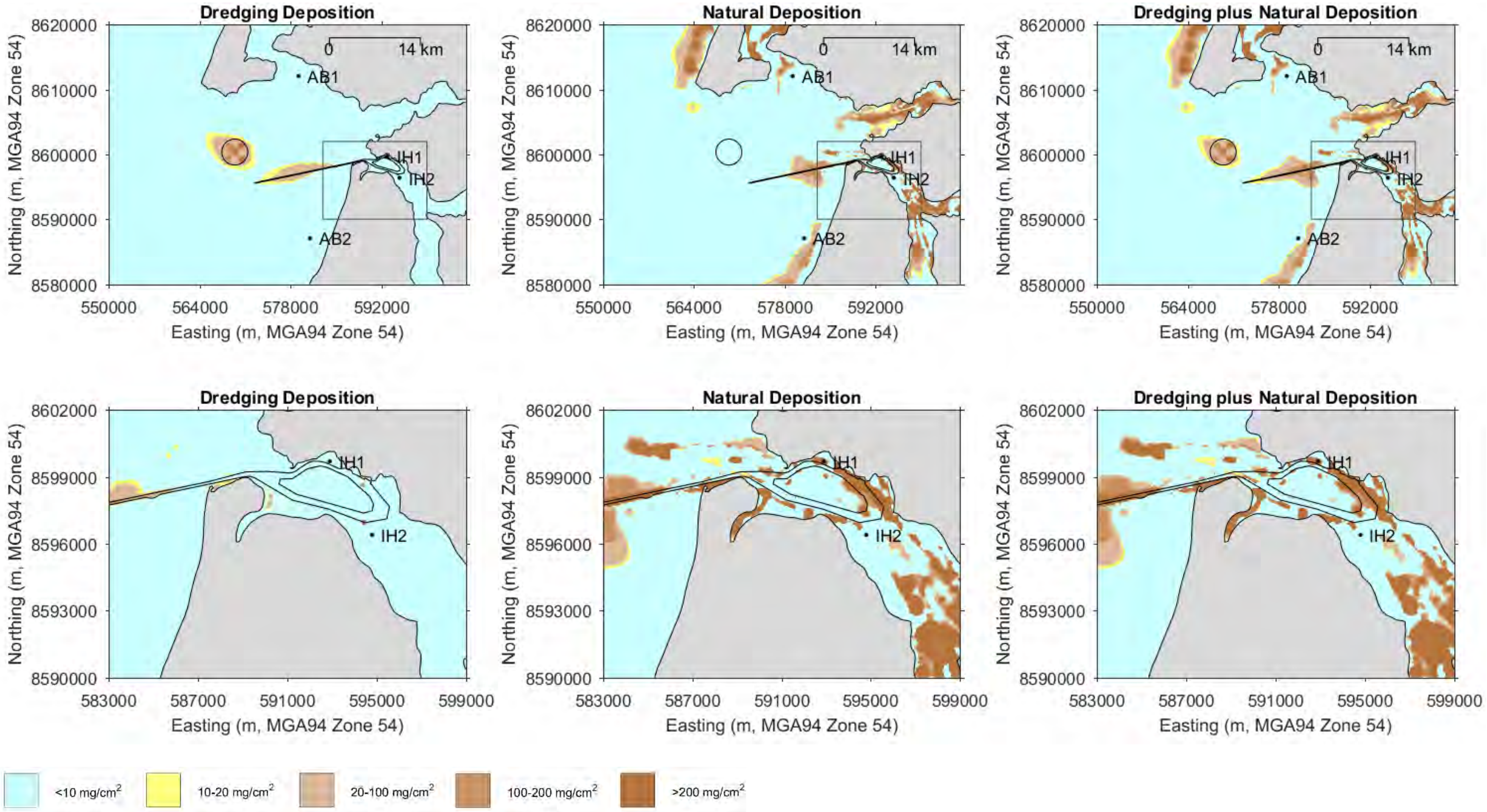

Figure 58. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

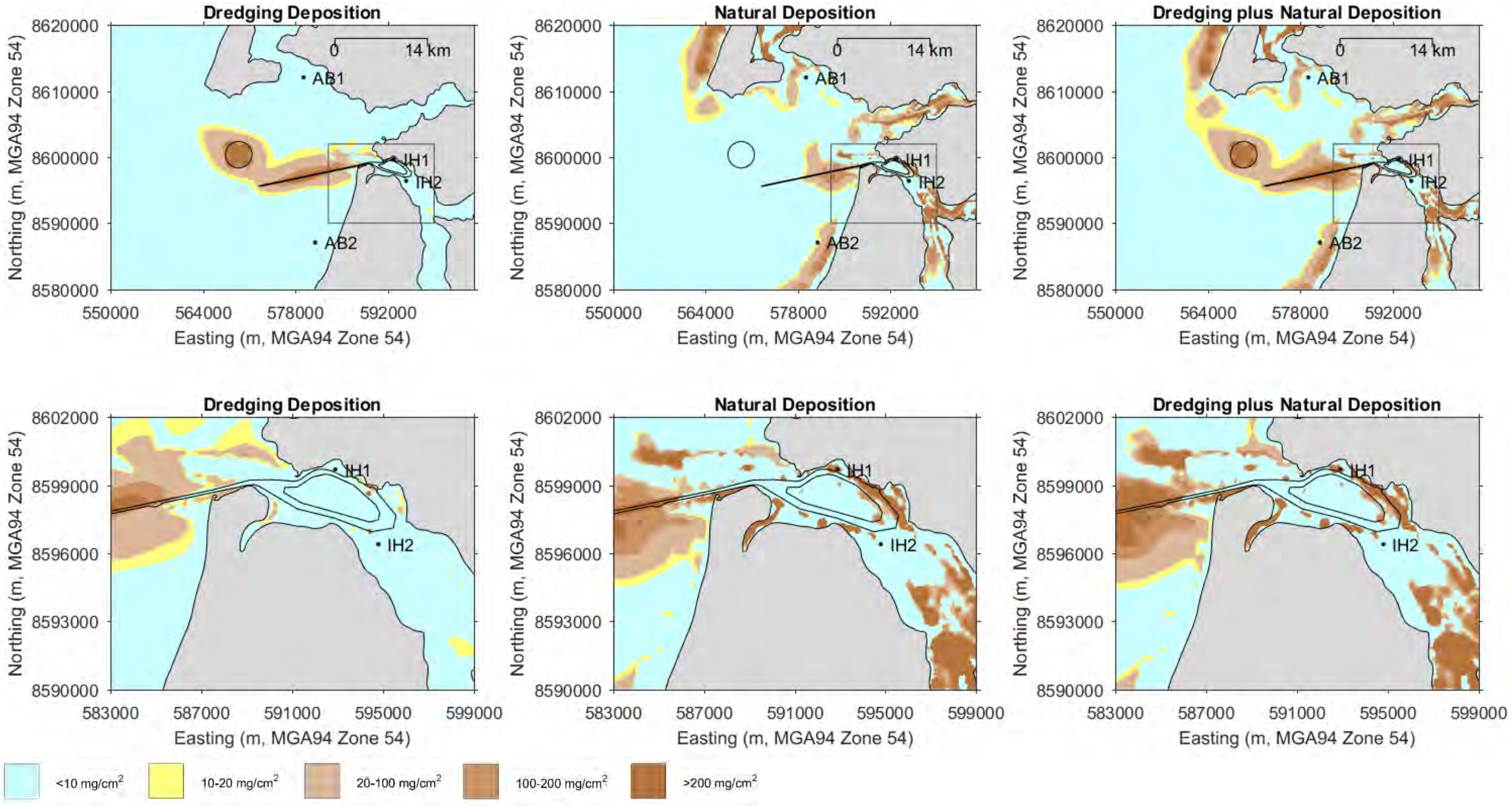

Figure 59. Deposition for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

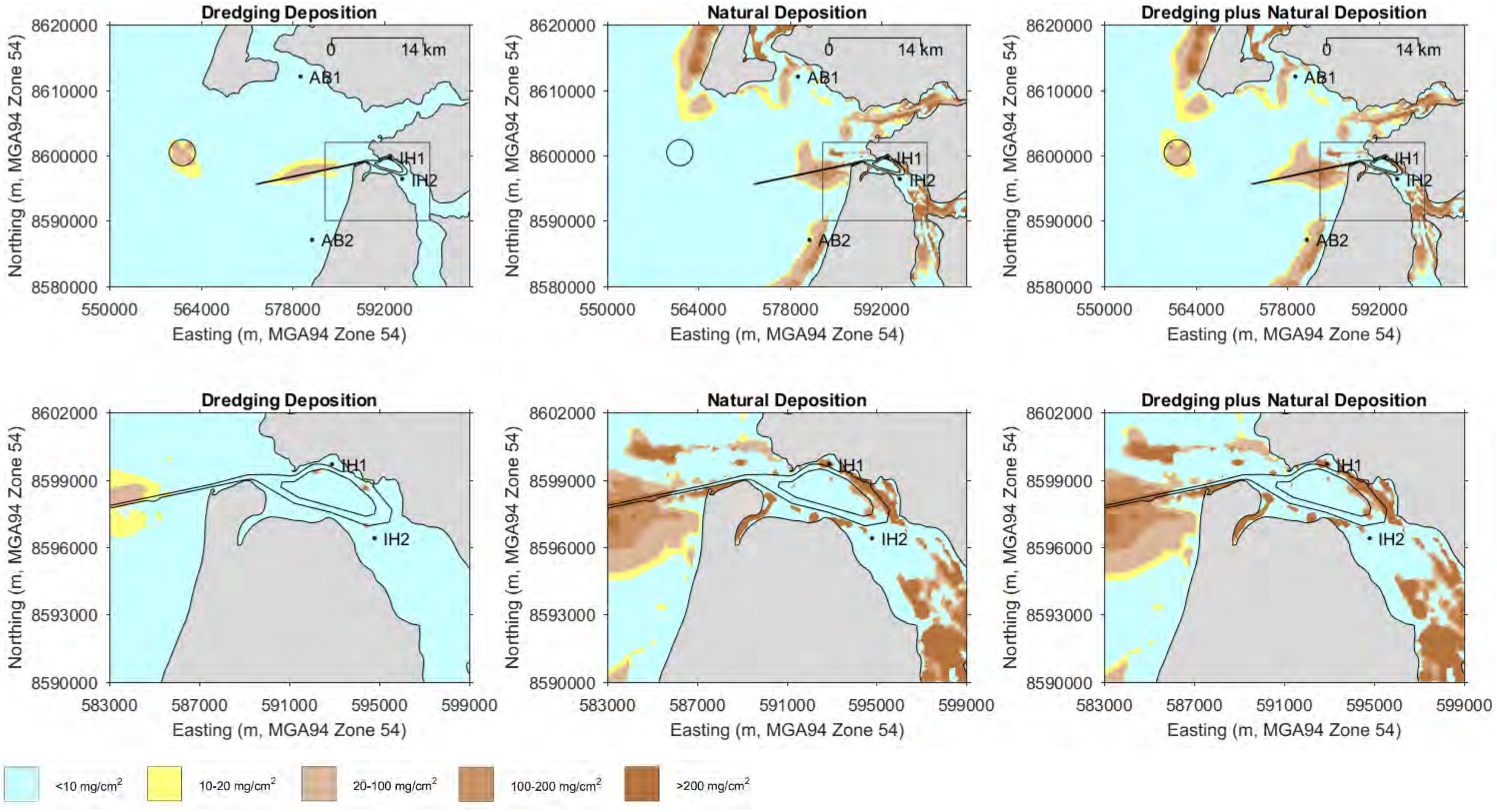

Figure 60. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

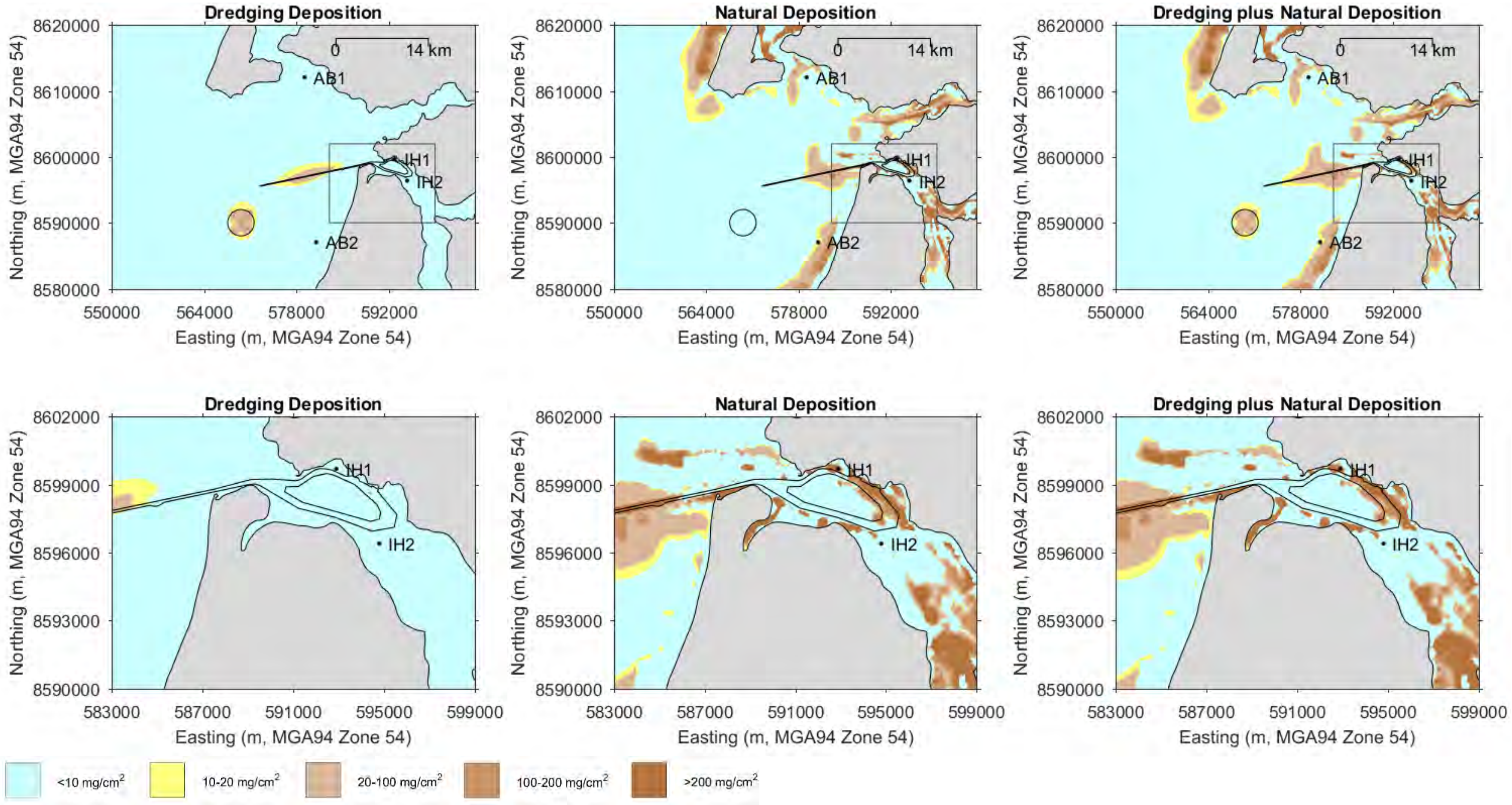

Figure 61. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

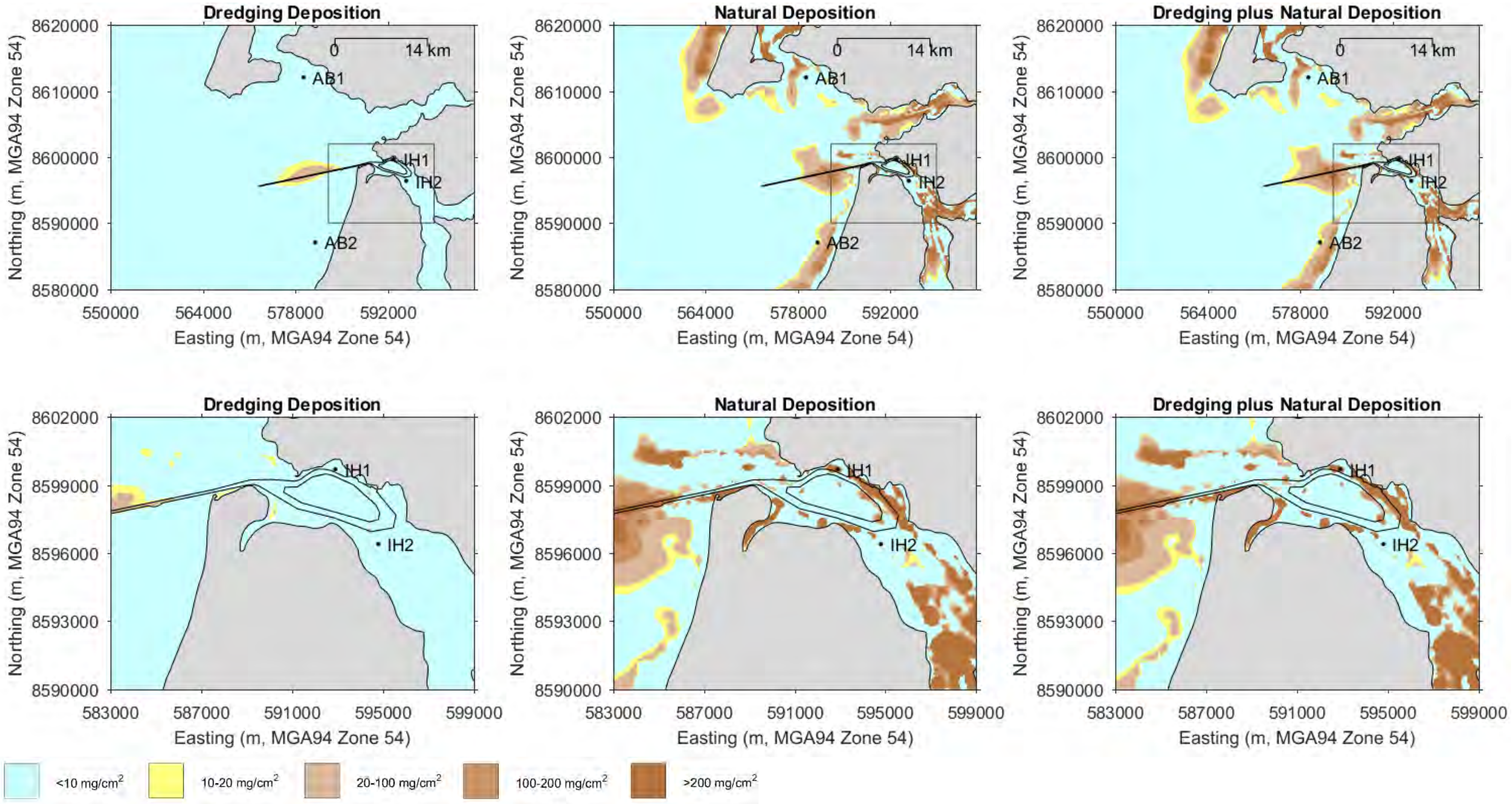

Figure 62. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material place at the onshore pond in the ambient dry season.

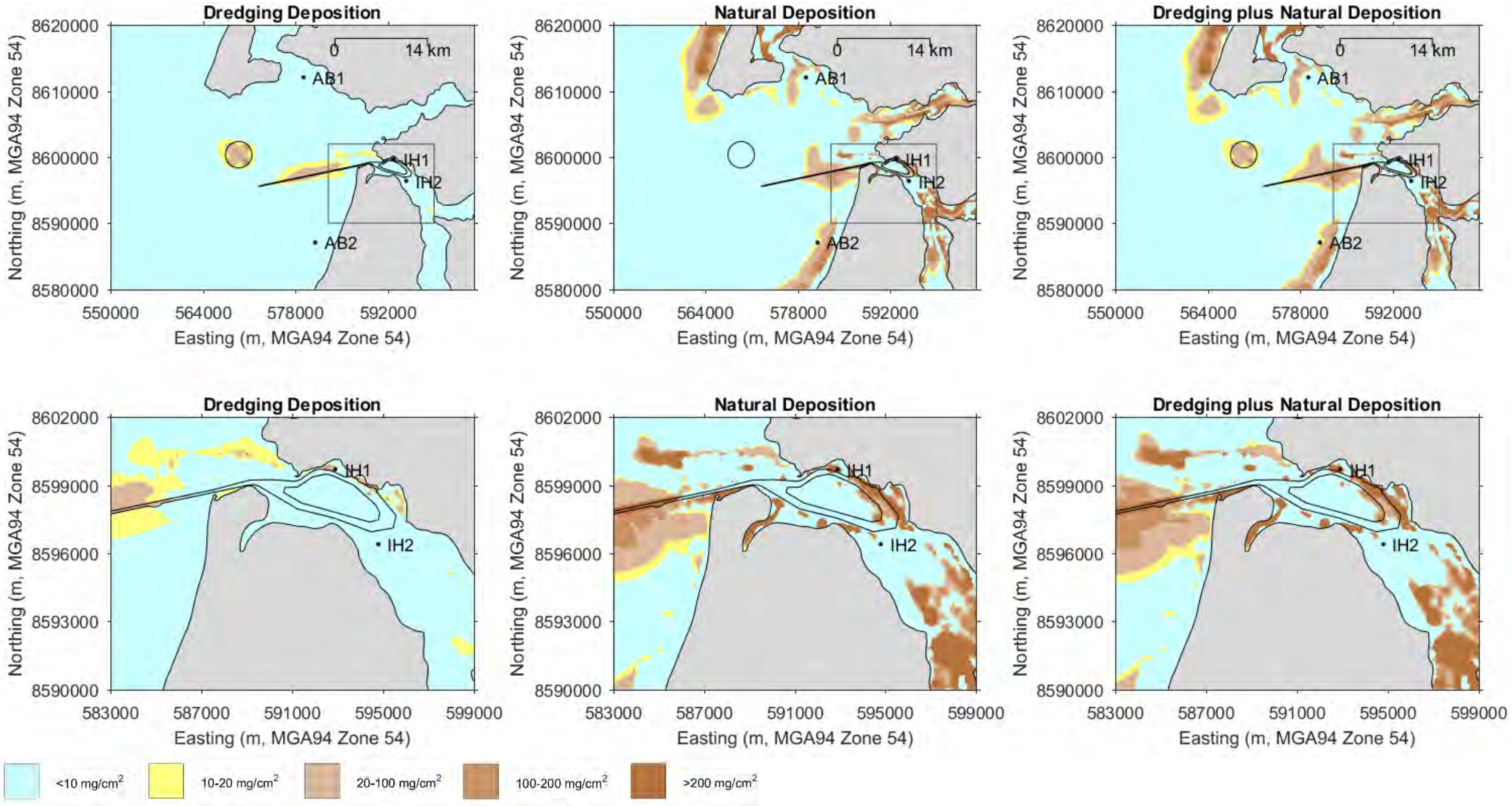

Figure 63. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the land reclamation area in the ambient dry season.

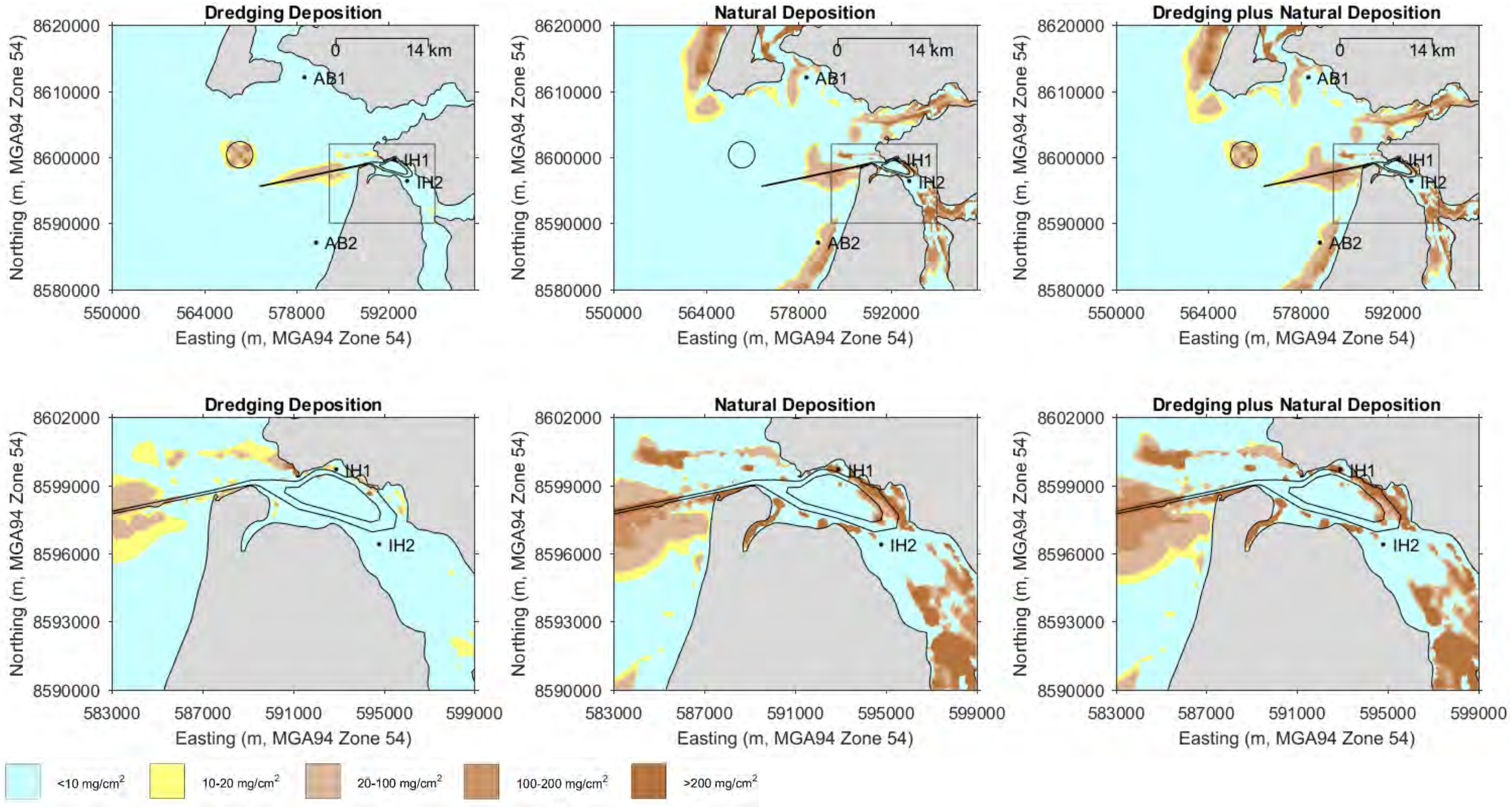

Figure 64. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the ambient dry season.

7.4. Long-term Resuspension

Results from the long-term resuspension simulations have been processed to show the retainment of sediment placed at the offshore DMPAs.

A time series plot of sediment volumes retained within the DMPAs are shown for material placed at the existing Albatross DMPA, the Albatross West DMPA and Albatross South DMPA over the seven month period between January and July 2019 in Figure 65. The 7 month run period encompasses the 2019 wet season when multiple tropical cyclonic events and a prolonged tropical low event occurred. As such the 2019 wet season can be considered to represent a worst case period for the resuspension of sediment from the DMPAs. Further, the simulation does not account for any consolidation of sediment which would naturally occur over time and as such the resuspension rates are considered to provide a conservative assessment.

From the time series of sediment volumes at the DMPA, it is apparent that material placed within the DMPA is only resuspended and transported outside of the DMPA during relatively short, discrete events. The largest resuspension event at all three sites occurred at the start of February and the second largest resuspension event occurred in mid to late March. These periods of resuspension coincide with a prolonged Tropical Low and TC Trevor, respectively, when significant wave heights at the Albatross WRB exceeded 2 m (see Figure 16). The plot also shows that natural resuspension of sediment at the DMPA sites does not occur as a result of the tidal currents and typical wave conditions. These results indicate that while the model simulation was only undertaken for a seven month period, no further resuspension of sediment during the remaining five months of the year and as such the results presented can be considered to be representative of annual resuspension rates (for a worst case year as noted above).

Of the three DMPA sites, material placed at Albatross South has the highest retainment (of 77%), while the lowest retainment (of 35%) occurred for the Albatross West DMPA (see Table 27). These differences in retainment result from the relative exposure of each of the DMPA sites to large wave events arriving from offshore. The retainment of the existing Albatross DMPA was 57%.

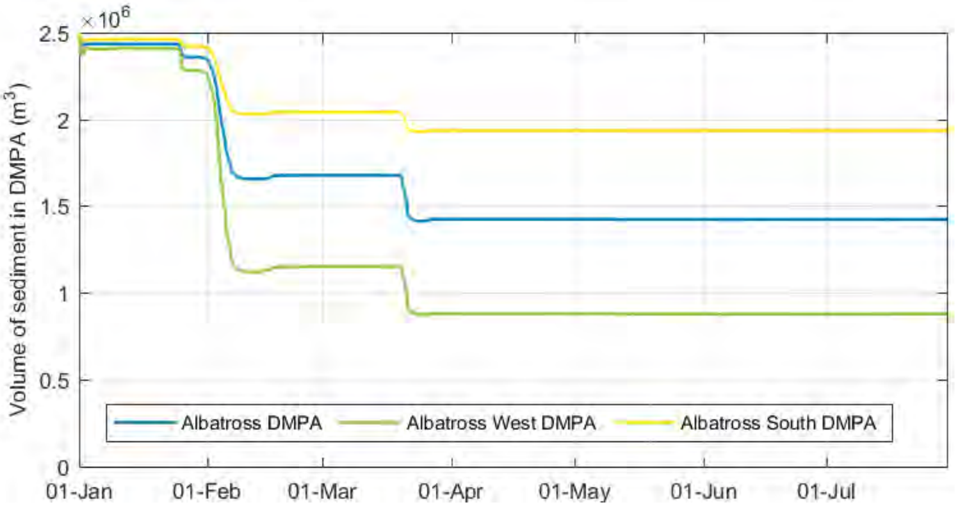

Figure 65. Time series of volume of material in the DMPA for placement at Albatross, Albatross West and Albatross South.

Table 27. Volume of sediment retained within the DMPAs at the end of the seven month model simulation period.

Placement site	Retained sediment volume	
	m^3	Percentage of placement volume
Albatross DMPA	1,422,900	57%
Albatross West DMPA	877,300	35%
Albatross South DMPA	1,935,400	77%

Spatial maps of sediment deposition at the end of the seven month simulation period are shown in Figure 66 to Figure 68. For reference, the thickness of the sediment placement over the entire of the DMPAs at the start of the model simulation was 0.2 m. Consistent with the time series plots shown in Figure 65, all three DMPA sites have experienced some erosion. Sediment resuspended from the DMPAs during the extreme wave events has been re-deposited to the south of the DMPAs.

Sediment depths outside of the DMPAs are very low, being of the order of 0.01 m (1 cm) or less. The only deposits of more than 0.01 m occur from the resuspension of material placed at the Albatross West DMPA, these deposits have a limited spatial extent (of around 3 km by 2 km) and are less than 0.02 m thick (Figure 67). It is important to note that the erosion and subsequent deposition of sediment predicted from the DMPAs will be very small compared to the natural changes which occurred throughout Albatross Bay over the 2018/19 wet season. Bathymetric analysis by PCS (2019f) showed that erosion of more than 0.1 m occurred in areas of the Albatross DMPA and erosion of up to 1 m occurred adjacent to the South Channel.

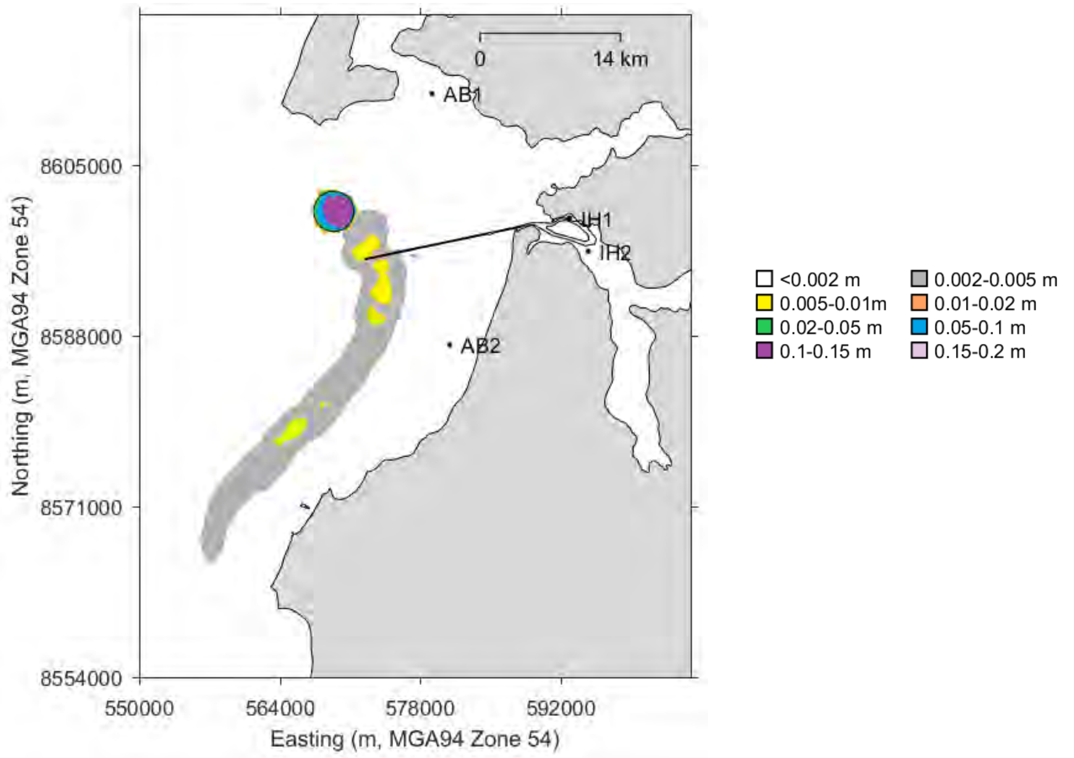

Figure 66. Sediment deposition at the end of the seven month model simulation period from the resuspension of sediment placed at the Albatross DMPA.

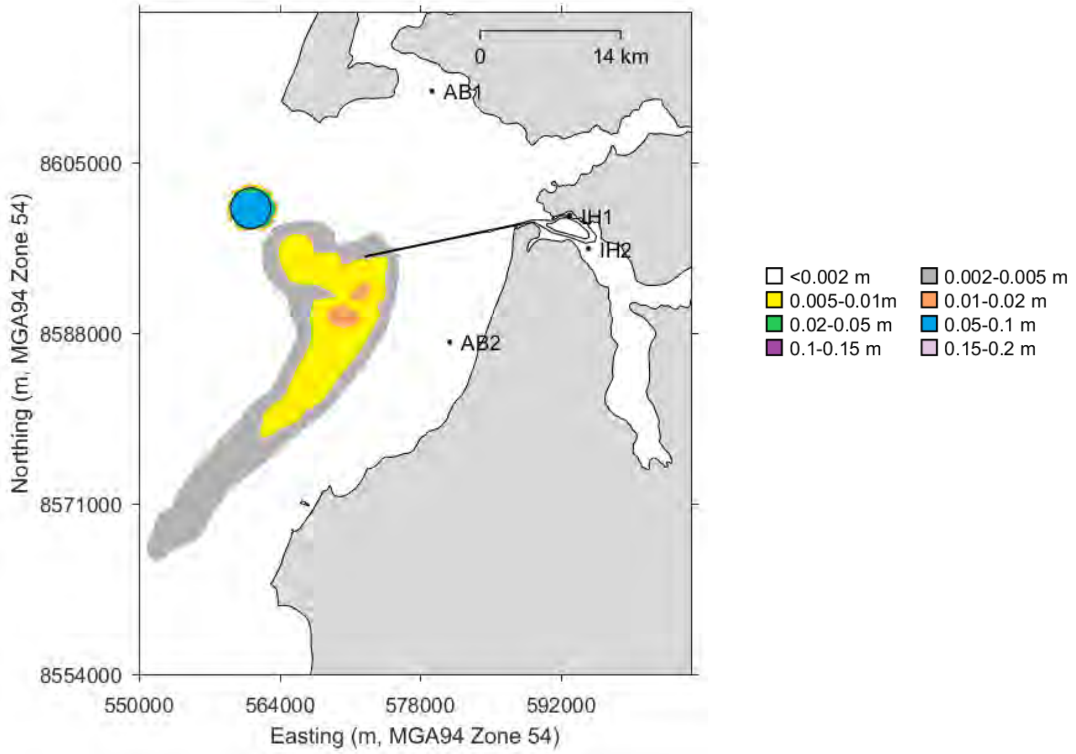

Figure 67. Sediment deposition at the end of the seven month model simulation period from the resuspension of sediment placed at the Albatross West DMPA.

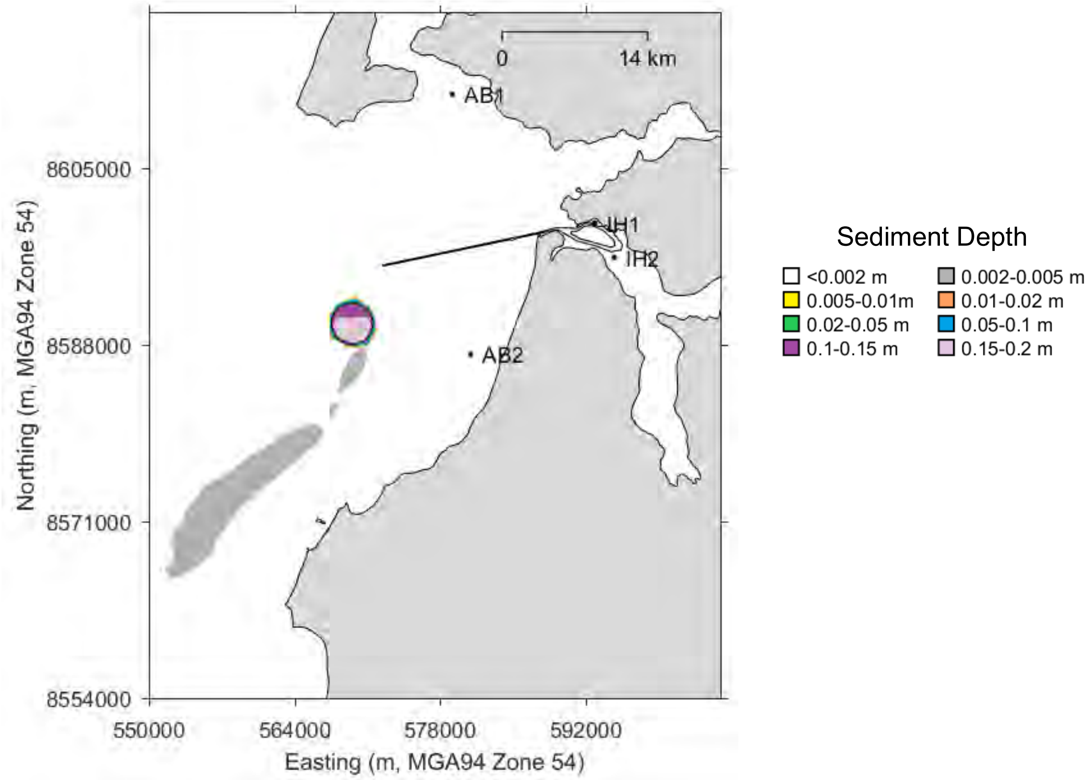

Figure 68. Sediment deposition at the end of the seven month model simulation period from the resuspension of sediment placed at the Albatross South DMPA.

Time series plots of sediment deposited within the Port of Weipa dredged areas (due to resuspension of material placed at the DMPAs) are shown in Figure 69. Volumes of sediment deposited within the dredged areas (the South Channel) are very low, being less than 8,200 m^3 (equivalent to 0.3% of the sediment placed at the DMPA – see Table 28). Based on this, the resuspension and subsequent deposition of sediment from the offshore DMPAs is not expected to noticeably increase future maintenance dredging volumes for any of the offshore DMPA options considered.

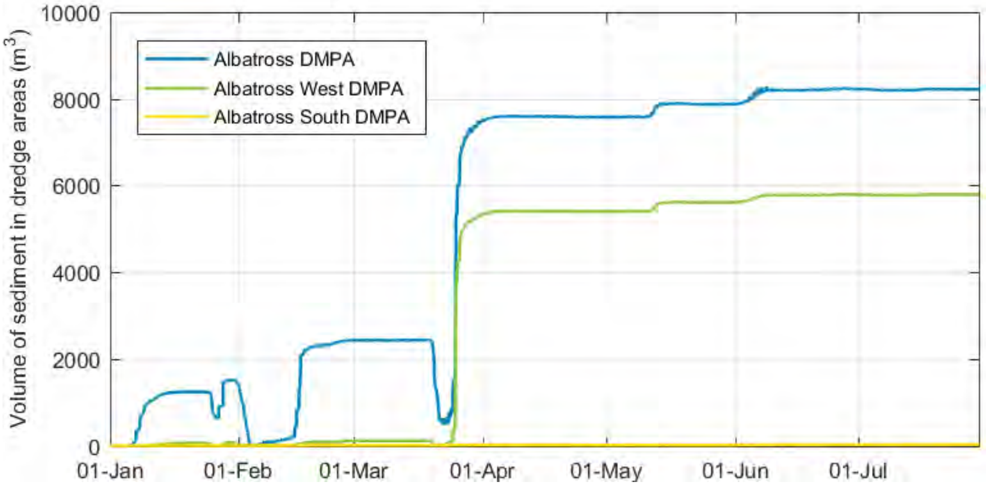

Figure 69. Time series of volume of material within the Port of Weipa dredge areas for placement at the existing Albatross DMPA (upper plot), the Albatross West DMPA (middle plot) and the Albatross South DMPA (lower plot).

Table 28. Volume of sediment retained within the Port of Weipa dredge areas at the end of the seven month model simulation period.

Placement site	Sediment volume in the Port of Weipa dredge areas	
	m^3	As percentage of placement volume
Albatross DMPA	8,200	0.3
Albatross West DMPA	5,800	0.2
Albatross South DMPA	20	<0.001

7.5. Summary

The plume modelling shows that IH1 and IH2 are the sensitive receptors most likely to experience increased SSC due to maintenance dredging, with increases in SSC at the sensitive receptors in Albatross Bay consistently being low. In particular, the spatial maps, time series and statistics presented show that:

- maintenance dredging of the worst case dredge volumes results in the largest increases in SSC. This is mainly due to the higher sediment disturbance rates associated with using a larger dredger (hopper capacity is five times larger) than the TSHD Brisbane. The TSHD Brisbane (or a similar size TSHD) has been assumed for typical and cyclonic sediment dredge volumes at the Port of Weipa, but would be impractical to use on its own for a worst case dredge volume (with the dredge duration becoming unrealistically long);
- although the increase in SSC at IH1 and IH2 varies between the offshore placement options (highest for the Albatross South DMPA and Albatross DMPA), the increases are generally low (less than 6 mg/l) for the typical and cyclonic volumes;
- the increases in 95th percentile SSC at both IH1 and IH2 are higher for the worst case volumes, with increases limited to 11 mg/l at all sensitive receptors and for all dredge scenarios modelled. For context the 50th percentile SSC at WQ1 and WQ4 (which are taken to be representative of conditions at IH1 and IH2) are 5 mg/l and 8 mg/l, respectively. The natural plus dredging SSC is therefore expected to remain below the intensity threshold of 22 mg/l and 30 mg/l at IH1 and IH2, respectively for the majority of the time (and as such the total duration above the defined intensity thresholds remains low);
- only for the worst case dredge volume is the duration of time that the SSC is above the SSC threshold predicted to increase above the 90th percentile natural duration over the dredge period, and then only at IH1 for the Albatross DMPA and Albatross South DMPA options. The duration above the threshold is predicted to remain below the maximum natural duration for all scenarios;
- the reclamation and the beach nourishment options increase the SSC at the sensitive receptors more than placement at the offshore DMPAs. Maximum increases in the 95th percentile SSC of 7.1 mg/l occur at IH1. The duration above the SSC threshold remains below the 90th percentile natural duration; and
- the model predicts that the SSC remained within natural conditions for all sensitive receptors for all dredge scenarios considered (i.e. the maximum natural duration threshold was not exceeded for any simulations).

With respect to sediment deposition, the spatial maps show that:

- sediment deposition associated with the dredging is small in relation to the natural deposition which occurs with only the deposition at the dredging and placement locations being visibly discernible above the natural deposition over the dredge duration.

With respect to the long-term resuspension of sediment placed at the DMPAs, the modelling results show that:

- sediment placed within the DMPAs is only resuspended and transported outside of the DMPA during relatively short, discrete events coinciding with extreme meteorological events which occur during the wet season (e.g. Tropical Cyclones);
- the retainment of sediment at the three DMPAs varies between 35% and 77%, depending on the relative exposure of the DMPA to the more extreme wave events (which arrive from offshore). The highest retainment is predicted to occur at Albatross South DMPA;
- erosion and deposition of sediment predicted from the DMPAs is expected to be very small compared to the natural changes which occurred throughout Albatross Bay; and
- the effect of resuspension of sediment placed at the offshore DMPAs is not predicted to result in significant deposition within any of the Port of Weipa dredge areas and is therefore not expected to noticeably increase future maintenance dredging volumes.

8. Conclusions

This report has presented numerical modelling results of the transport of suspended sediment released into the marine environment by natural processes and by maintenance dredging at the Port of Weipa.

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 26 different maintenance dredging scenarios. These scenarios considered two different metocean conditions which could occur during the dredging program, three different dredge volumes (to account for interannual variations in sedimentation rates) and six different placement options. This approach significantly increases the confidence in the model results presented, providing an indication of the range of effects which could potentially occur.

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

- the natural SSC is generally much higher than the SSC resulting from maintenance dredging. Limited net residual transport of the suspended sediment from maintenance dredging is predicted and as a result the only areas where the increases in SSC from maintenance dredging creates a clear increase in total SSC (natural plus dredging) is at the offshore DMPAs where the natural SSC is low and at the beach nourishment site;
- IH1 and IH2 are the sensitive receptors where there is most likely to be an increase in SSC due to maintenance dredging. The relative magnitude and duration of the increase is dependent on the volume dredged, the metocean conditions when the dredging occurs and the placement site;
- the SSC was predicted to remain within natural conditions for the sensitive receptors for all dredge scenarios considered. Only for the worst case dredge volume was the duration above the SSC threshold value for longer than the 90th percentile natural duration (and then only at one sensitive receptor (IH1) and for two options (placement at the Albatross DMPA and Albatross South DMPA with dredging occurring during the energetic dry season));
- the deposition resulting from maintenance dredging is comparably small in spatial extent and low in intensity in comparison to the natural deposition. In most cases it is only possible to clearly distinguish between the natural and natural plus dredging deposition at the dredging and placement locations;
- the highest deposition at IH1 due to maintenance dredging is for the placement of sediment at the land reclamation area, with an equivalent daily rate of up to 1 mg/cm^2/day (which is still below the literature based thresholds for seagrass but does not account for natural deposition which is predicted to be an order of magnitude higher);
- the long term resuspension modelling predicts that sediment placed within all three of the offshore DMPAs modelled will only be resuspended as a result of extreme meteorological conditions during the wet season (e.g. TCs). For the 2018/2019 wet season modelled, conditions were far more extreme than typical wet season conditions (even for a cyclonic year) and as such the retainment rates from the model of between 35% and 77% present a worst case scenario; and
- the long term resuspension modelling predicted that the deposition of the sediment resuspended from the offshore DMPA sites will be focused in the areas directly adjacent to the sites and that any deposition is not expected to noticeably increase future maintenance dredging volumes.

Overall, the results show that for the typical and cyclonic dredge volumes the three offshore DMPA options and the onshore pond option result in small increases in SSC and deposition and the increases are very small in relation to the natural conditions at the sensitive receptors. The land reclamation and beach nourishment options are predicted to result in higher increases in SSC and deposition for typical dredge volumes, this is due to the beach nourishment assuming unconfined placement and the land reclamation modelling assuming a partial failure of the reclamation liner. As such, the increases in SSC and deposition for both options can be considered to represent a worst case scenario and they could be reduced through additional design considerations or risk mitigation measures. The only time when the modelling predicts that the maintenance dredging could result in a significant increase in the duration of time the SSC thresholds were exceeded was for the worst case dredge volume when a large and small TSHD were working concurrently. Based on this it is recommended that real-time monitoring of turbidity is undertaken for any future maintenance dredge programs which require two dredgers (one of which a large TSHD). Real-time monitoring will allow an adaptive management approach to be adopted during such dredge programs to ensure that the SSC remains within the range of natural variability (ensuring that there is no impact on local receptors).

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Appendices

Appendix A – Spatial SSC Maps

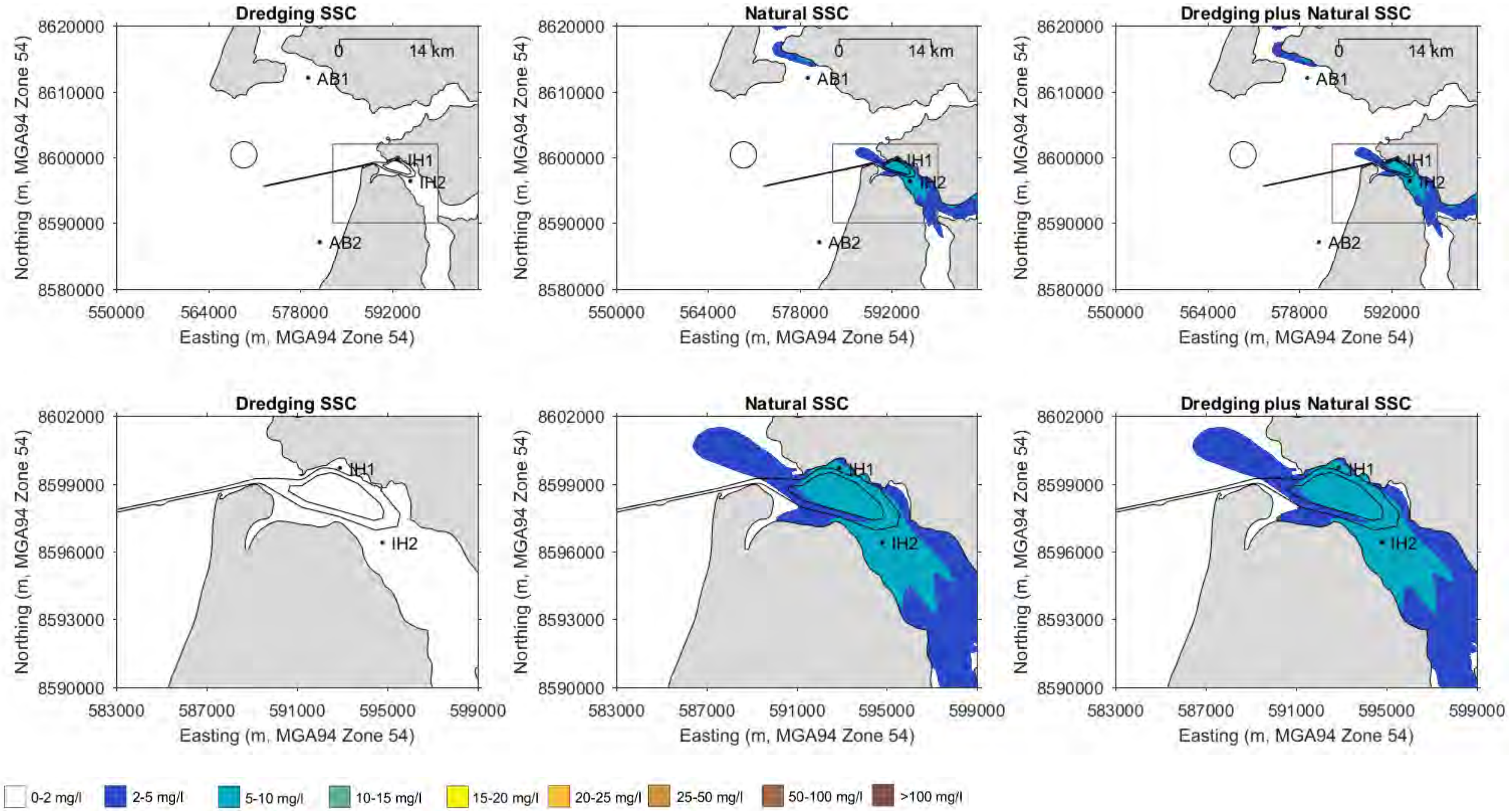

Figure A1. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

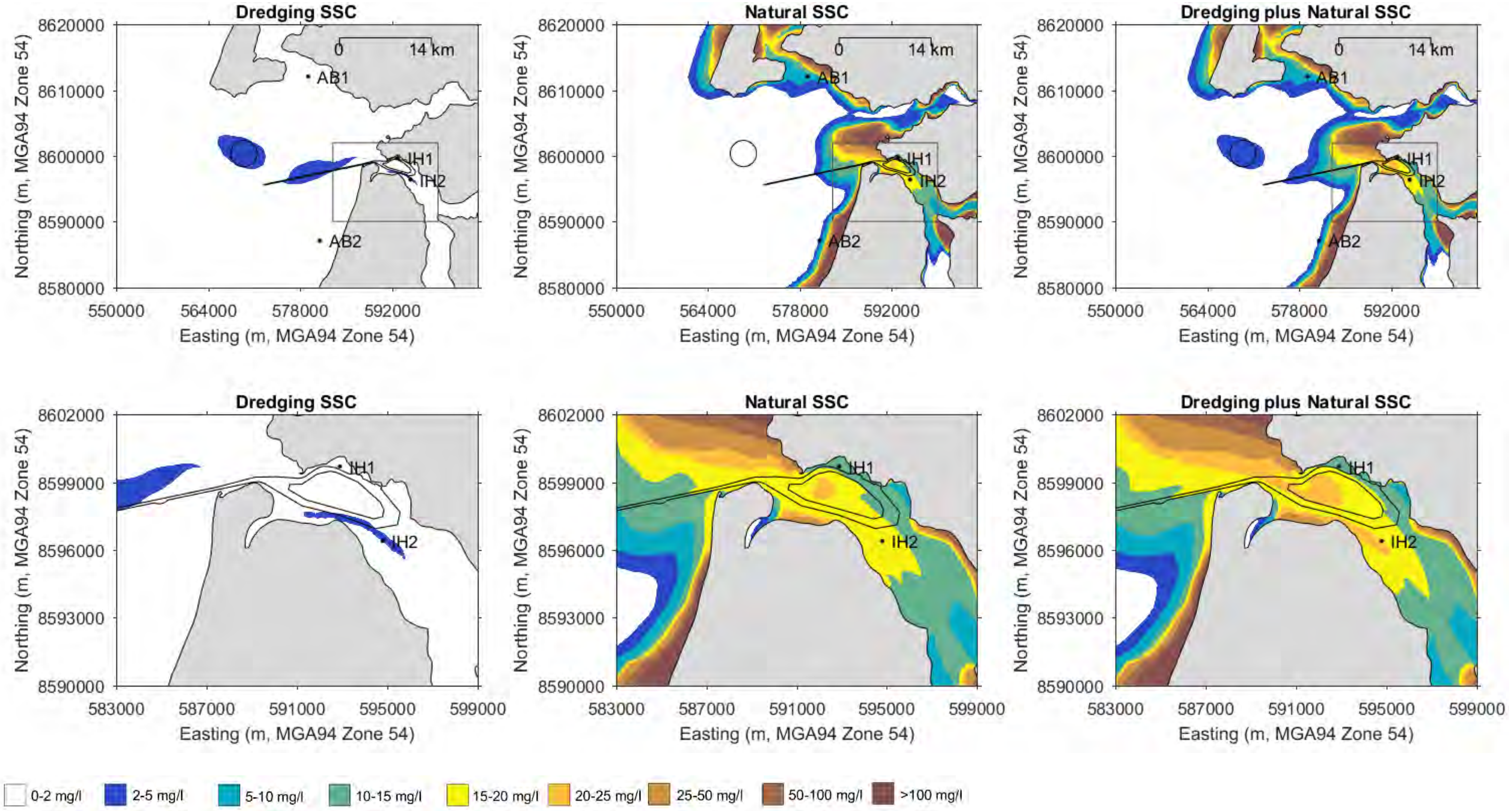

Figure A2. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

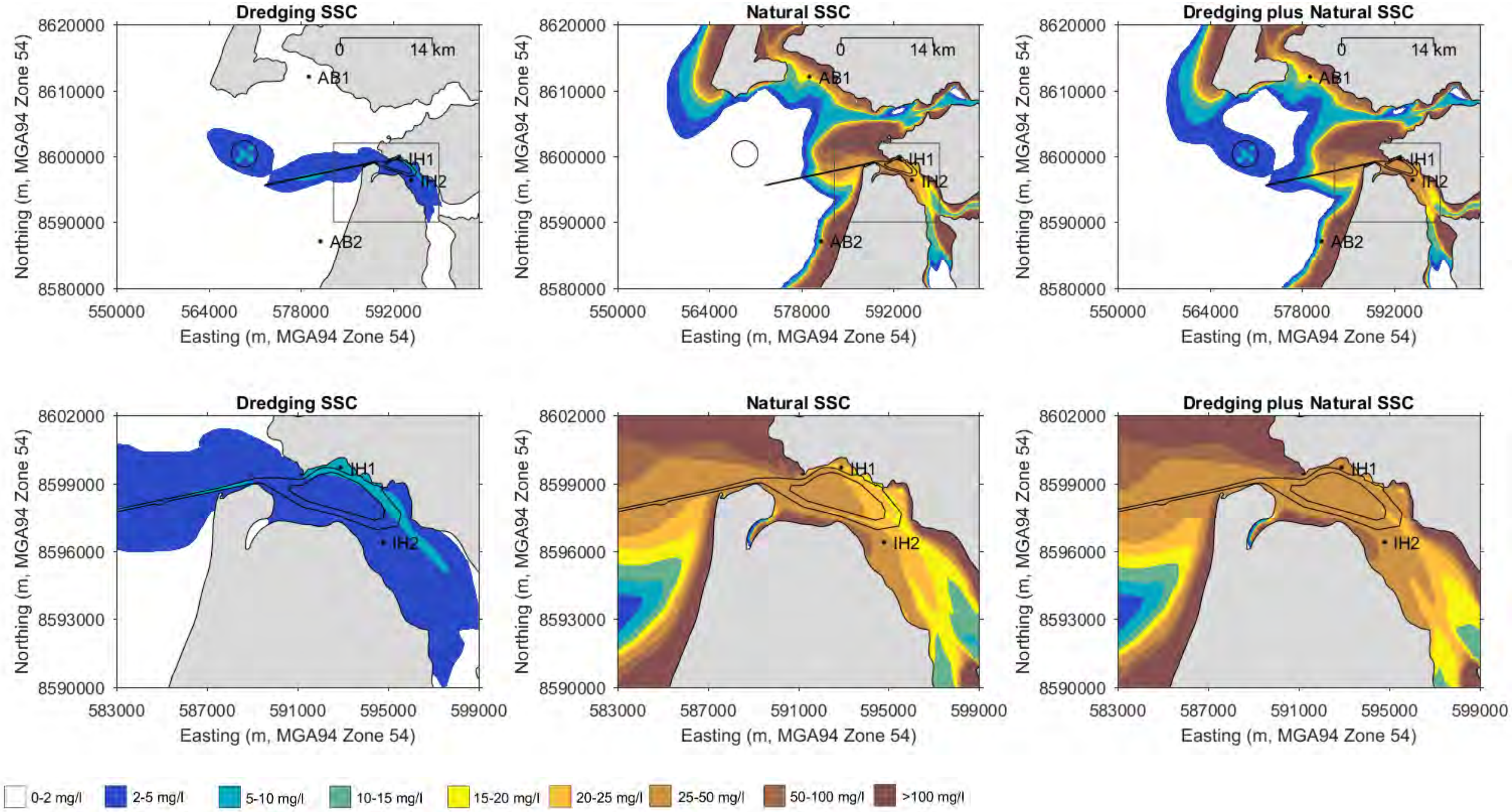

Figure A3. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

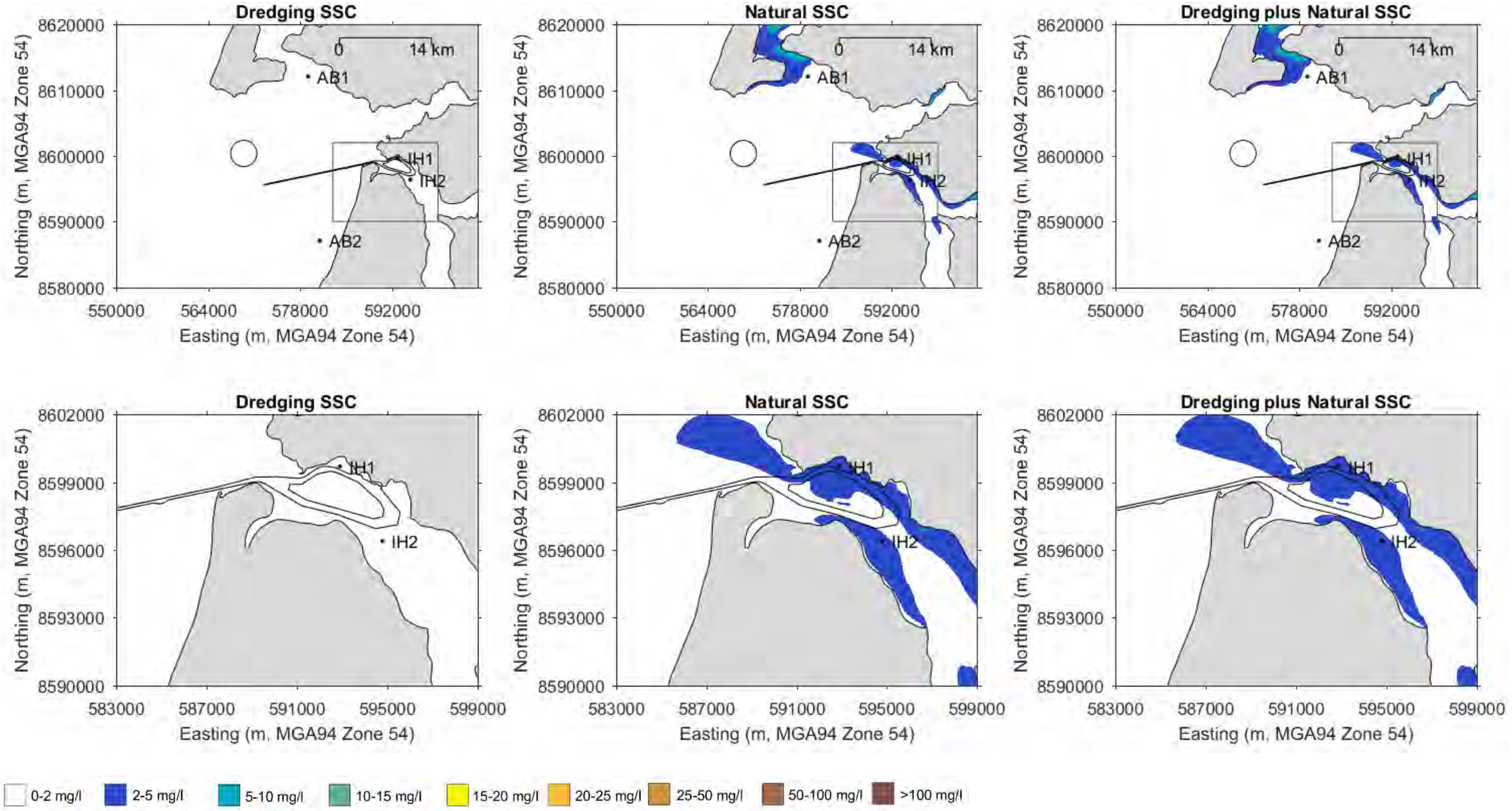

Figure A4. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

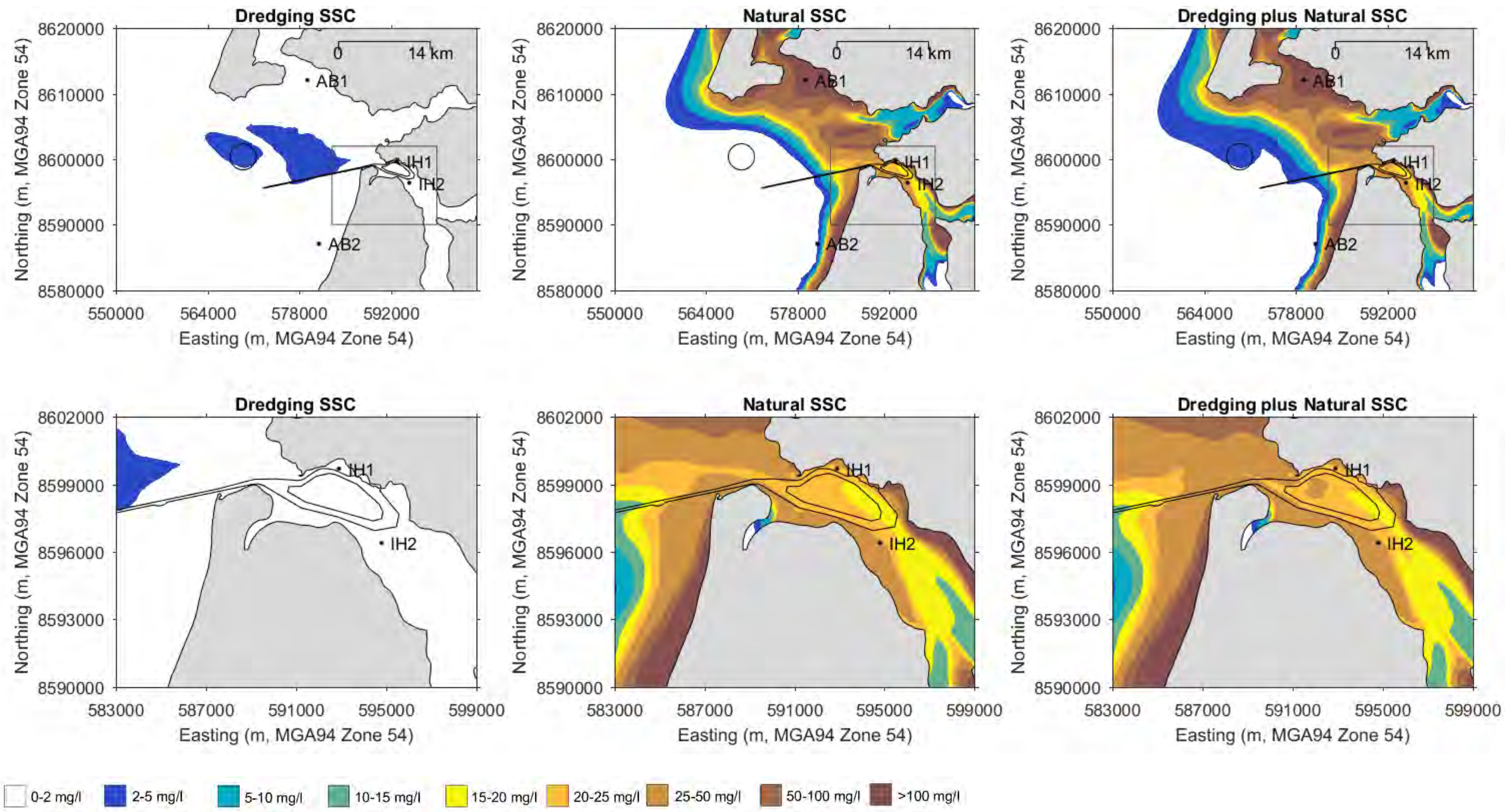

Figure A5. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

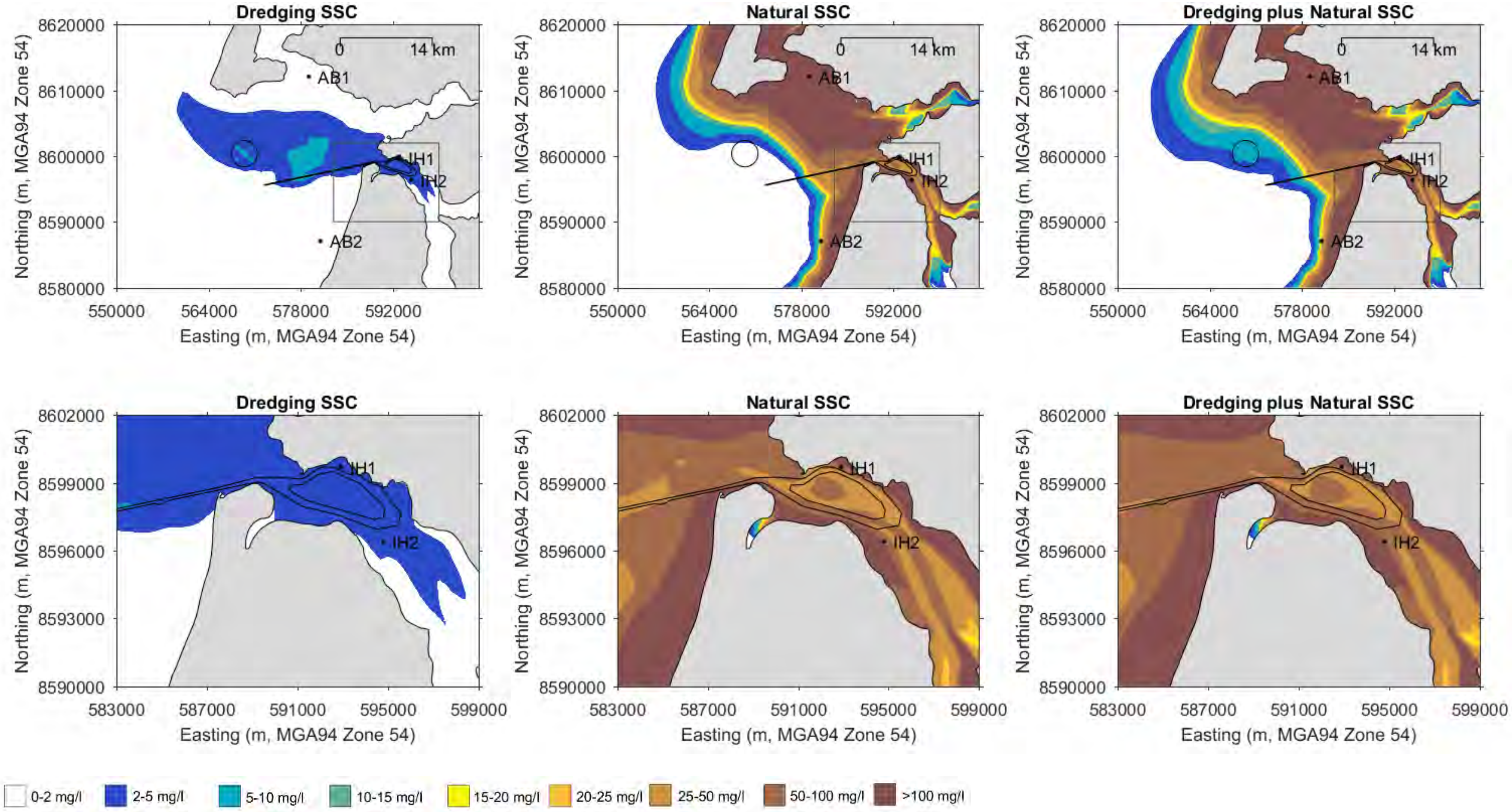

Figure A6. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

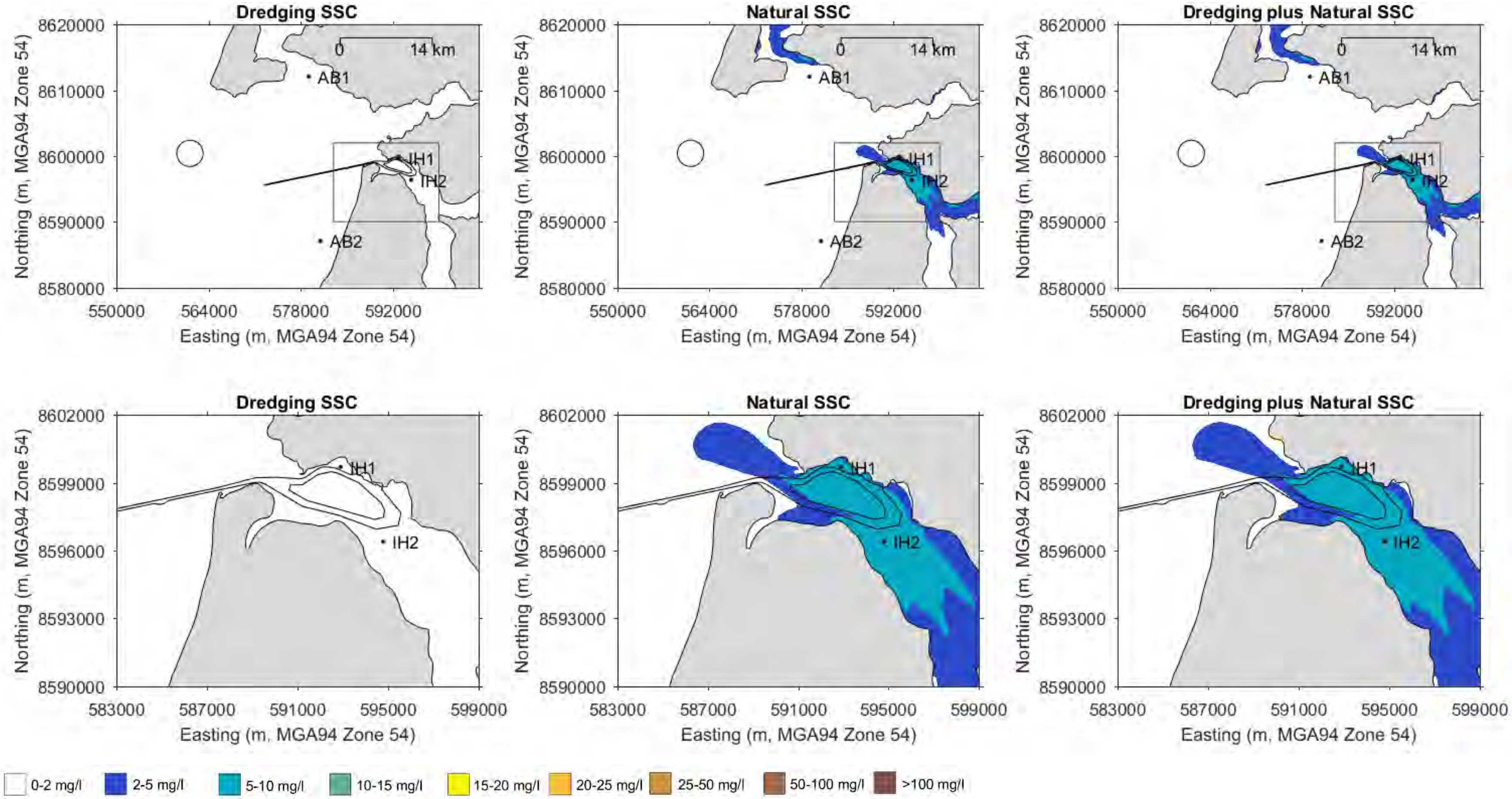

Figure A7. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

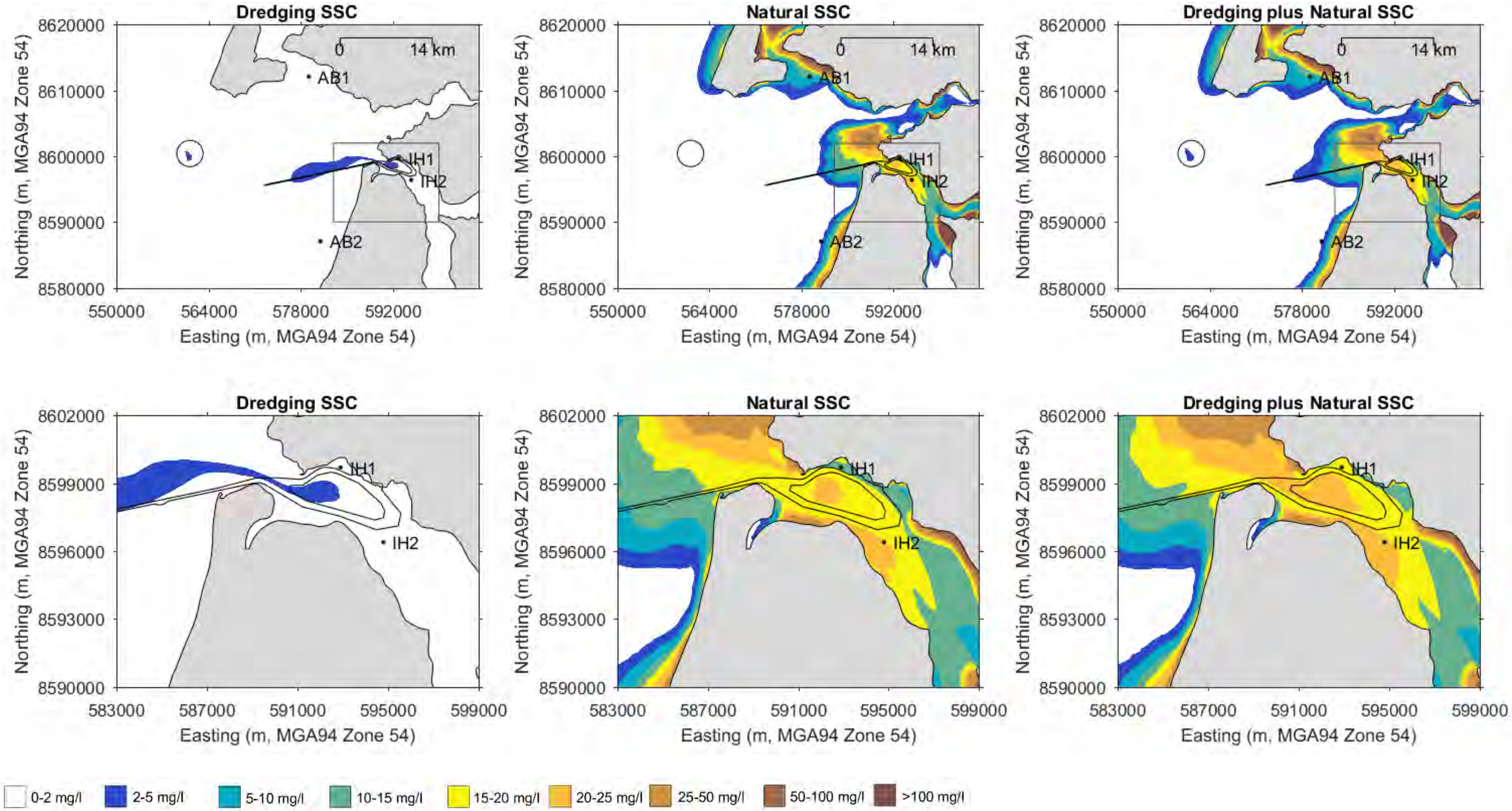

Figure A8. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

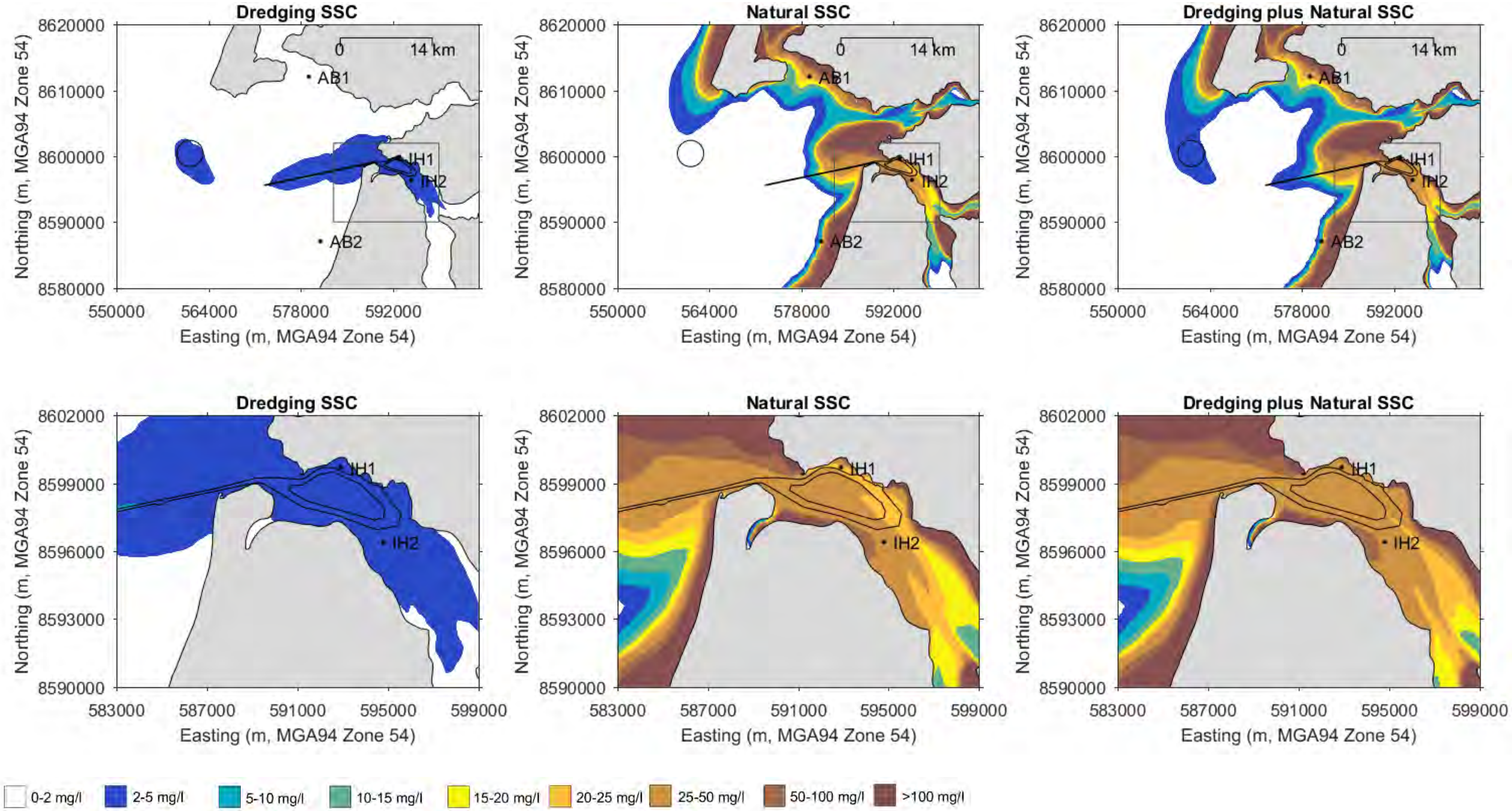

Figure A9. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

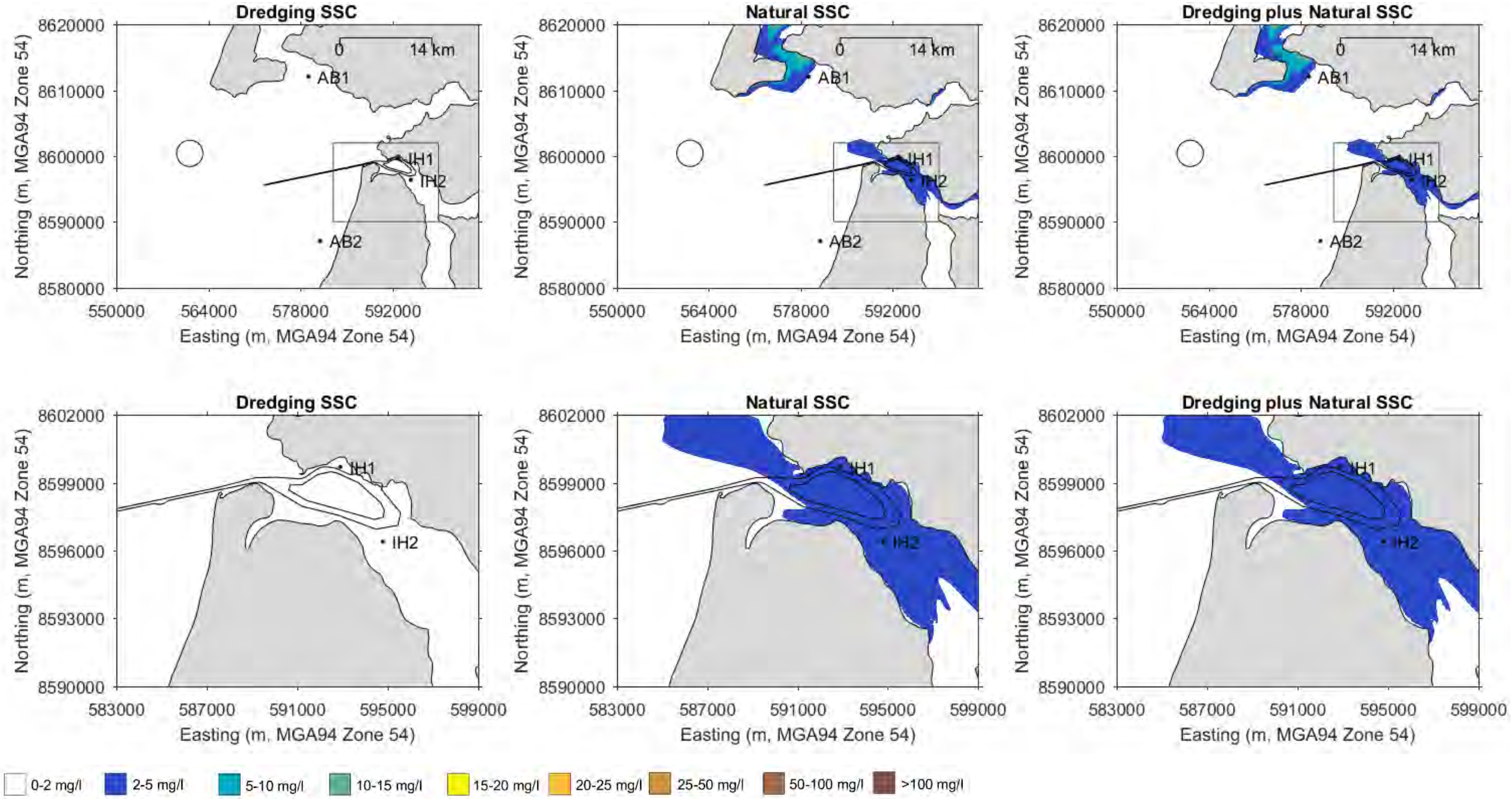

Figure A10. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

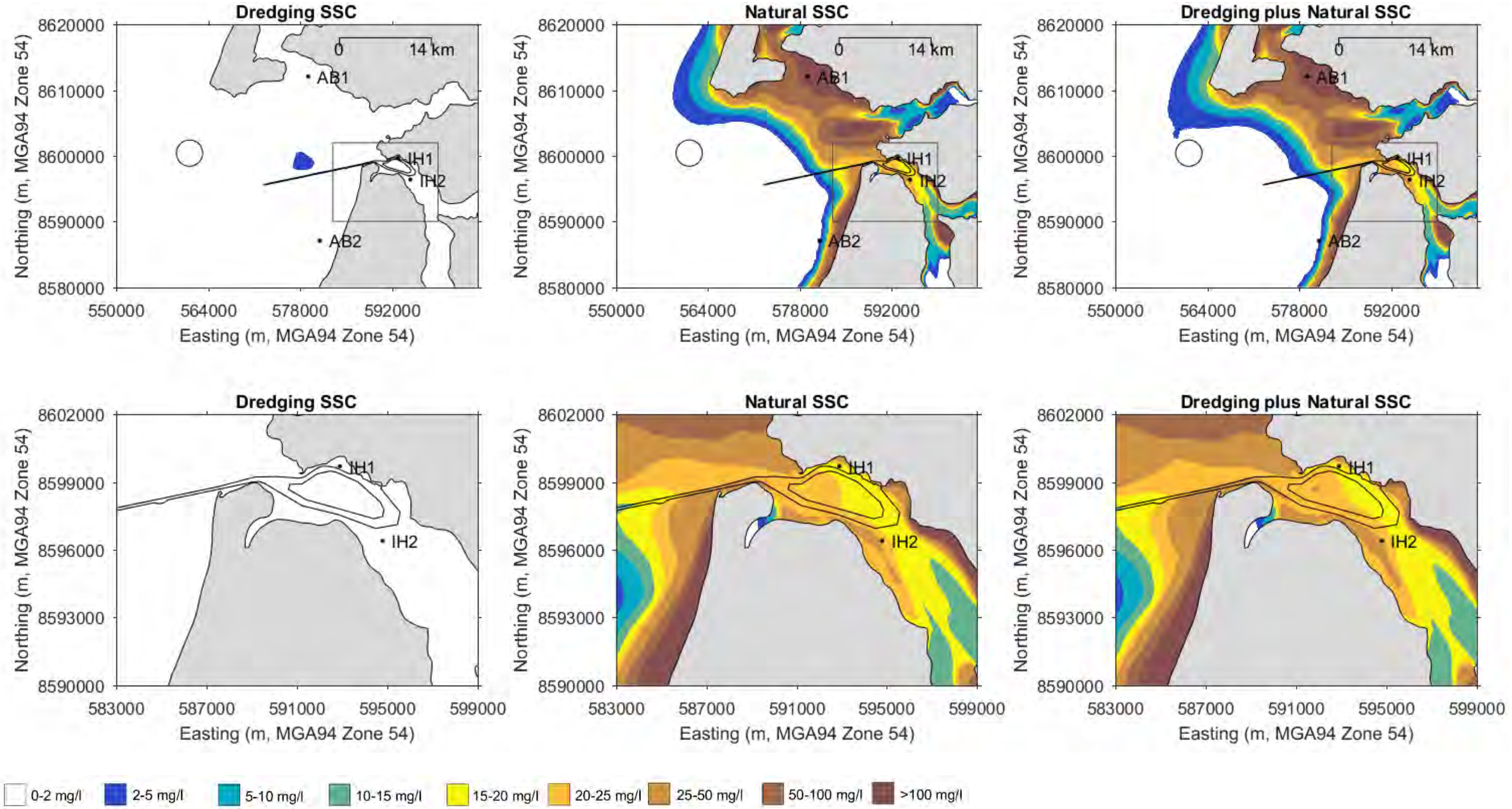

Figure A11. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

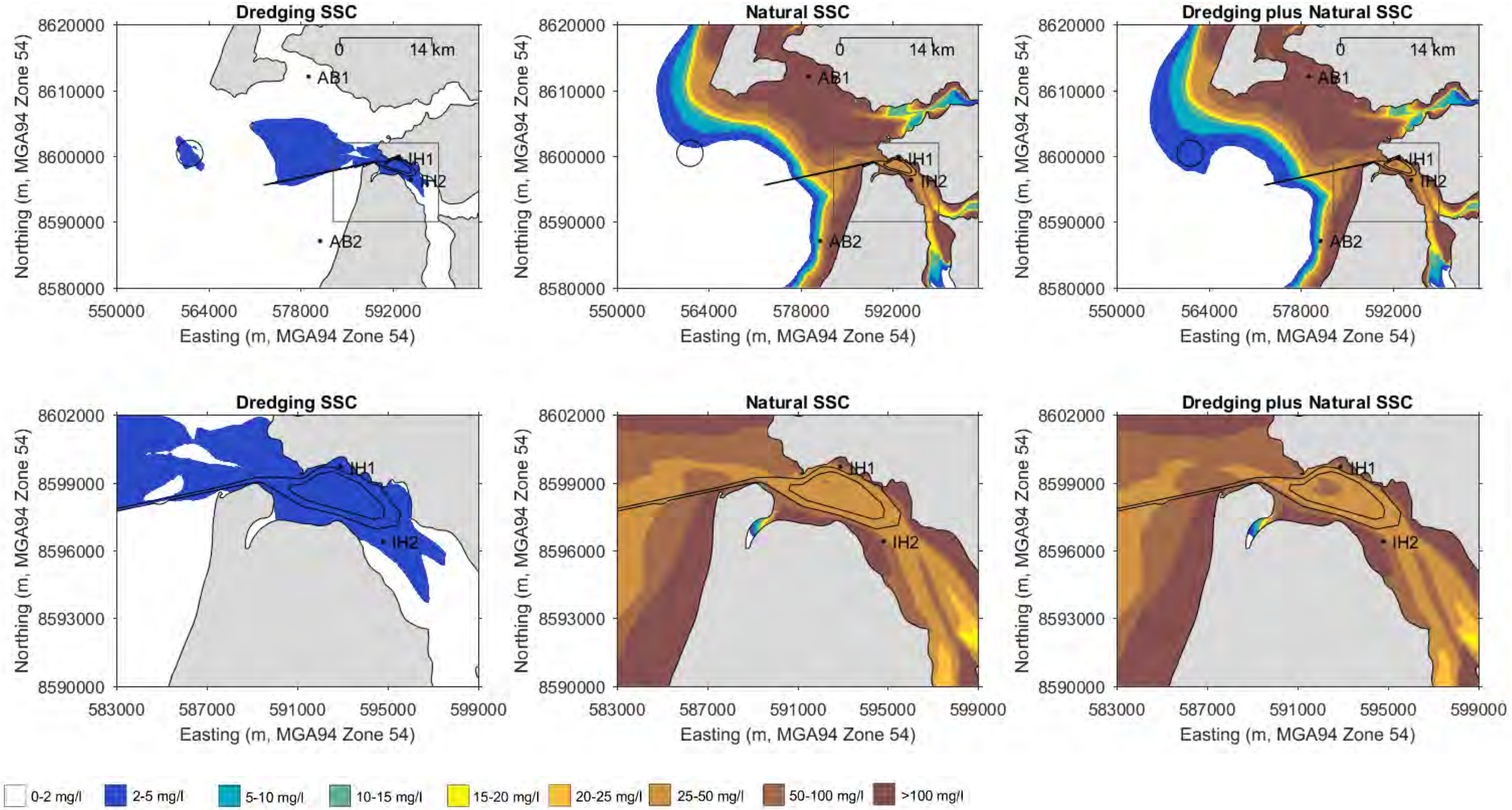

Figure A12. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

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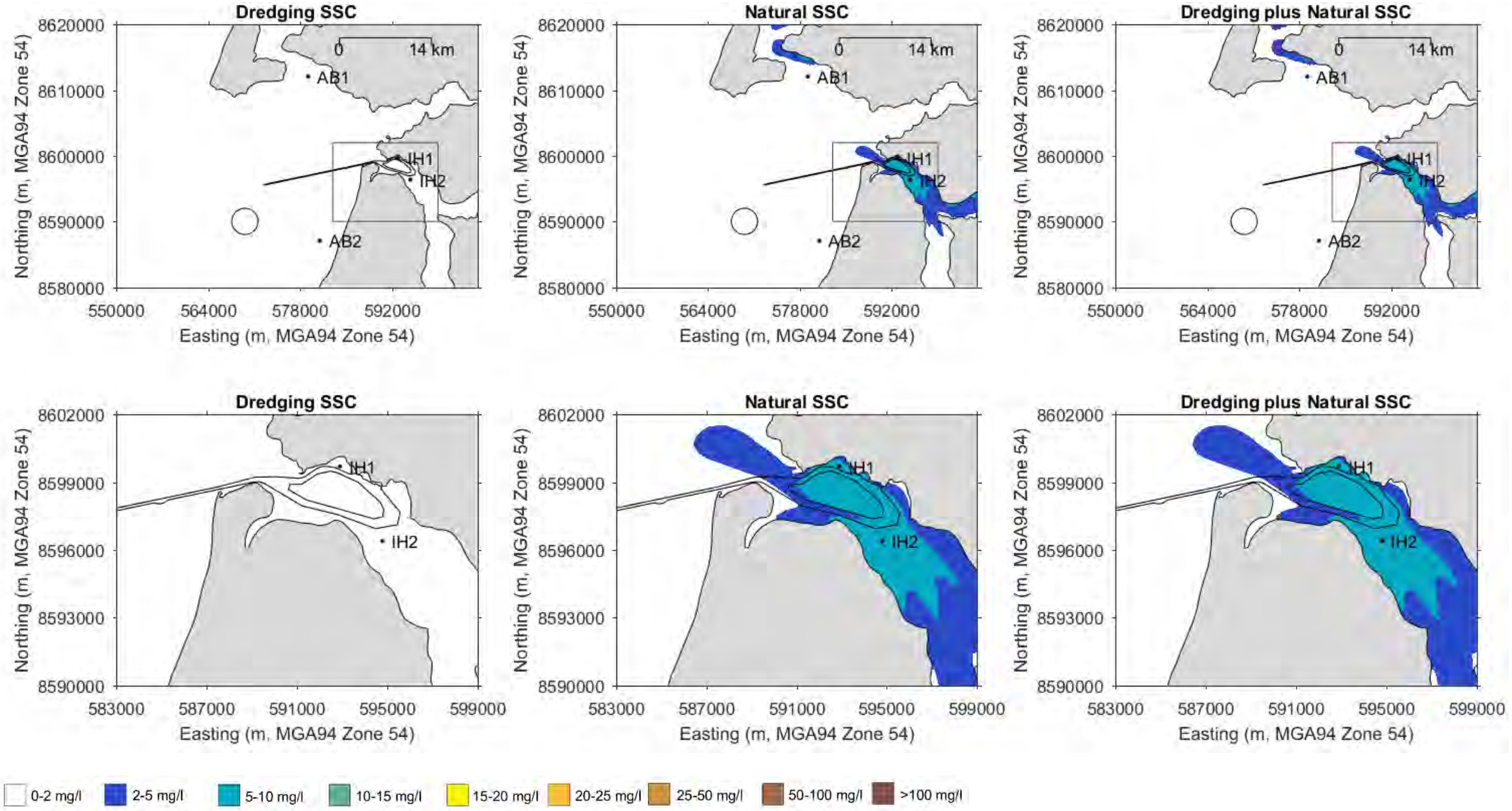


Figure A13. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

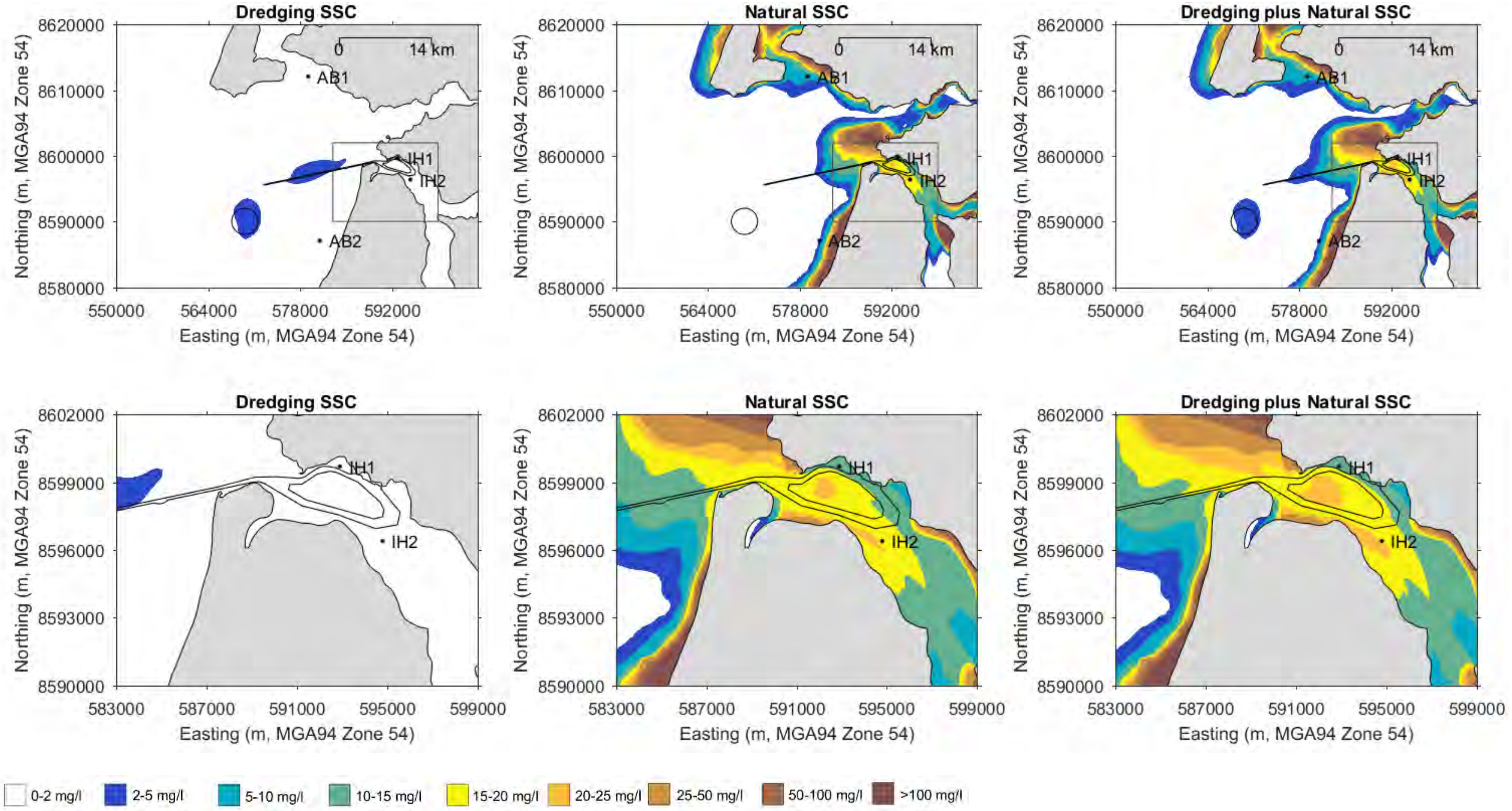


Figure A14. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

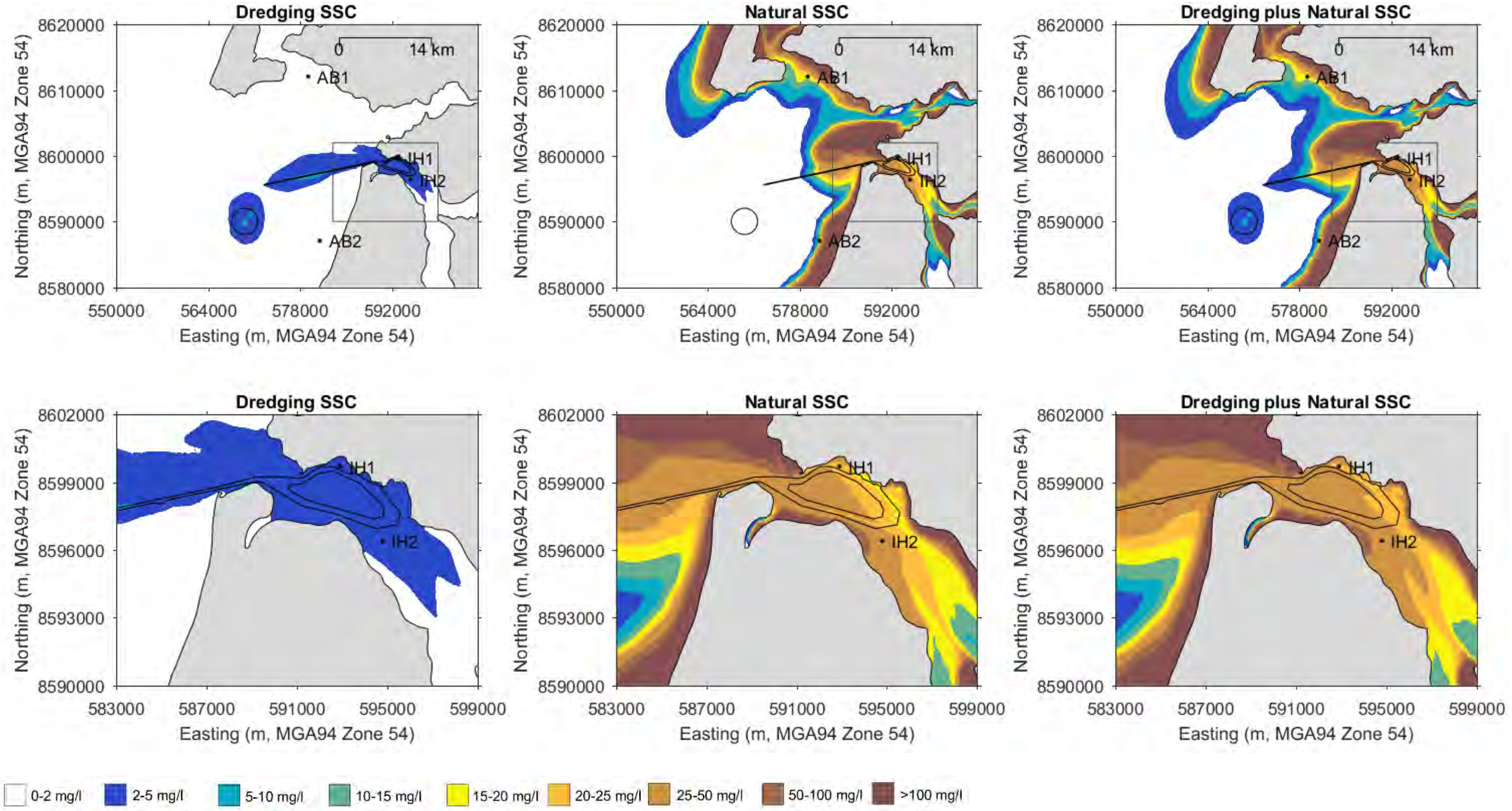


Figure A15. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

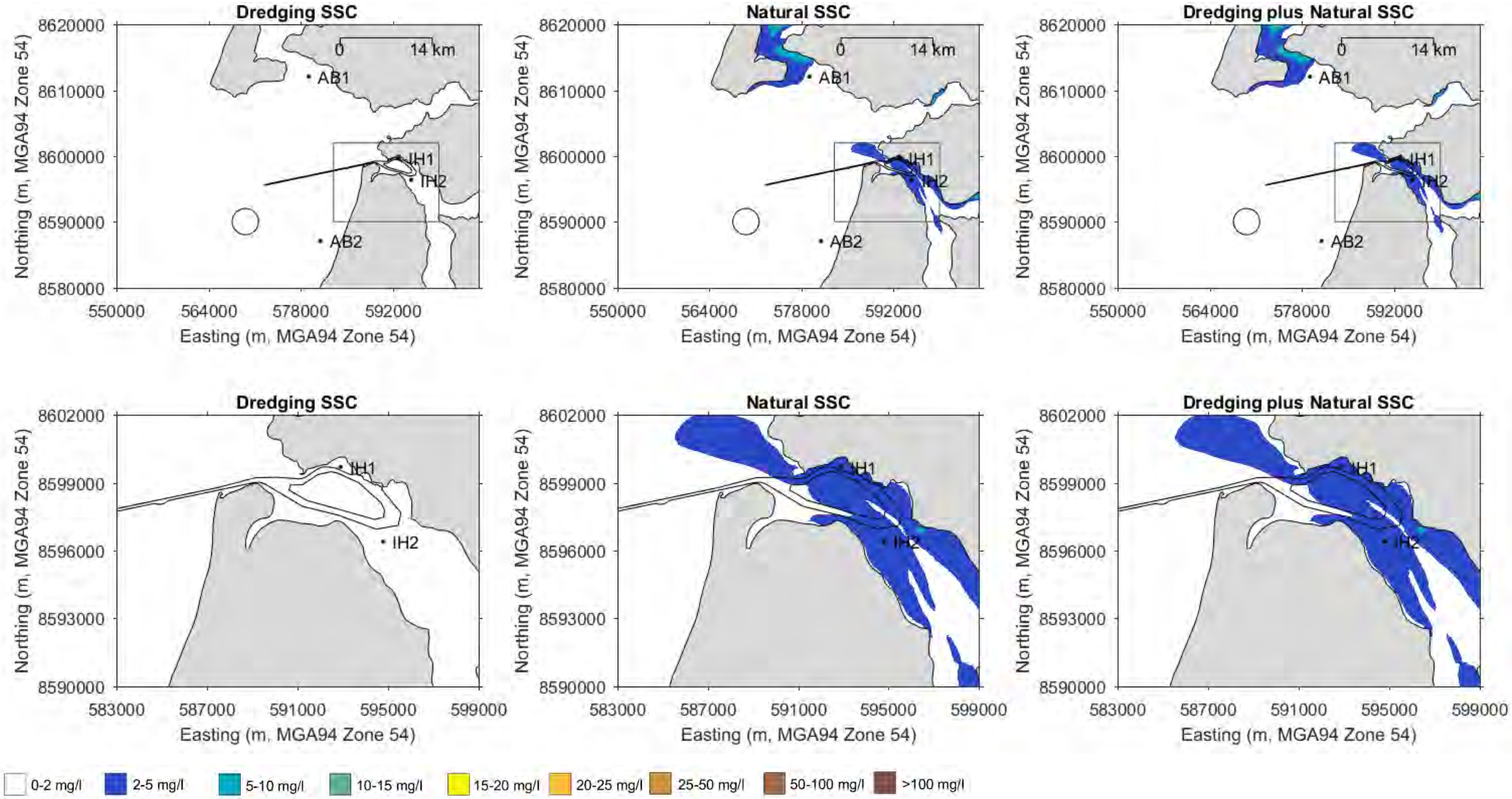


Figure A16. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

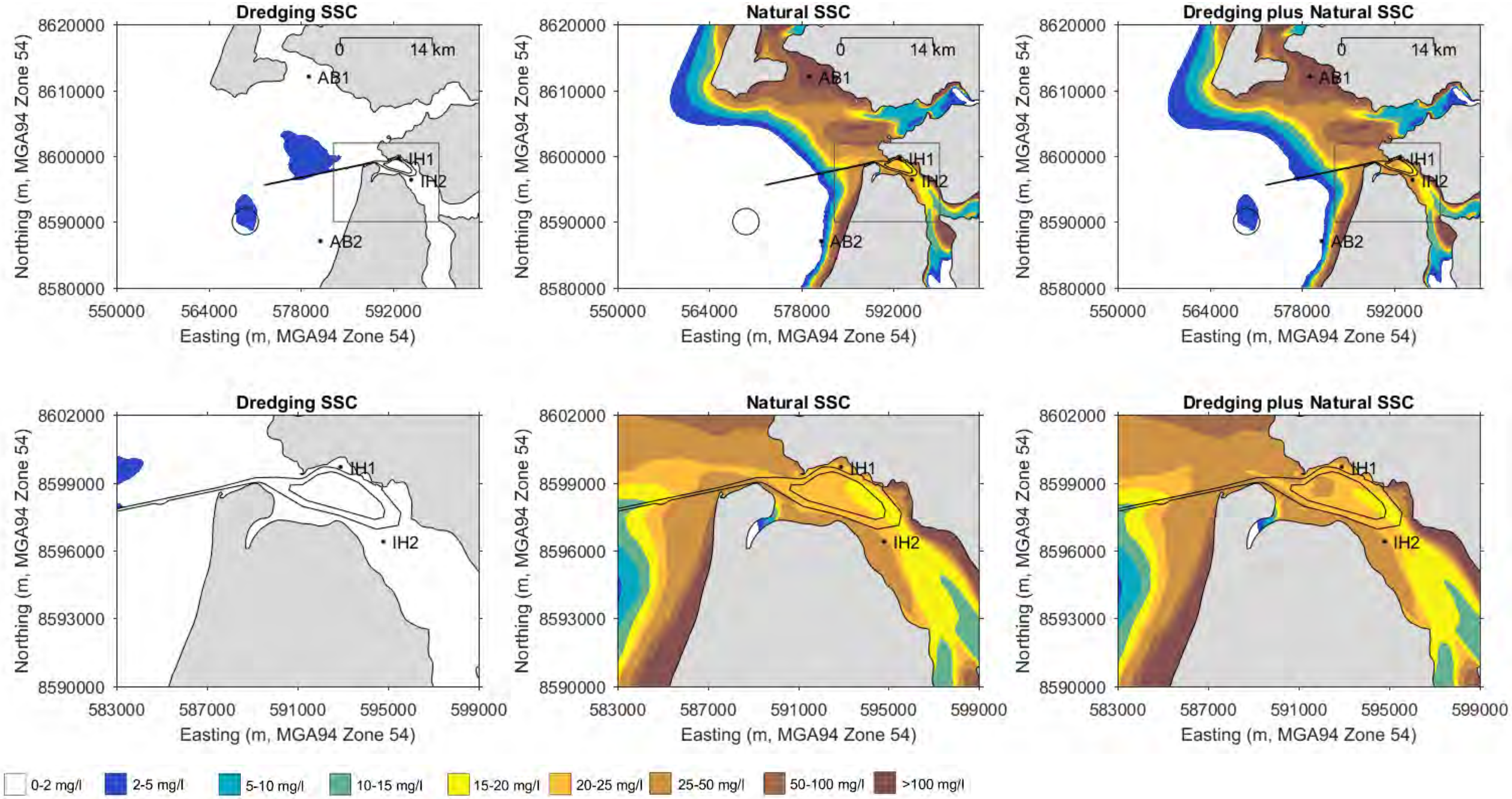


Figure A17. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

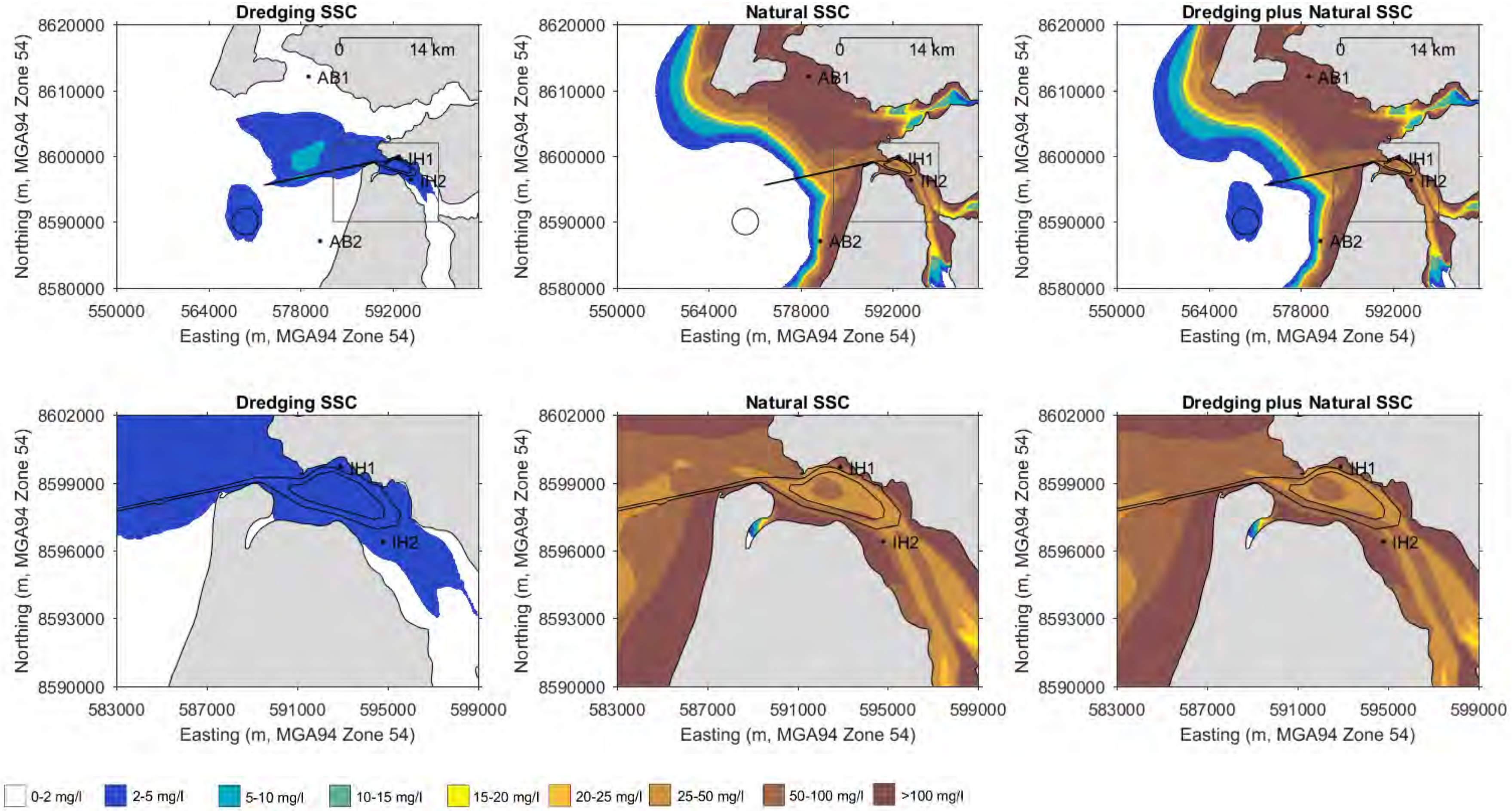


Figure A18. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

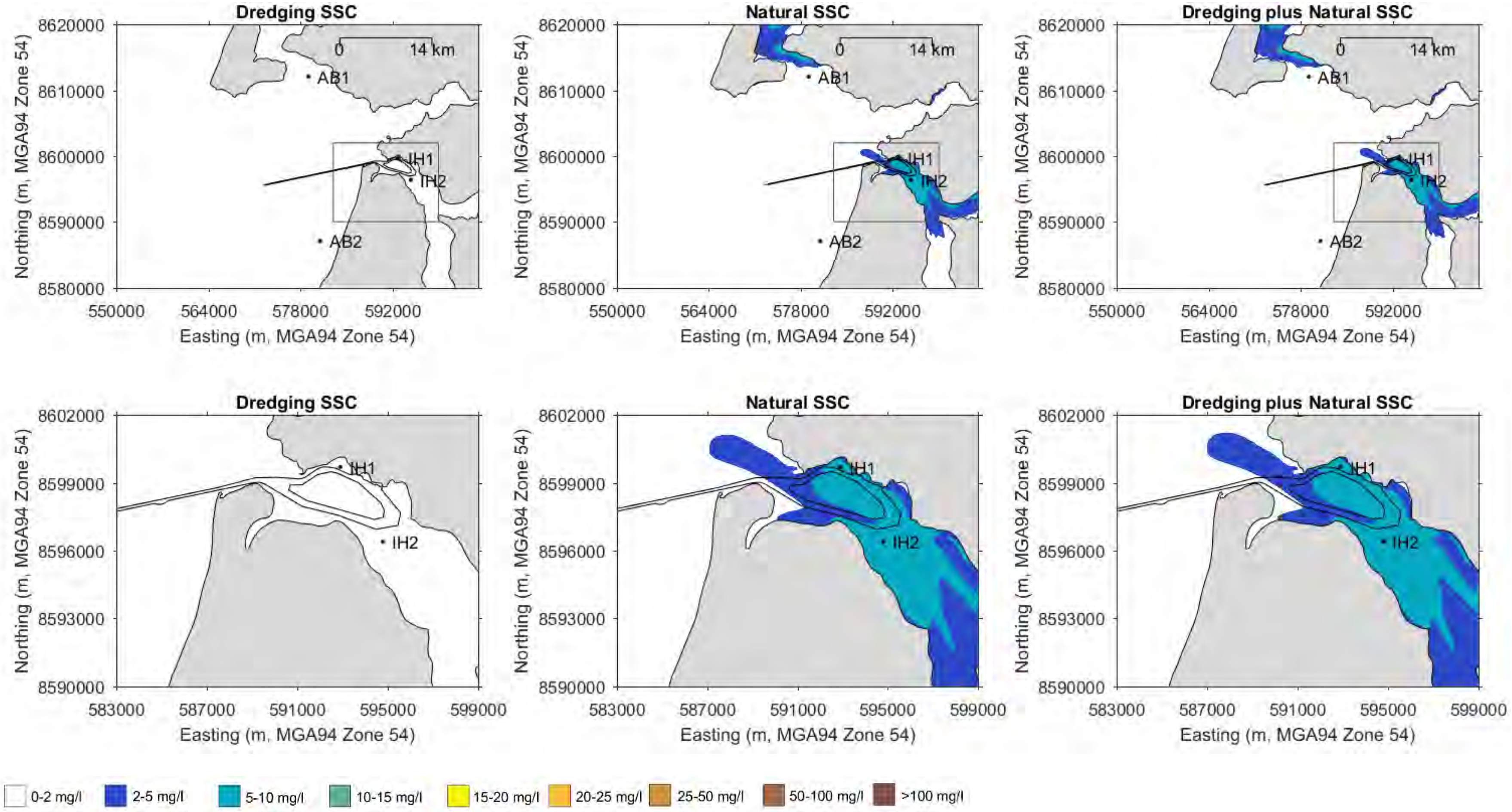


Figure A19. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

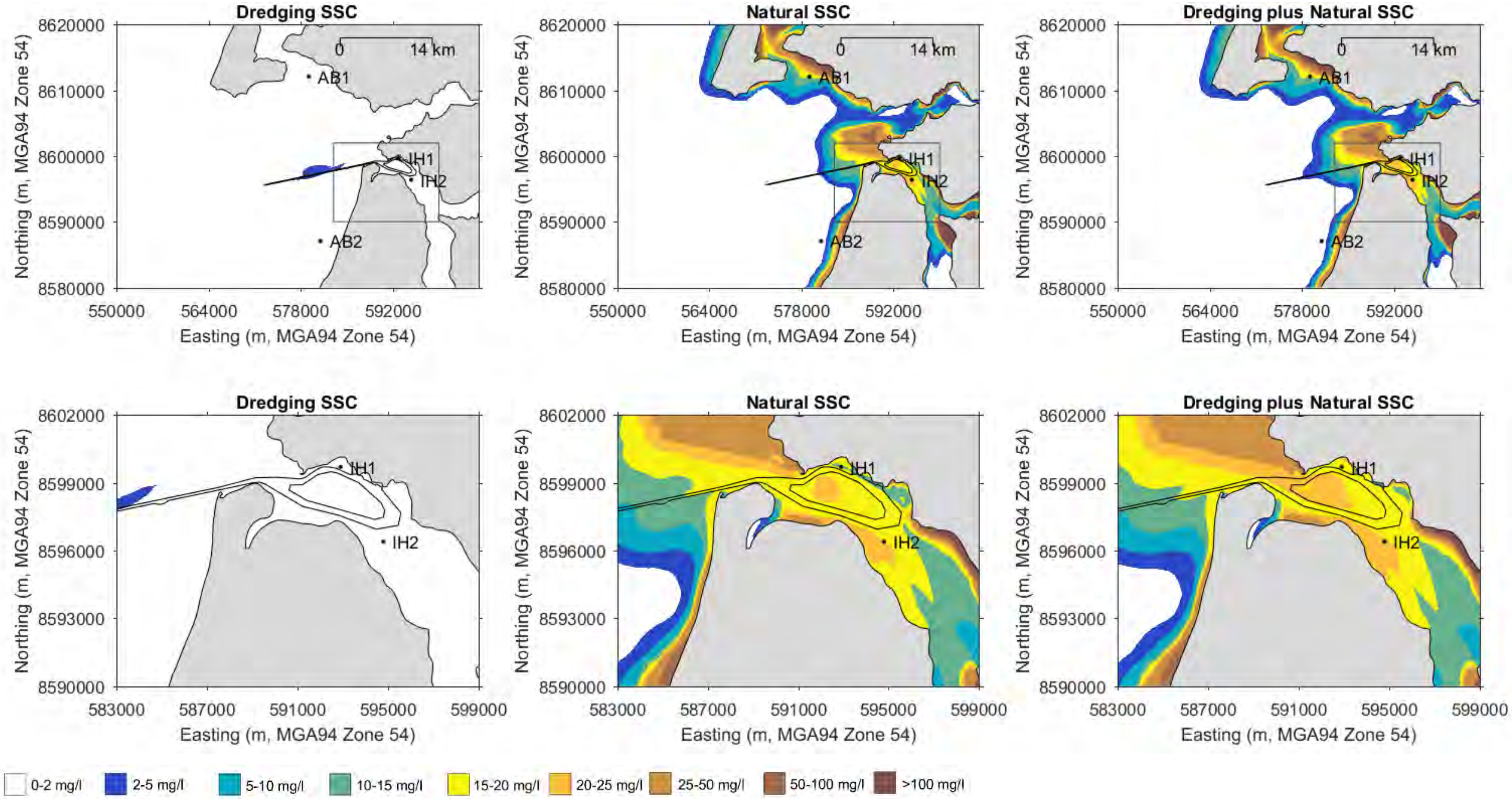


Figure A20. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

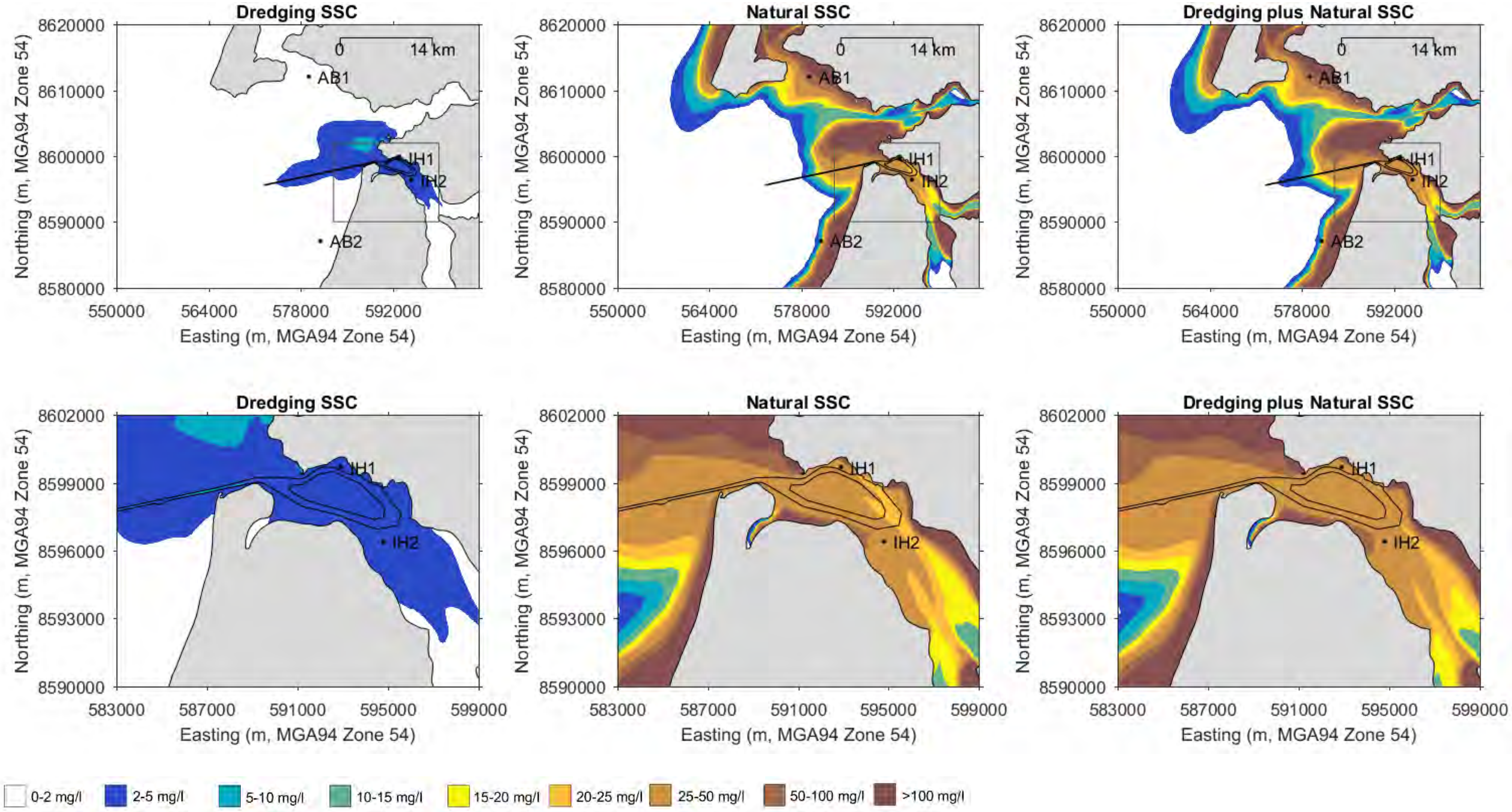
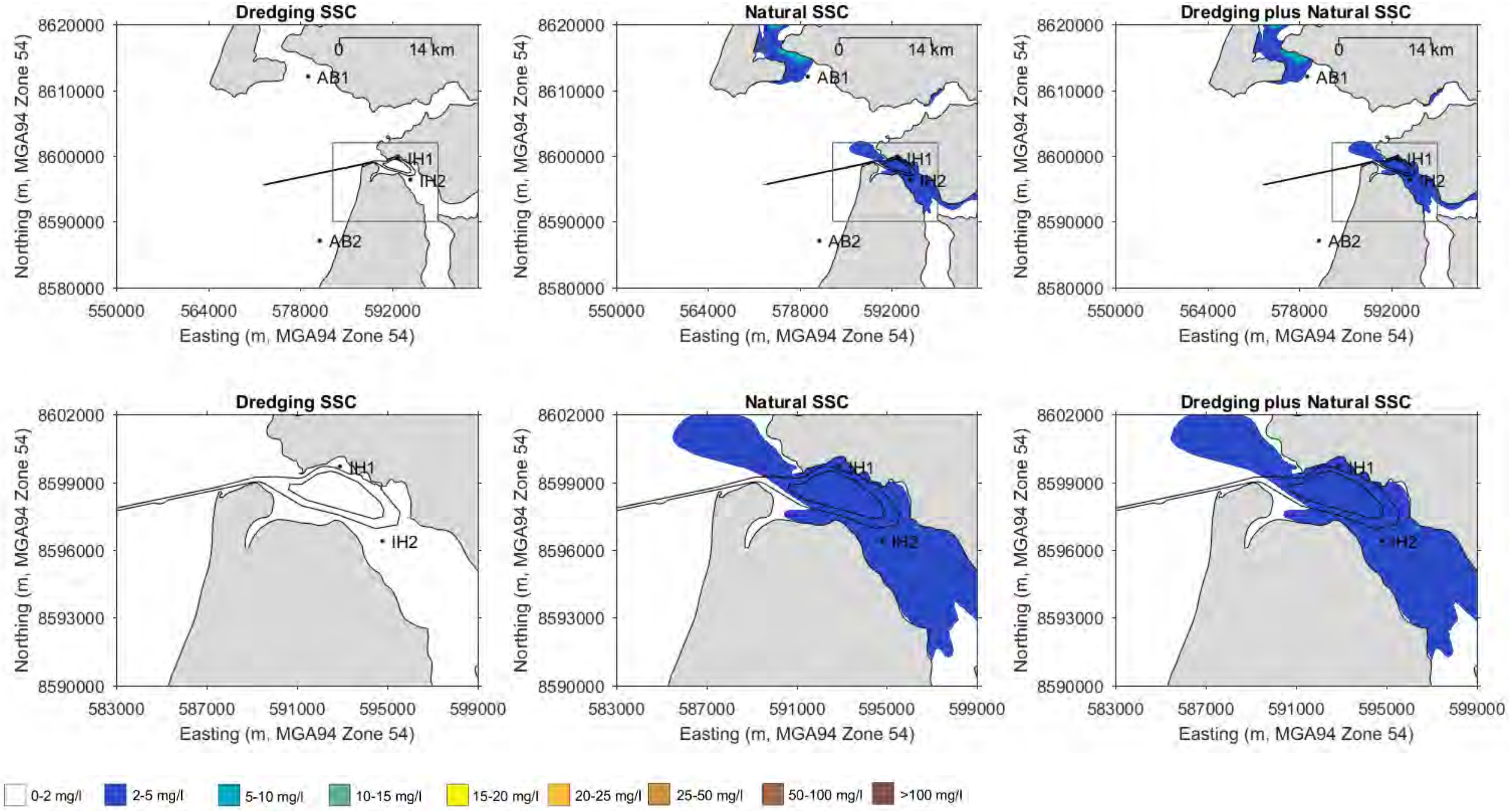


Figure A21. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.



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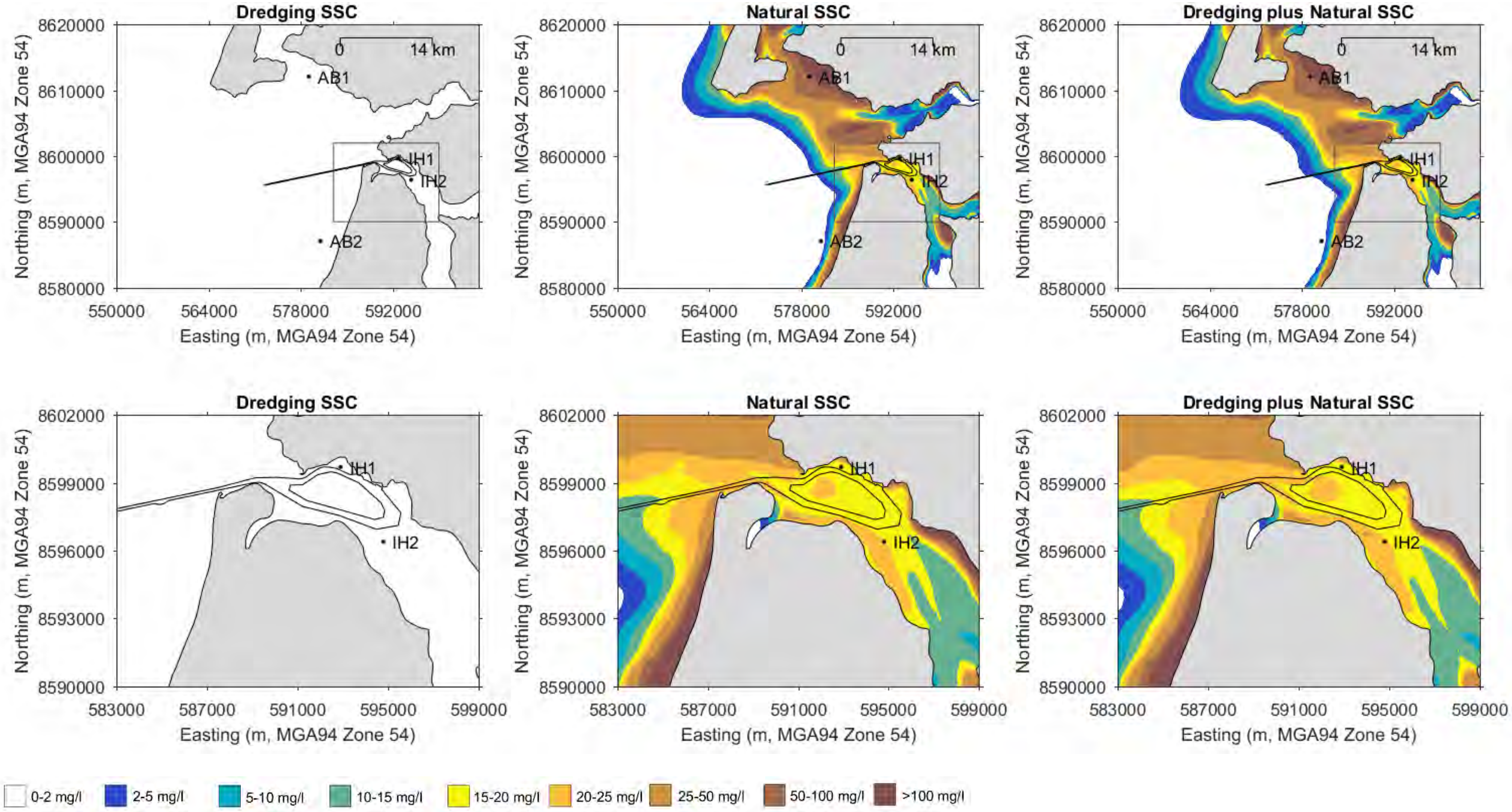
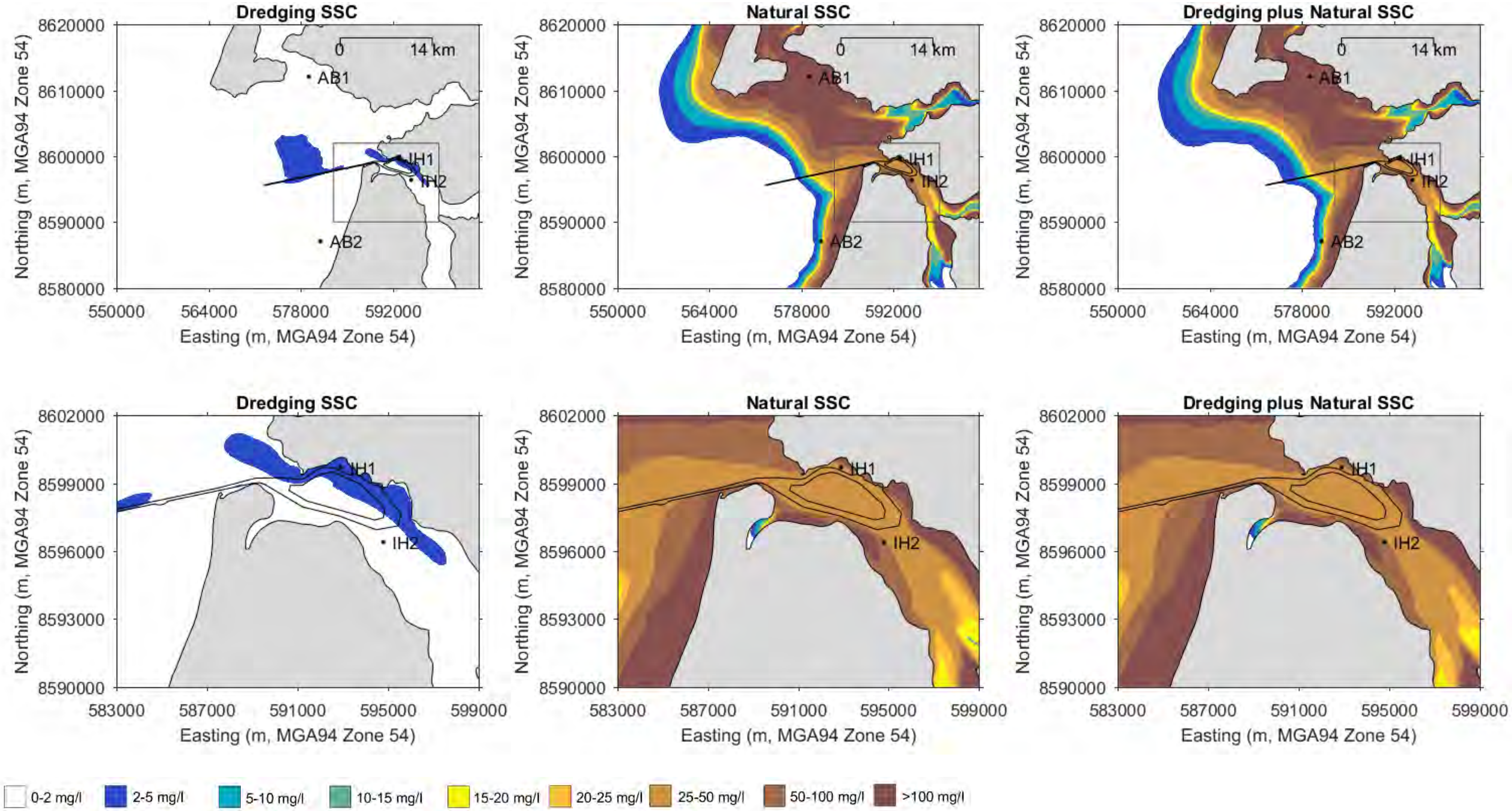


Figure A23. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.



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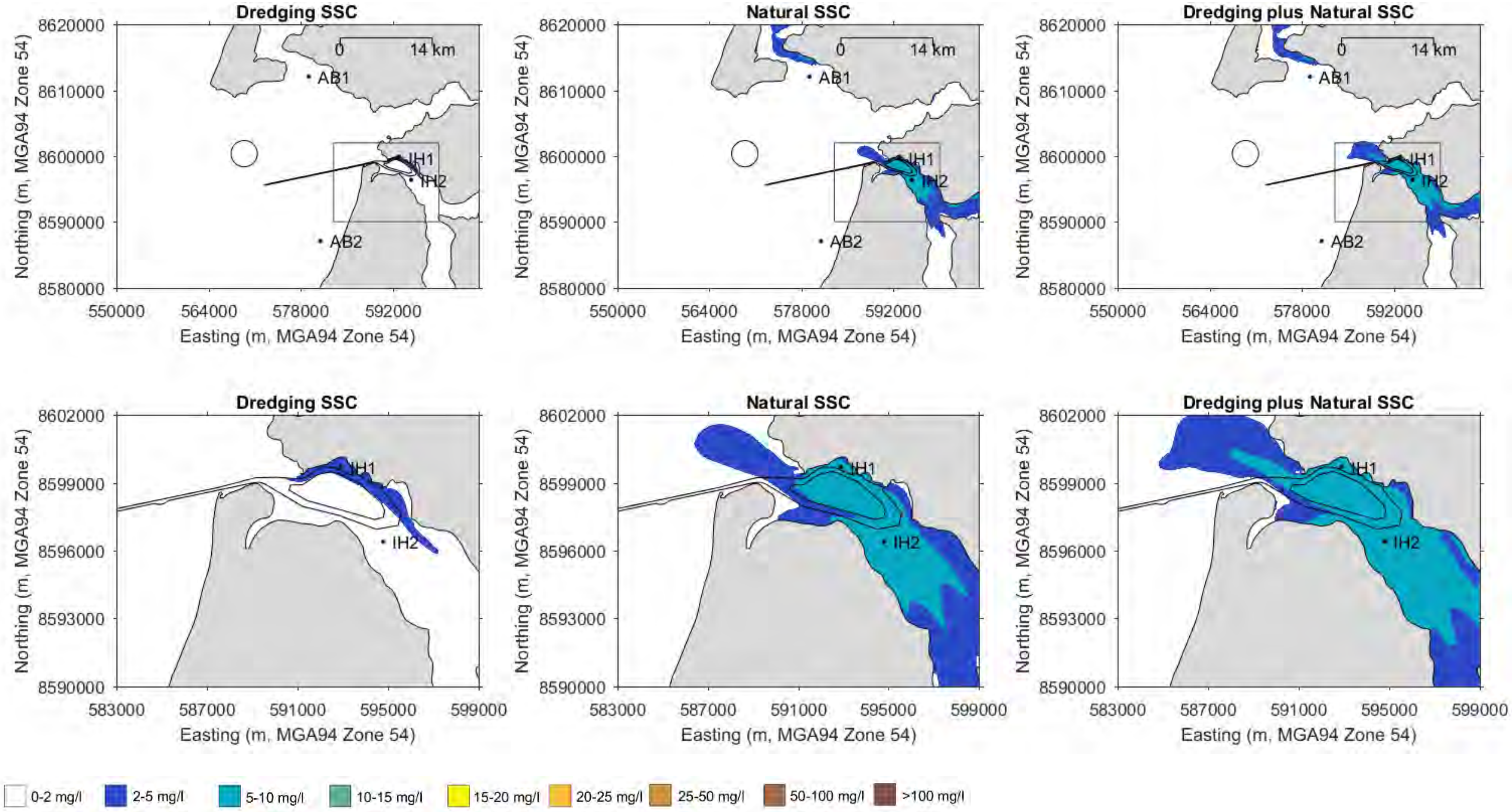
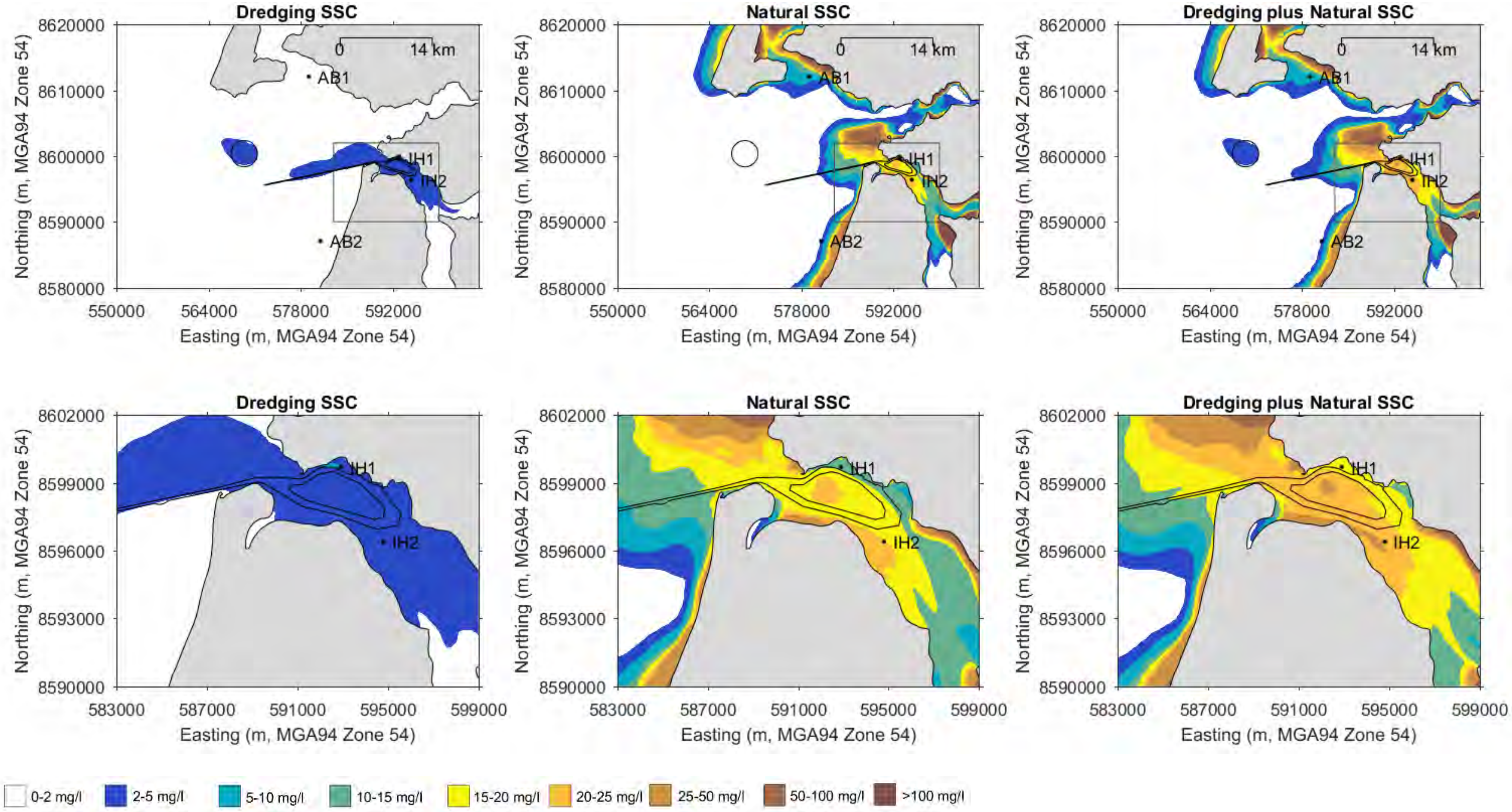


Figure A25. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the ambient dry season.



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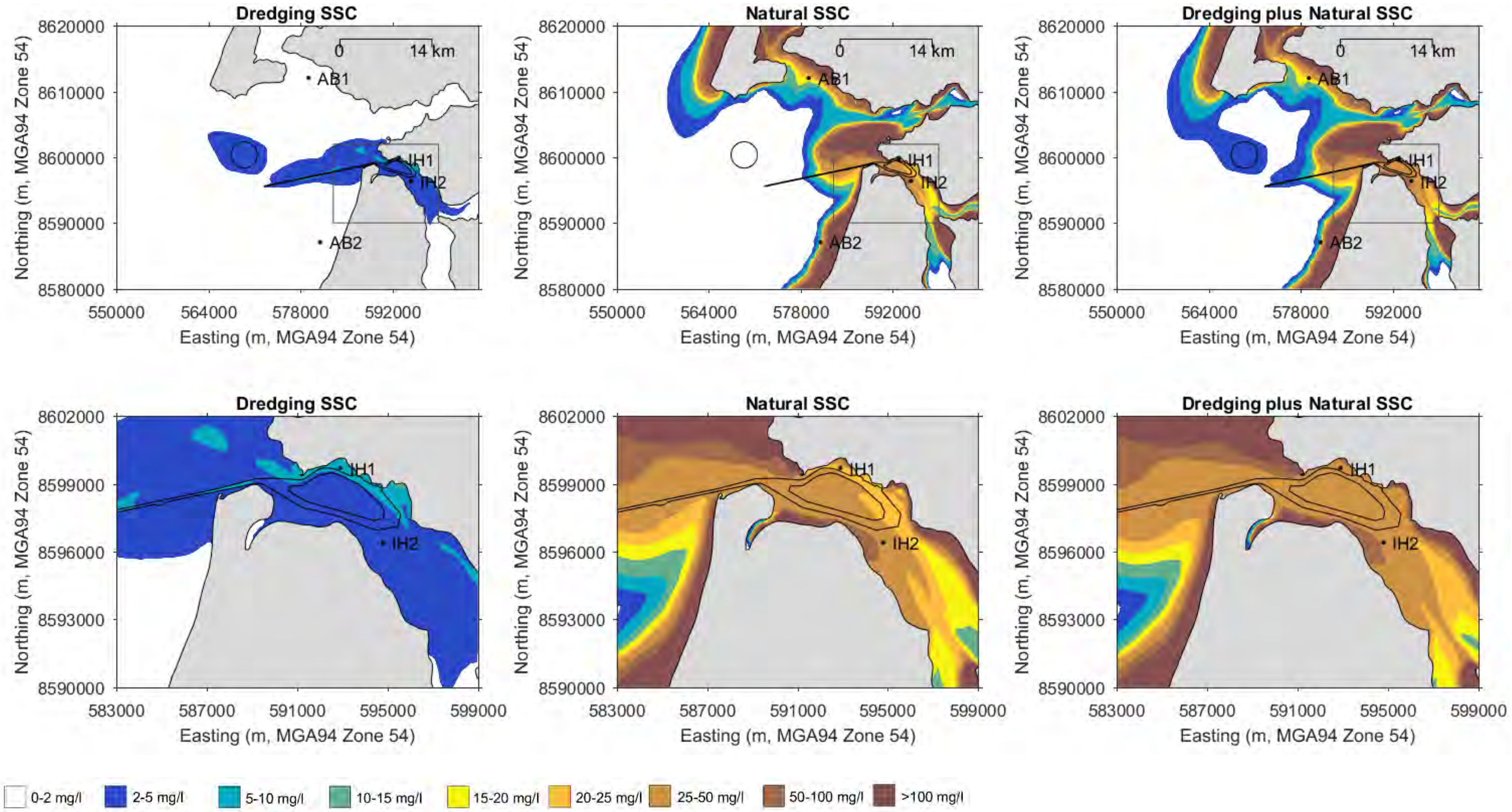

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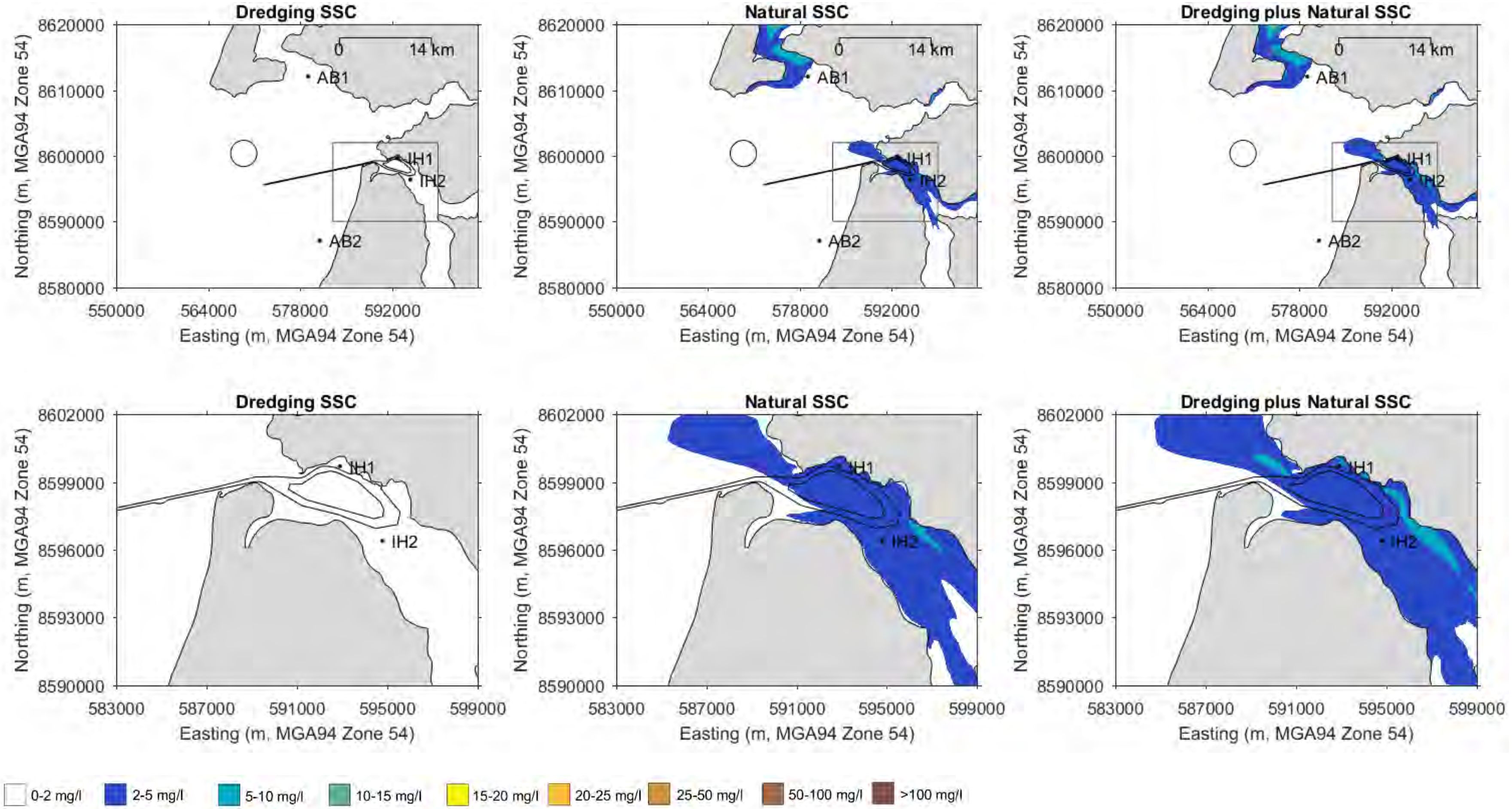

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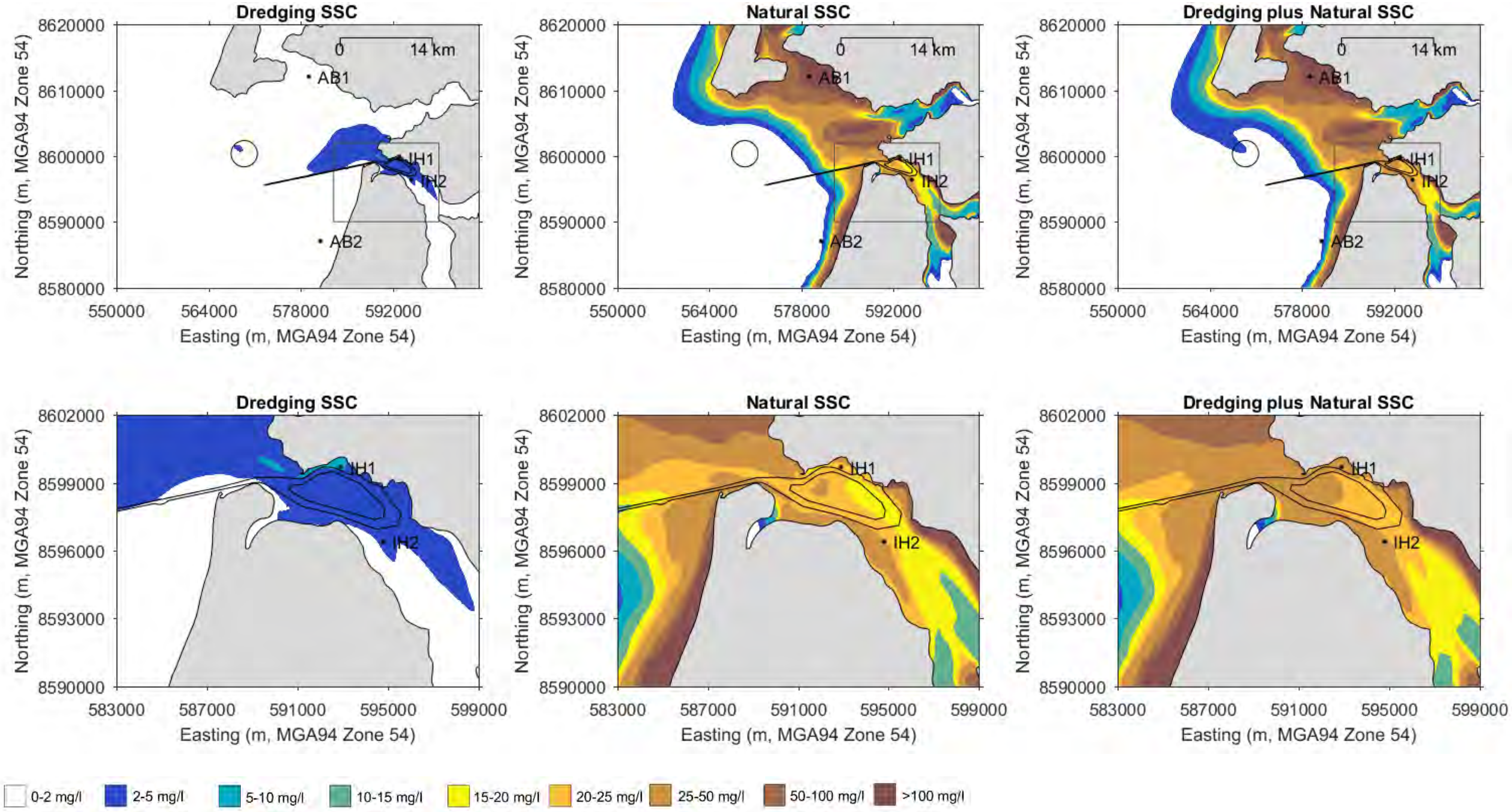


Figure A29. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the energetic dry season.

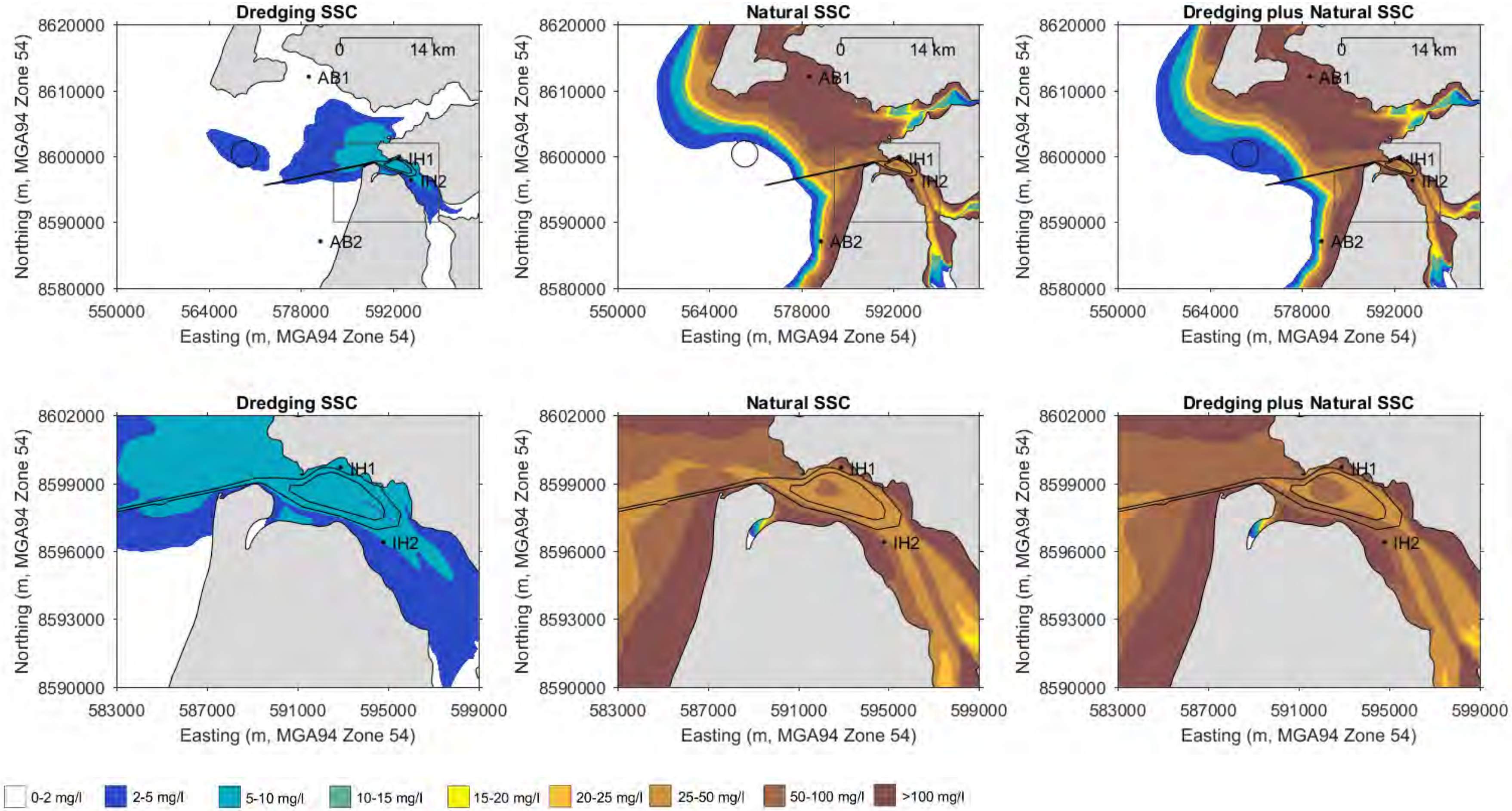


Figure A30. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the energetic dry season.

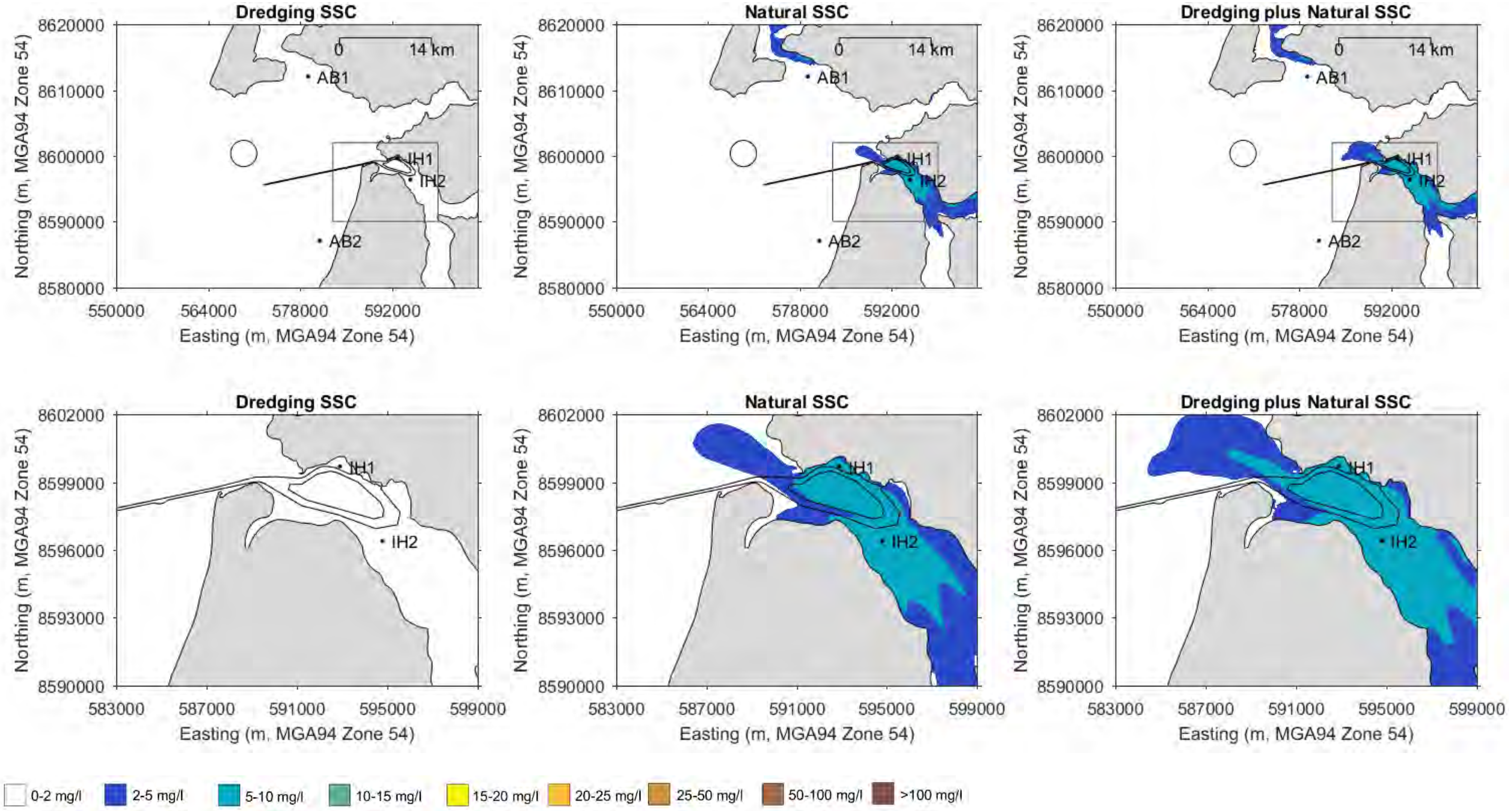
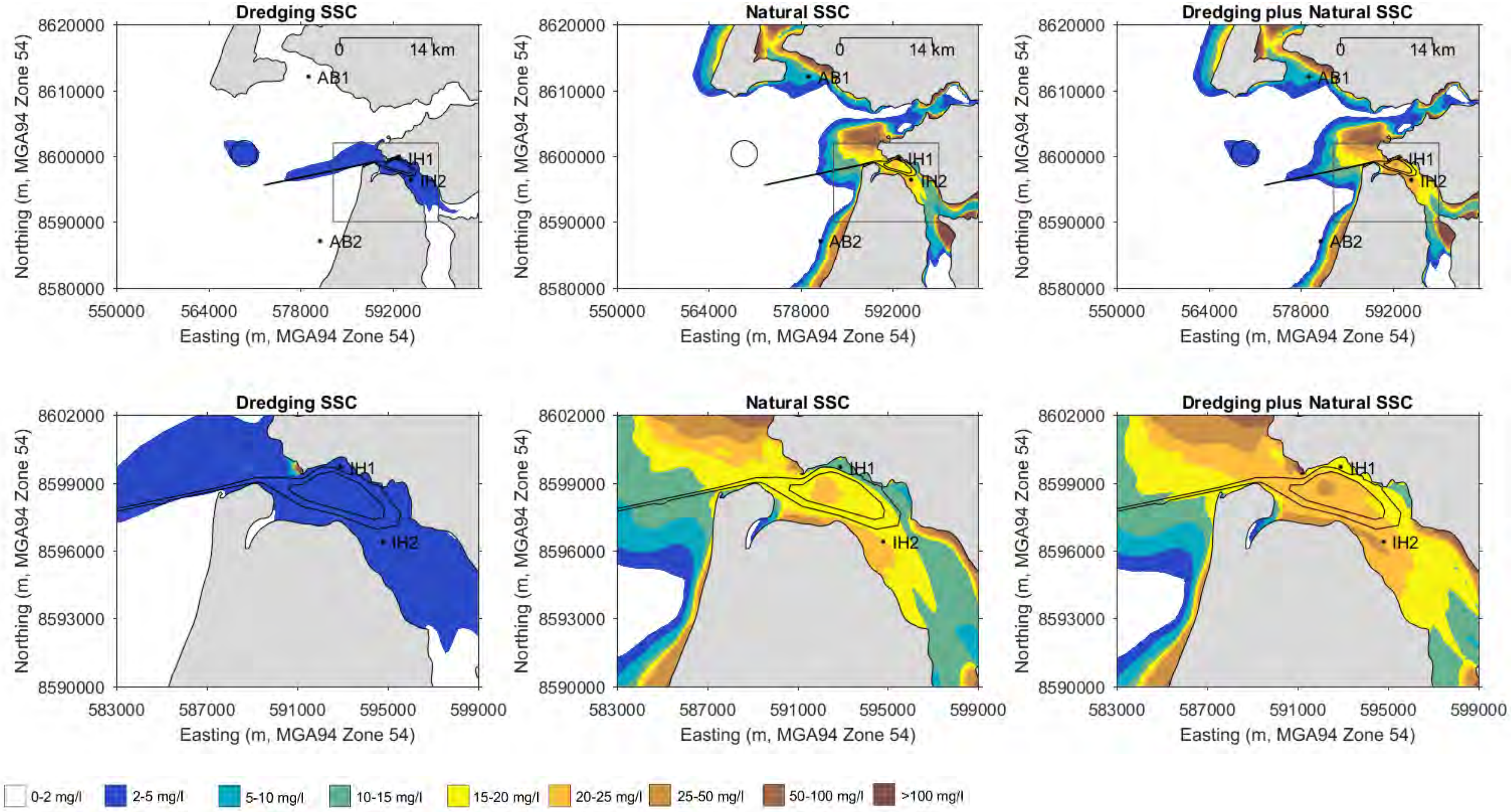


Figure A31. 20th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the ambient dry season.



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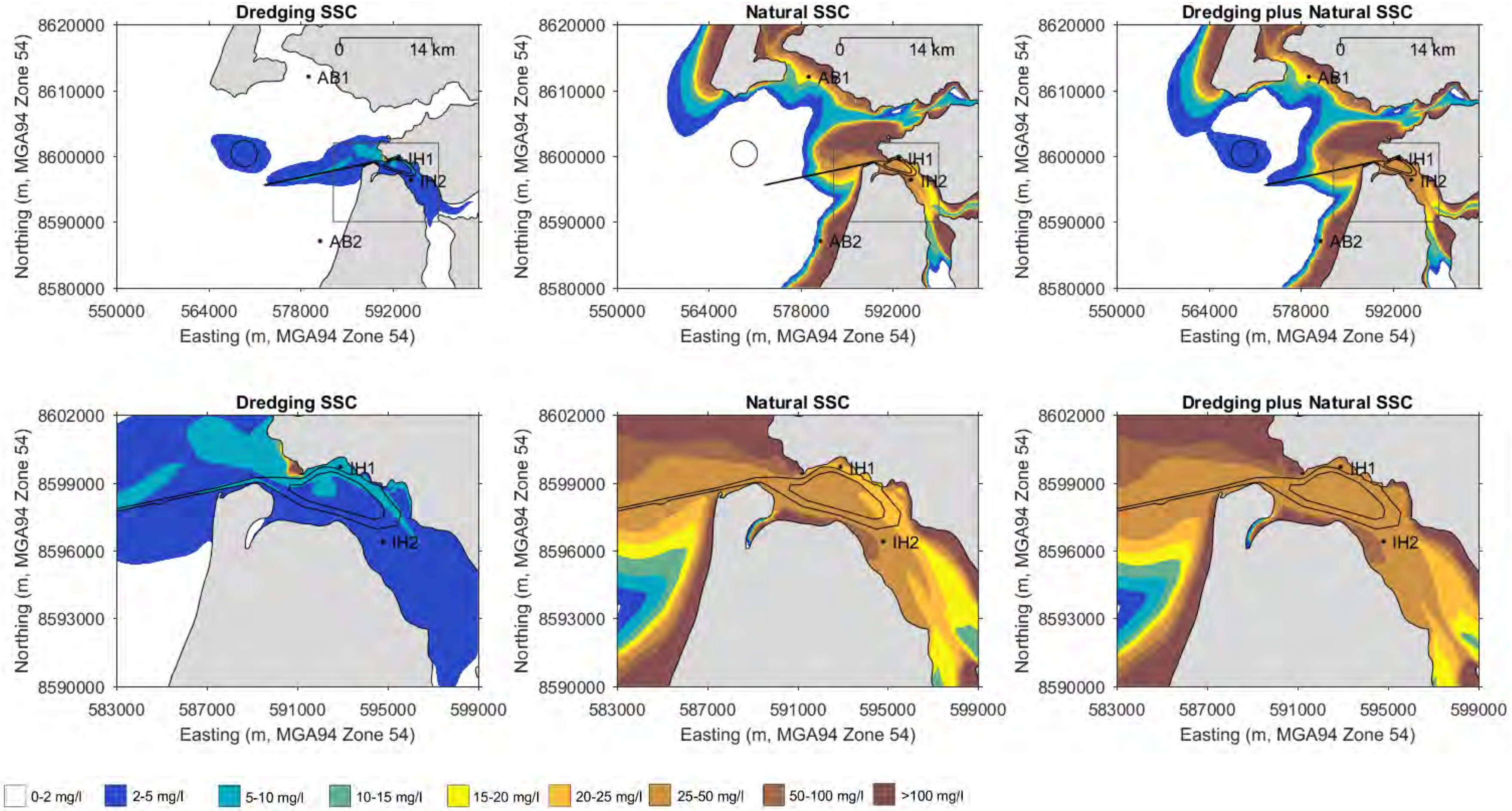
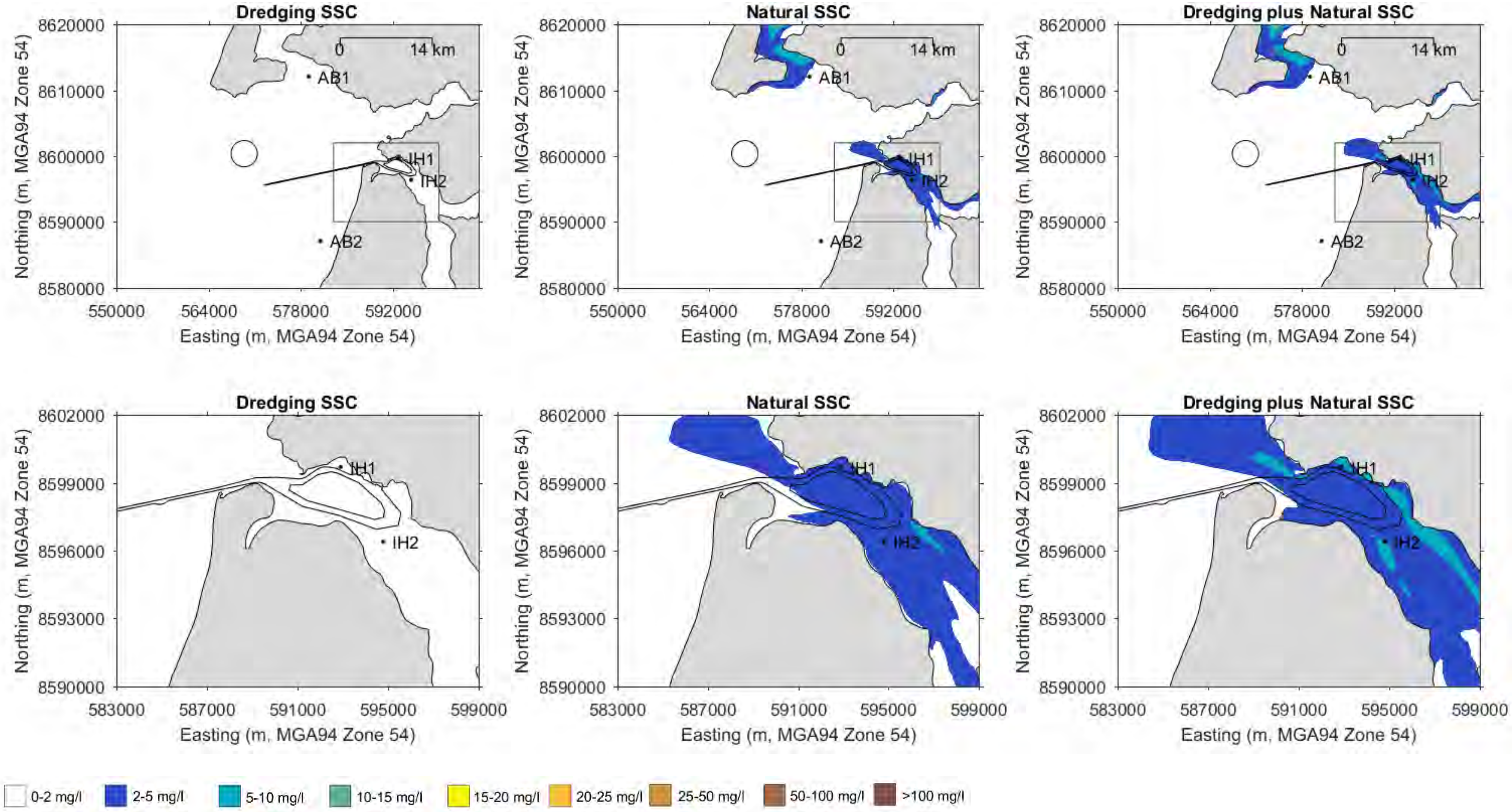


Figure A33. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the ambient dry season.



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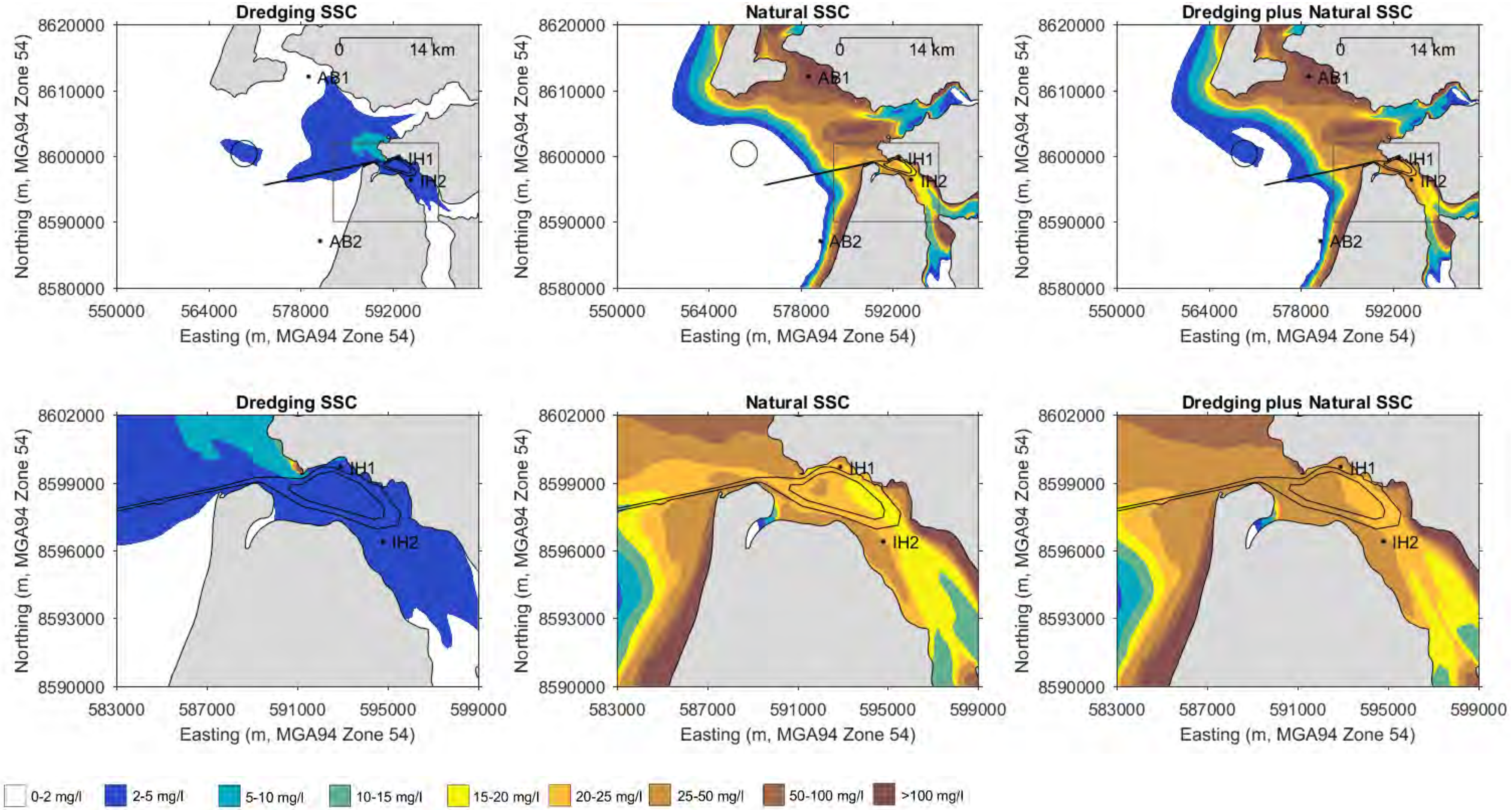


Figure A35. 80th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the energetic dry season.

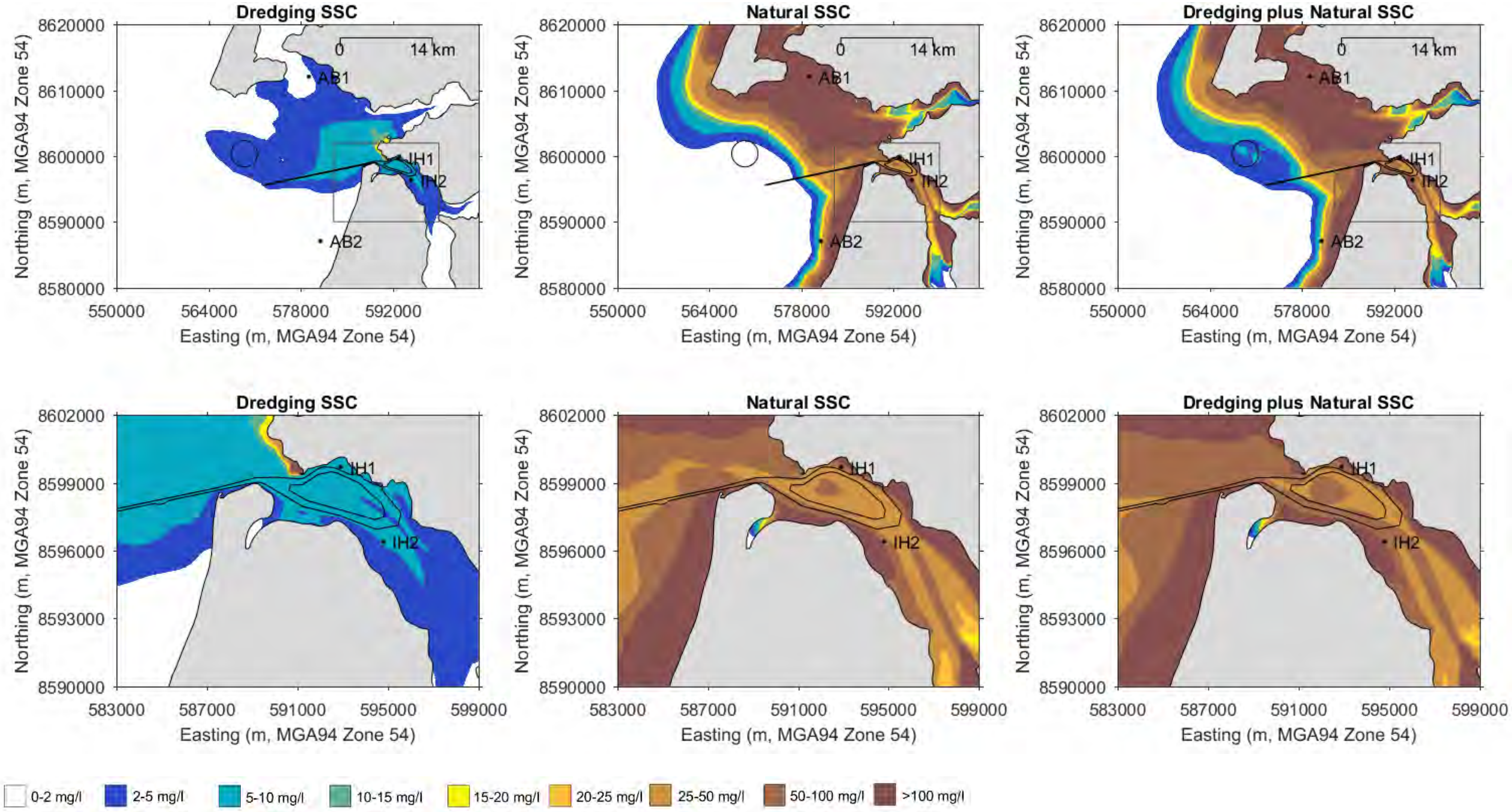


Figure A36. 95th percentile SSC for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the energetic dry season.

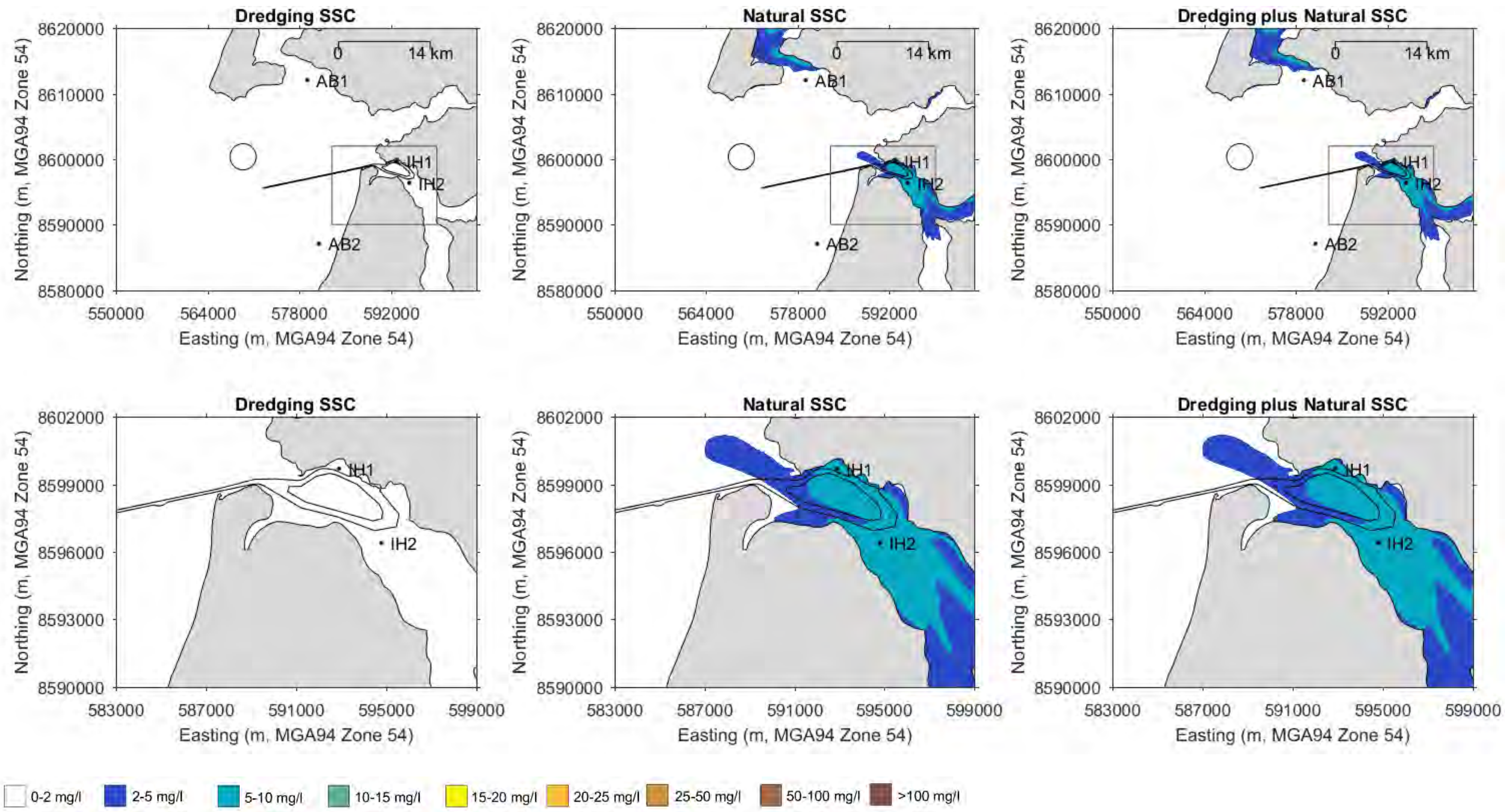


Figure A37. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

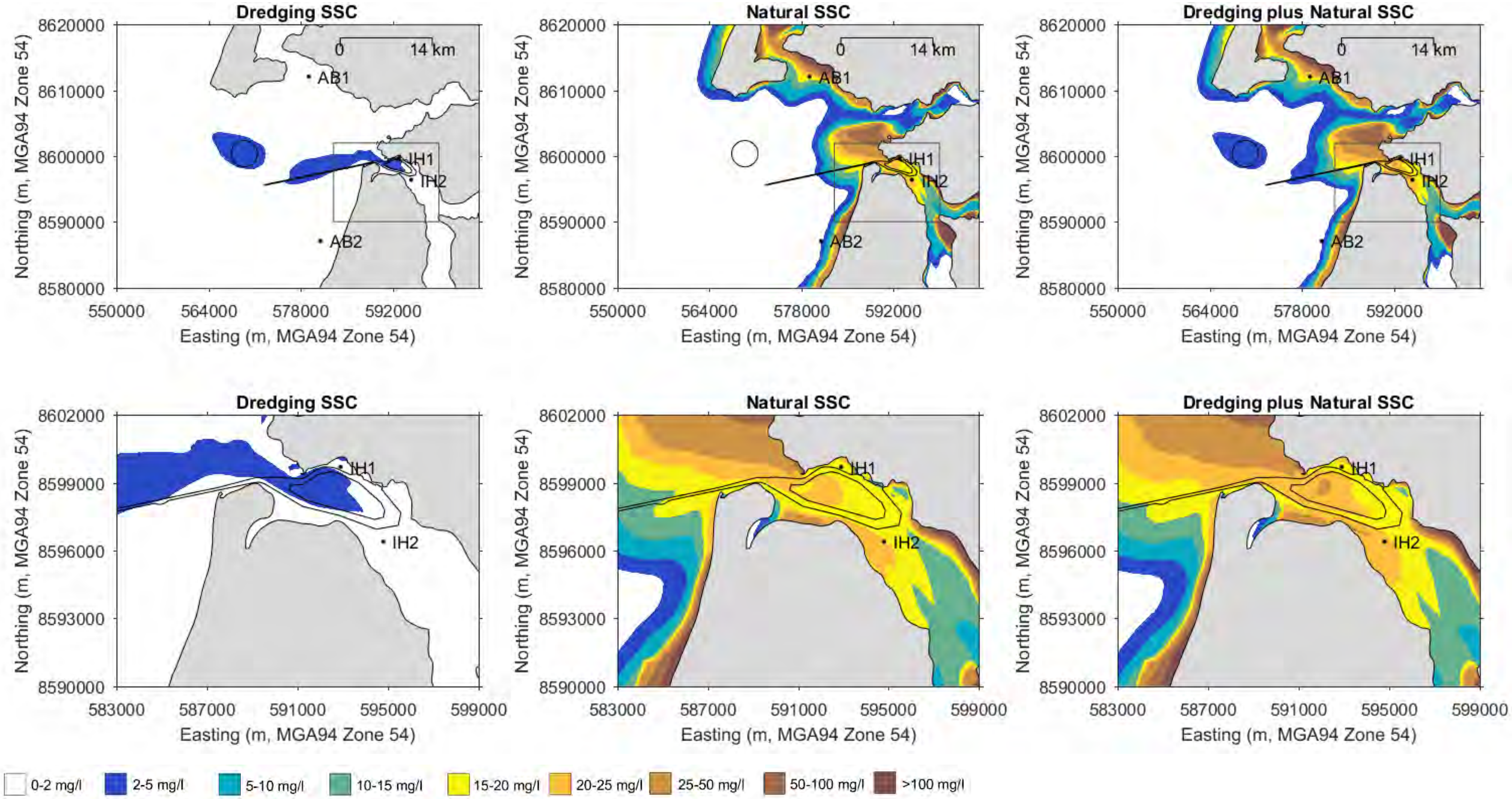


Figure A38. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

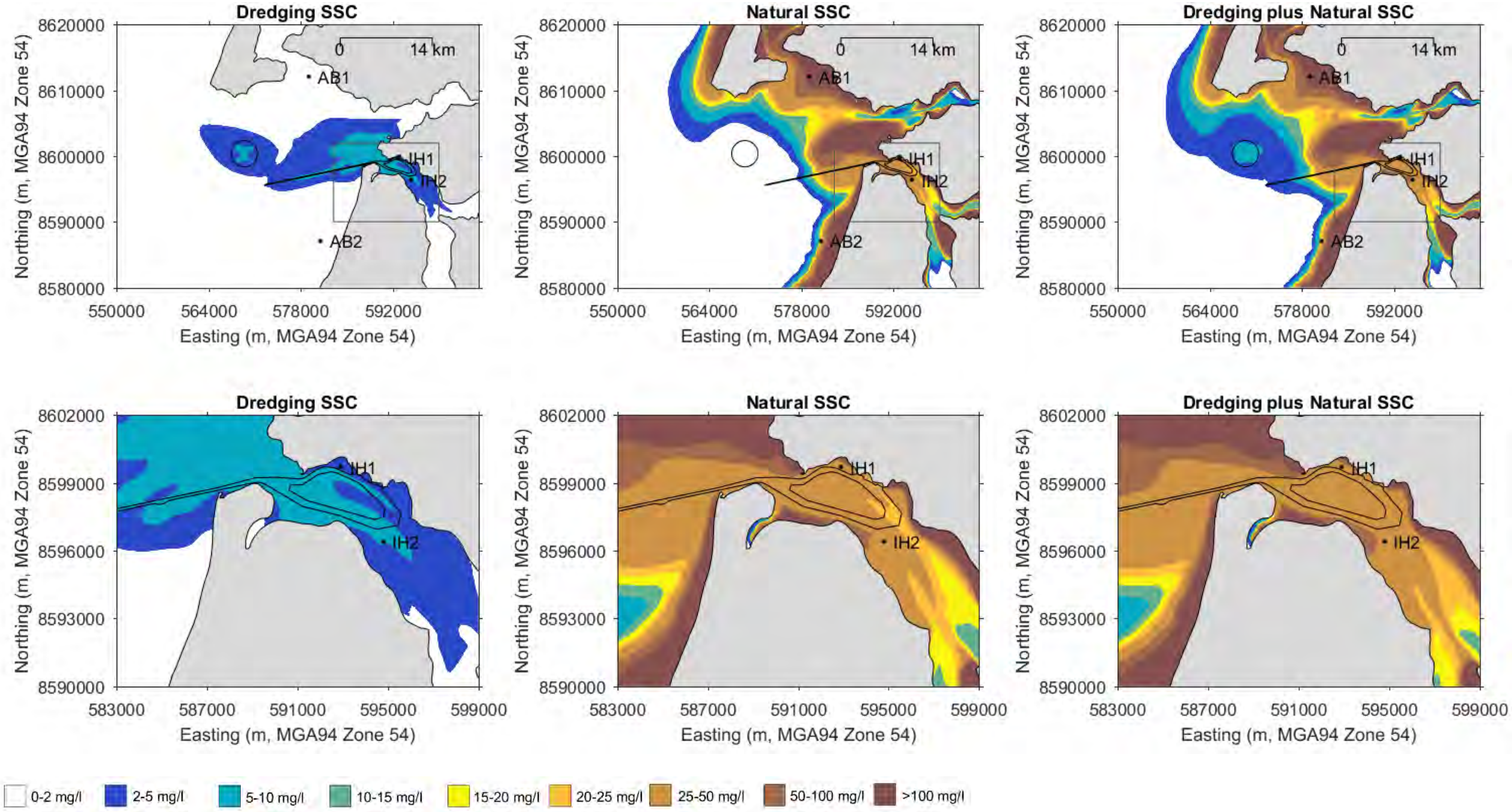


Figure A39. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

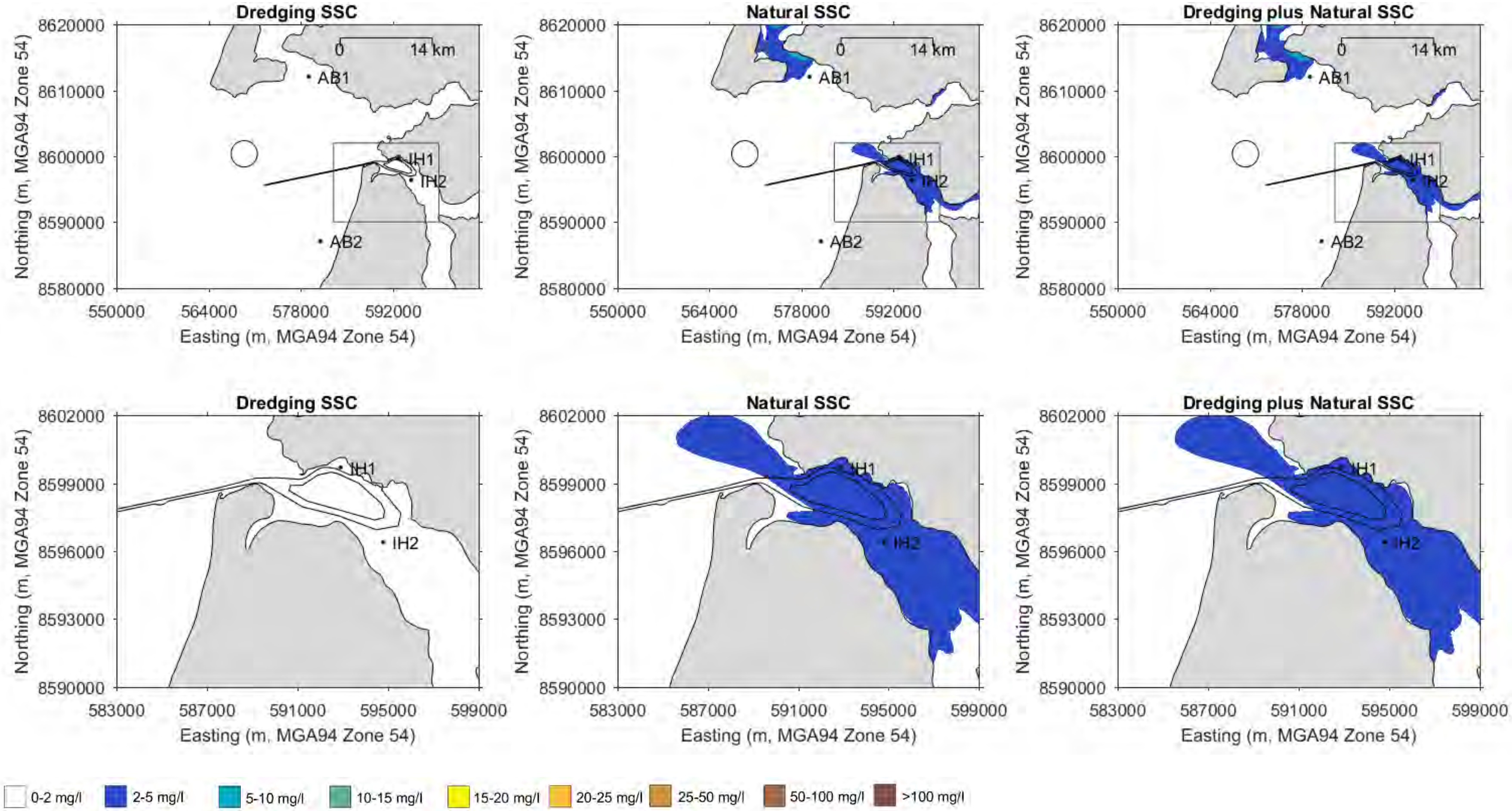


Figure A40. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

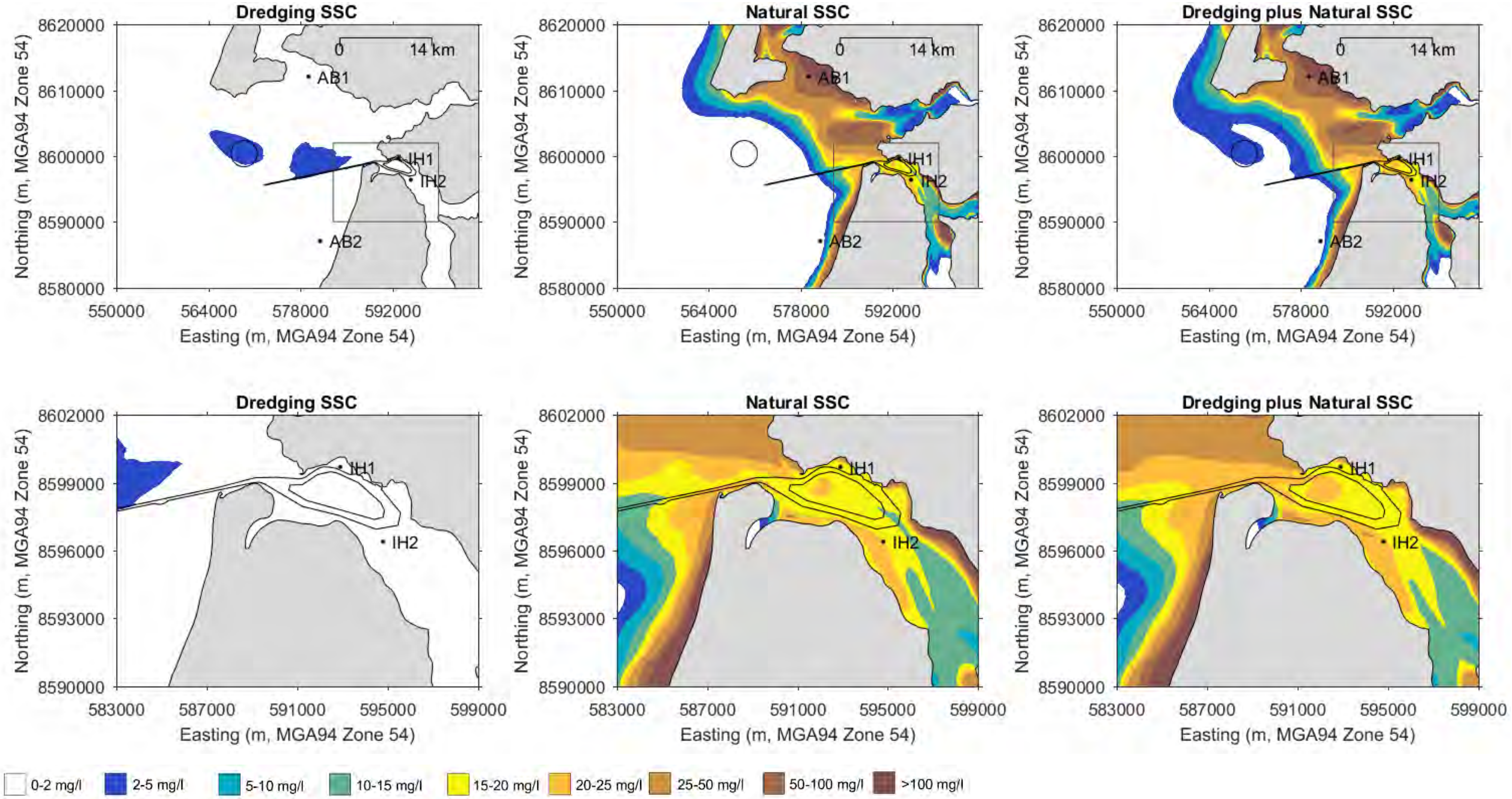


Figure A41. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

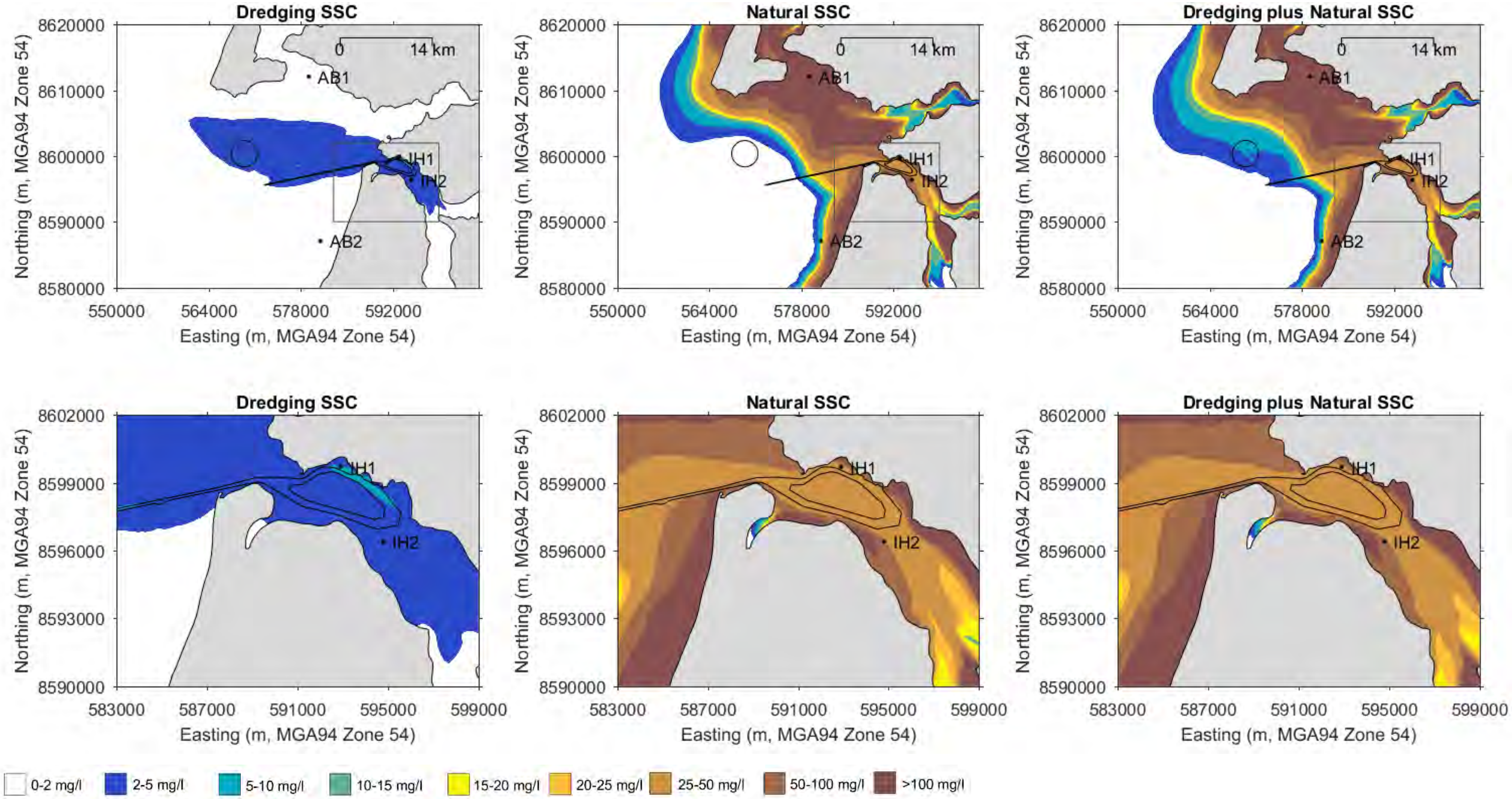


Figure A42. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

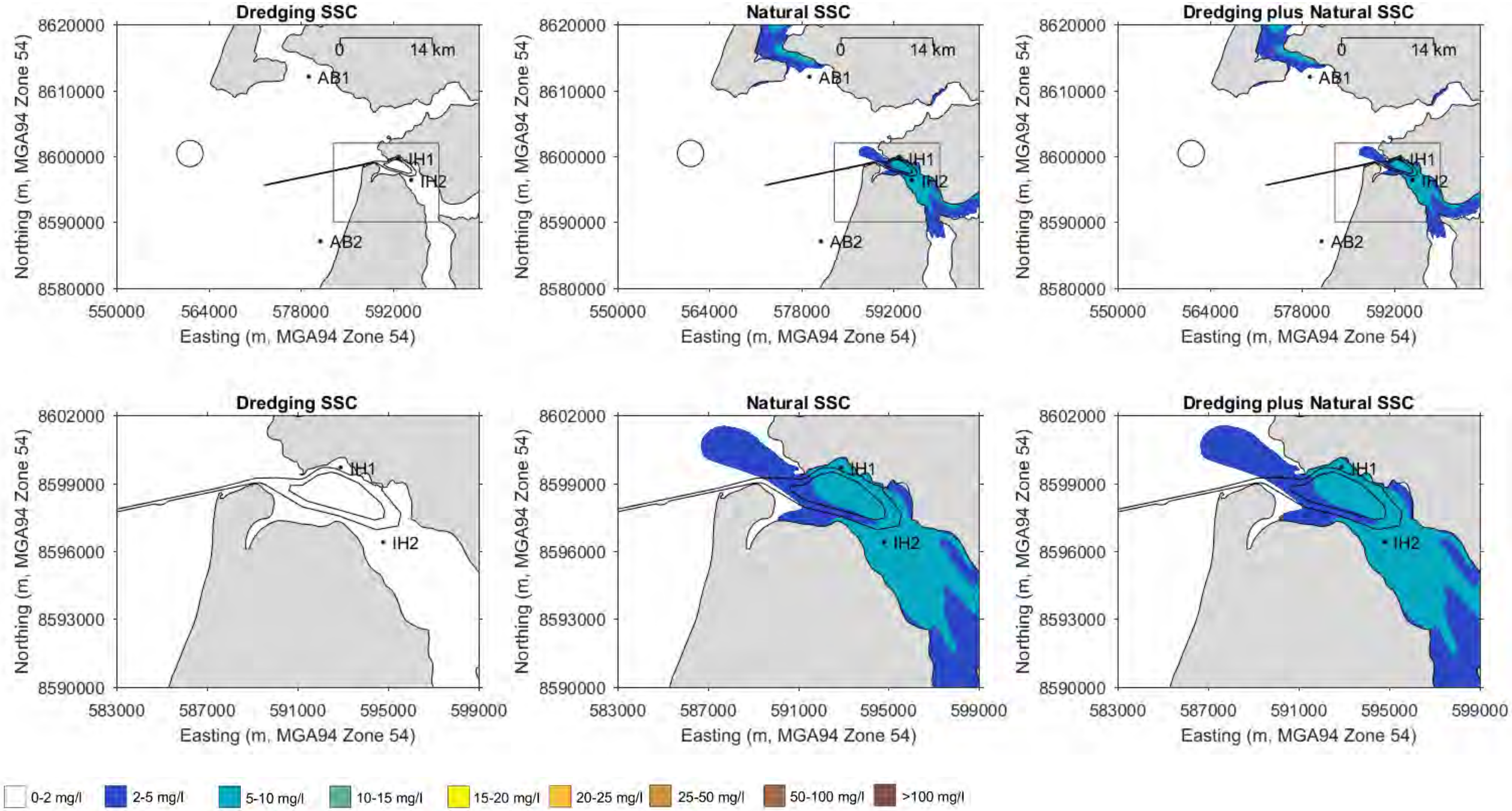


Figure A43. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

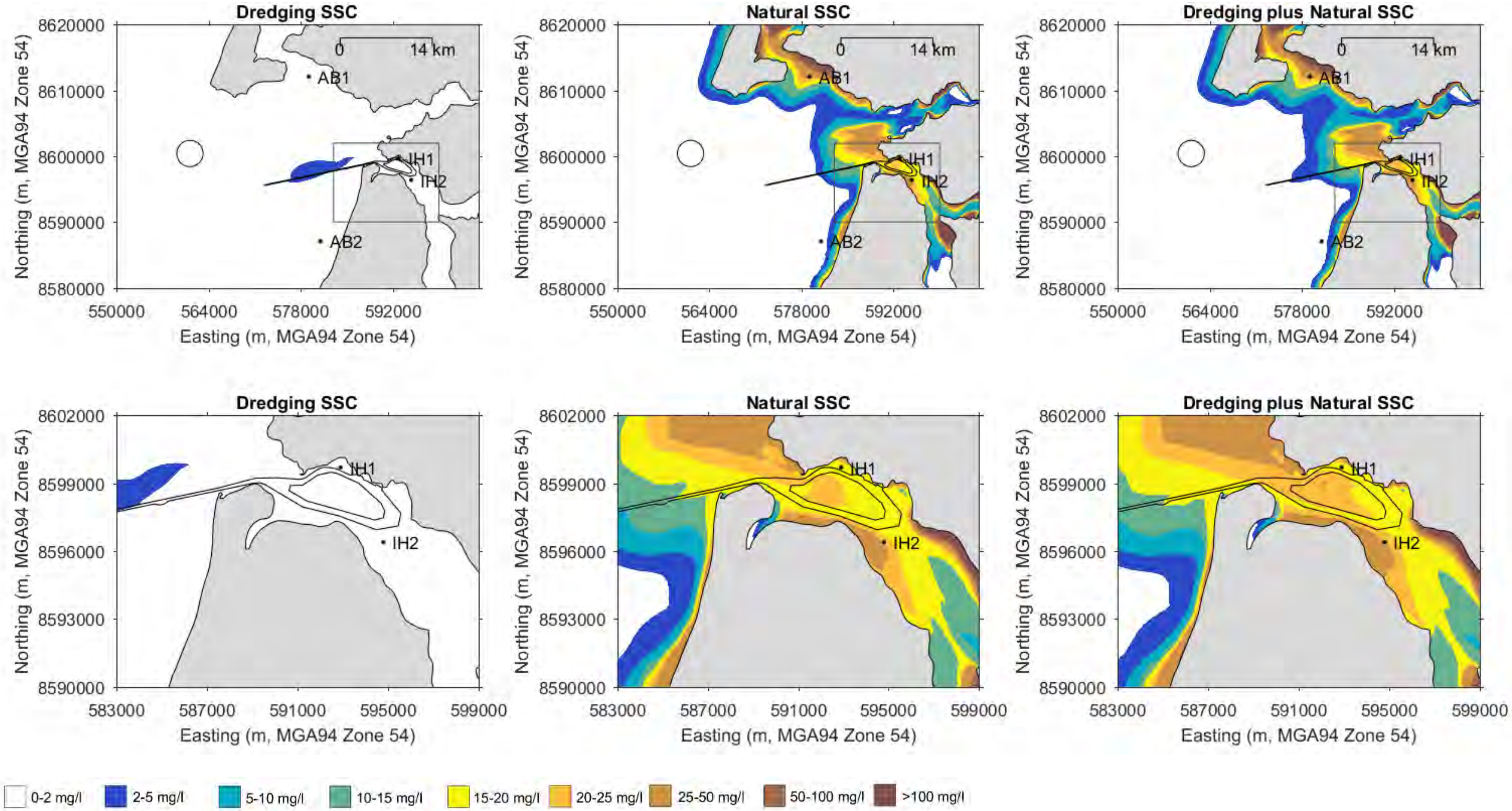


Figure A44. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

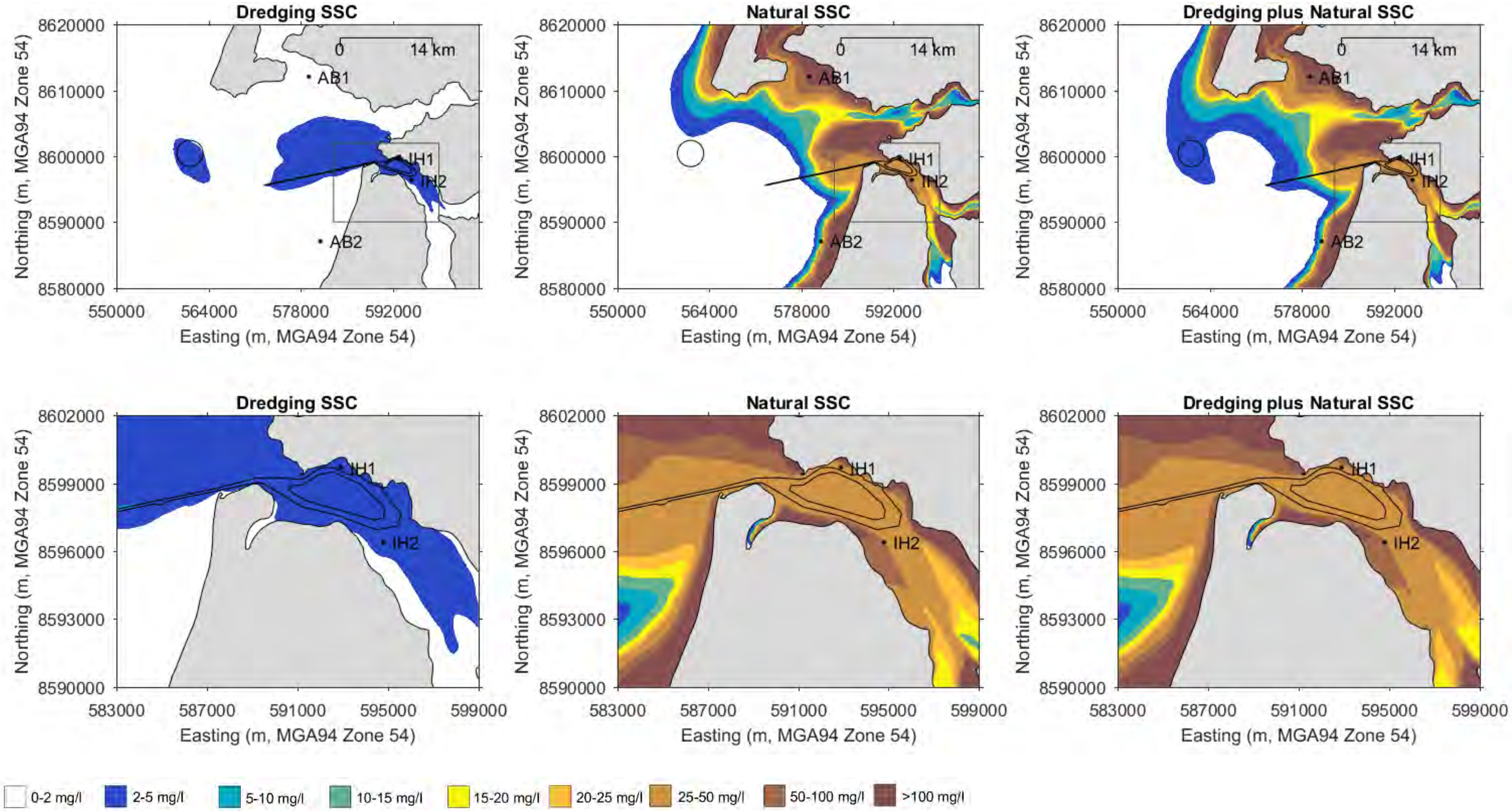


Figure A45. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

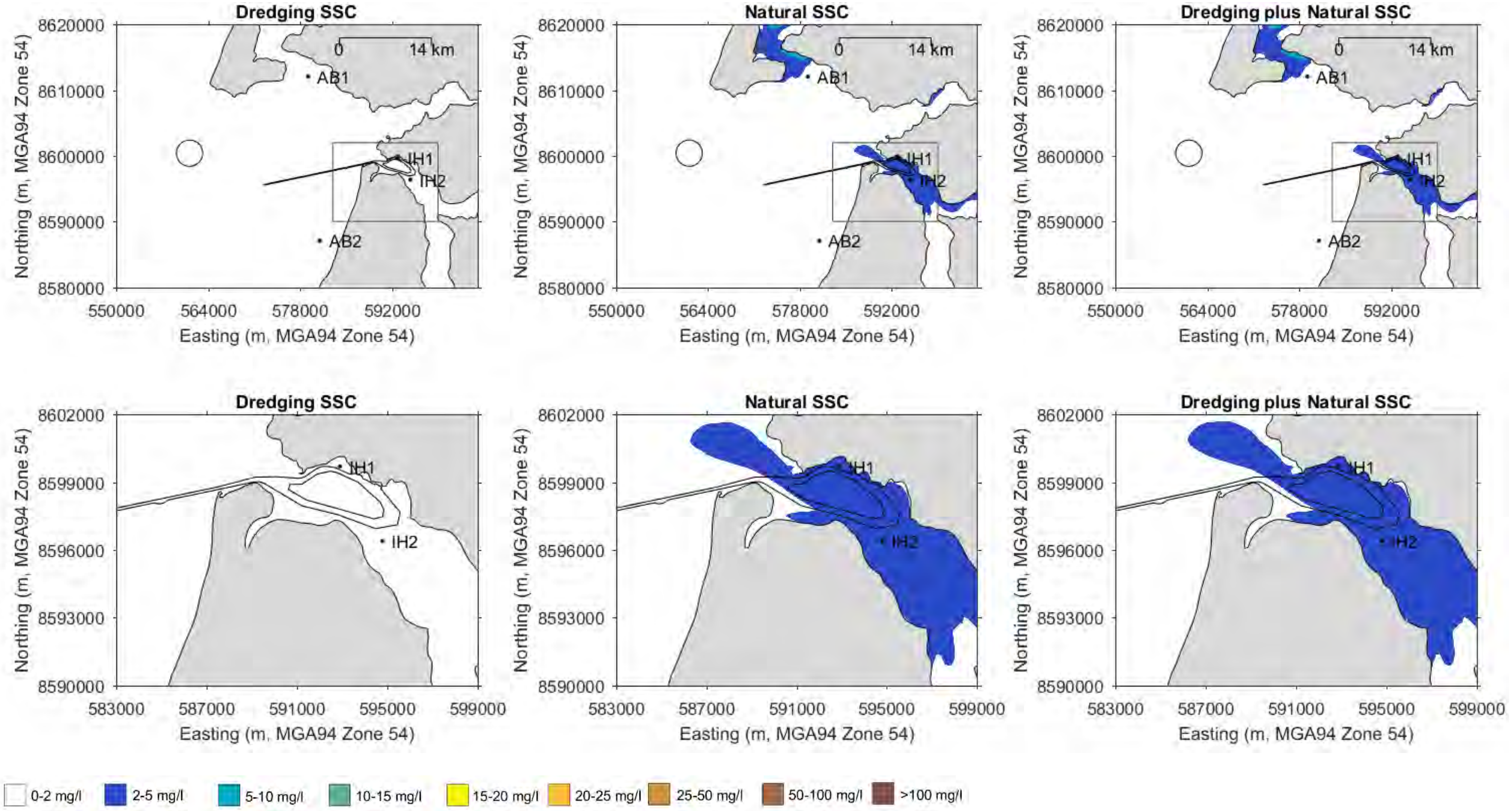


Figure A46. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

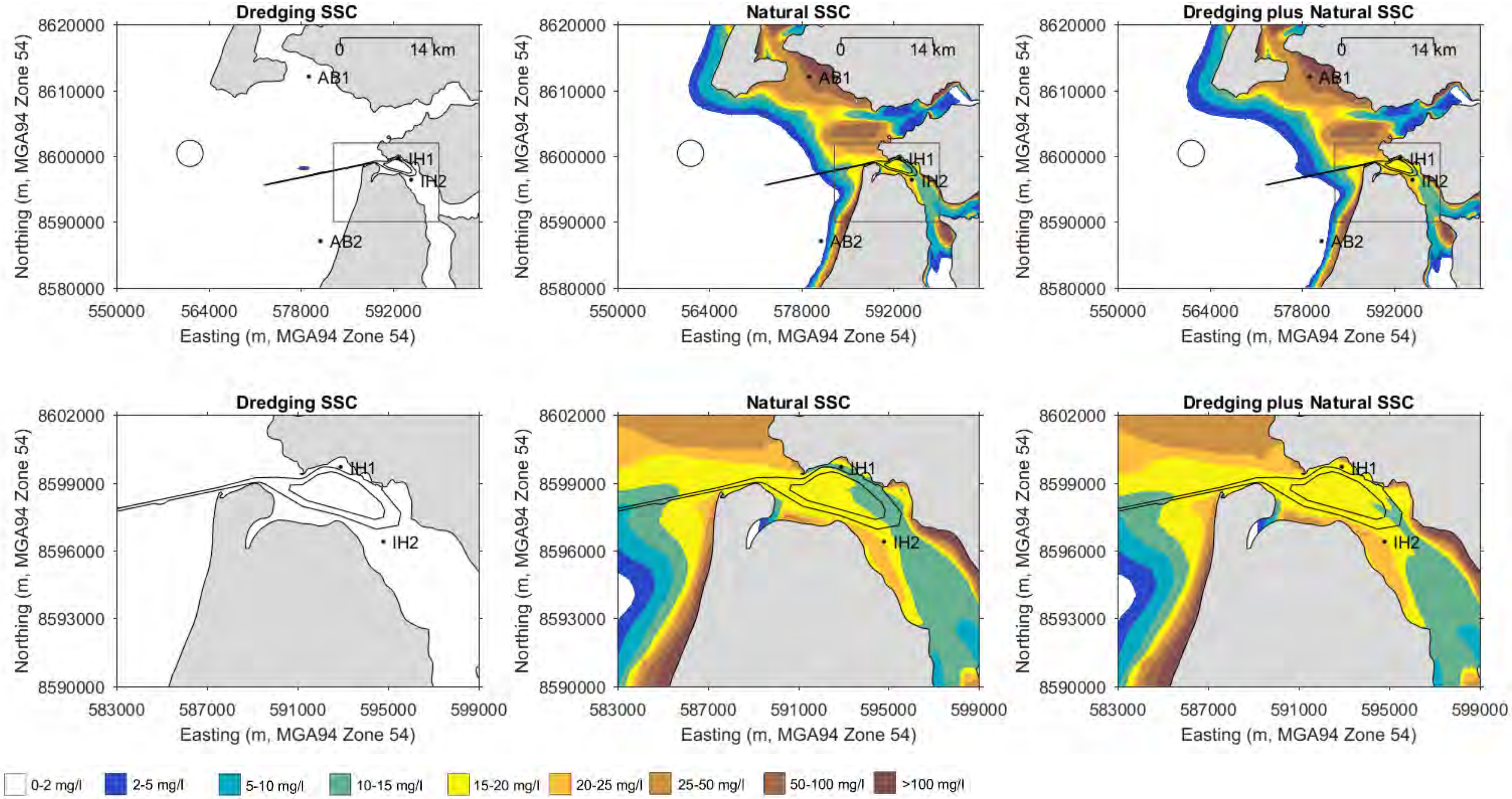


Figure A47. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

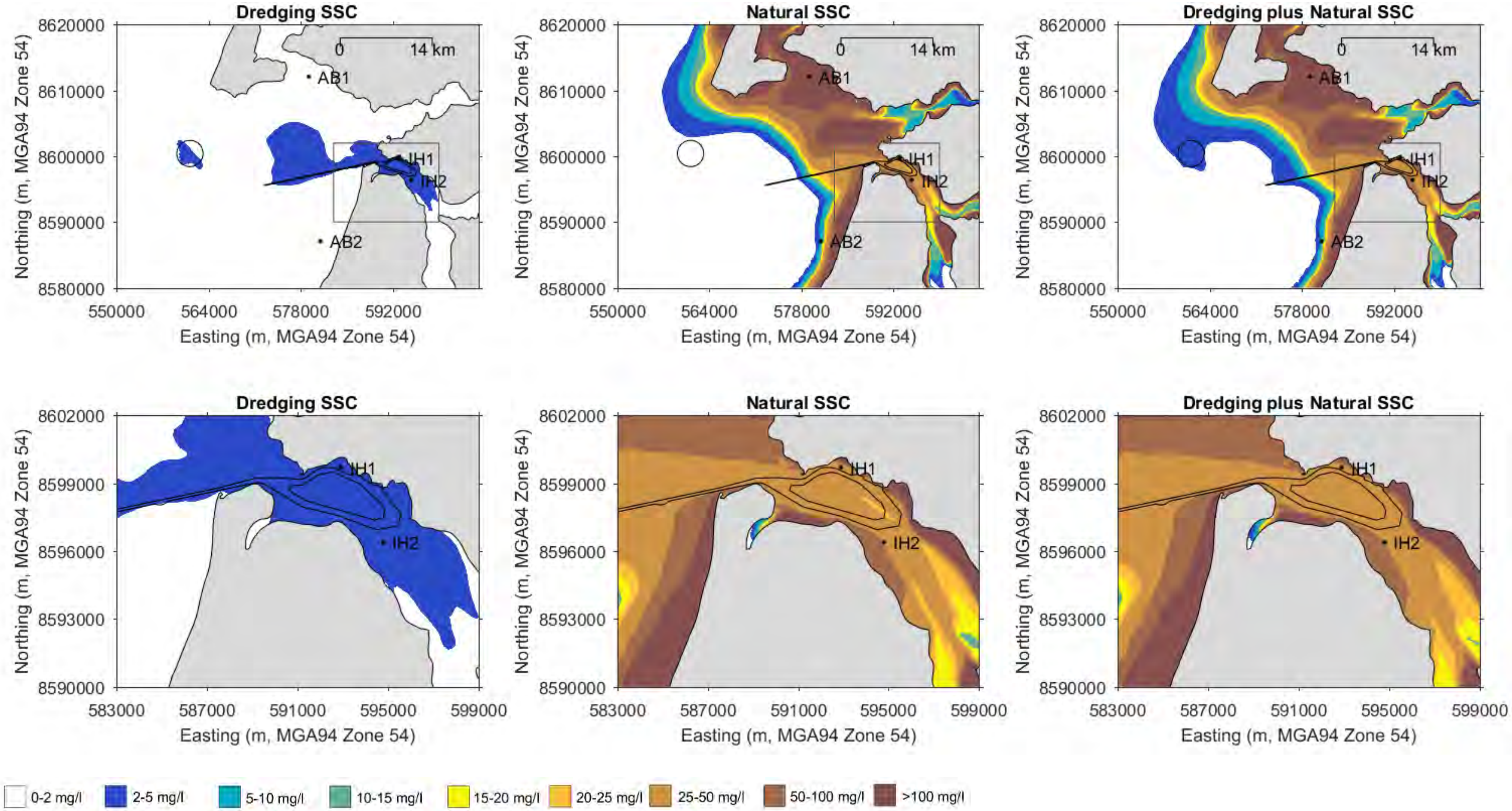


Figure A48. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

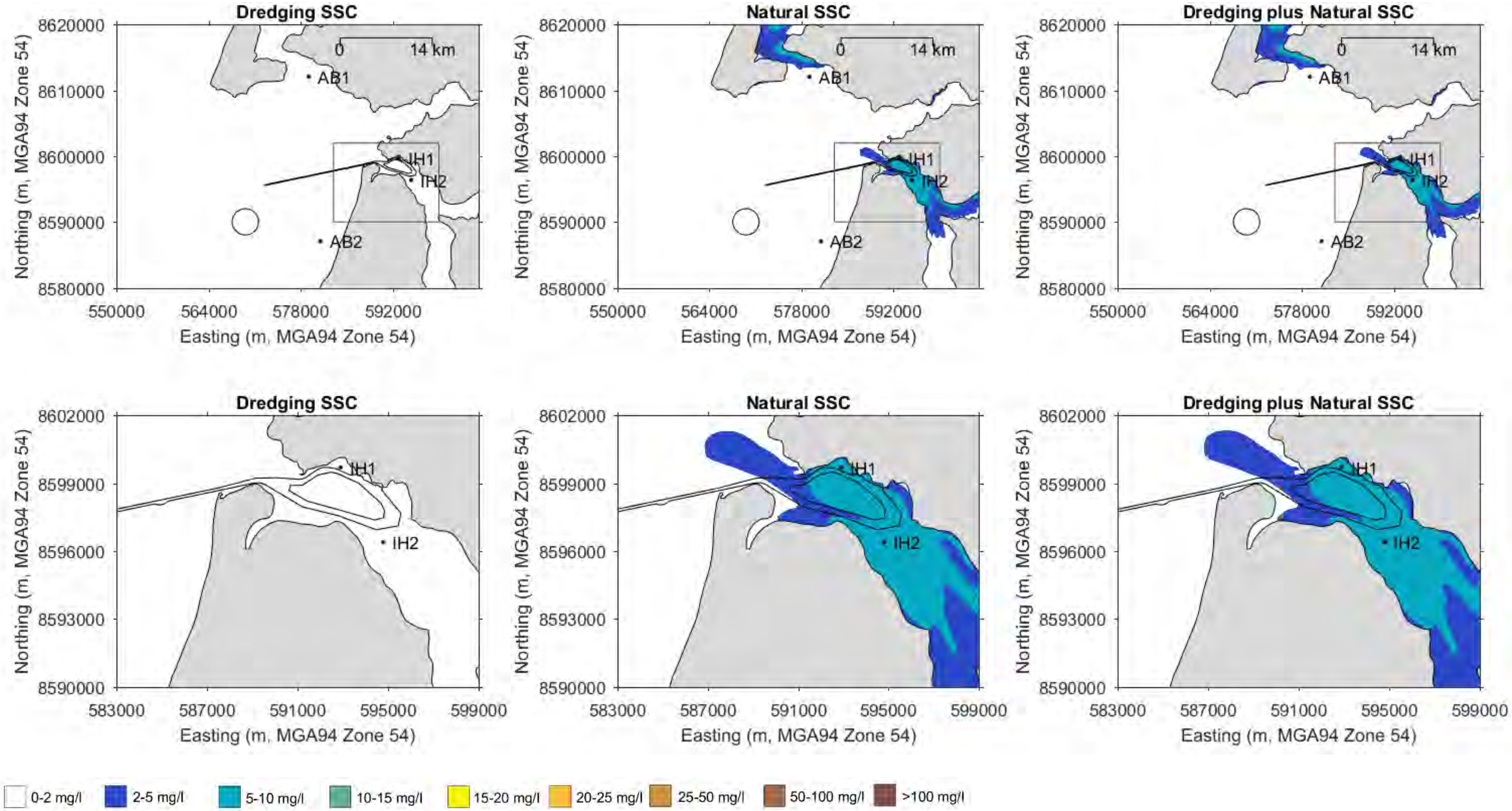


Figure A49. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

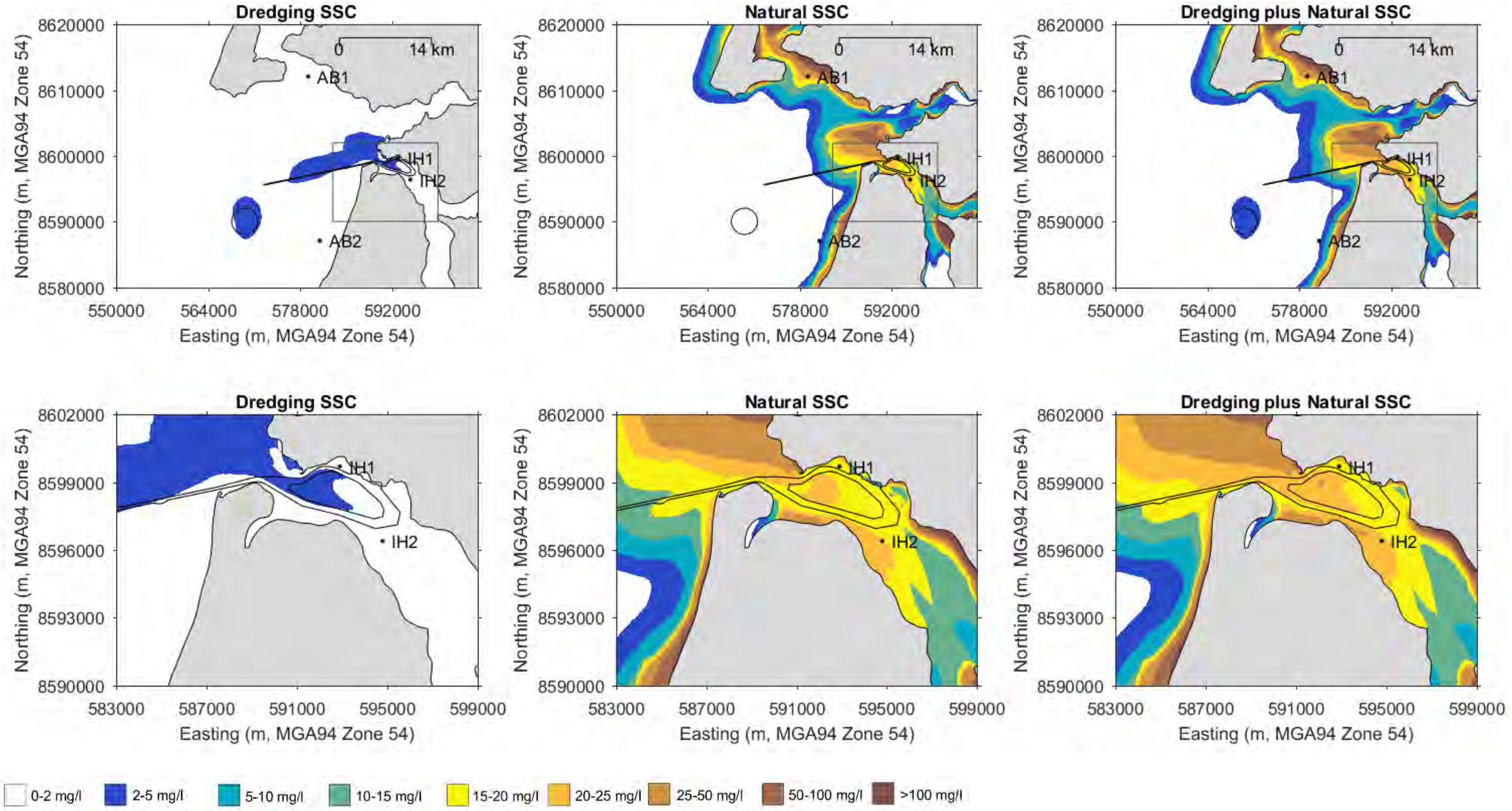


Figure A50. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

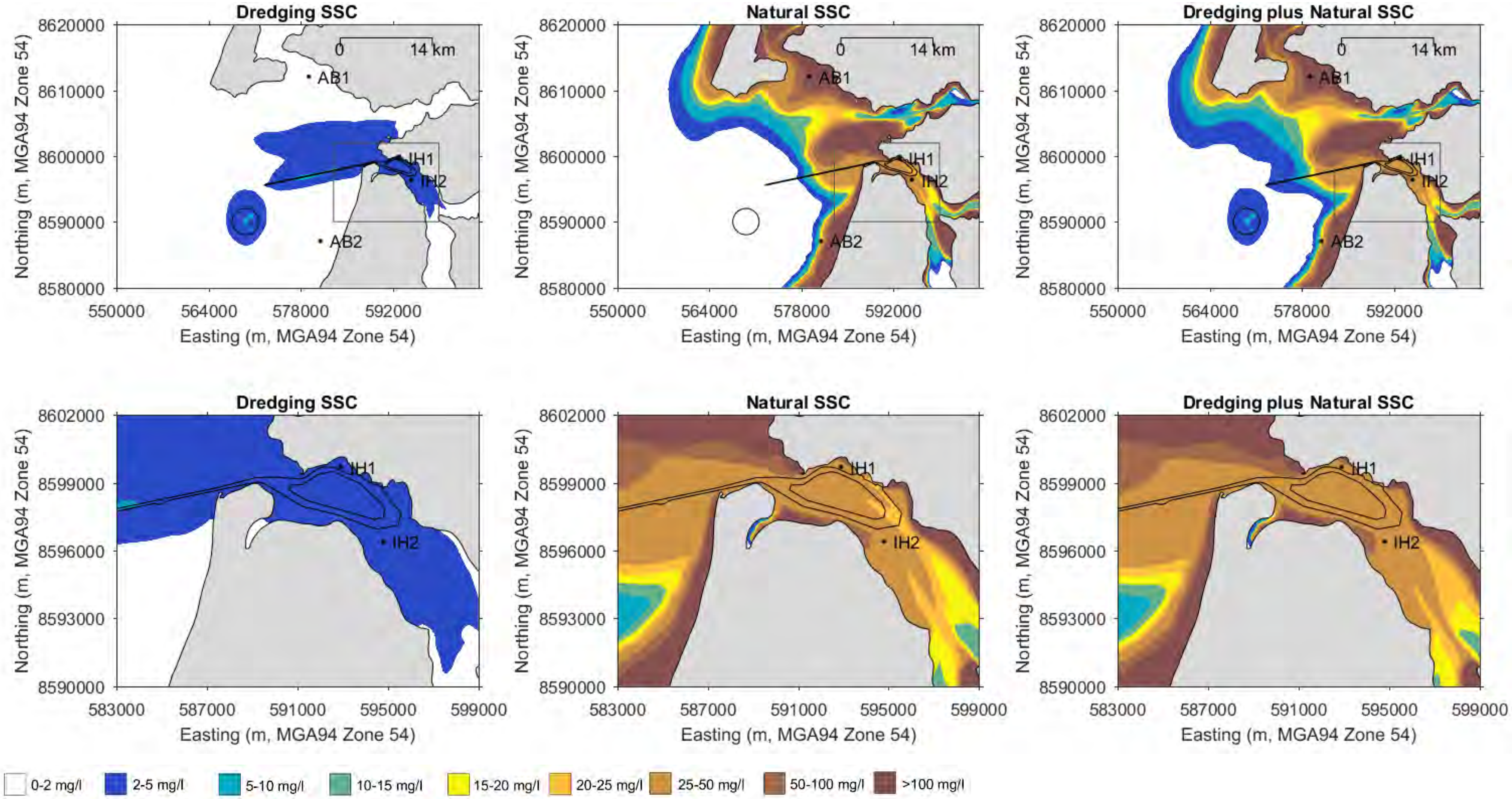


Figure A51. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

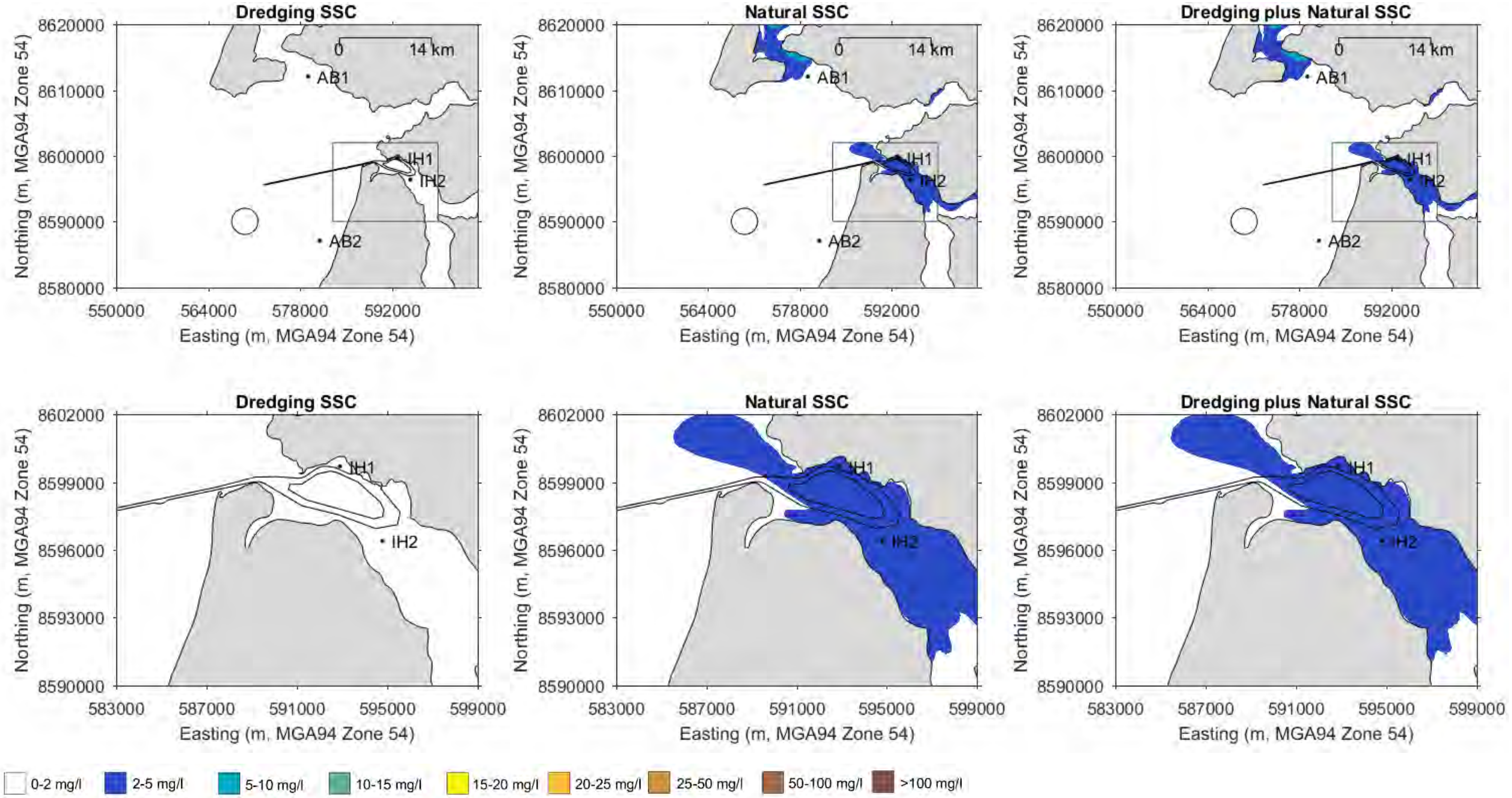


Figure A52. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

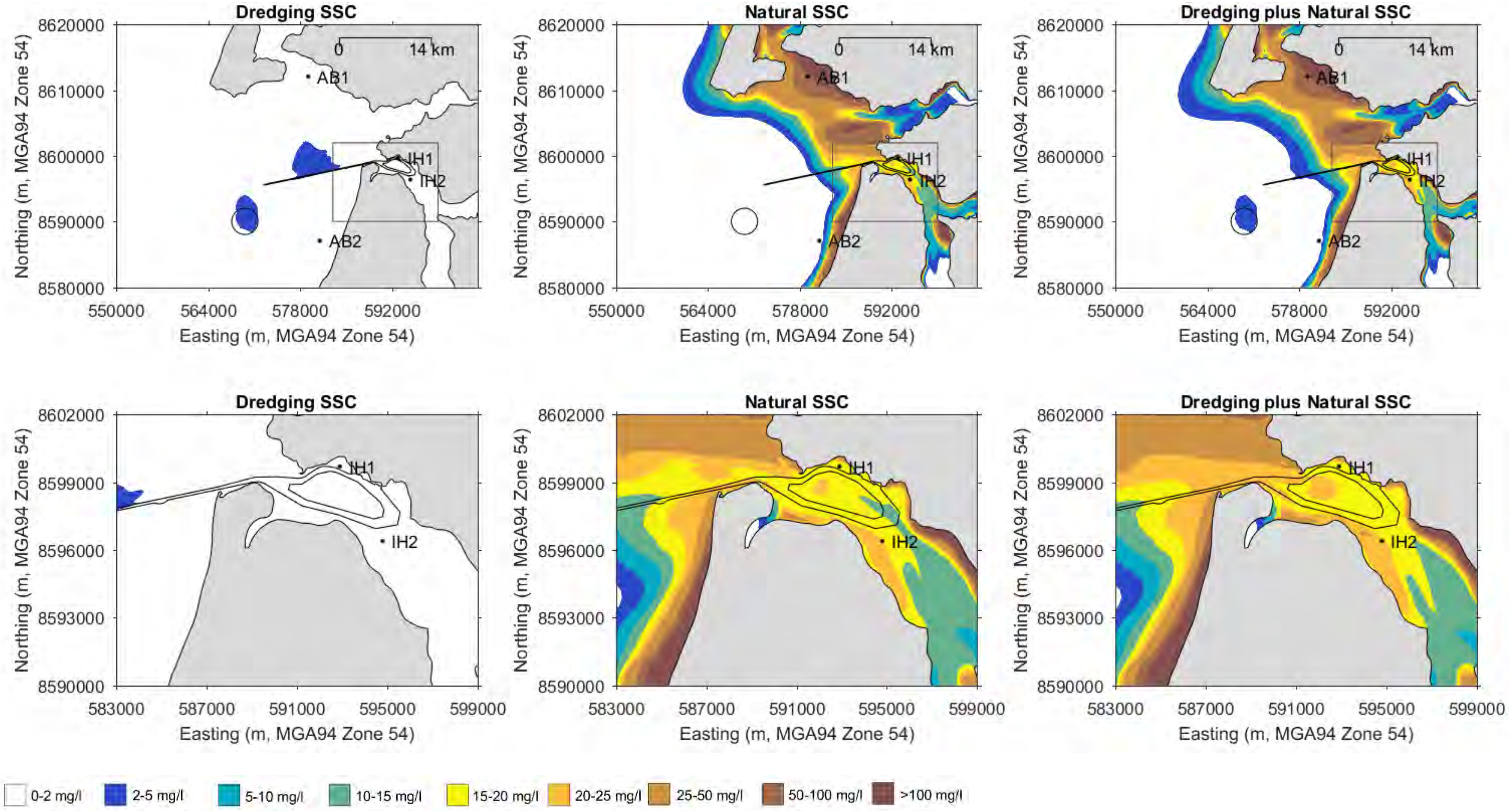


Figure A53. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

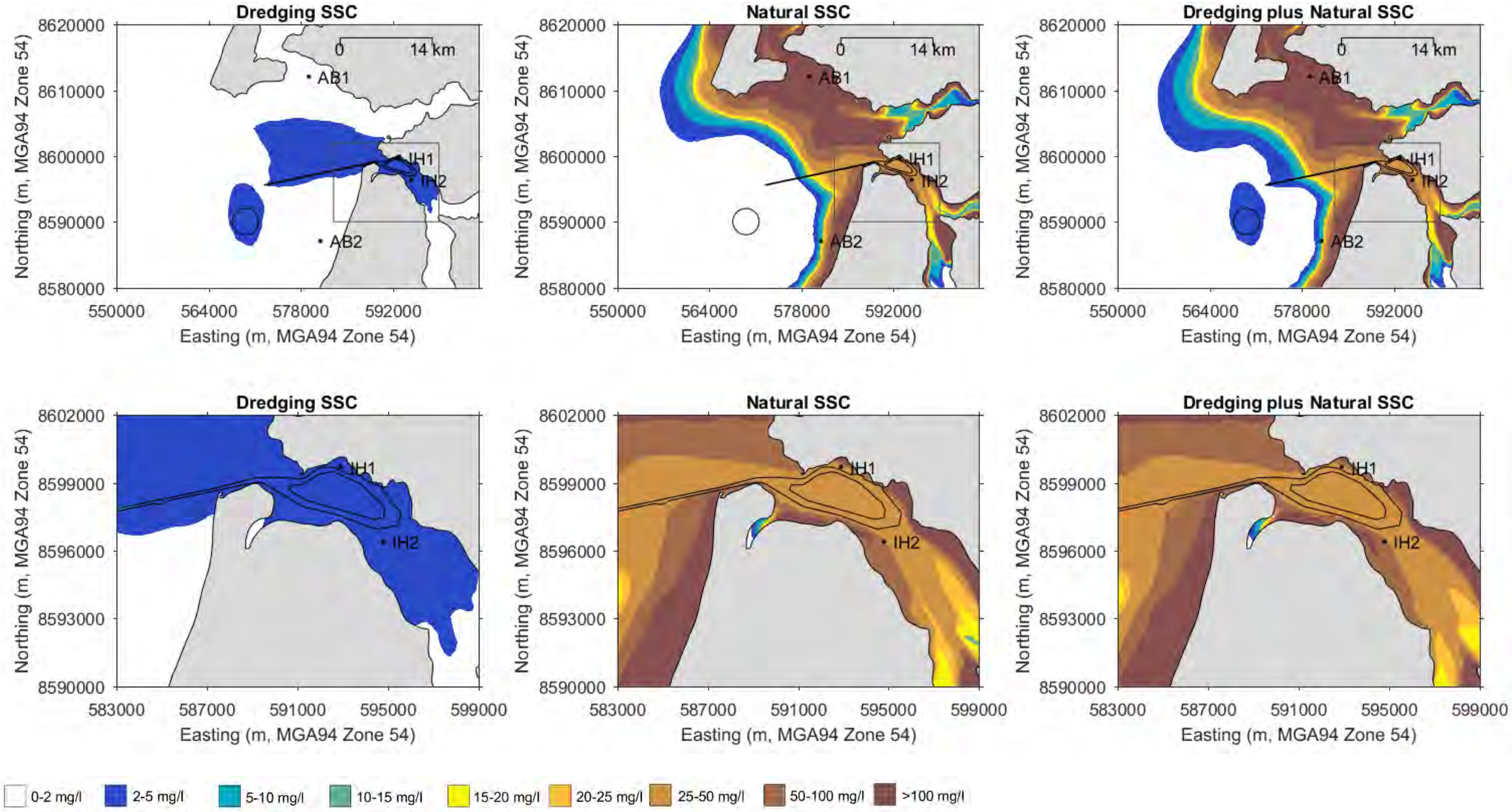


Figure A54. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

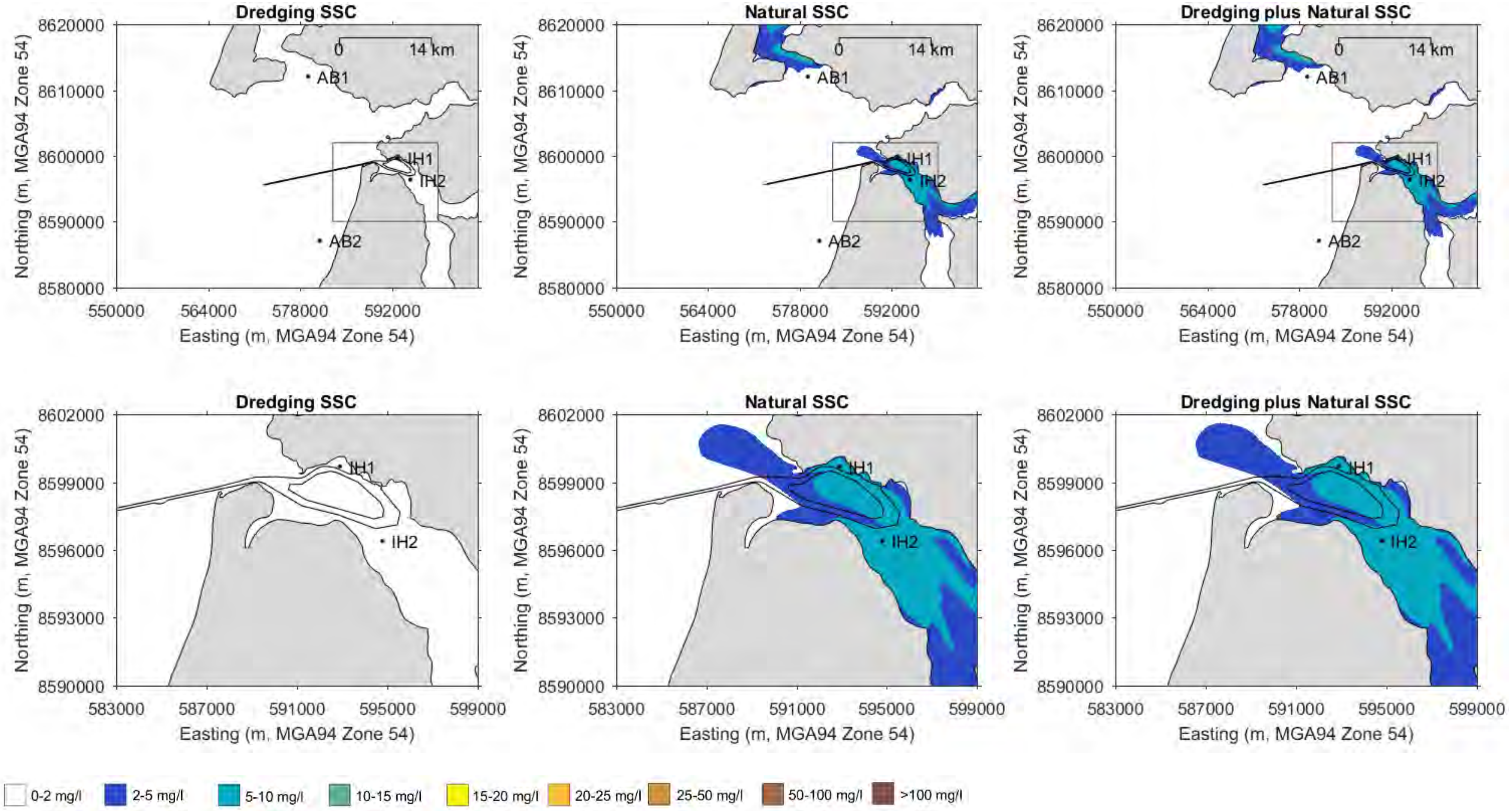


Figure A55. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

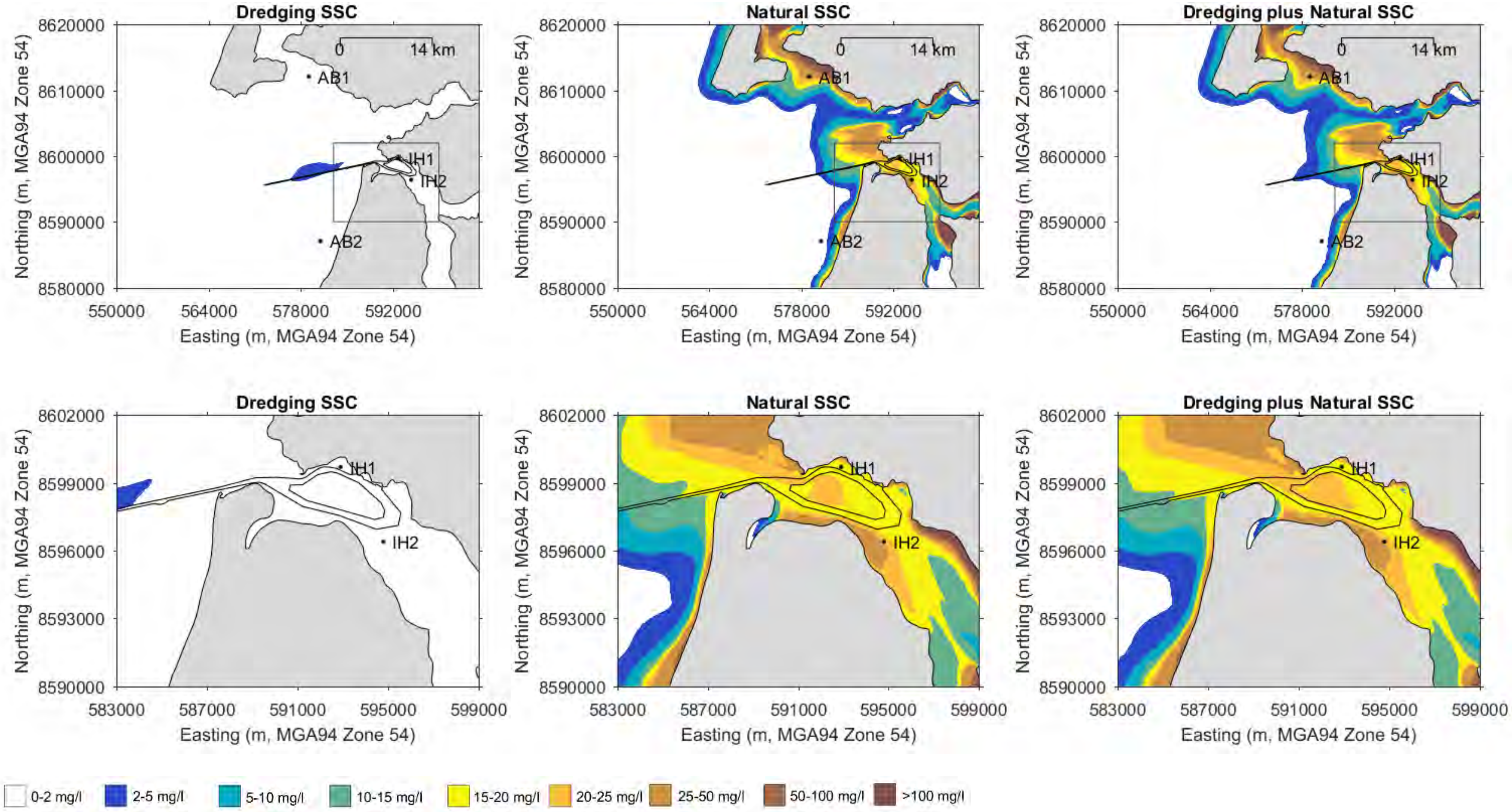


Figure A56. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

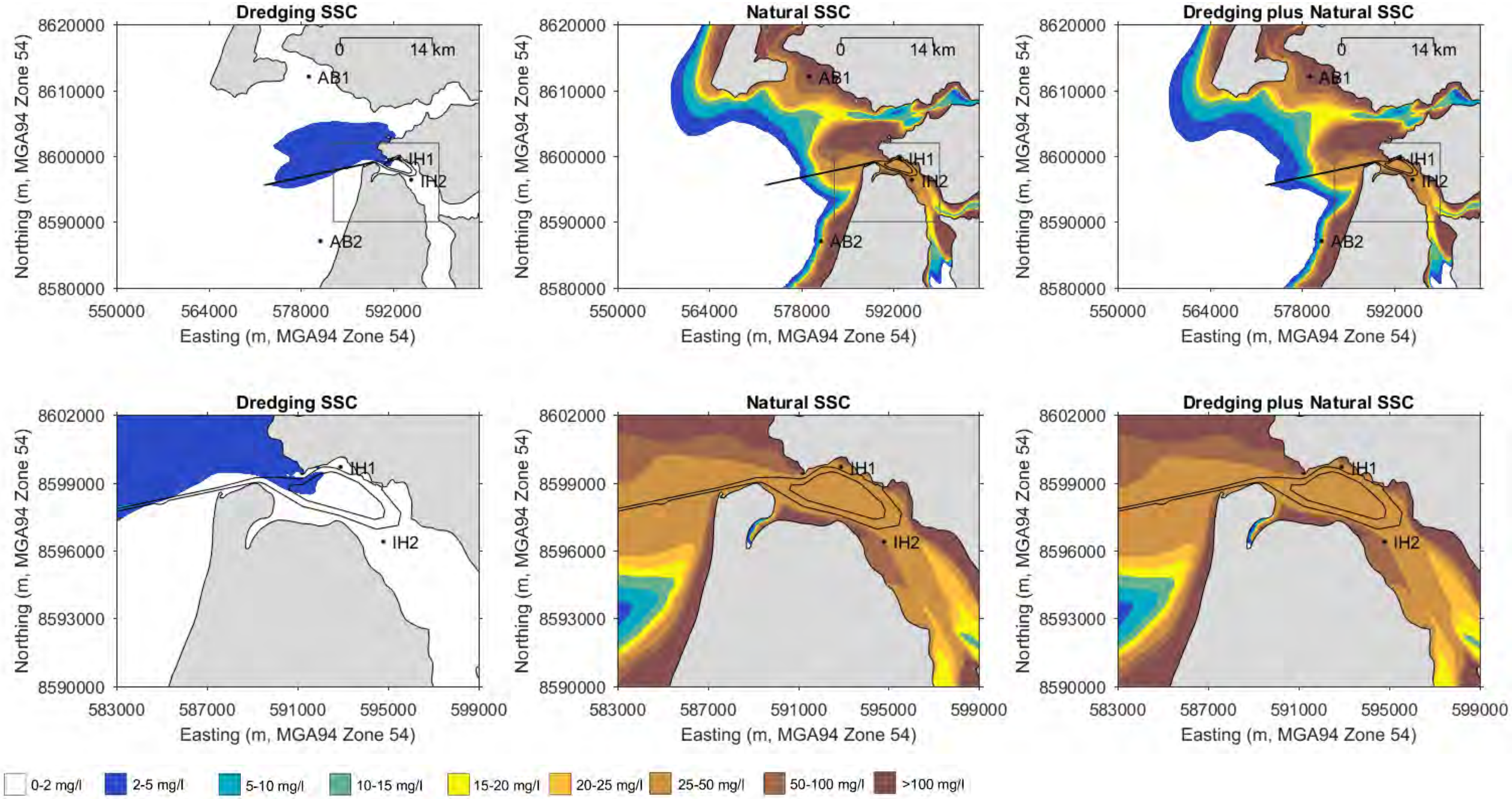


Figure A57. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

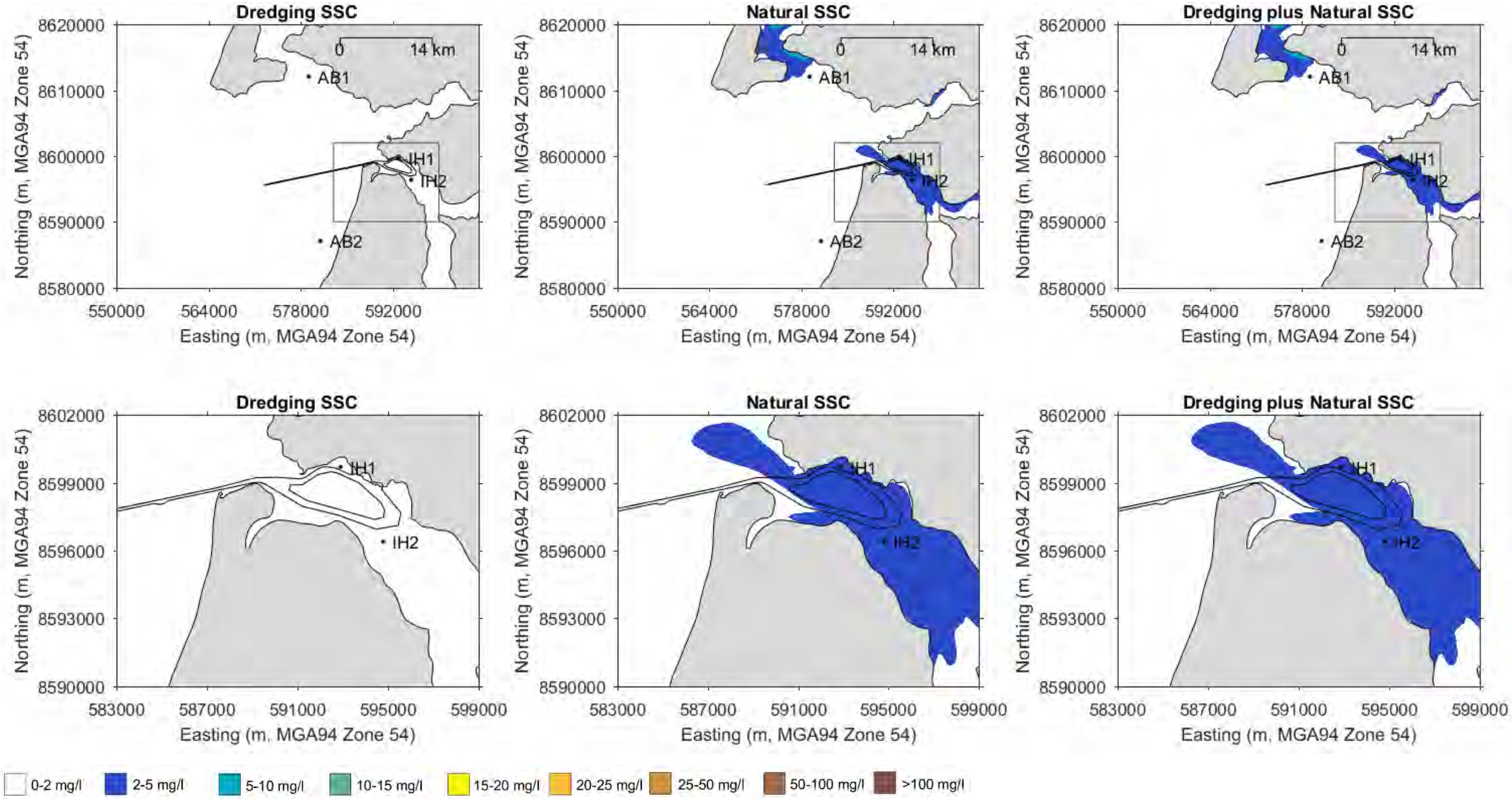


Figure A58. 20th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.

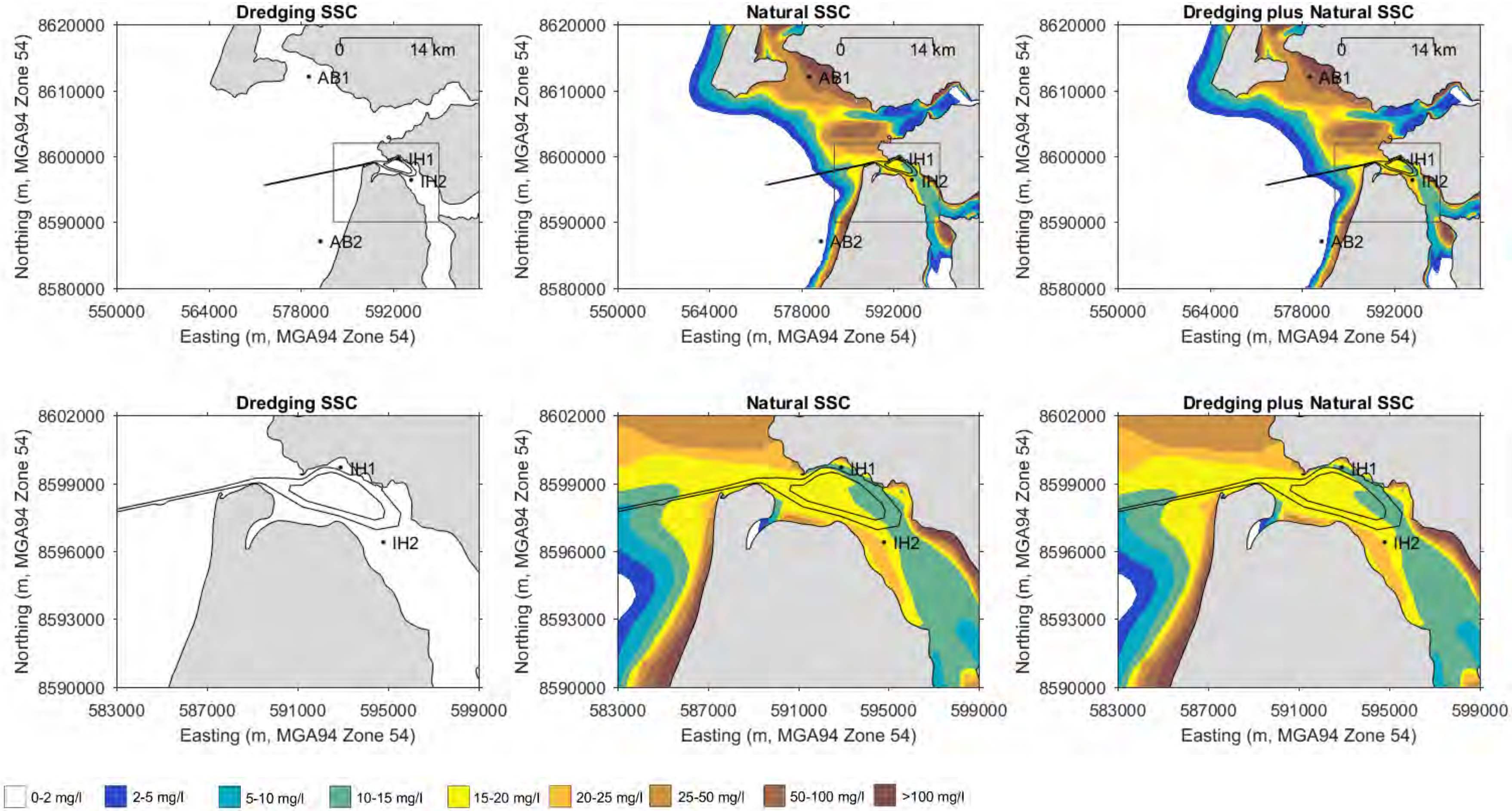


Figure A59. 80th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.

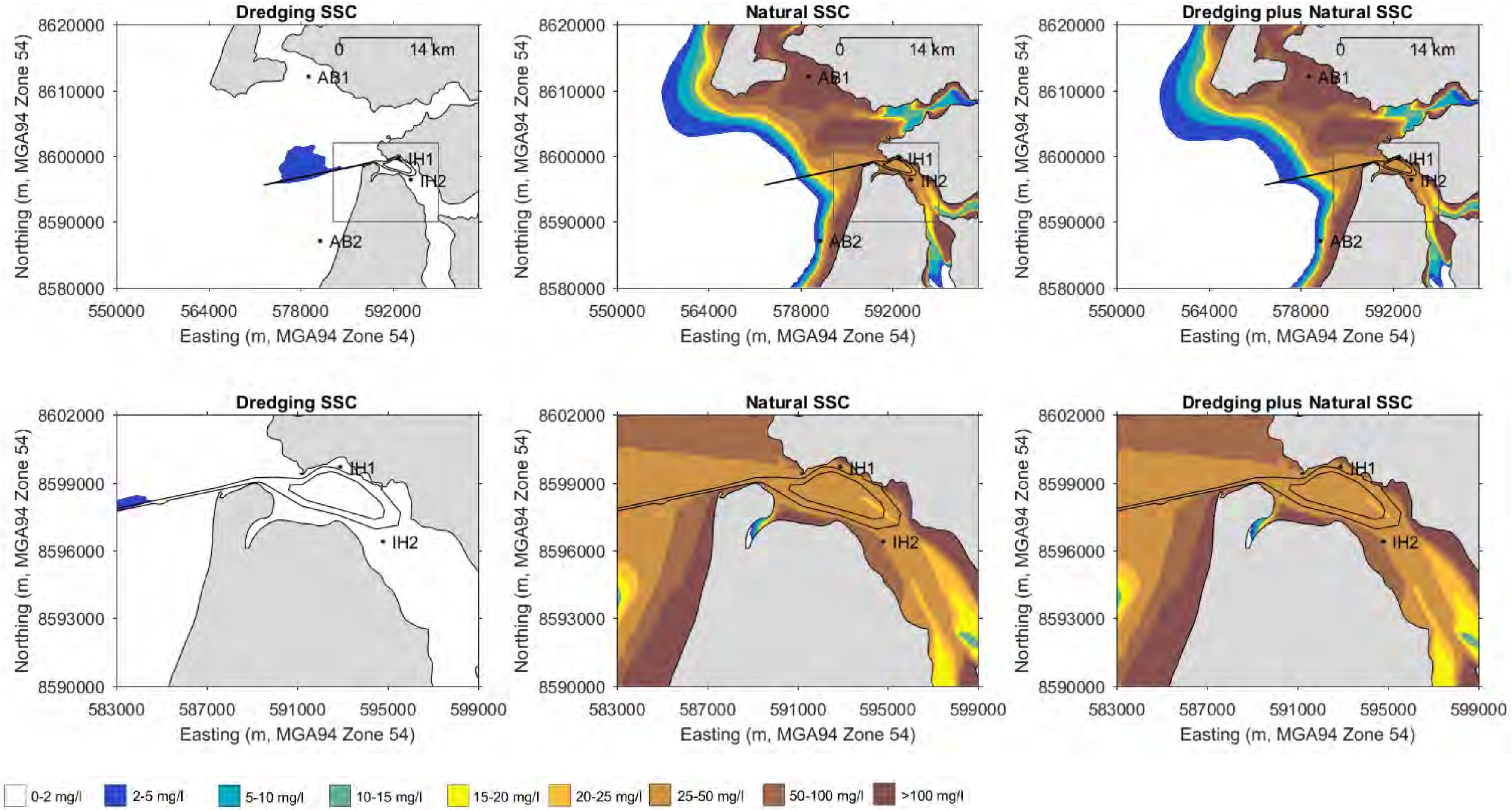


Figure A60. 95th percentile SSC for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.

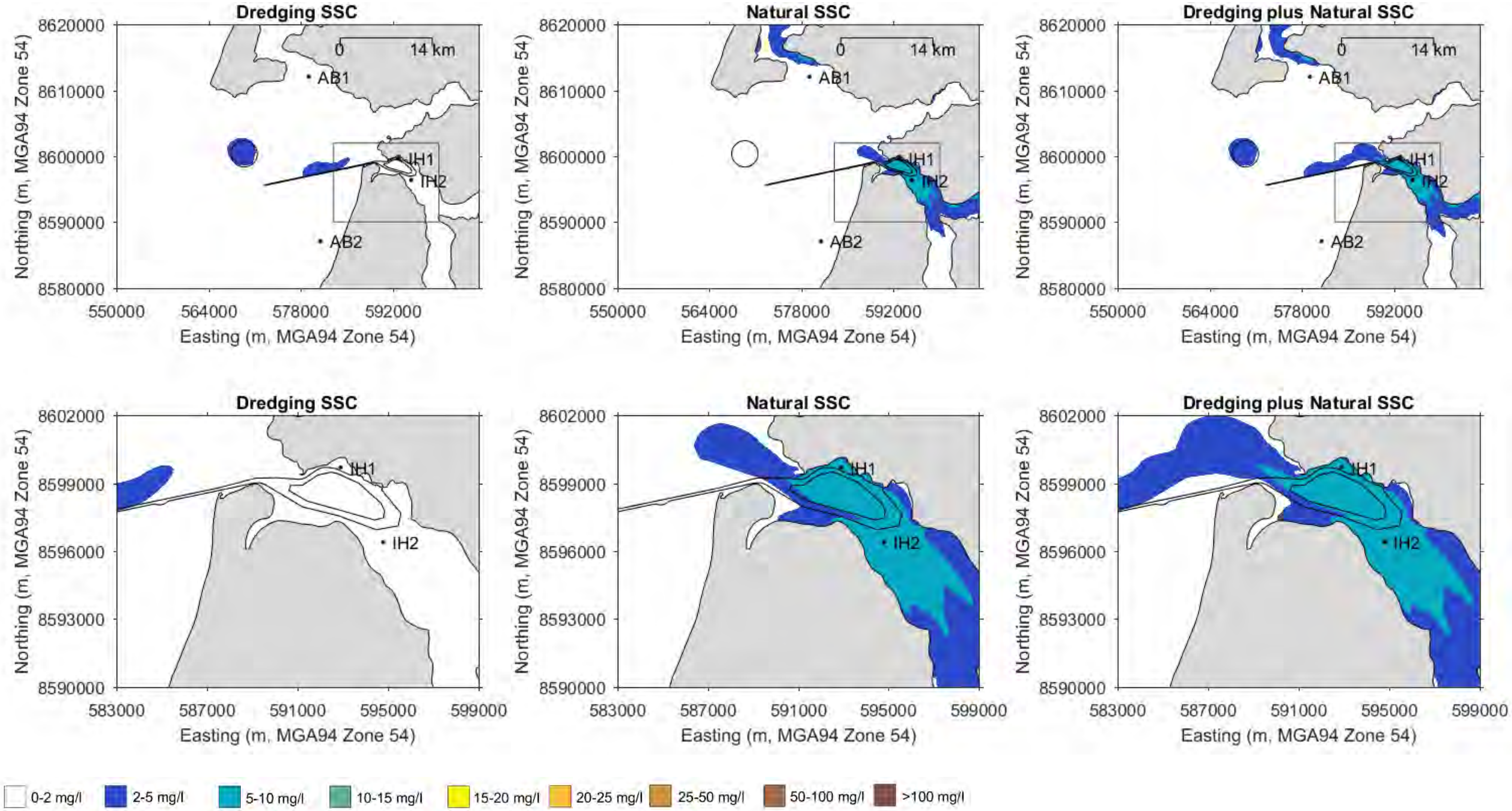


Figure A61. 20th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

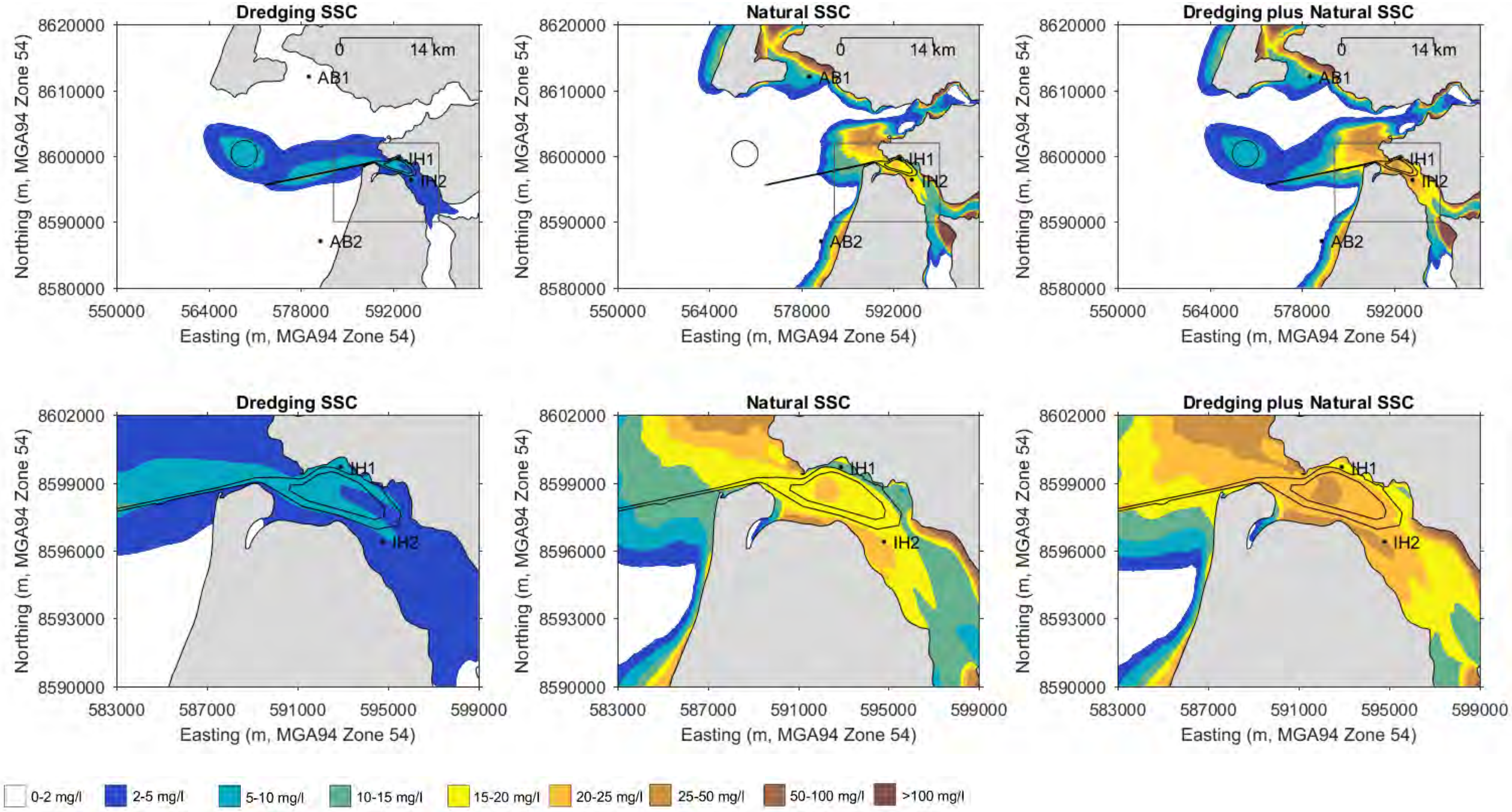


Figure A62. 80th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

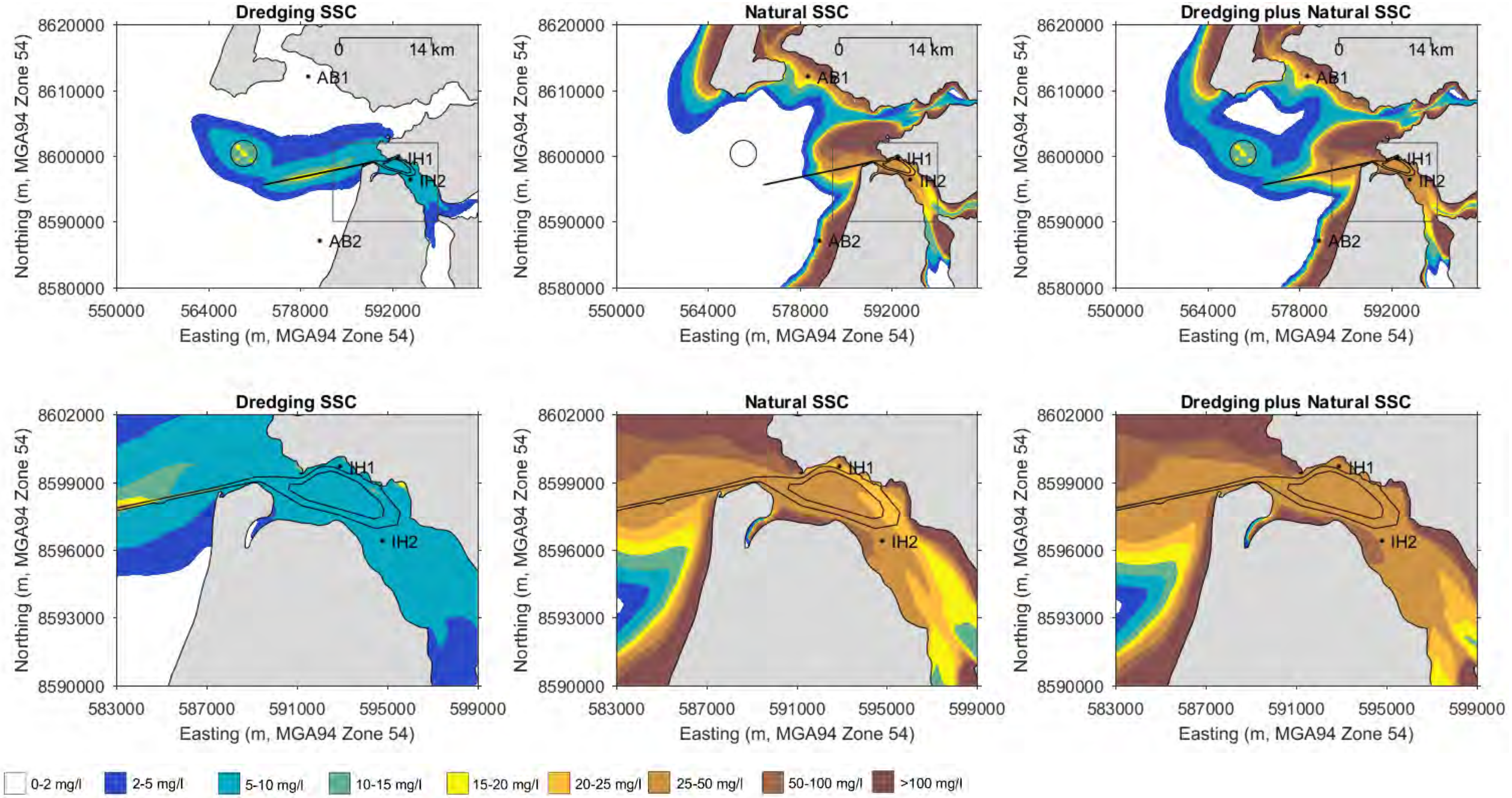


Figure A63. 95th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

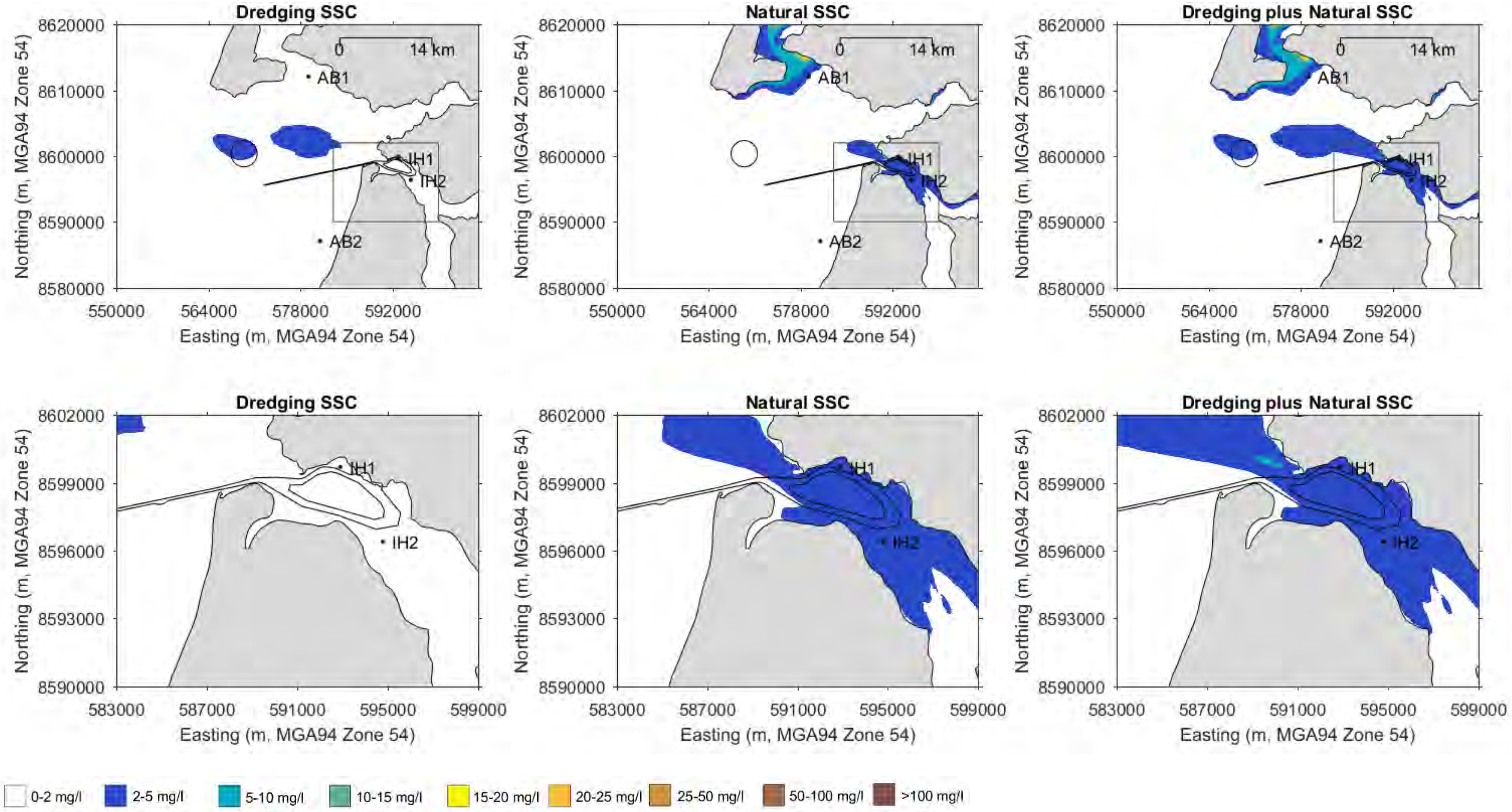


Figure A64. 20th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

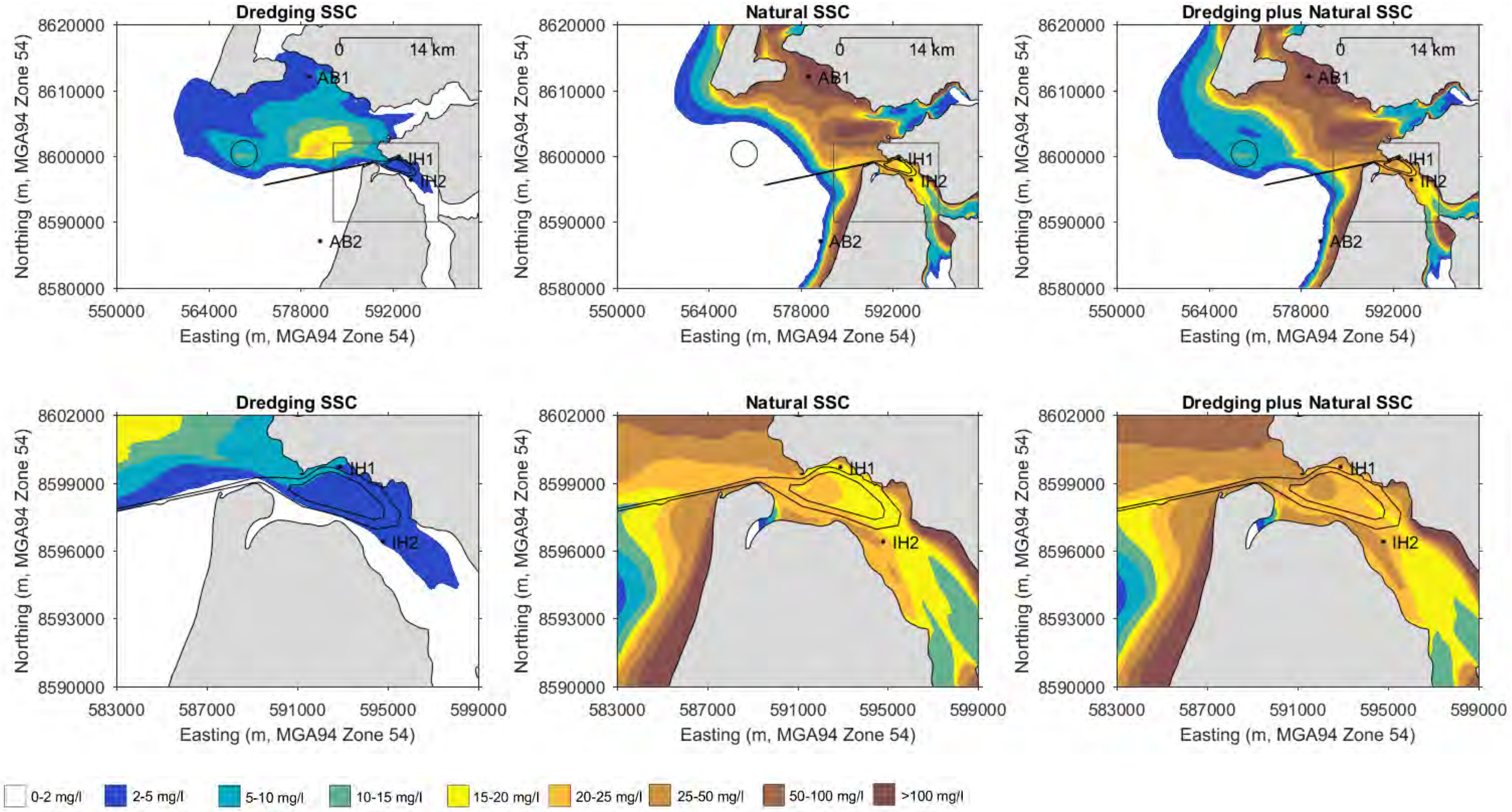


Figure A65. 80th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

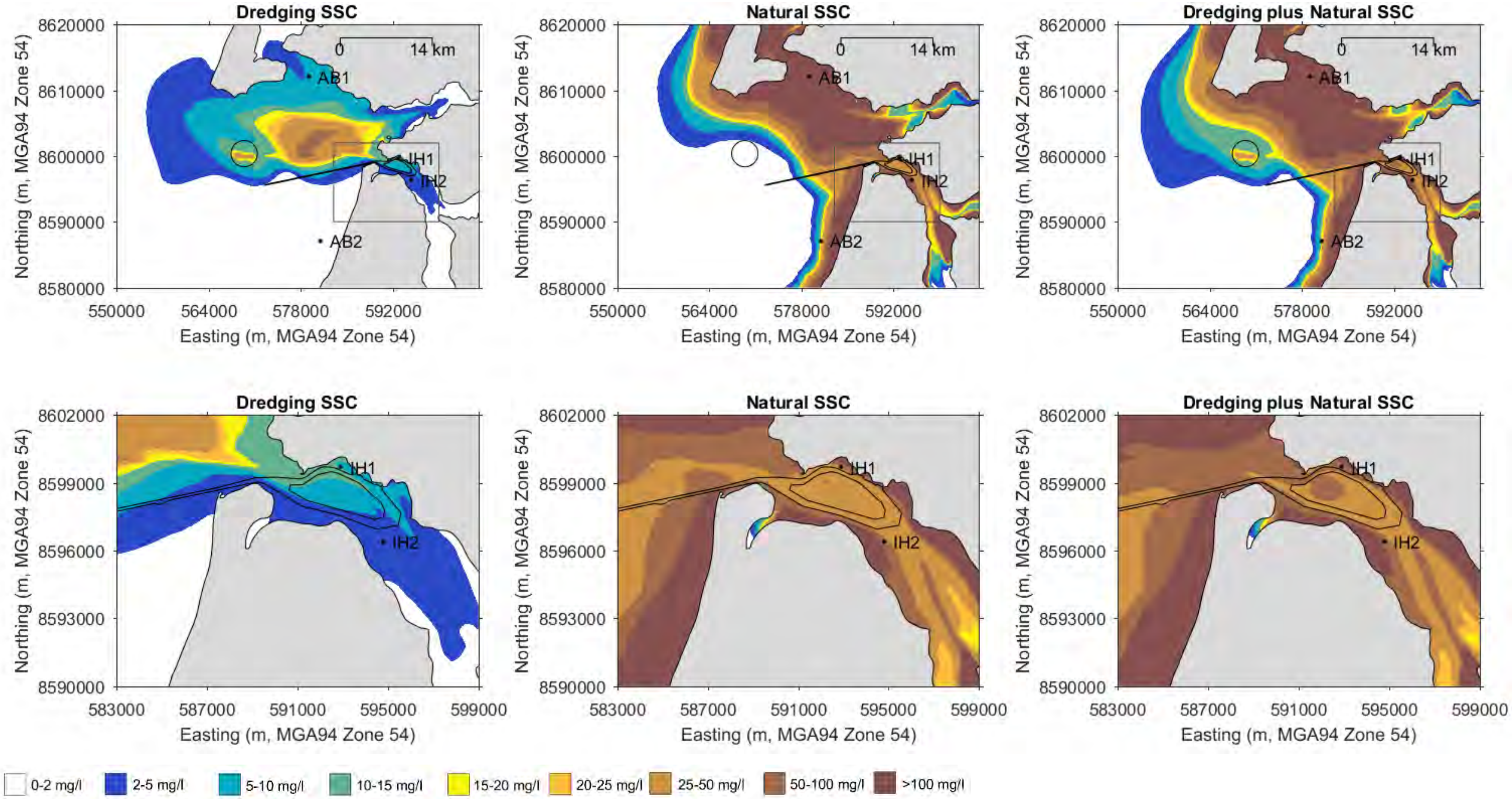


Figure A66. 95th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

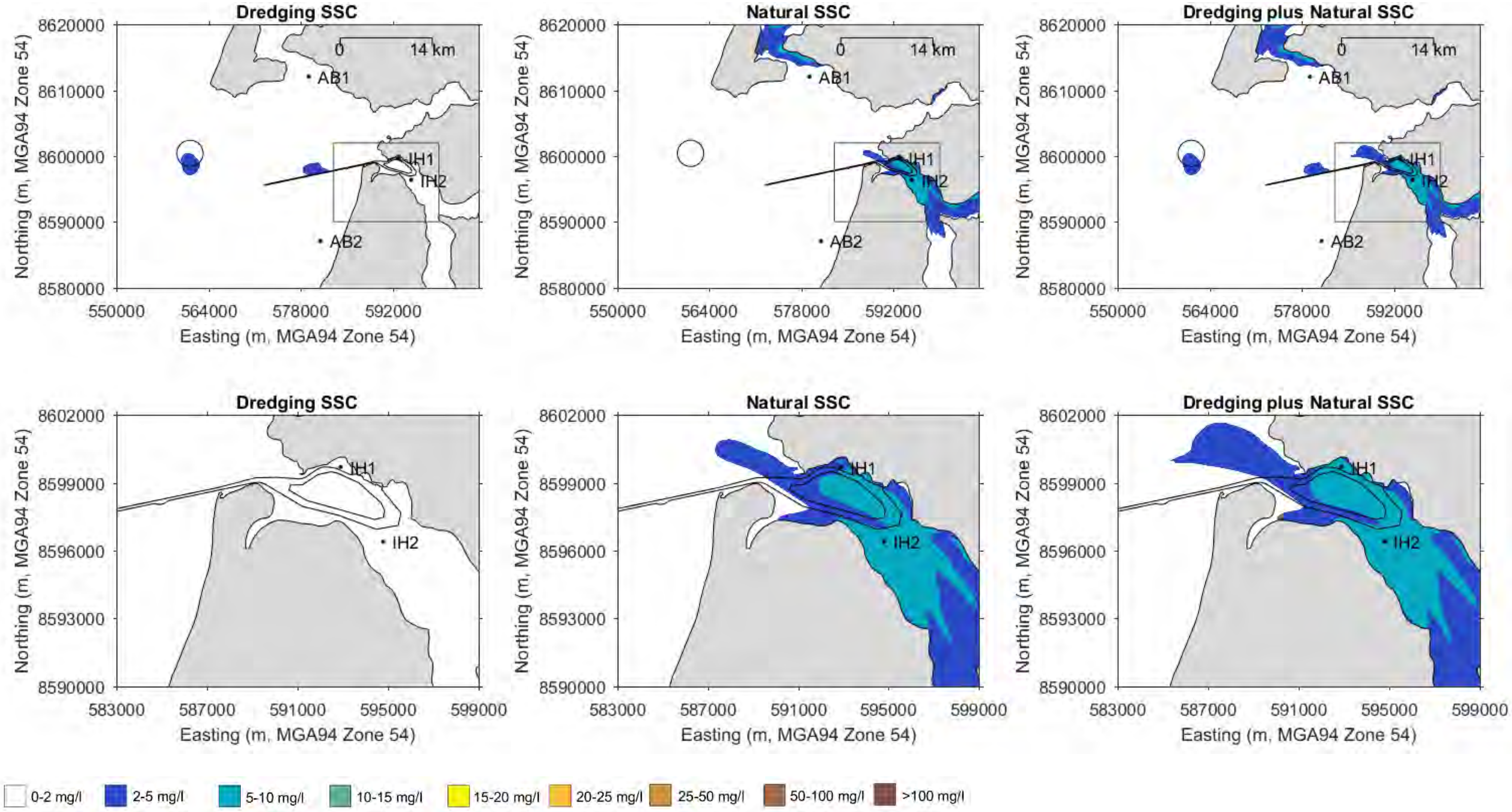


Figure A67. 20th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

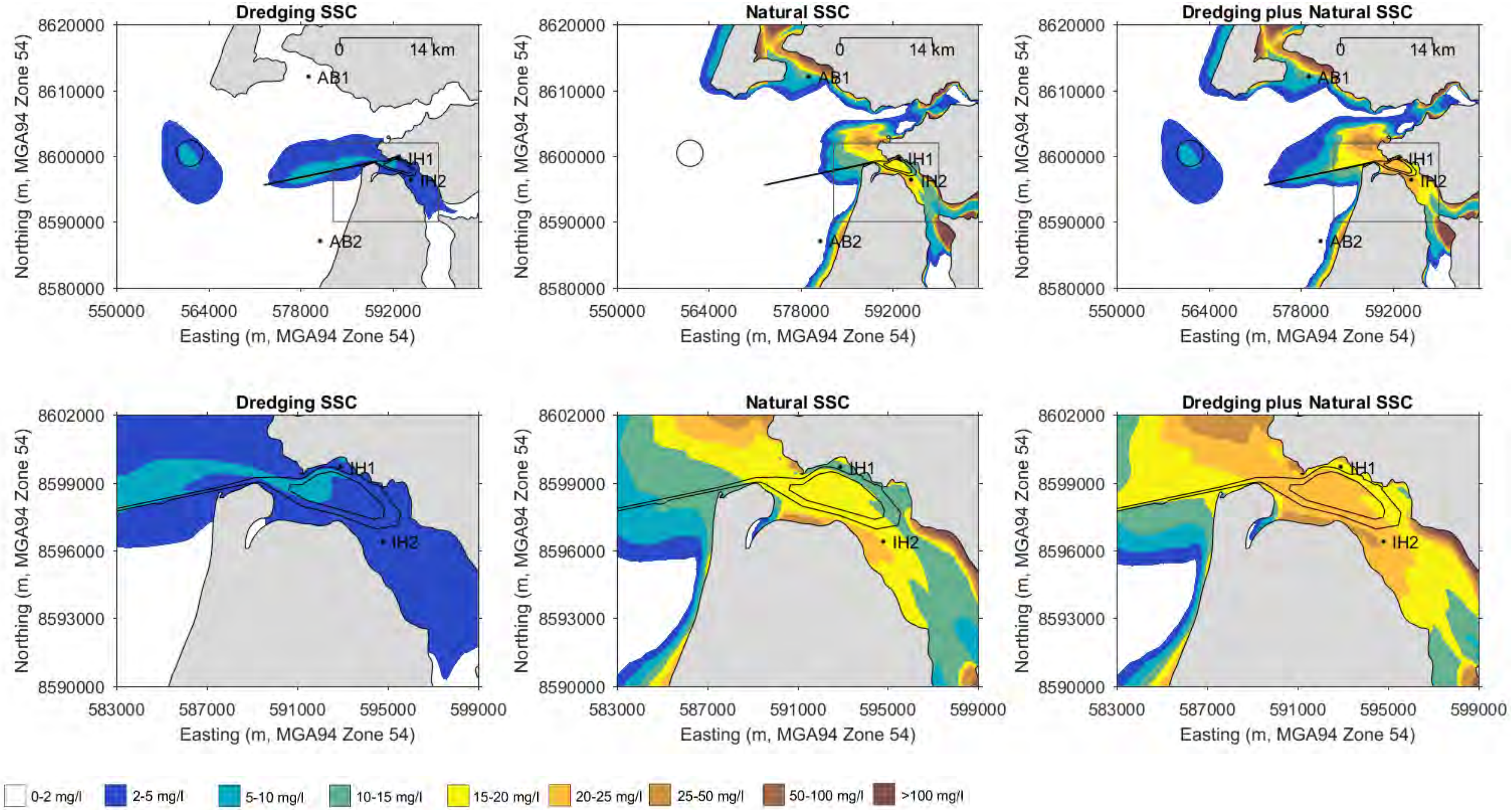


Figure A68. 80th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

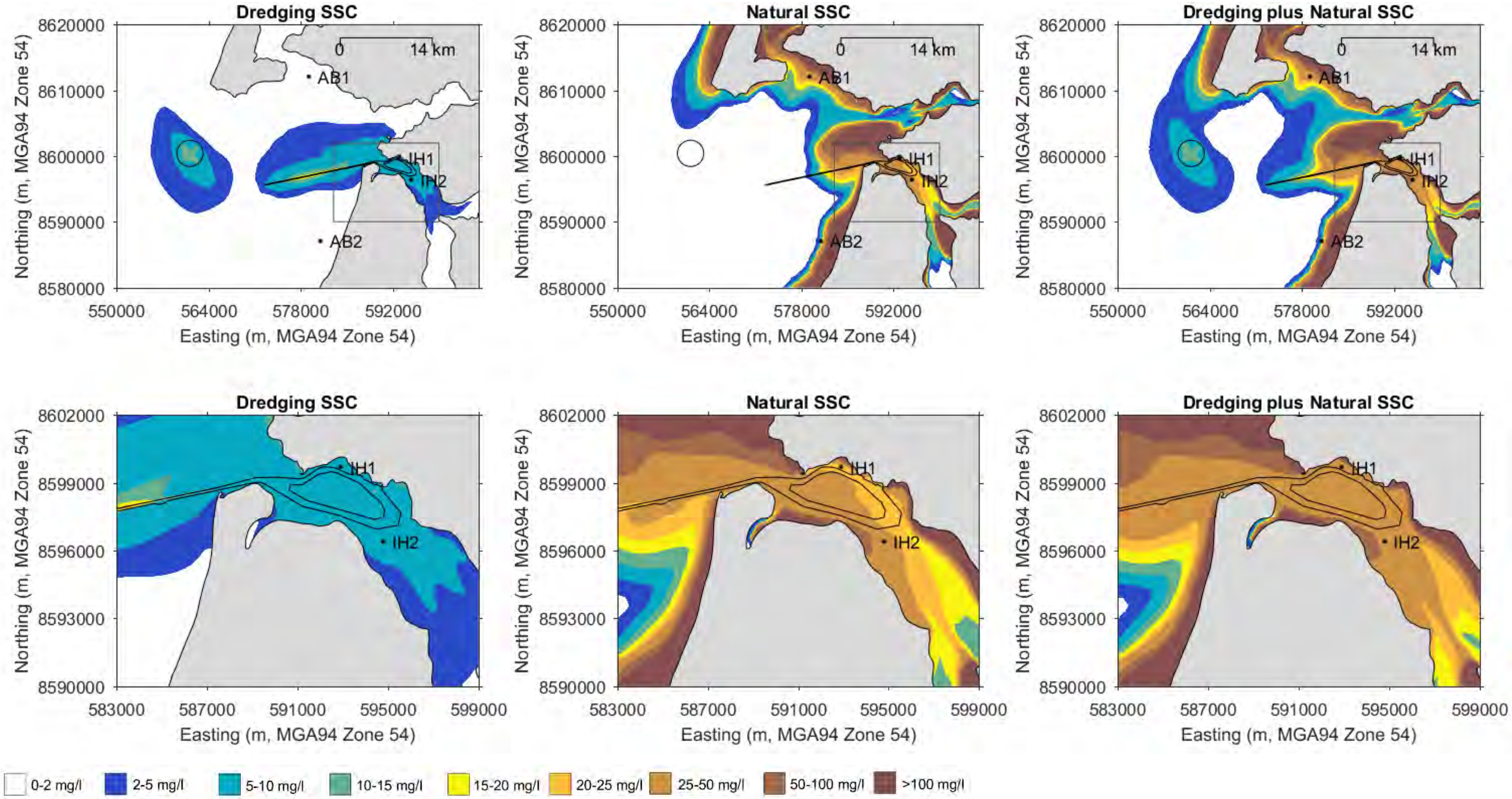


Figure A69. 95th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

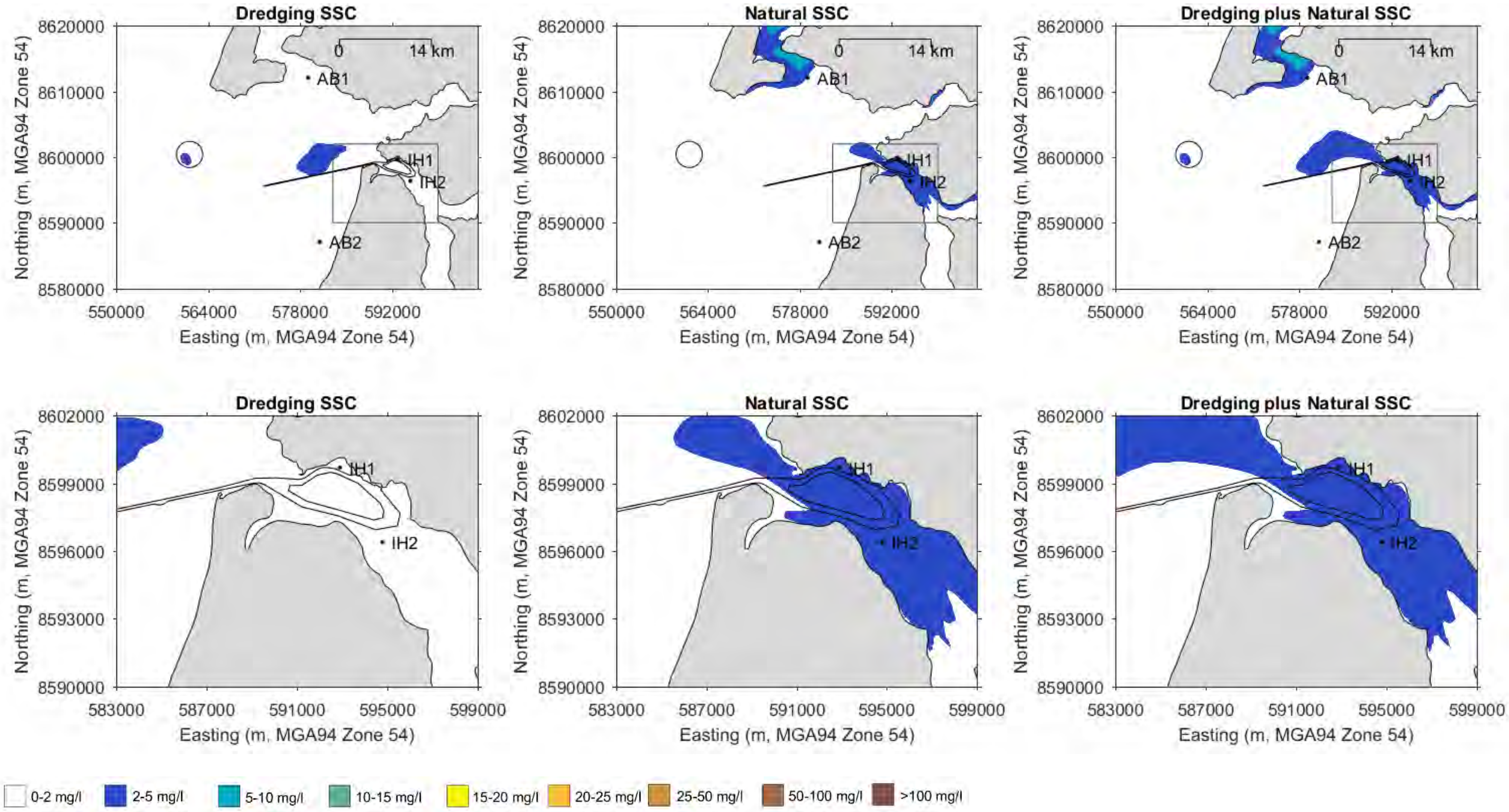


Figure A70. 20th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

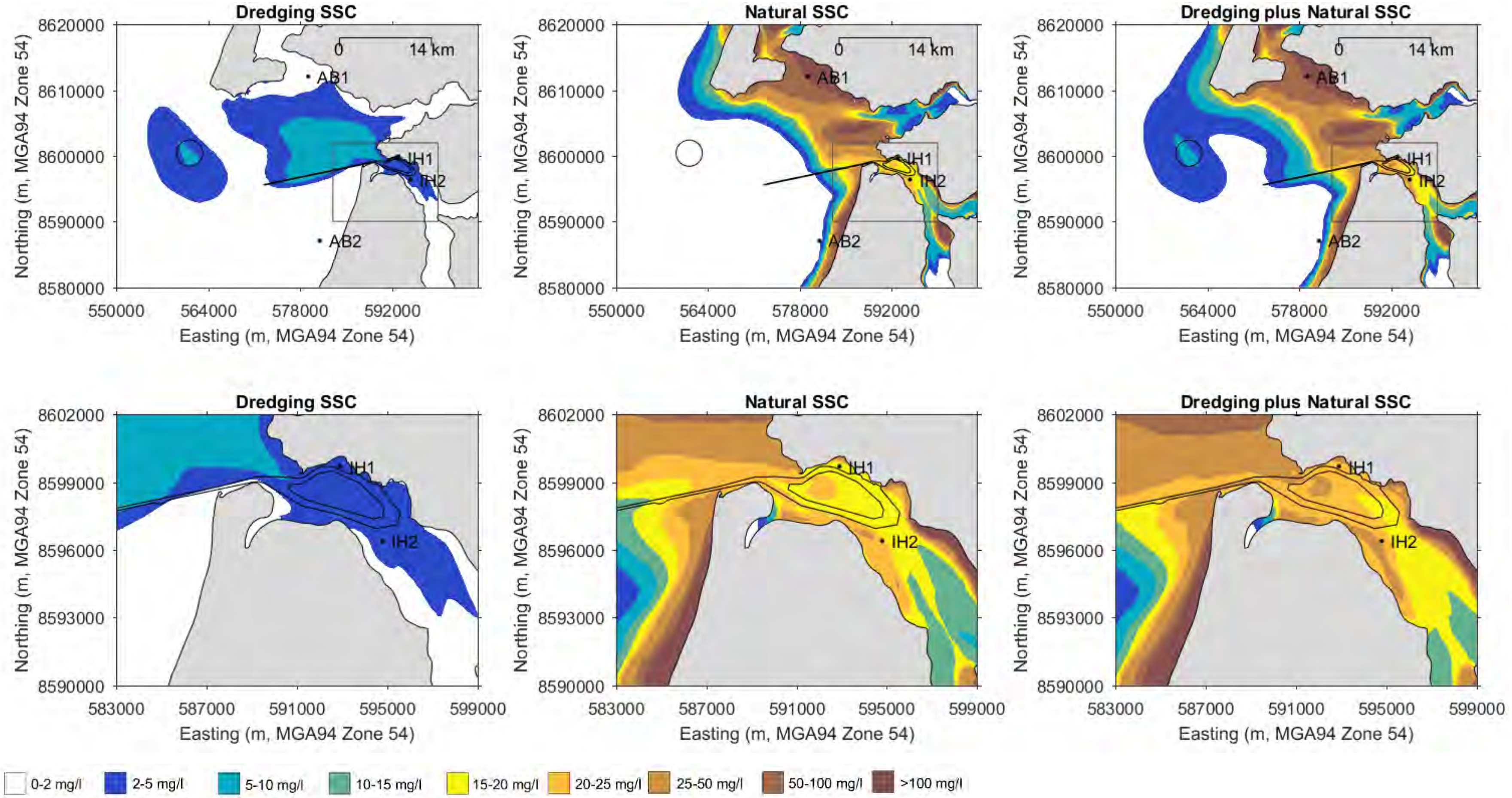


Figure A71. 80th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

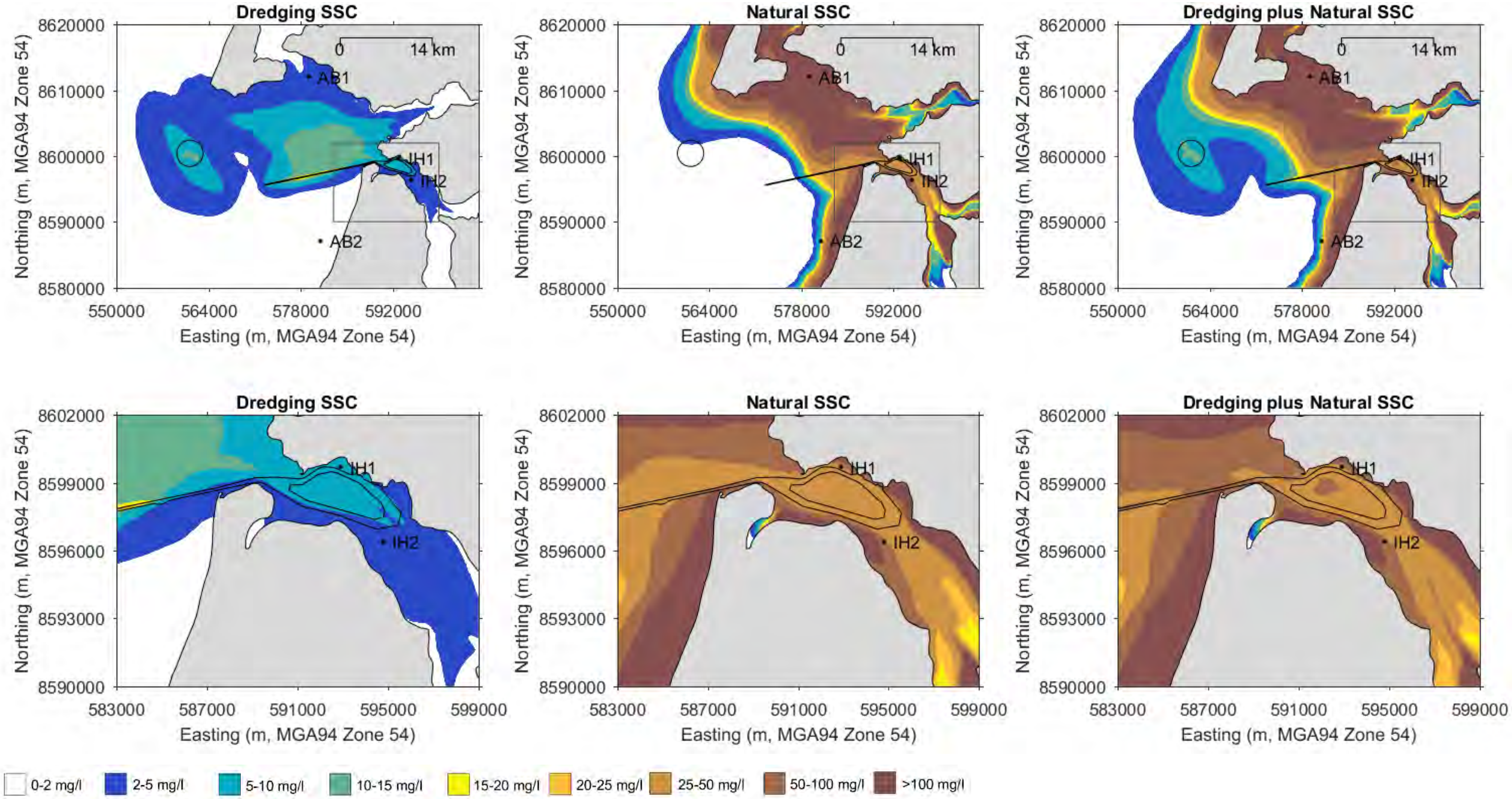


Figure A72. 95th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

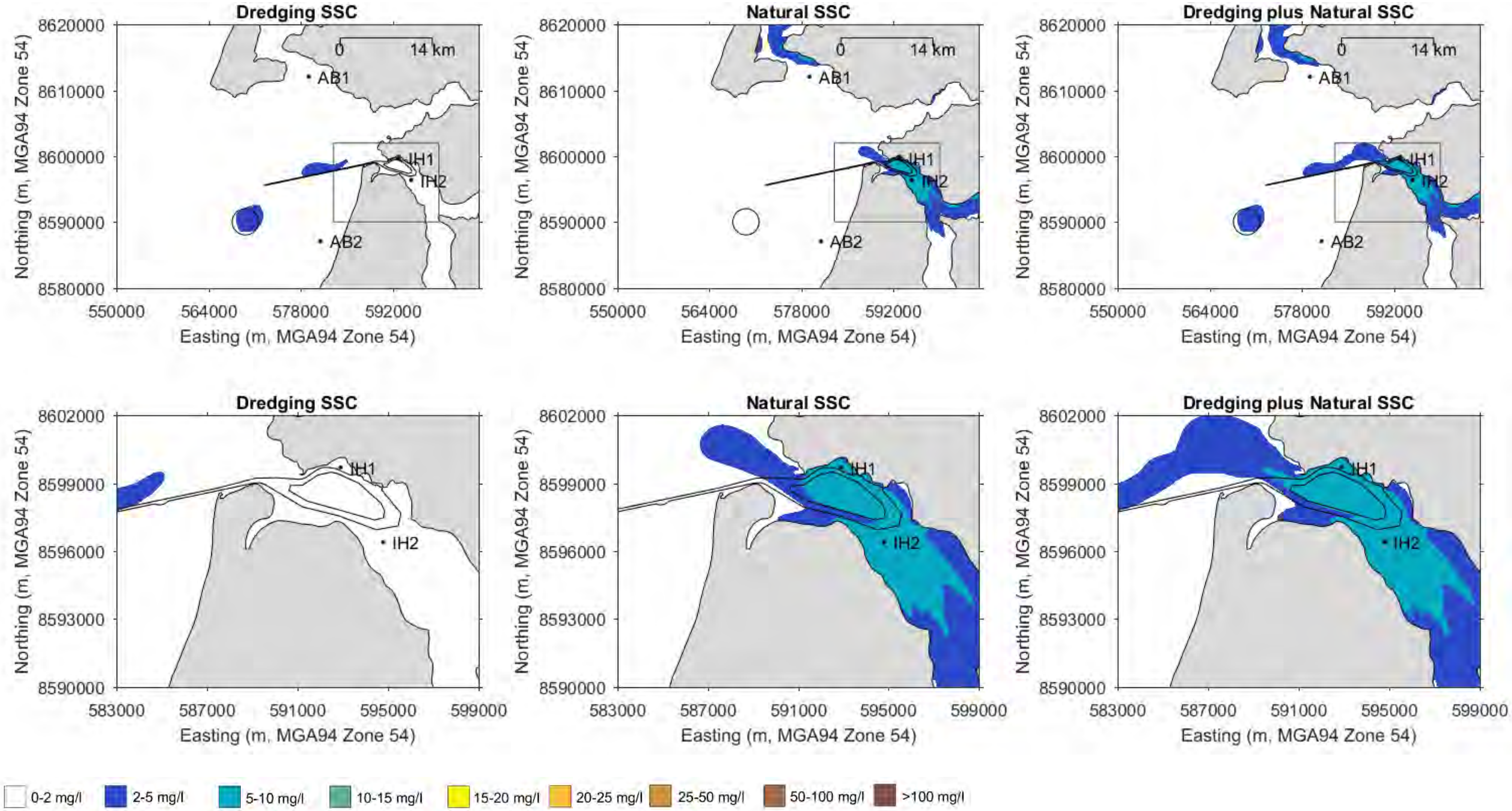


Figure A73. 20th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

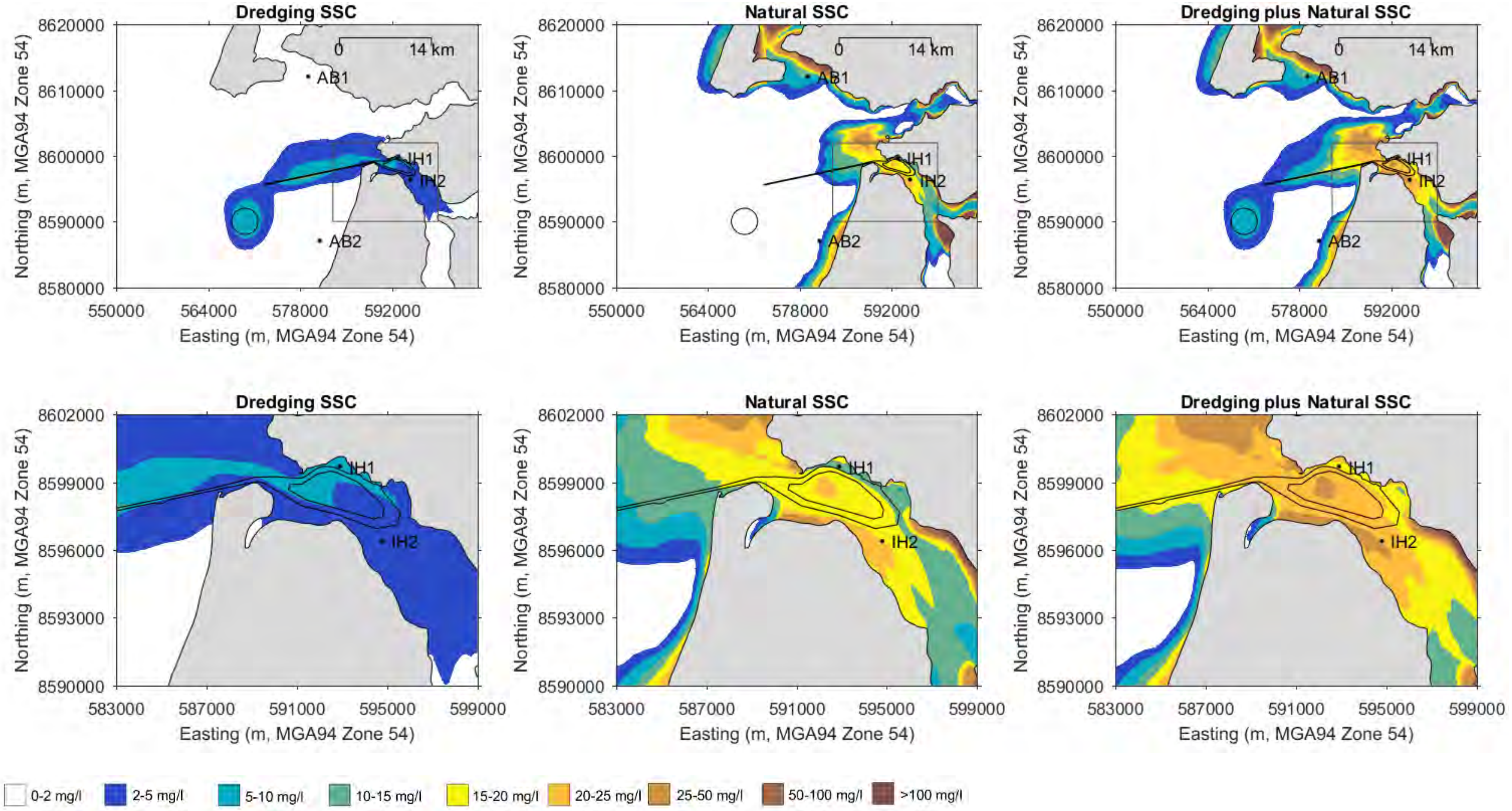


Figure A74. 80th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

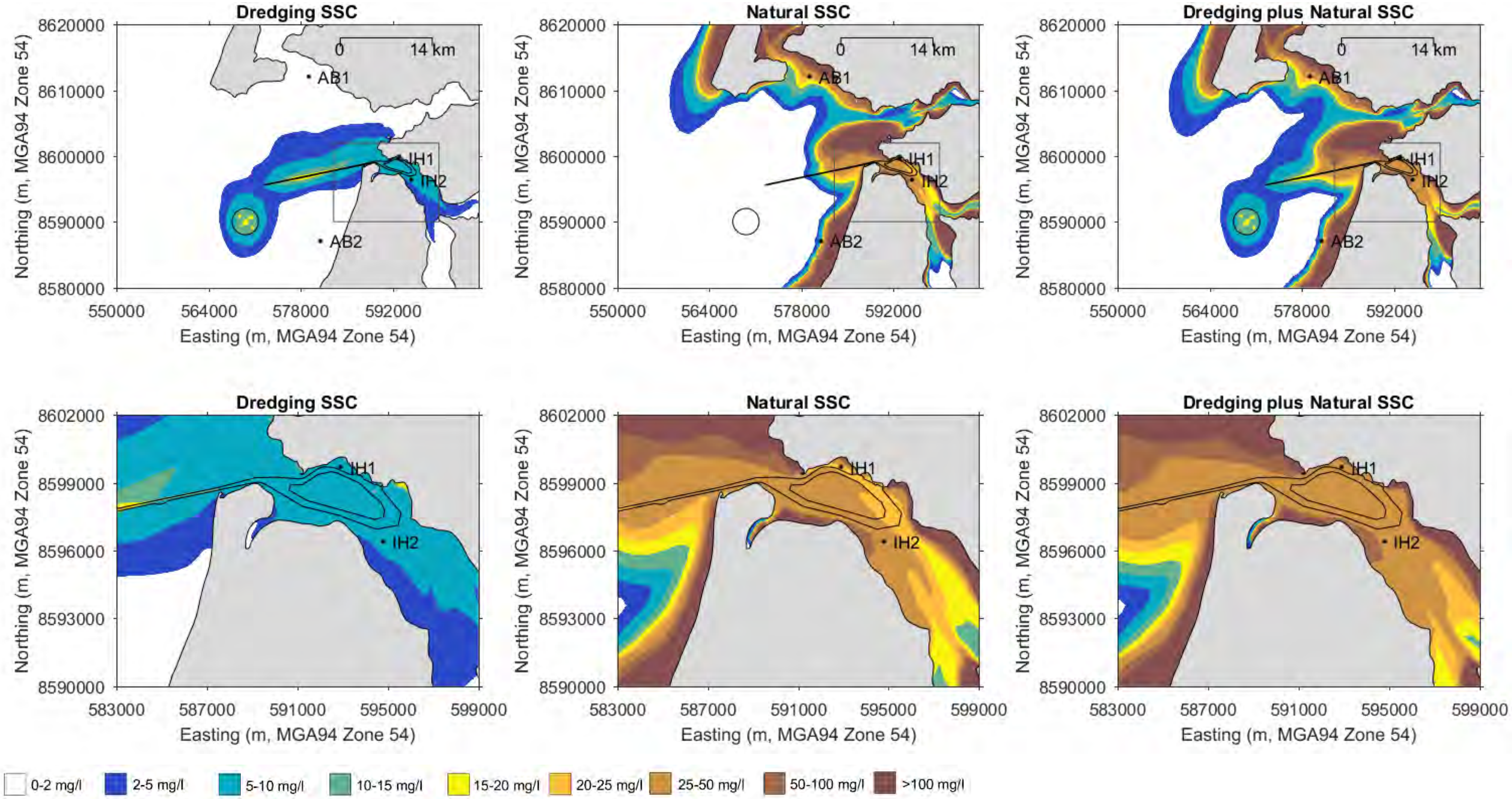


Figure A75. 95th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

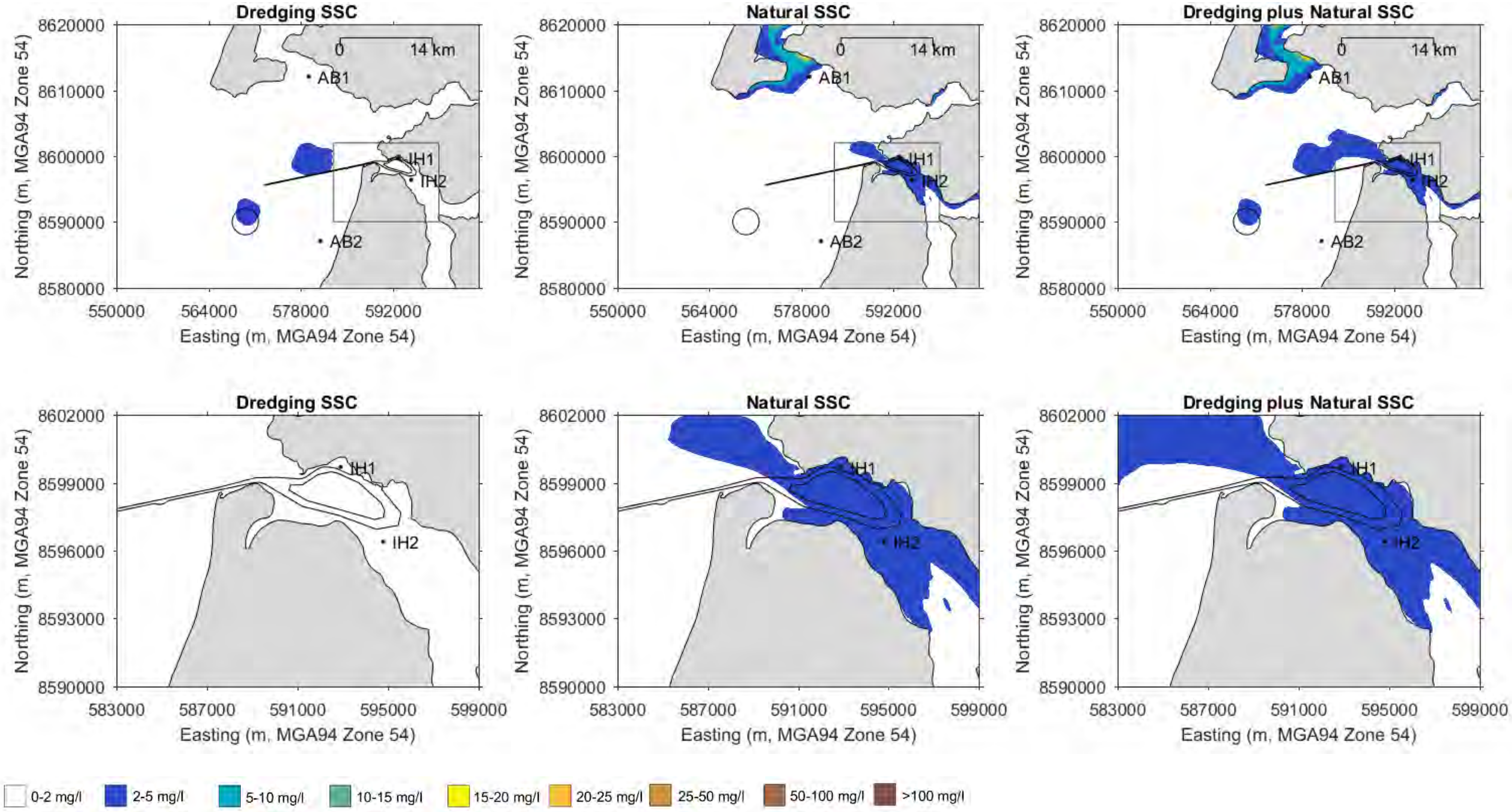


Figure A76. 20th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

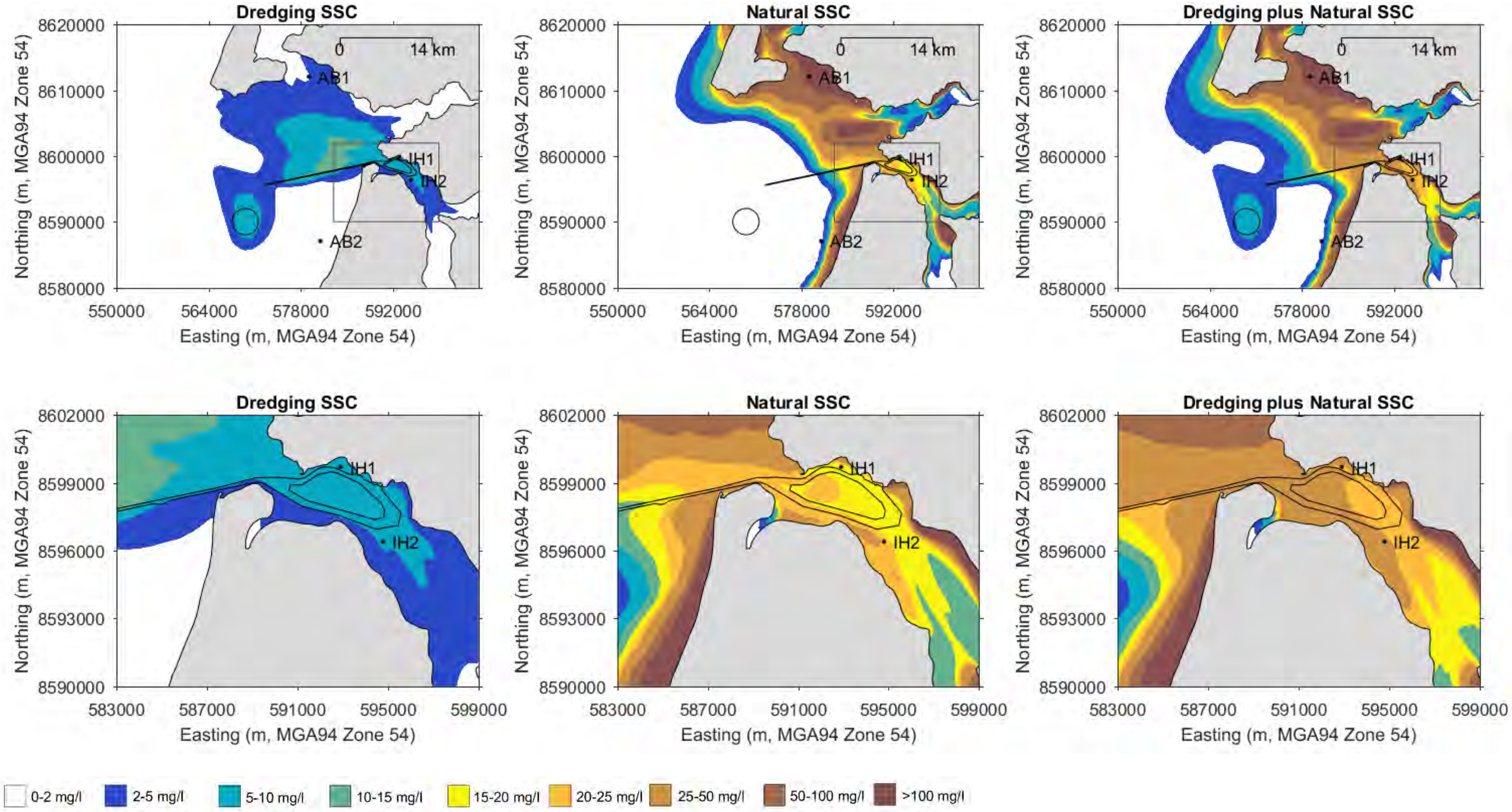


Figure A77. 80th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

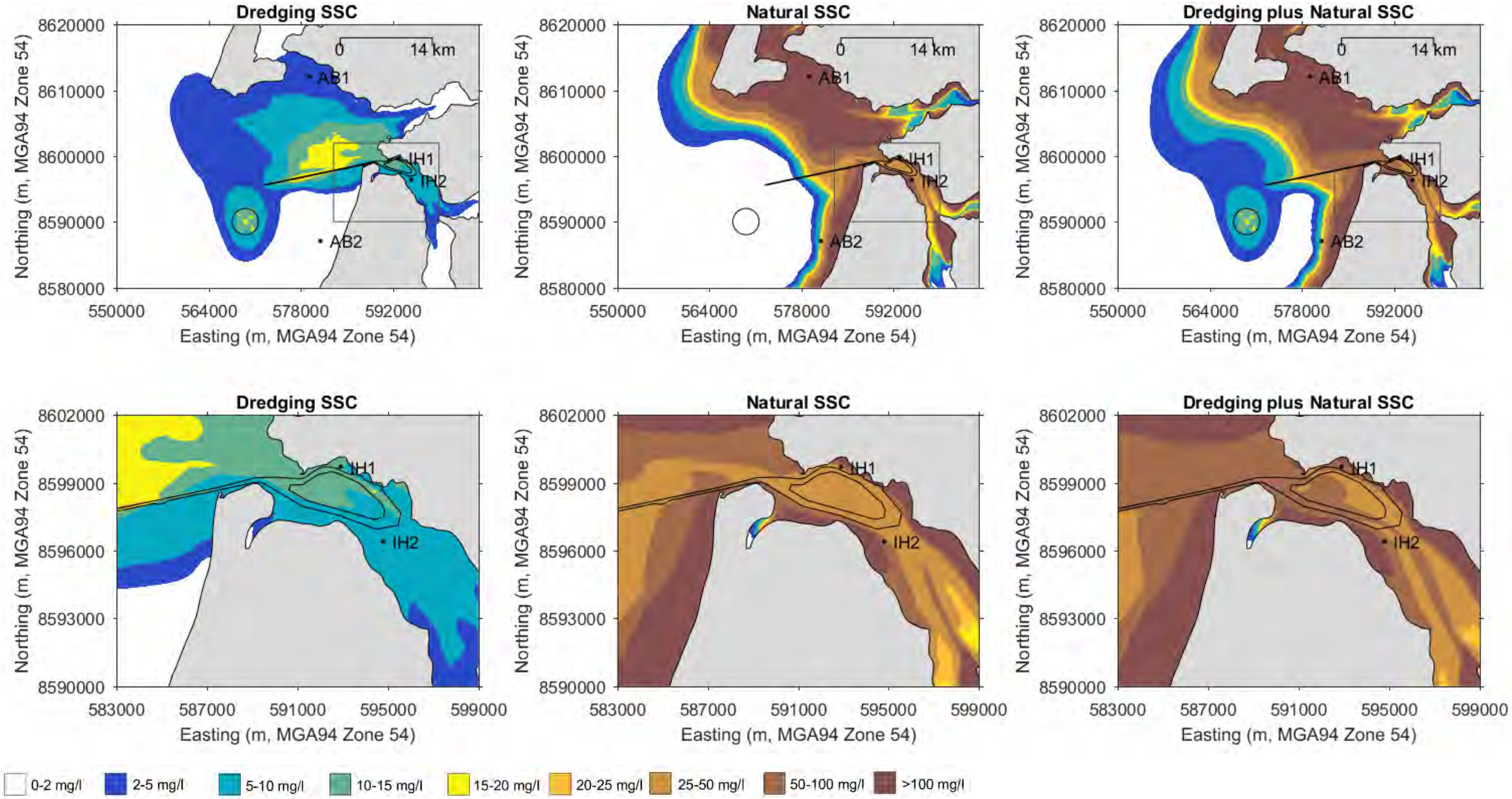


Figure A78. 95th percentile SSC for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

Appendix B – Time Series Plots

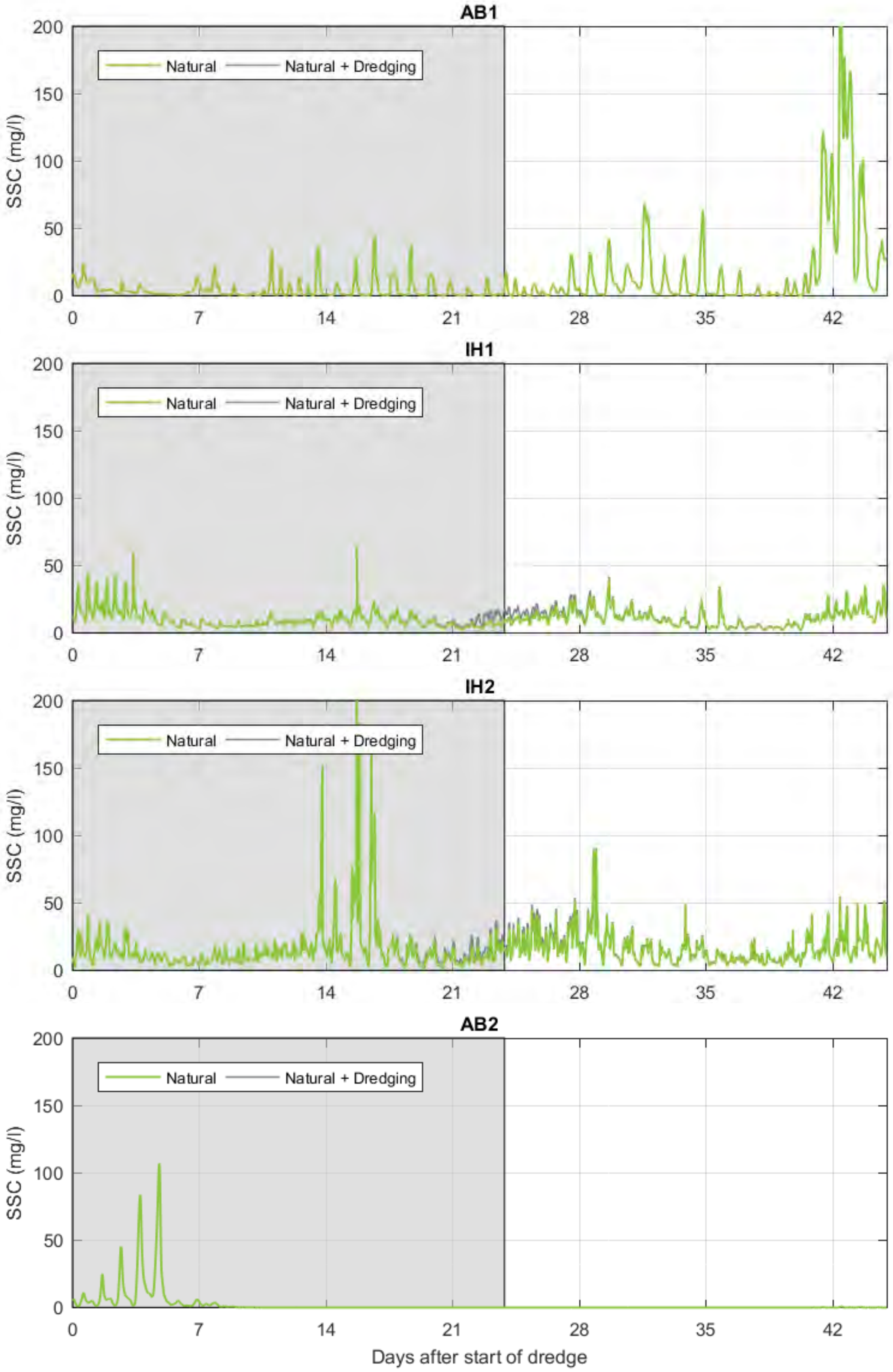


Figure B1. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

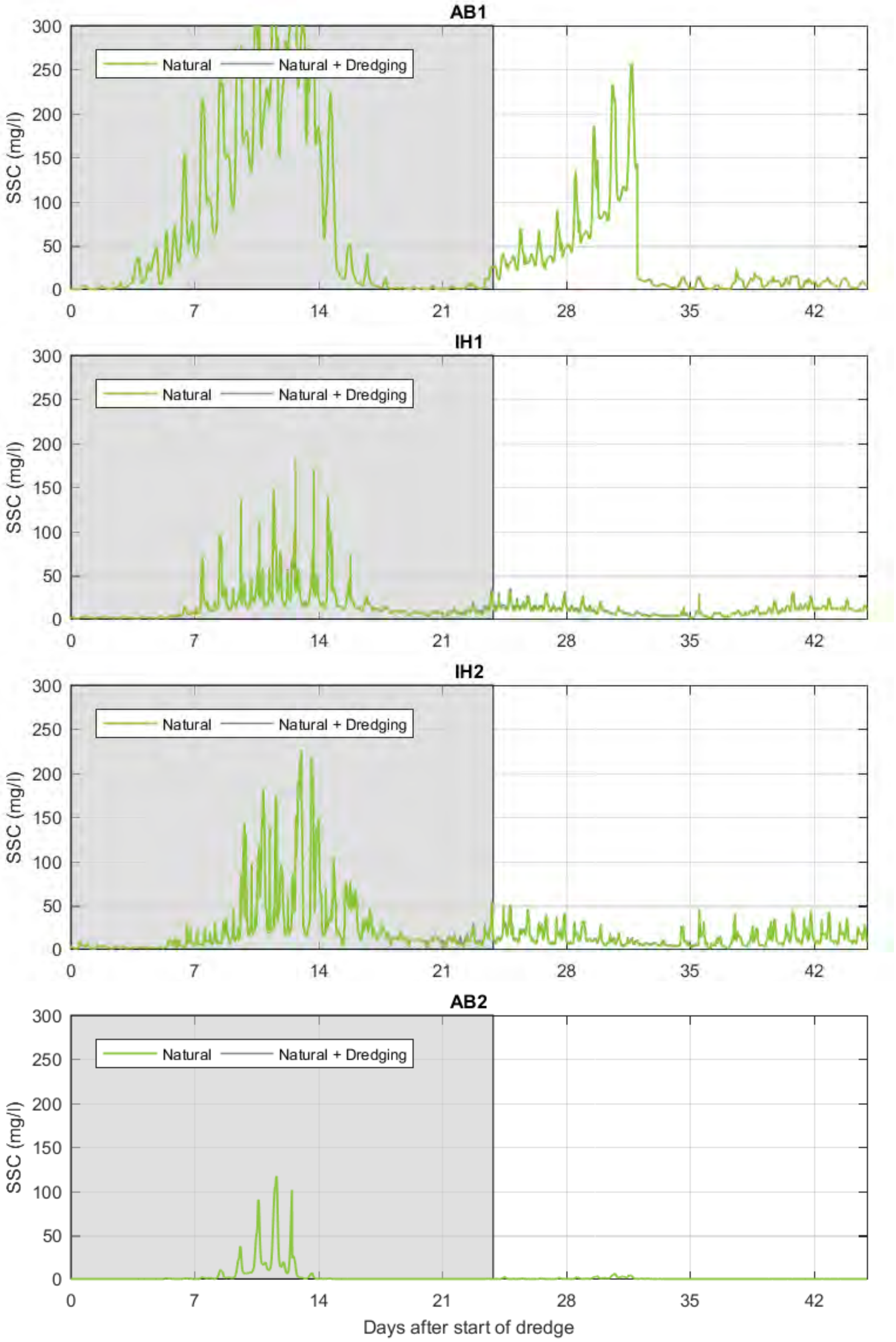


Figure B2. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

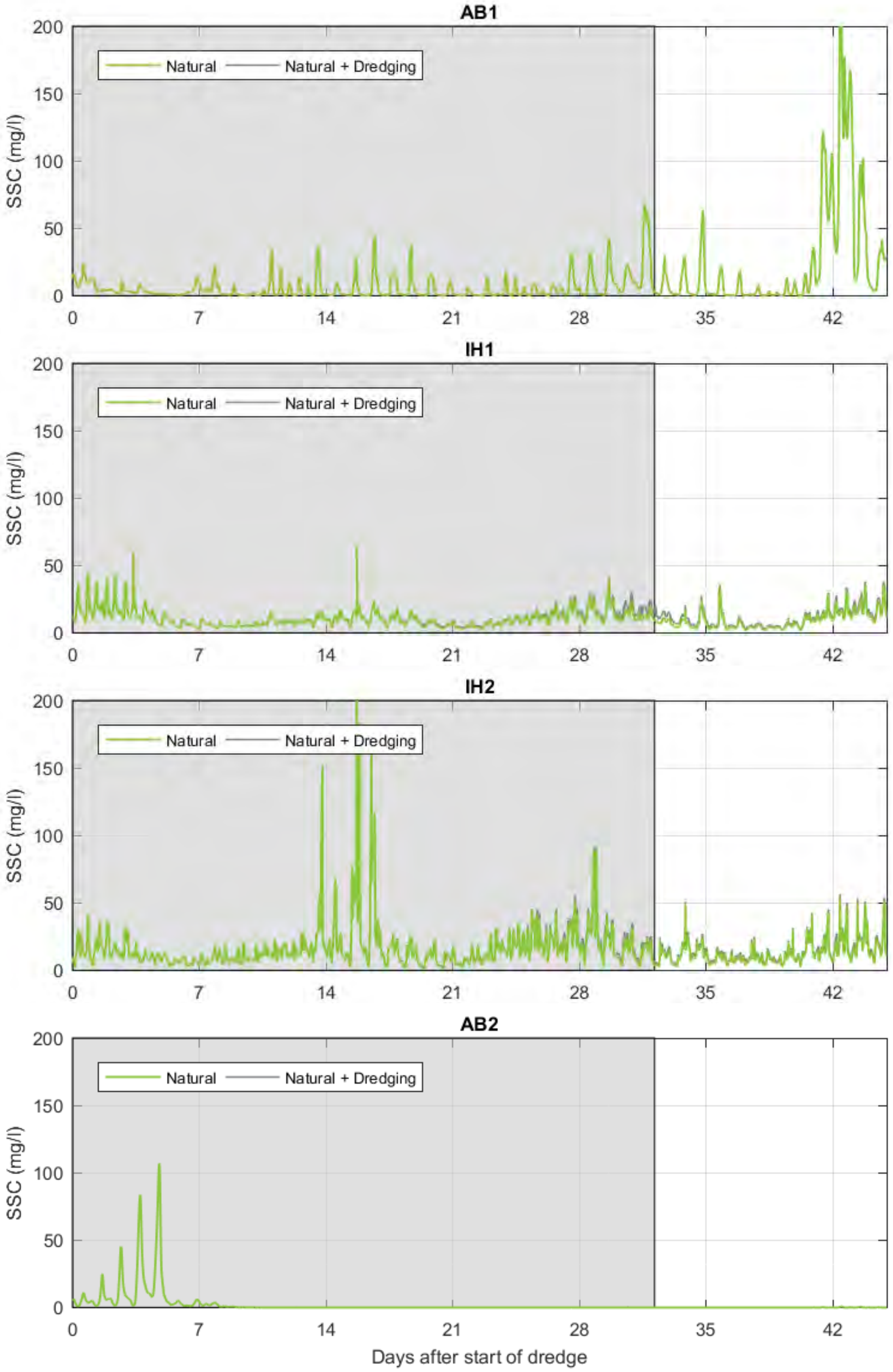


Figure B3. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

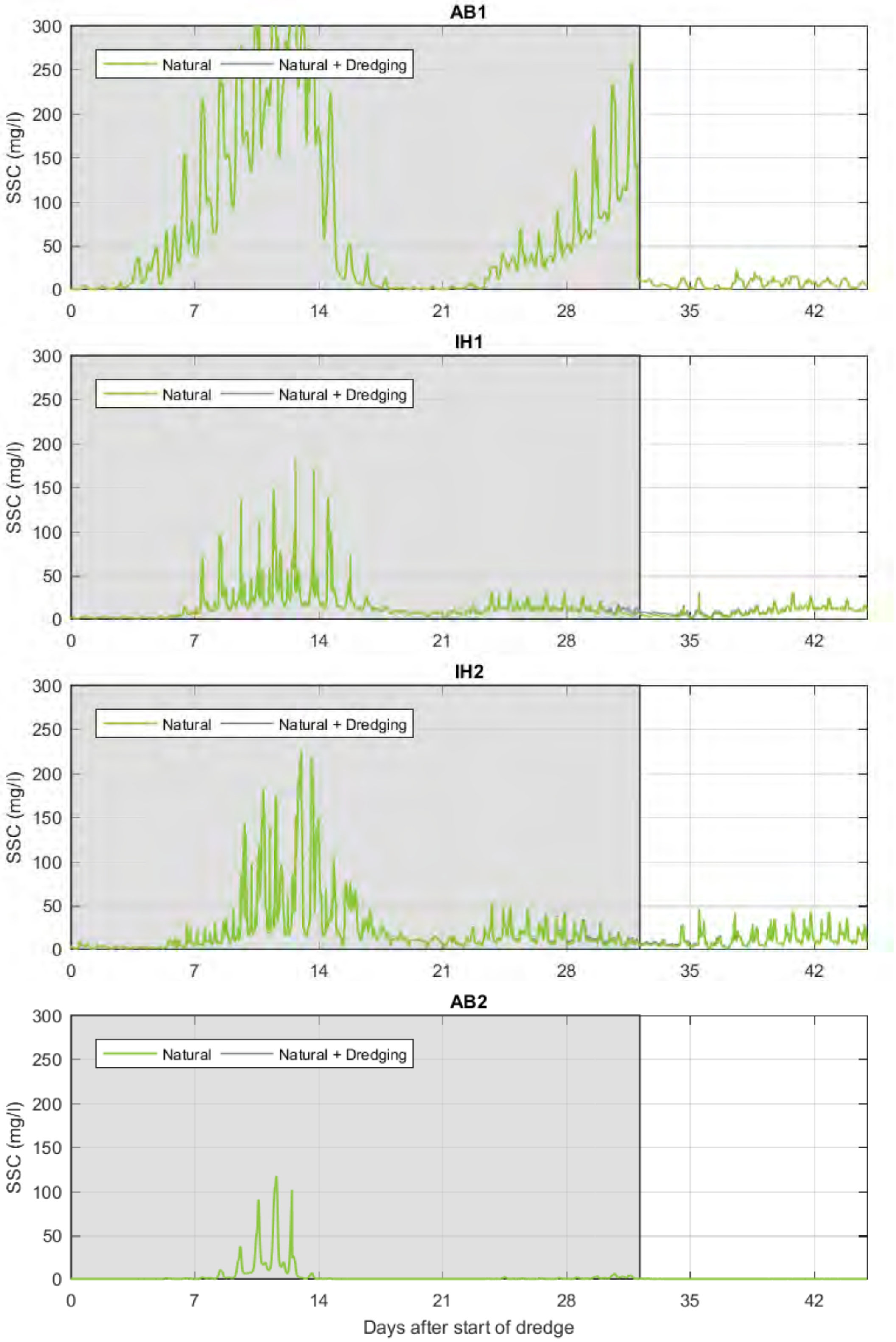


Figure B4. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

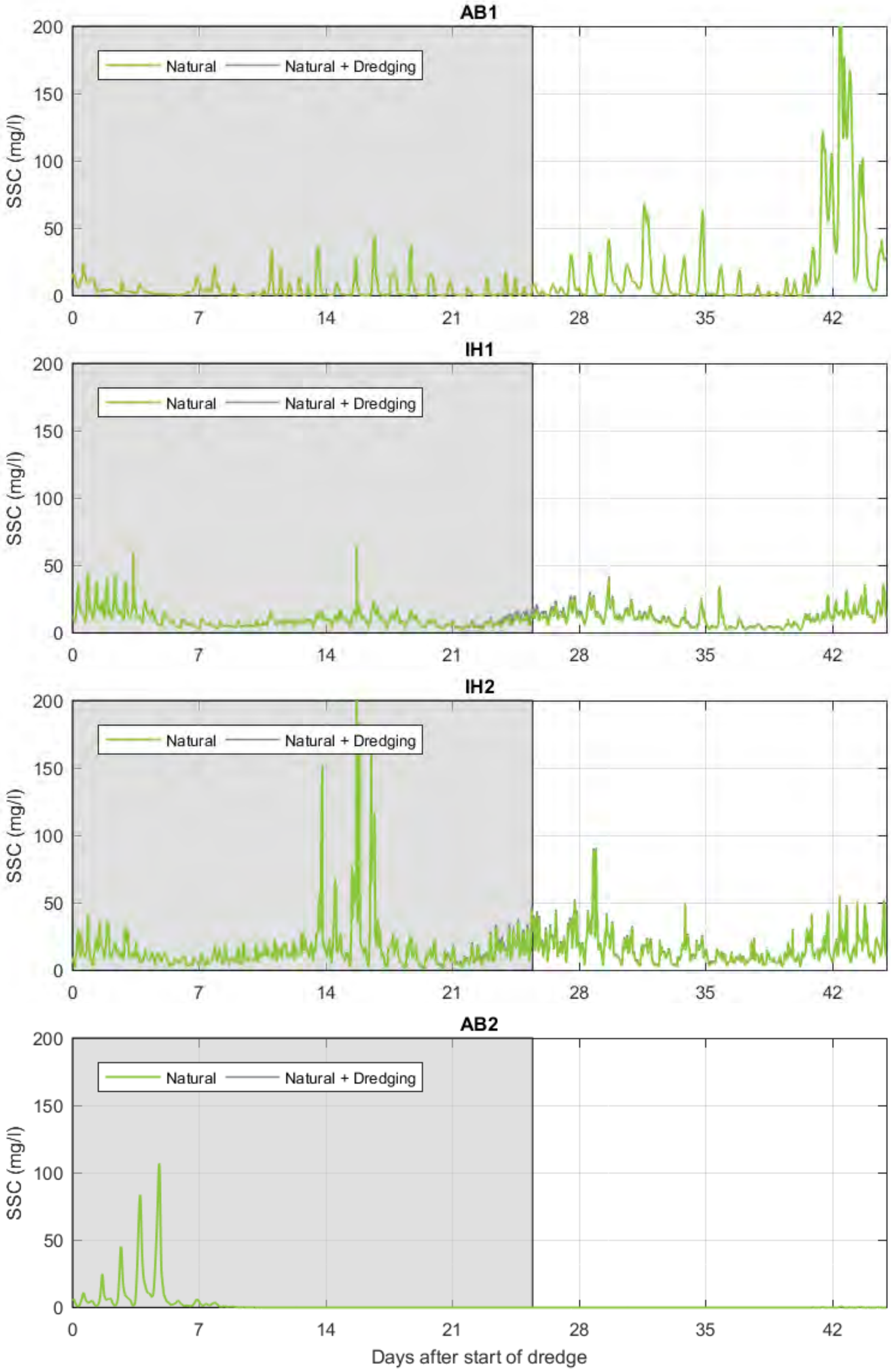


Figure B5. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

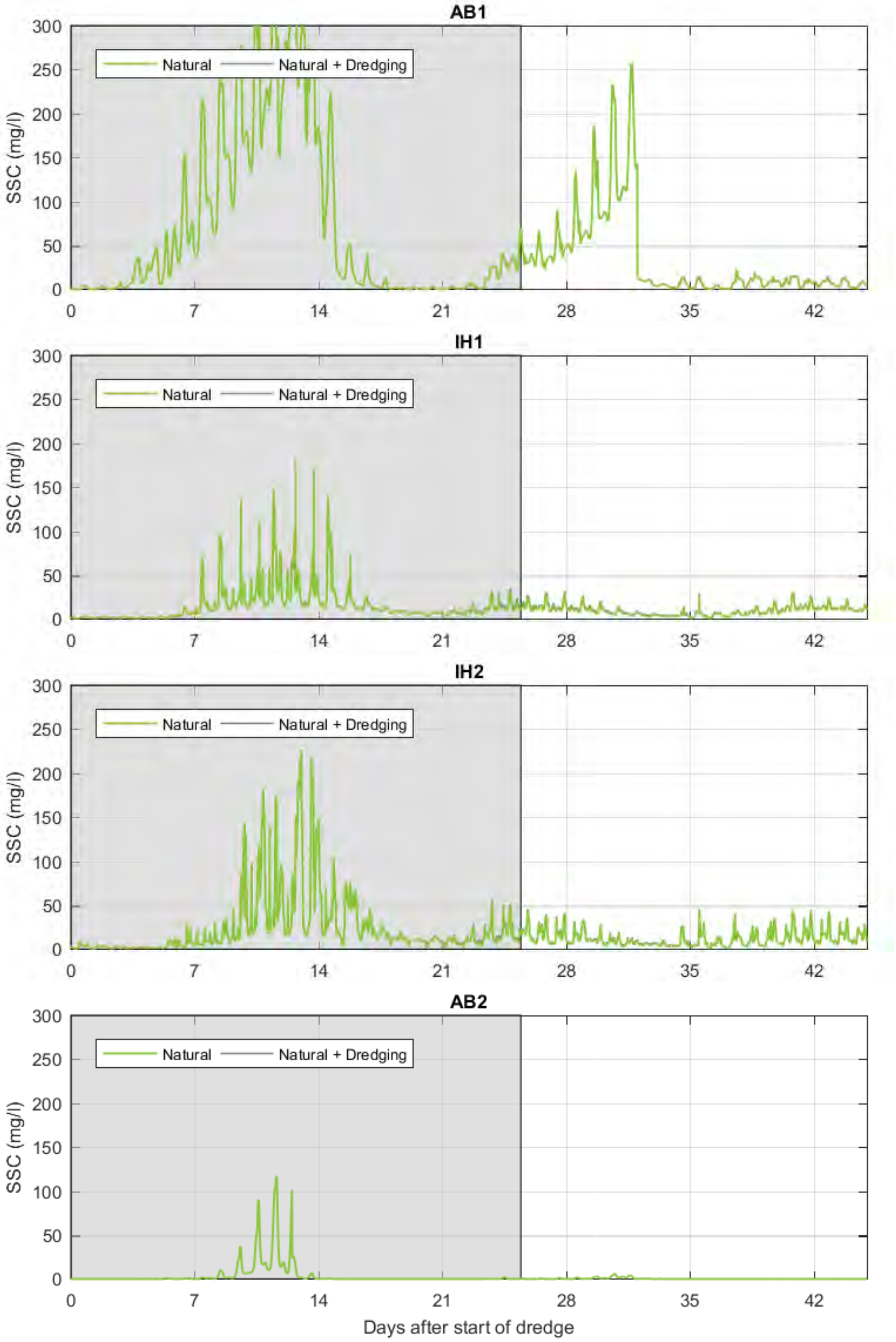


Figure B6. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

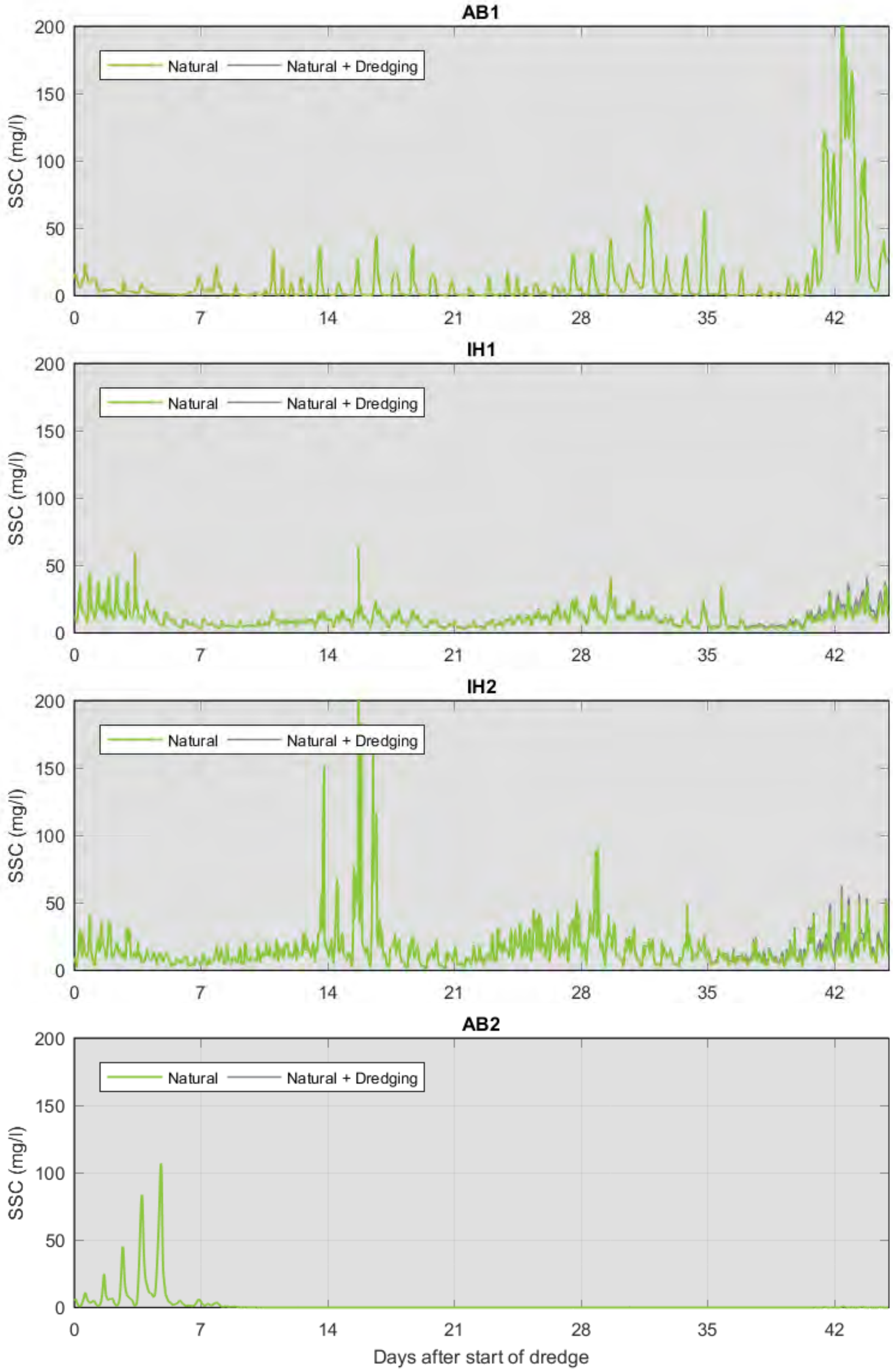


Figure B7. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

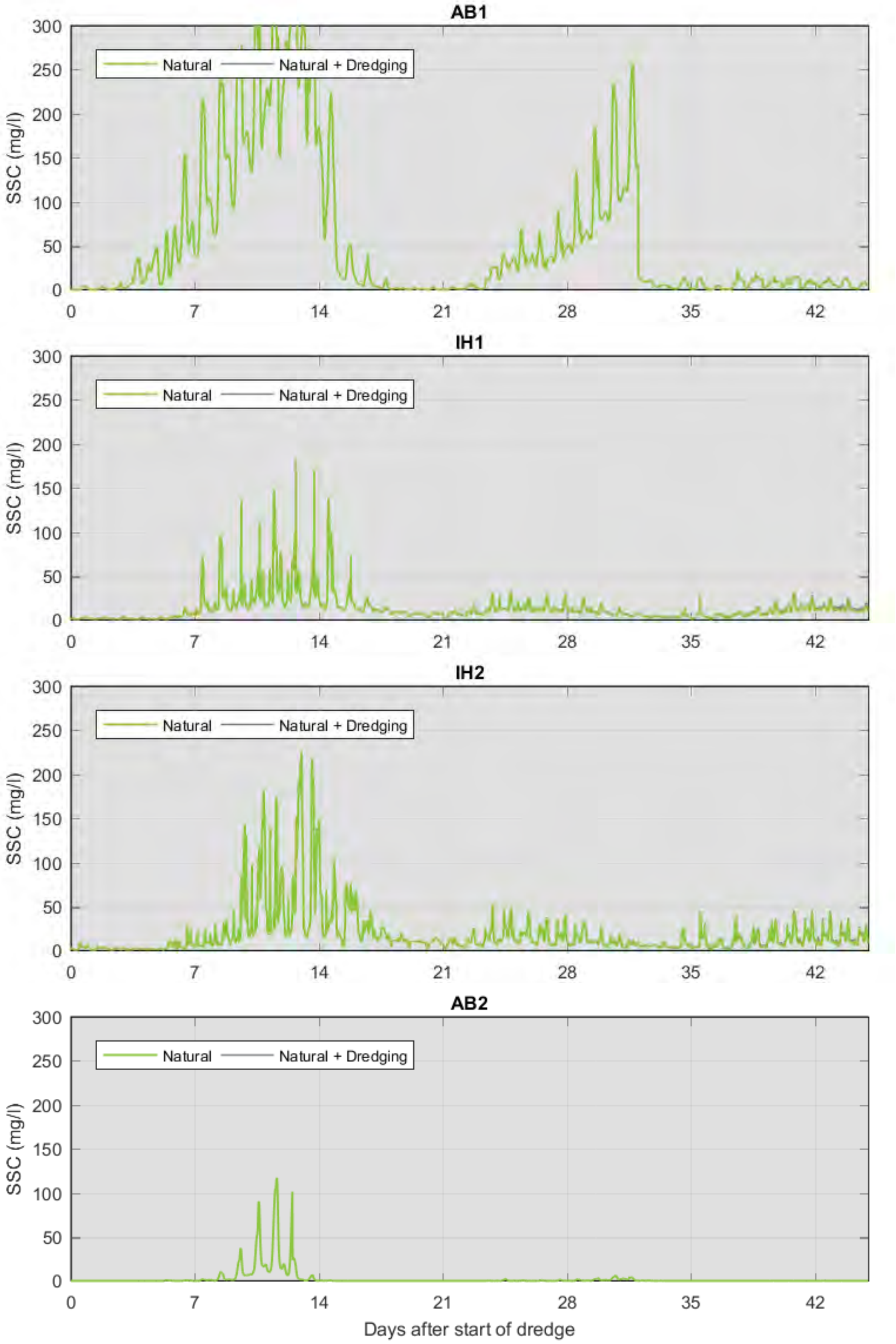


Figure B8. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.

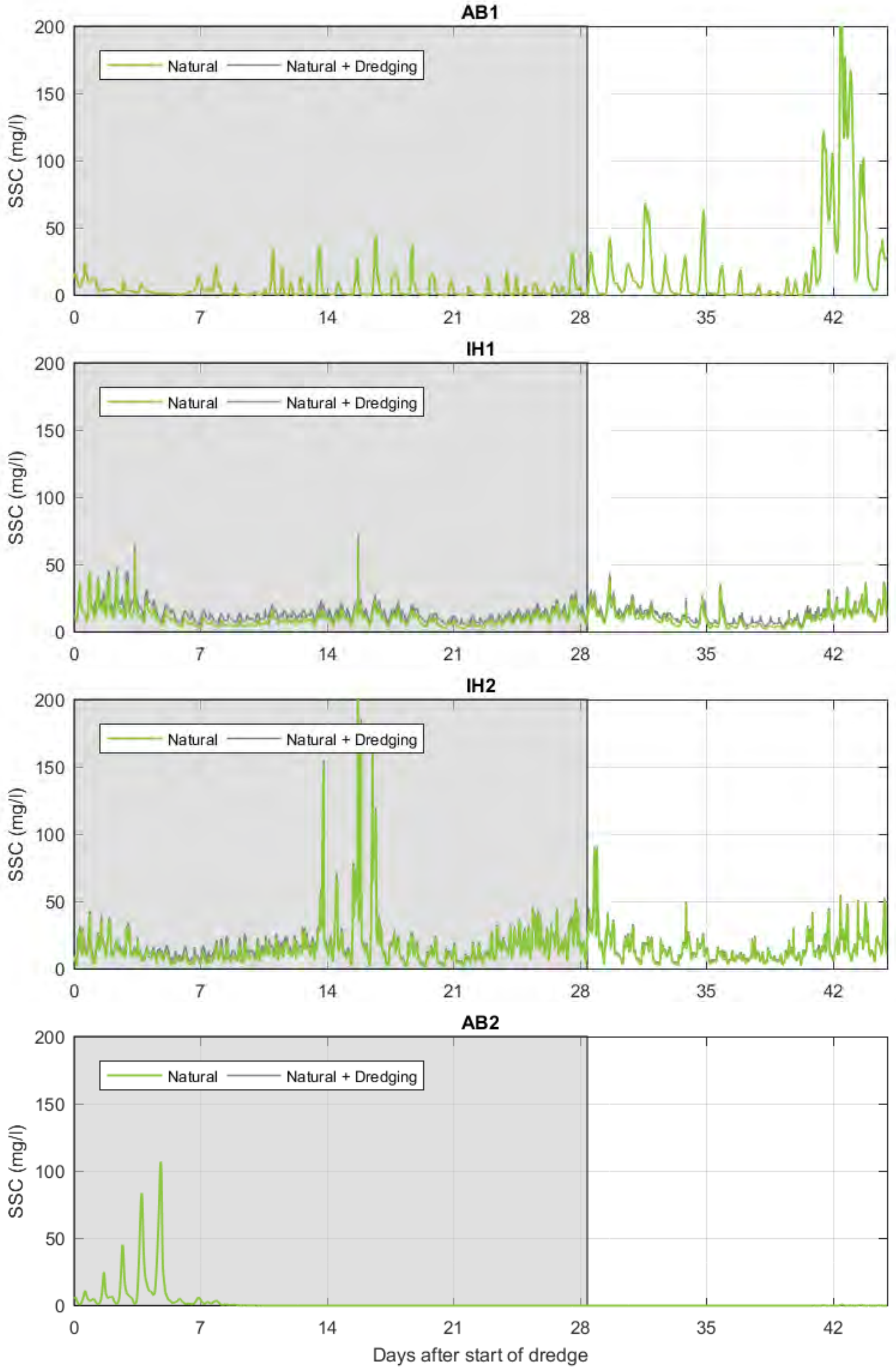


Figure B9. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the ambient dry season.

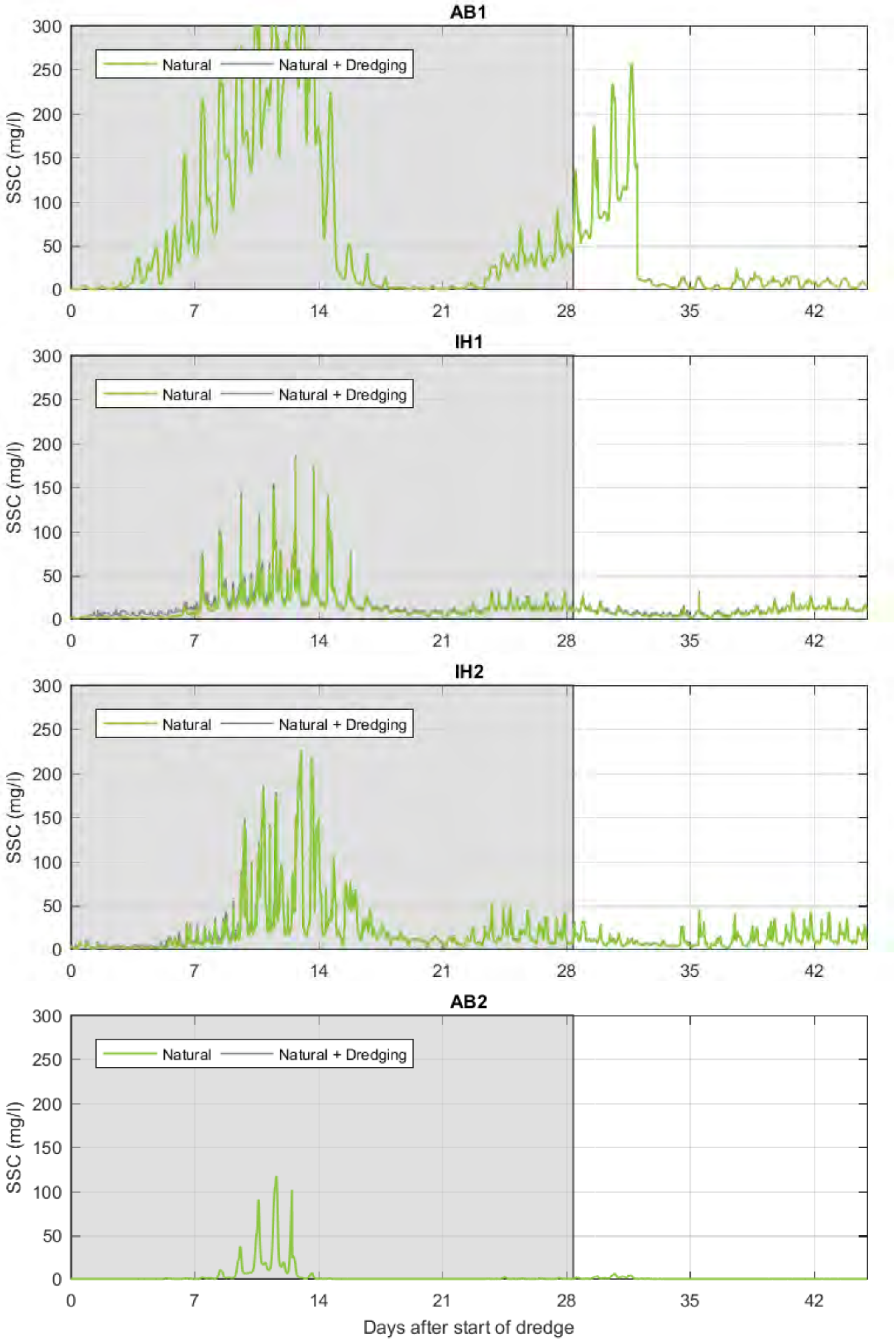


Figure B10. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the energetic dry season.

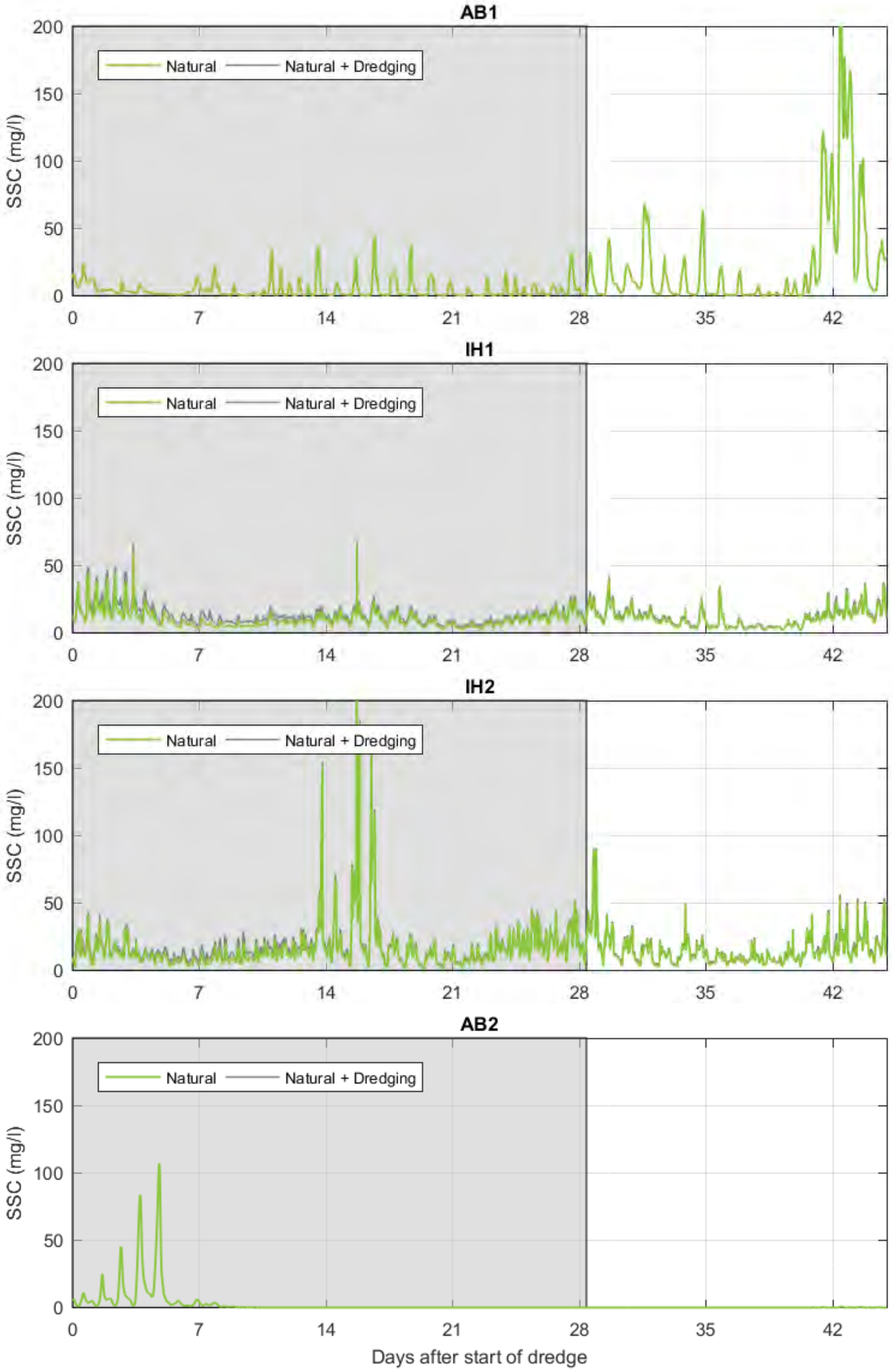


Figure B11. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the ambient dry season.

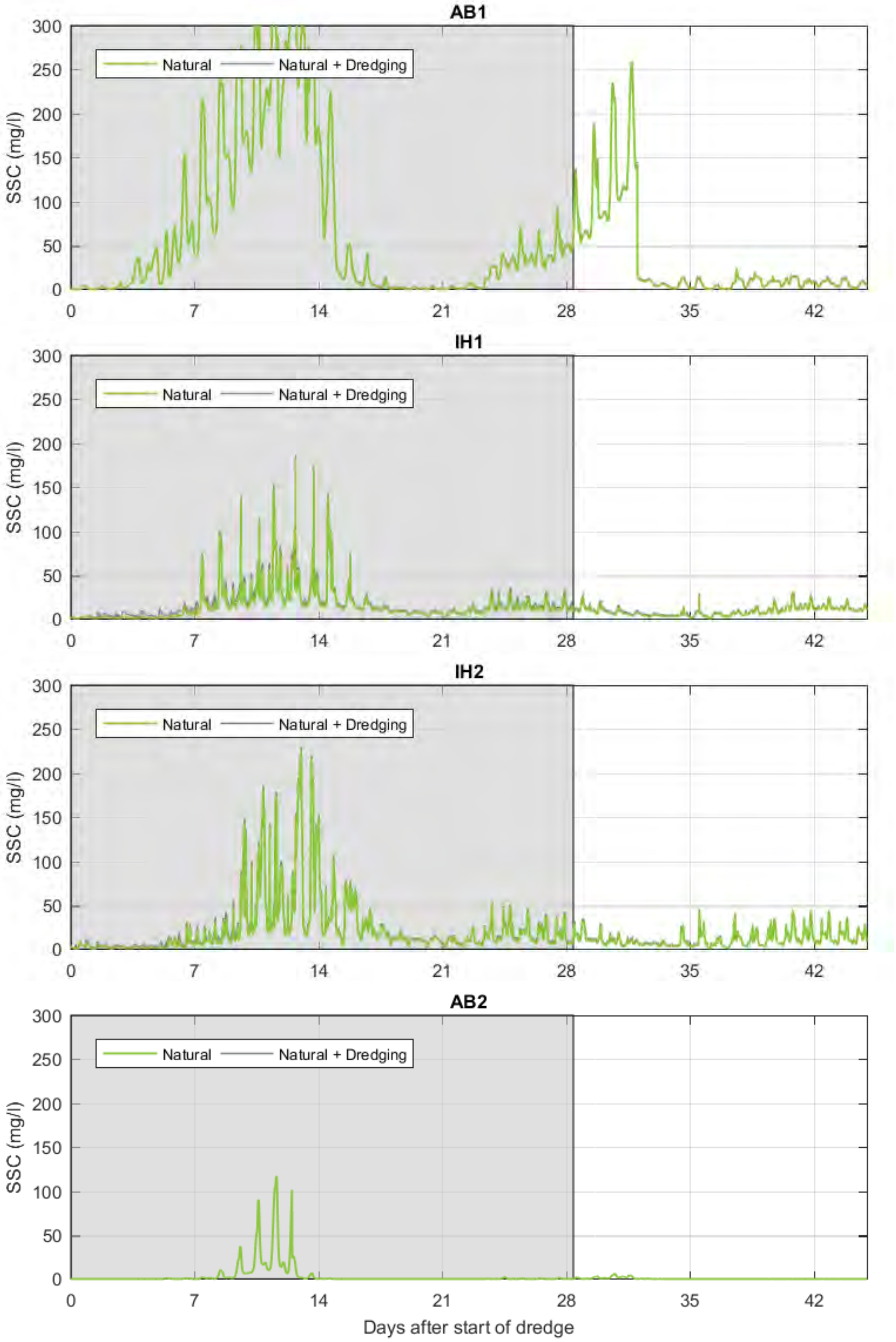


Figure B12. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the energetic dry season.

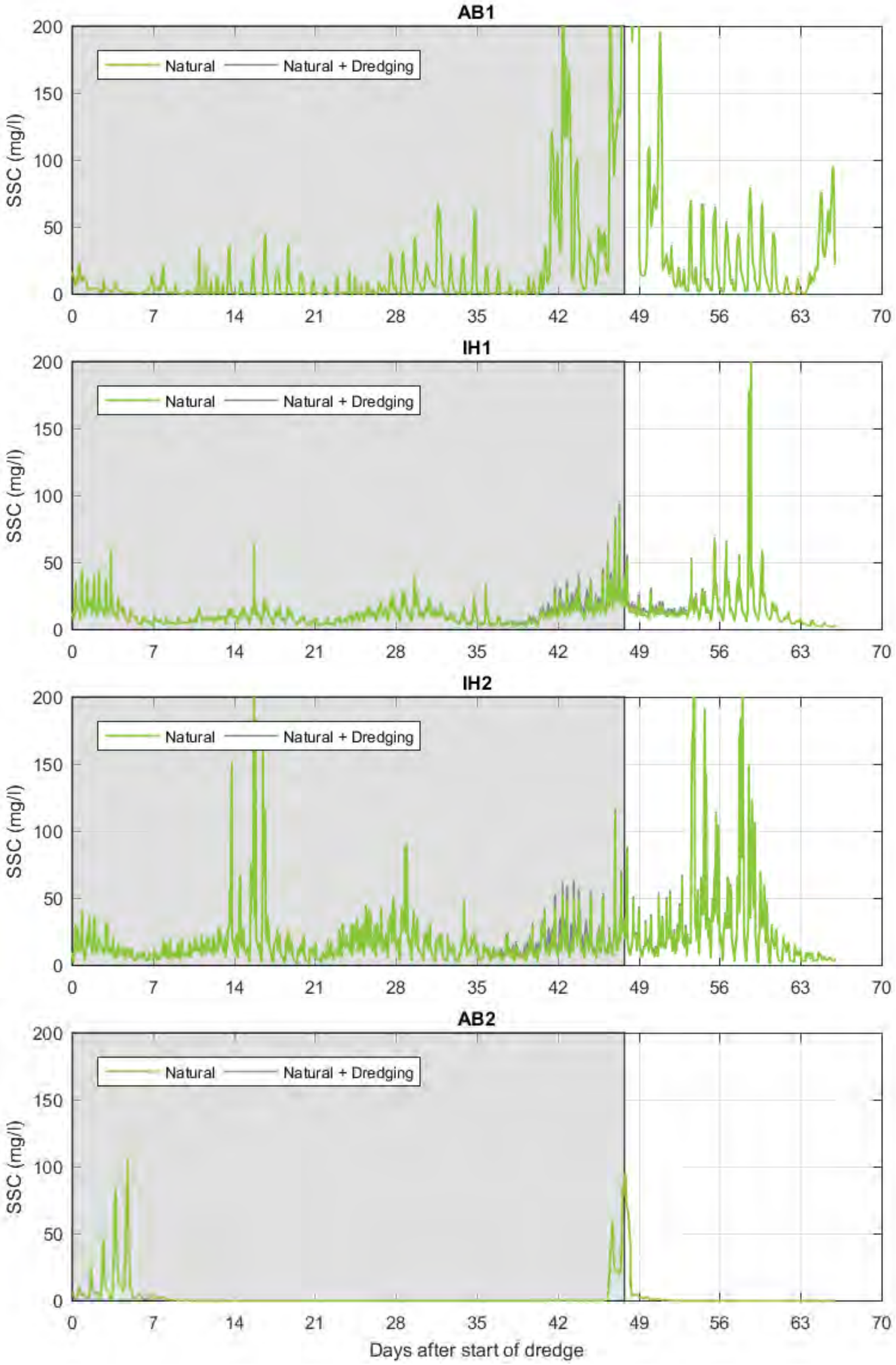


Figure B13. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

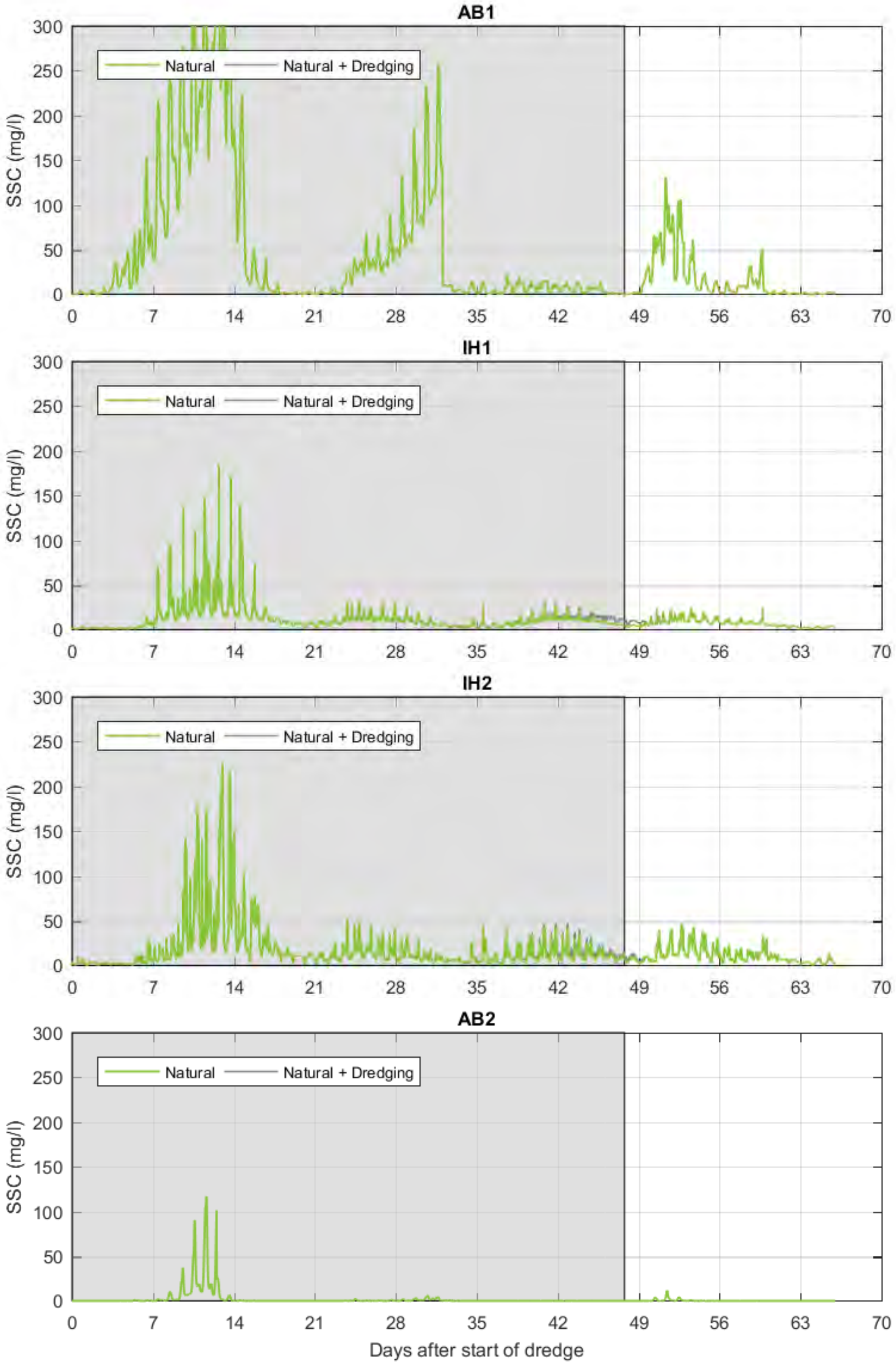


Figure B14. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

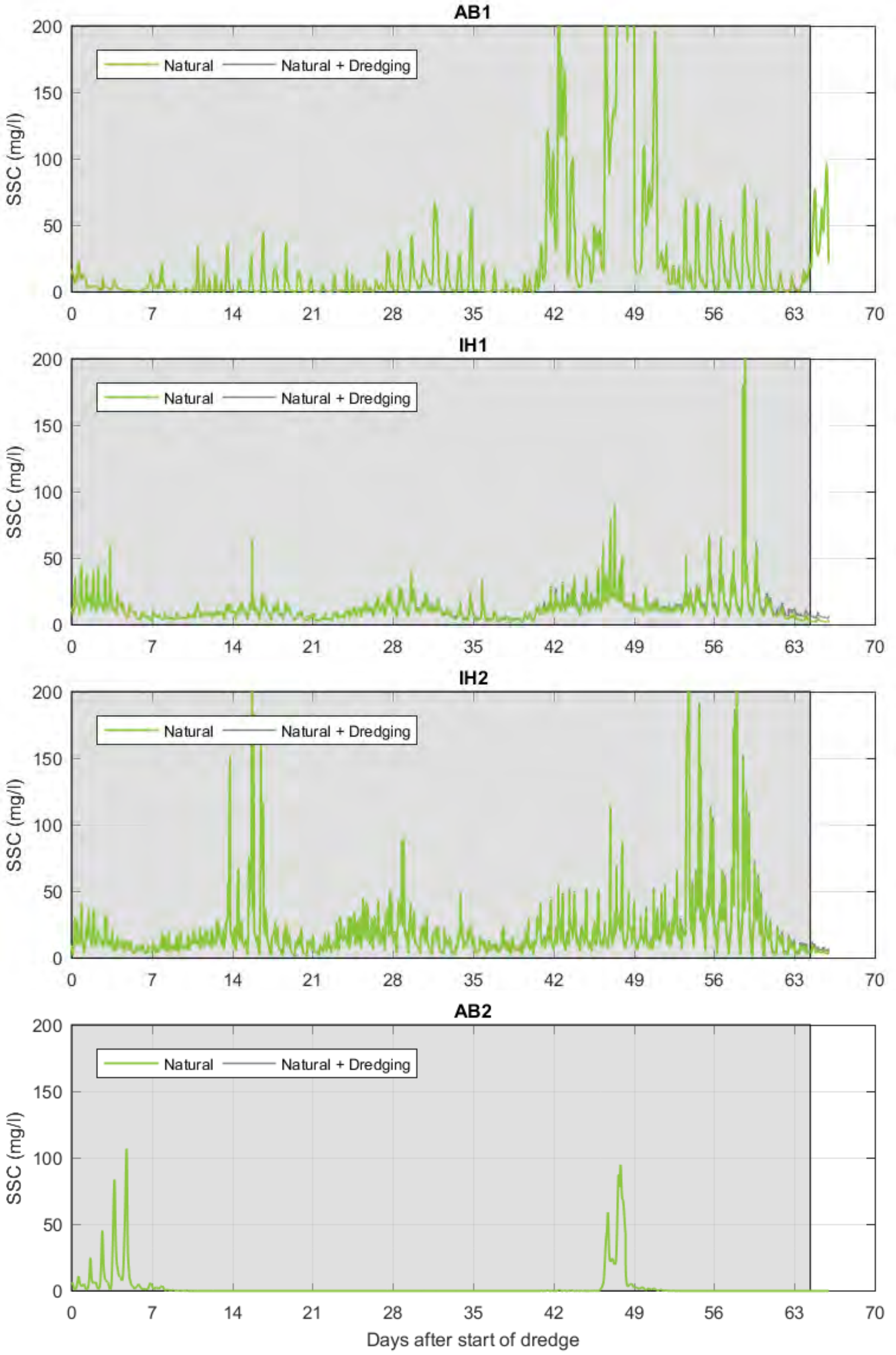


Figure B15. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

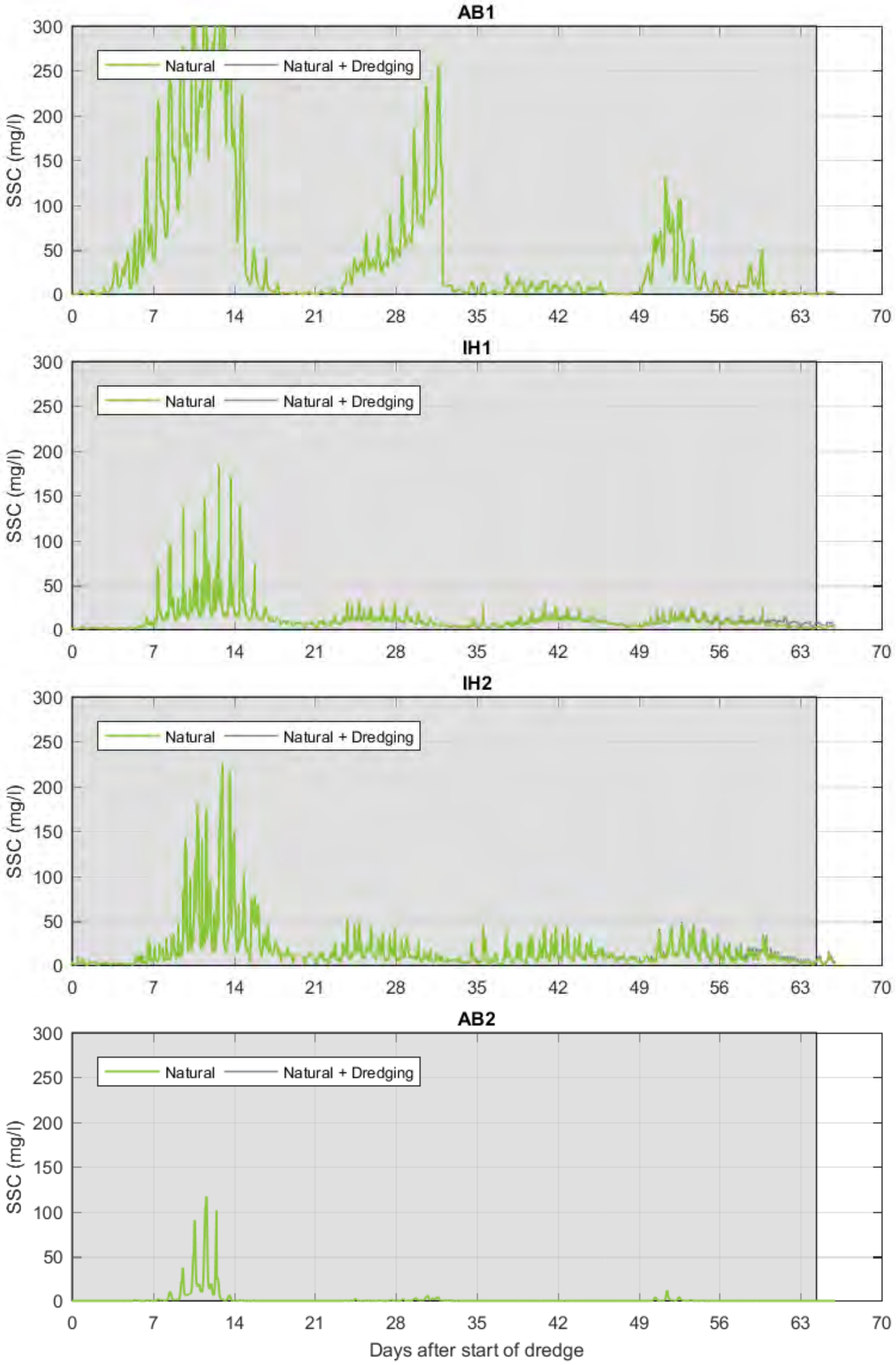


Figure B16. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

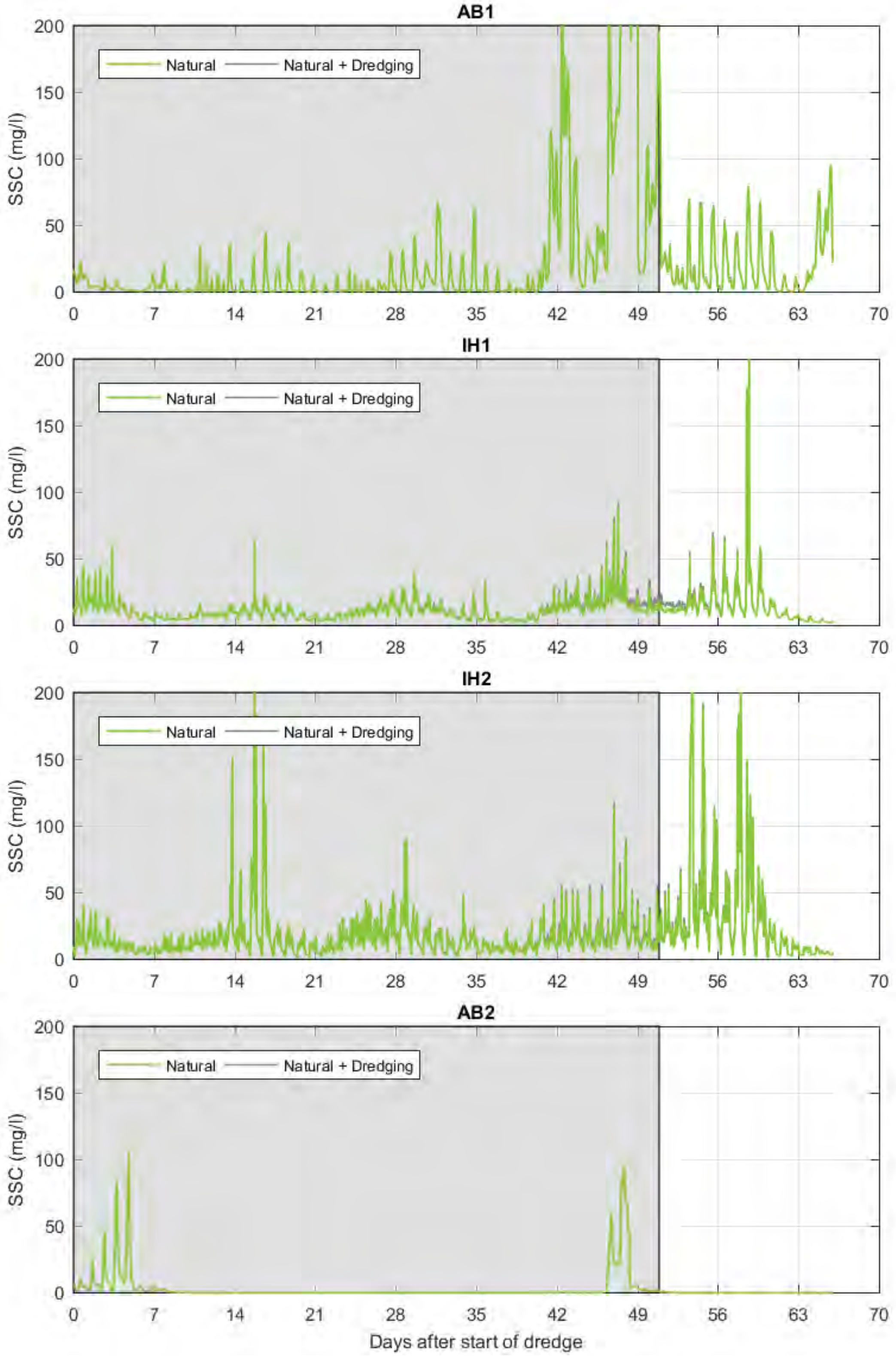


Figure B17. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

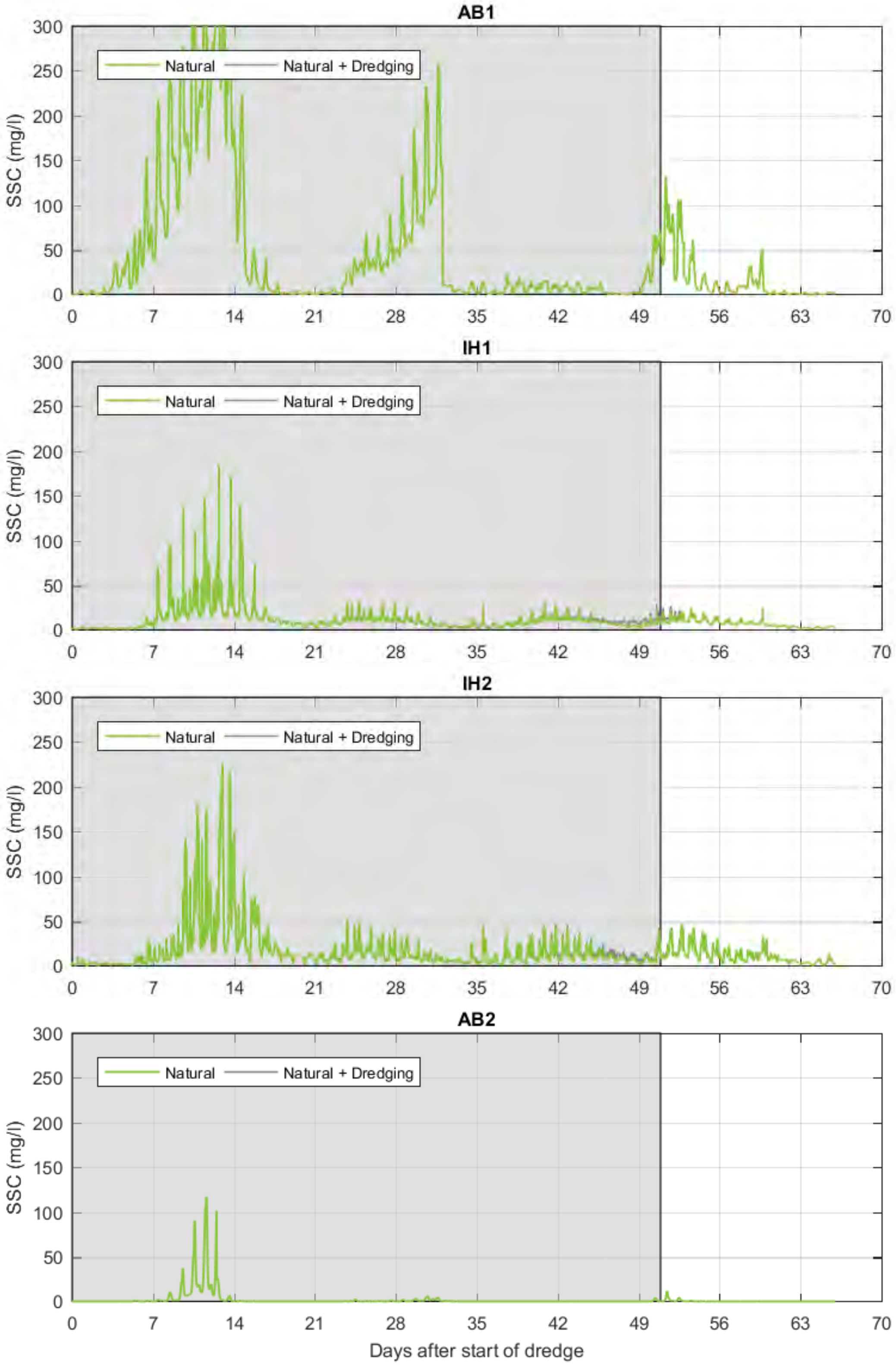


Figure B18. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

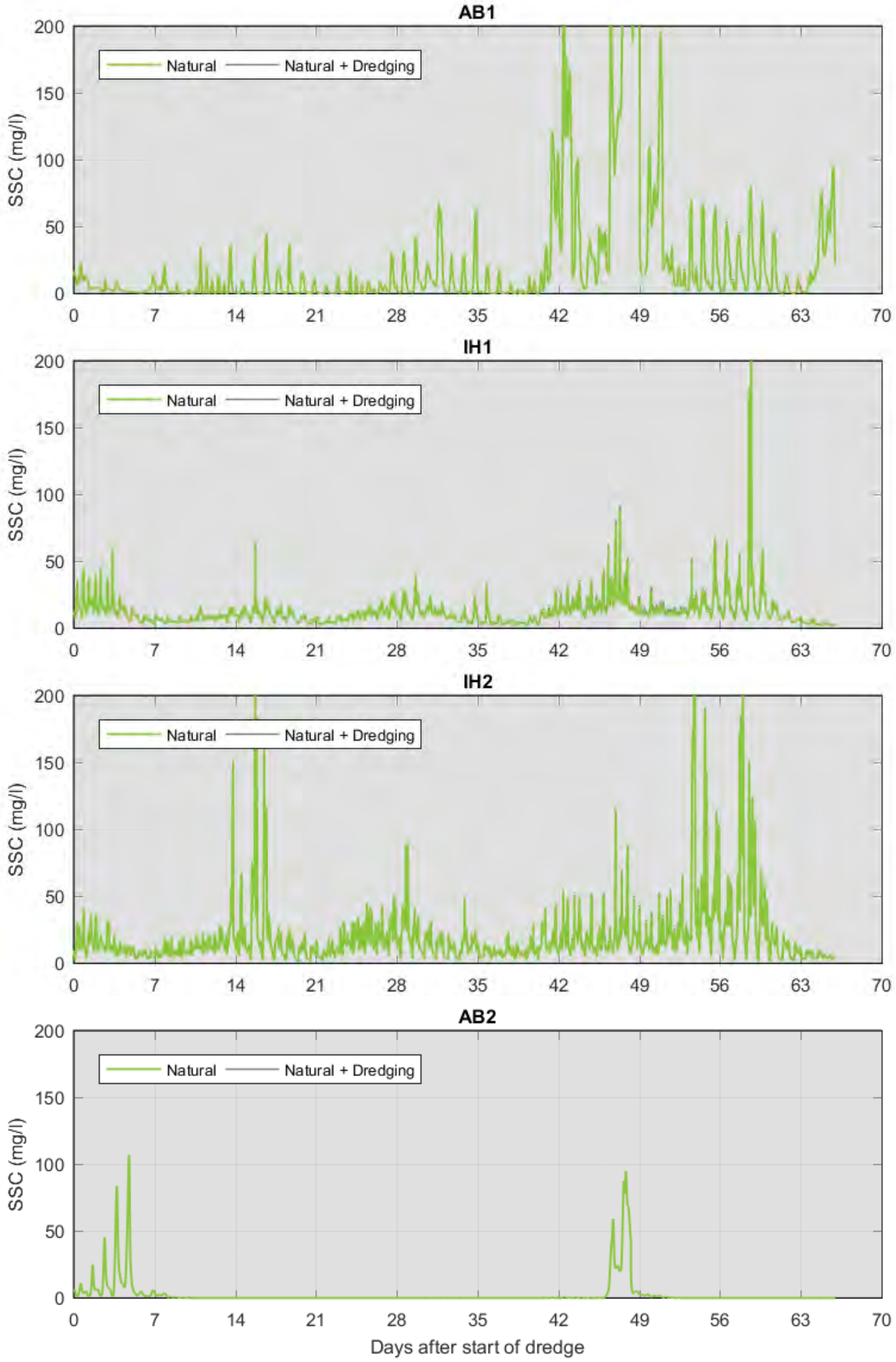


Figure B19. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

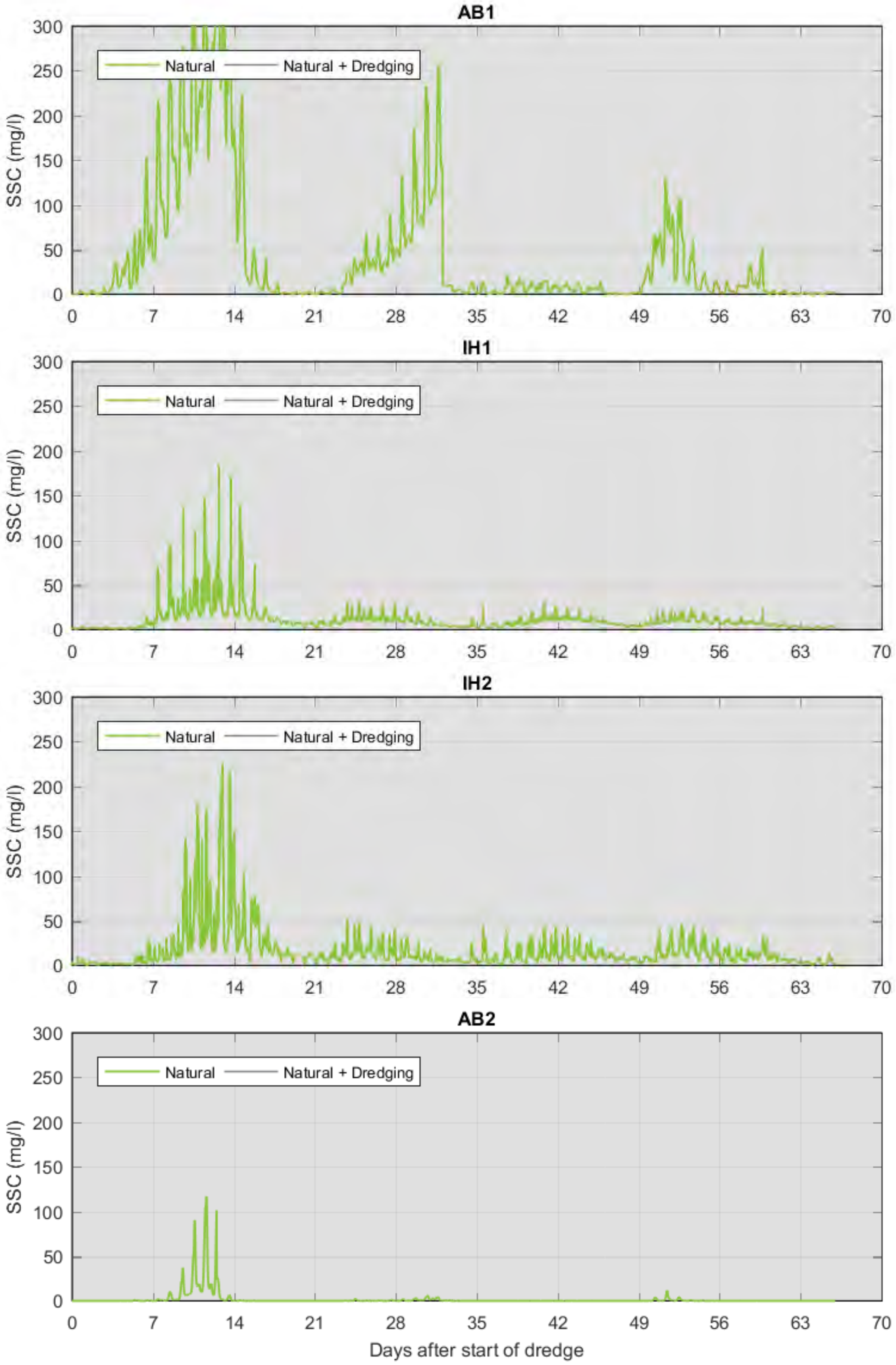


Figure B20. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.

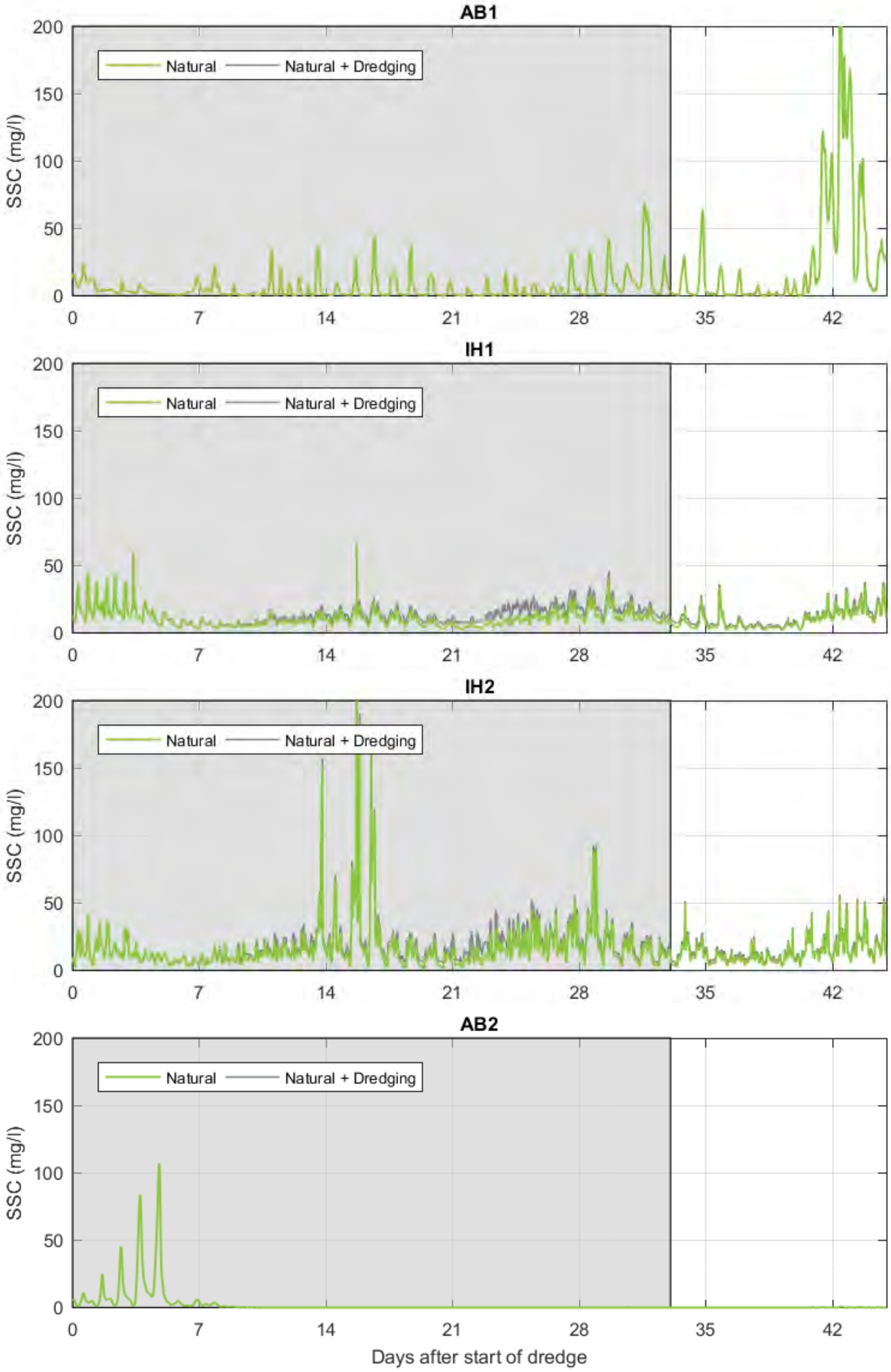


Figure B21. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

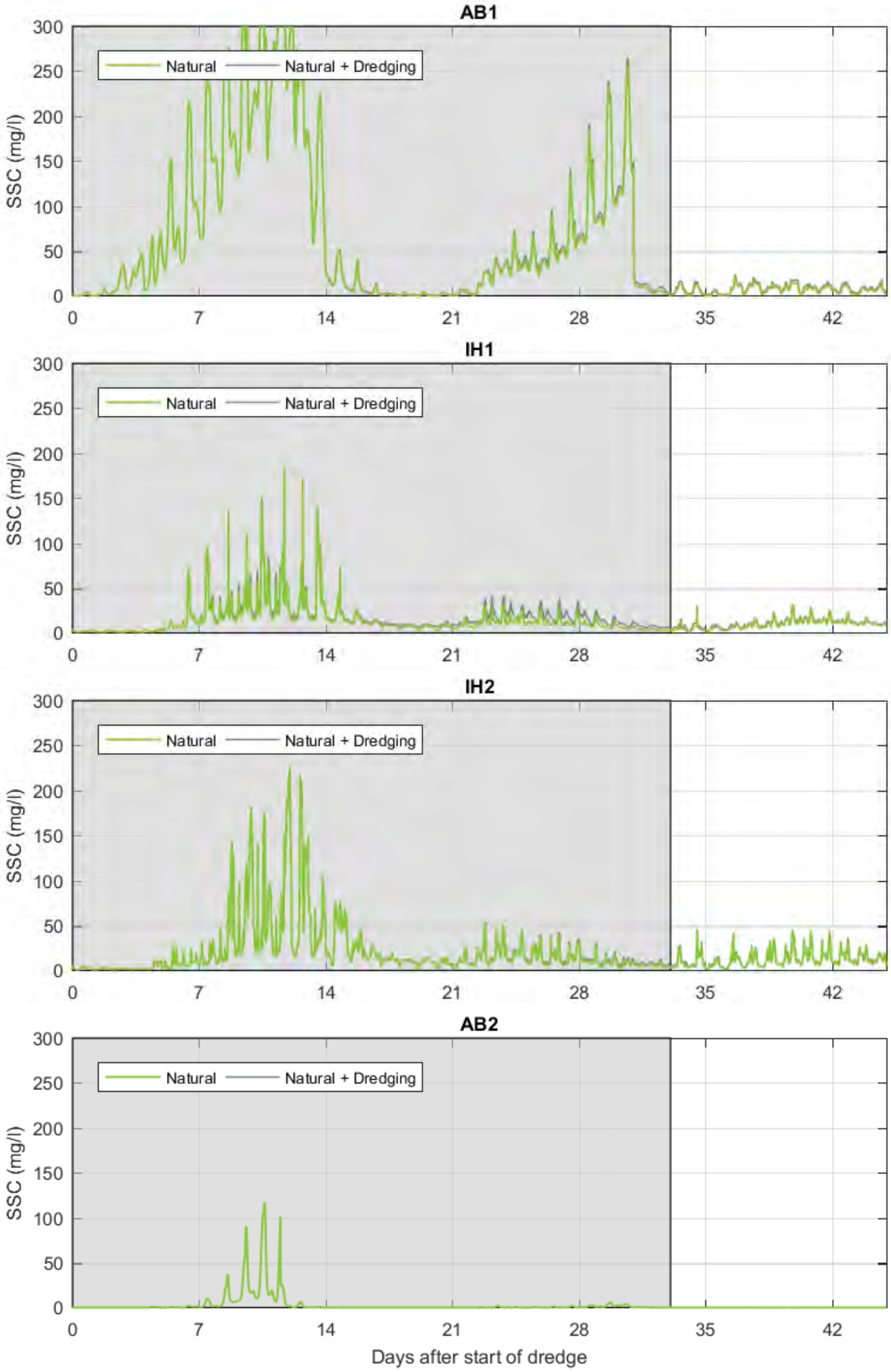


Figure B22. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

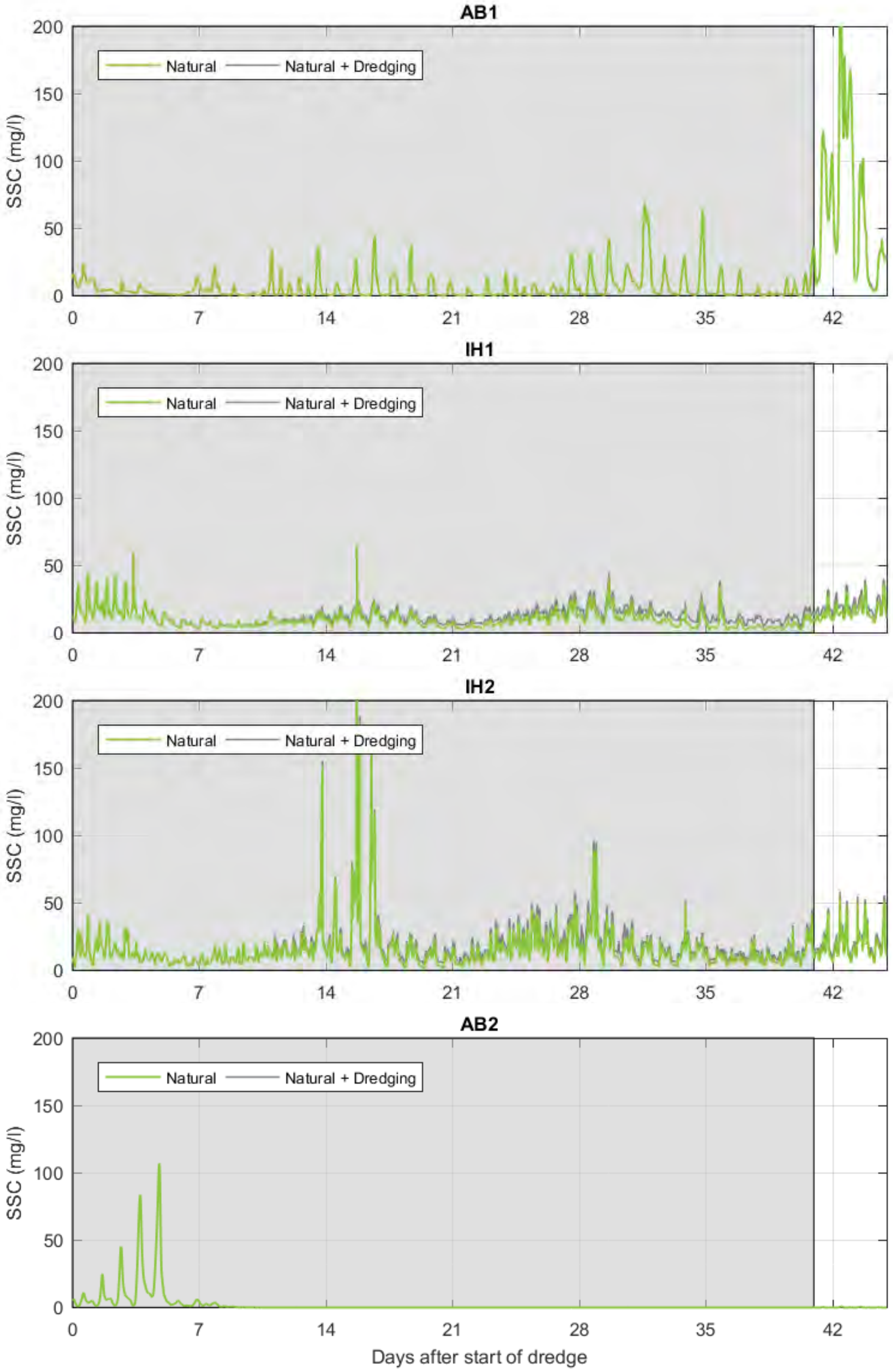


Figure B23. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

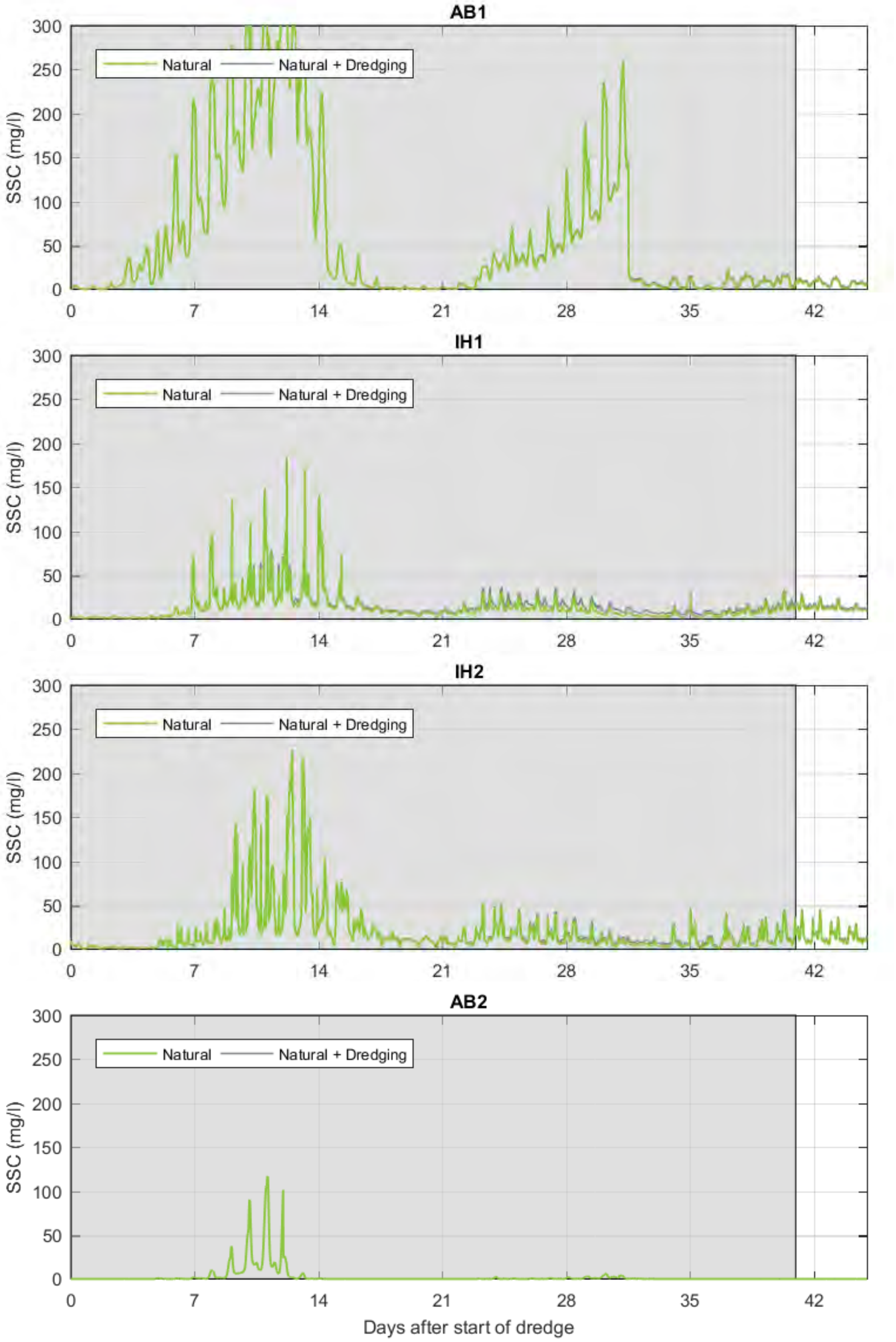


Figure B24. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

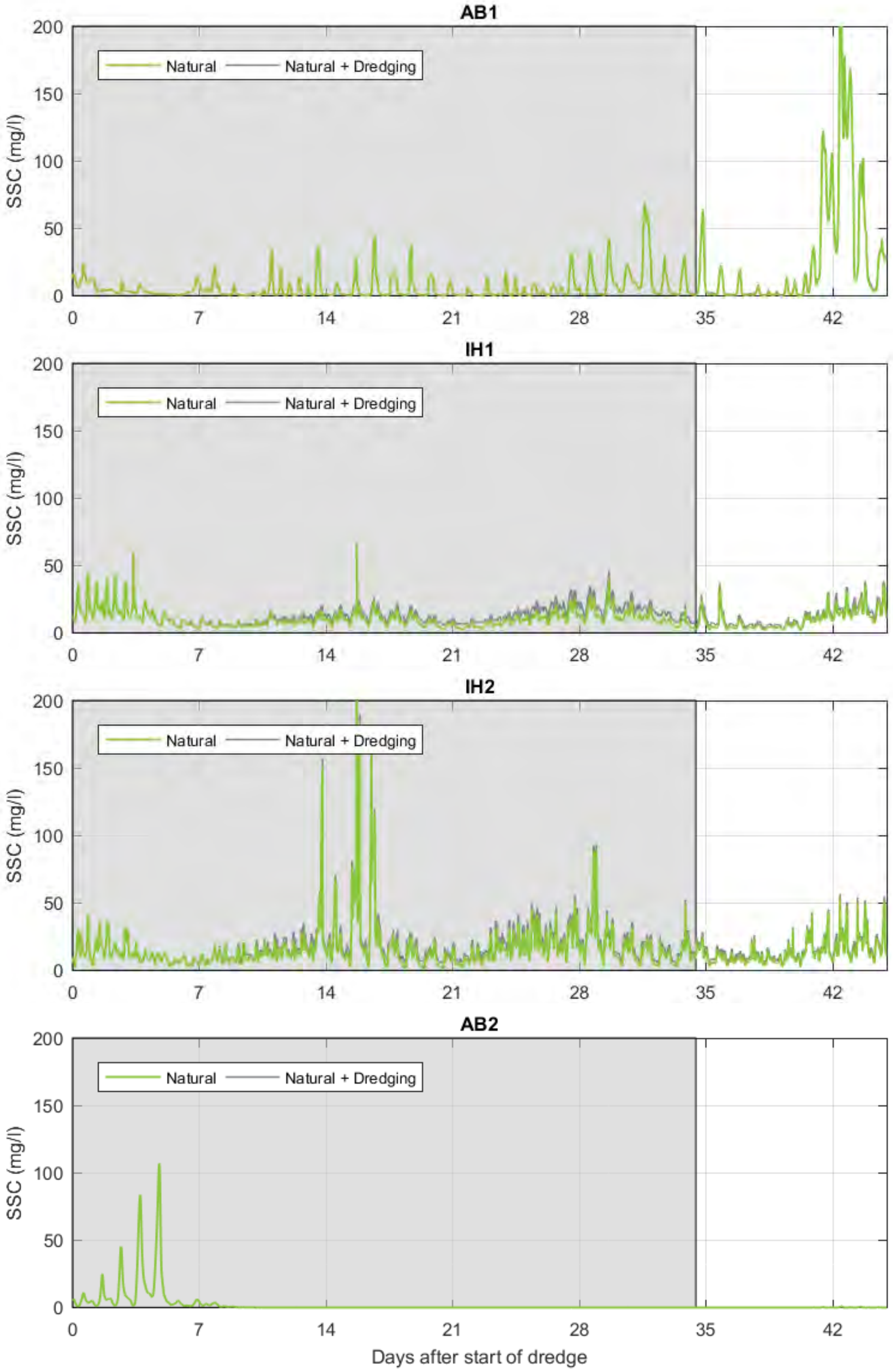


Figure B25. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

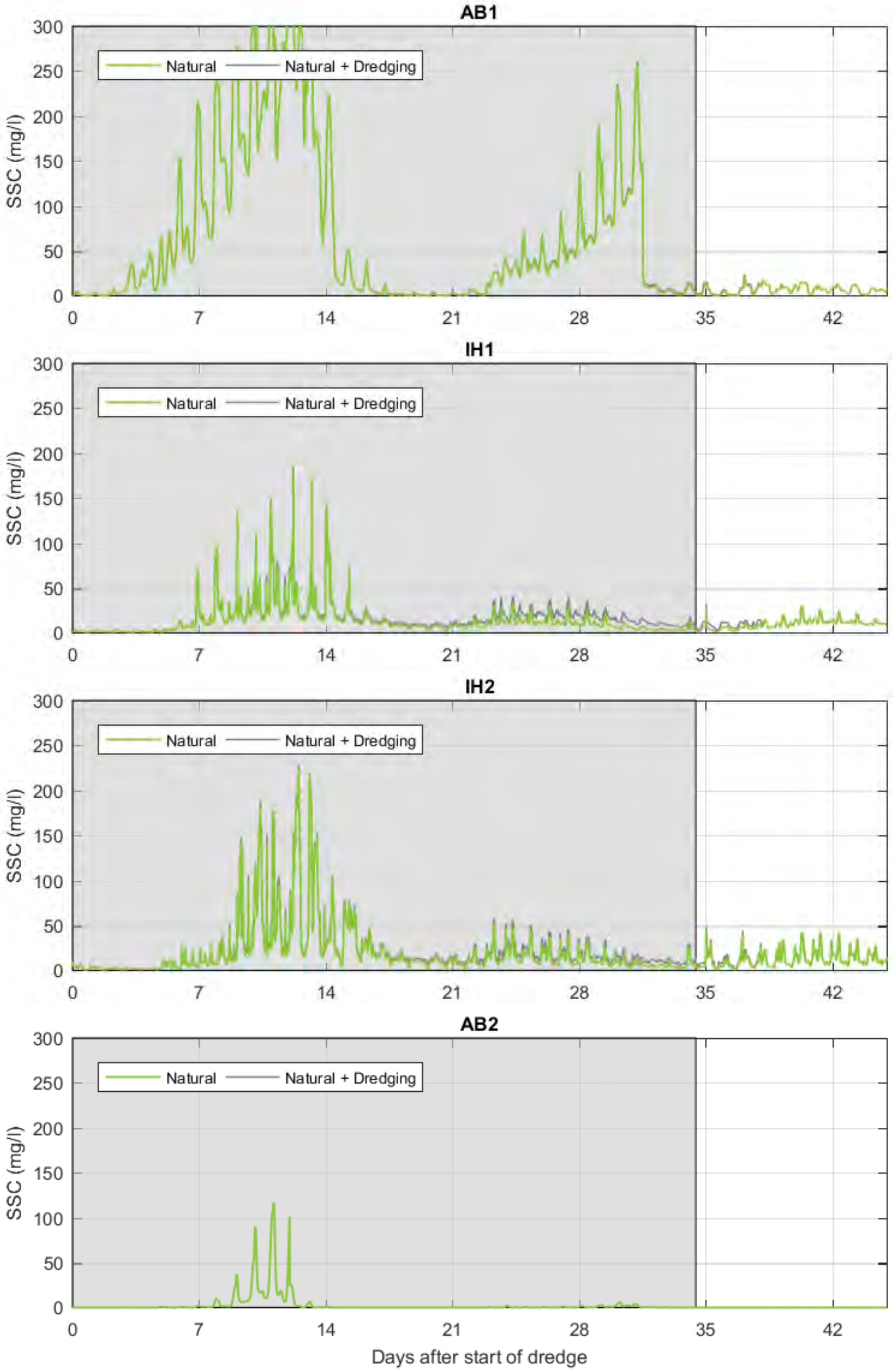


Figure B26. Time series of SSC at AB1, IH1, IH2 and AB2 for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

Appendix C – Spatial Deposition Maps

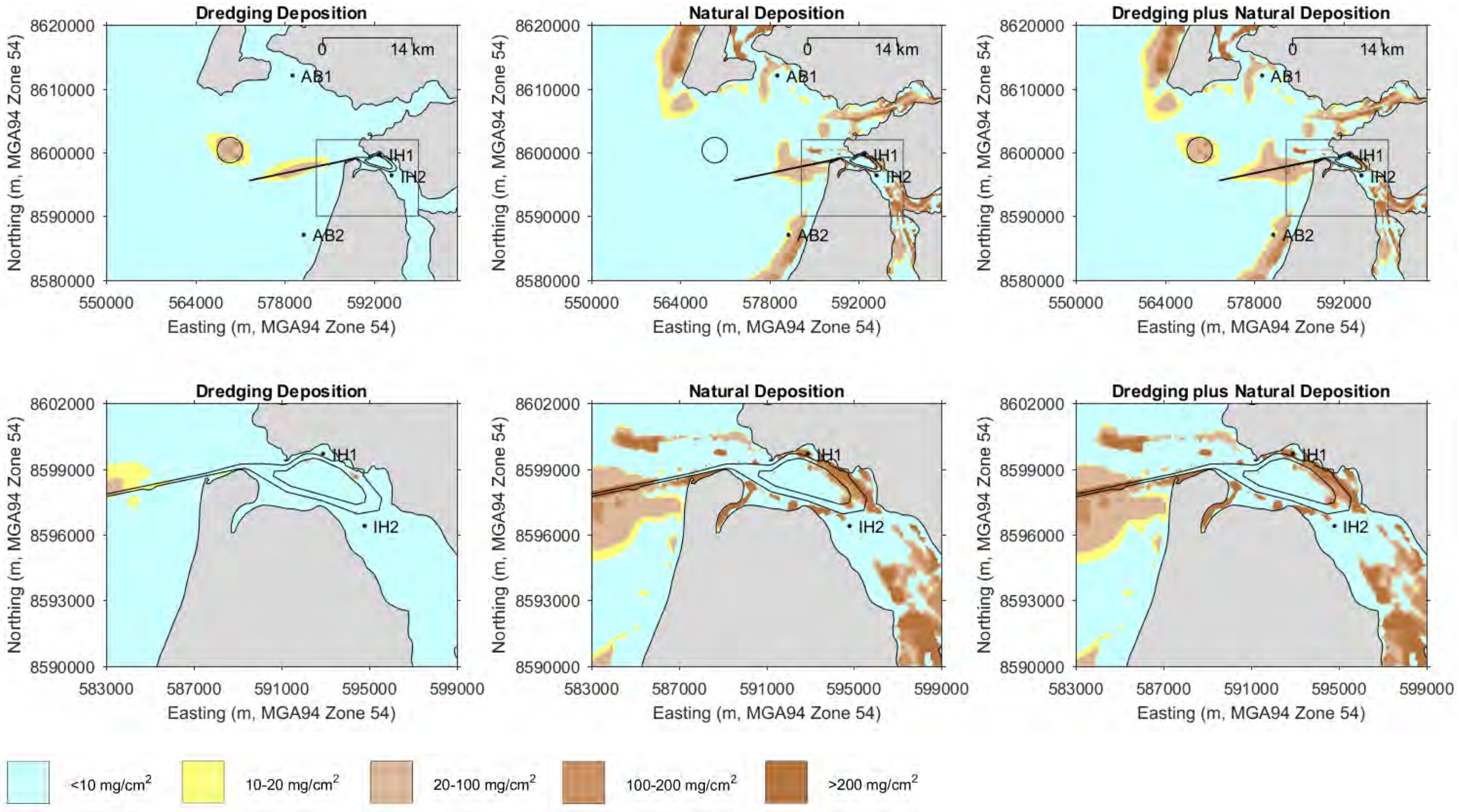


Figure C1. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

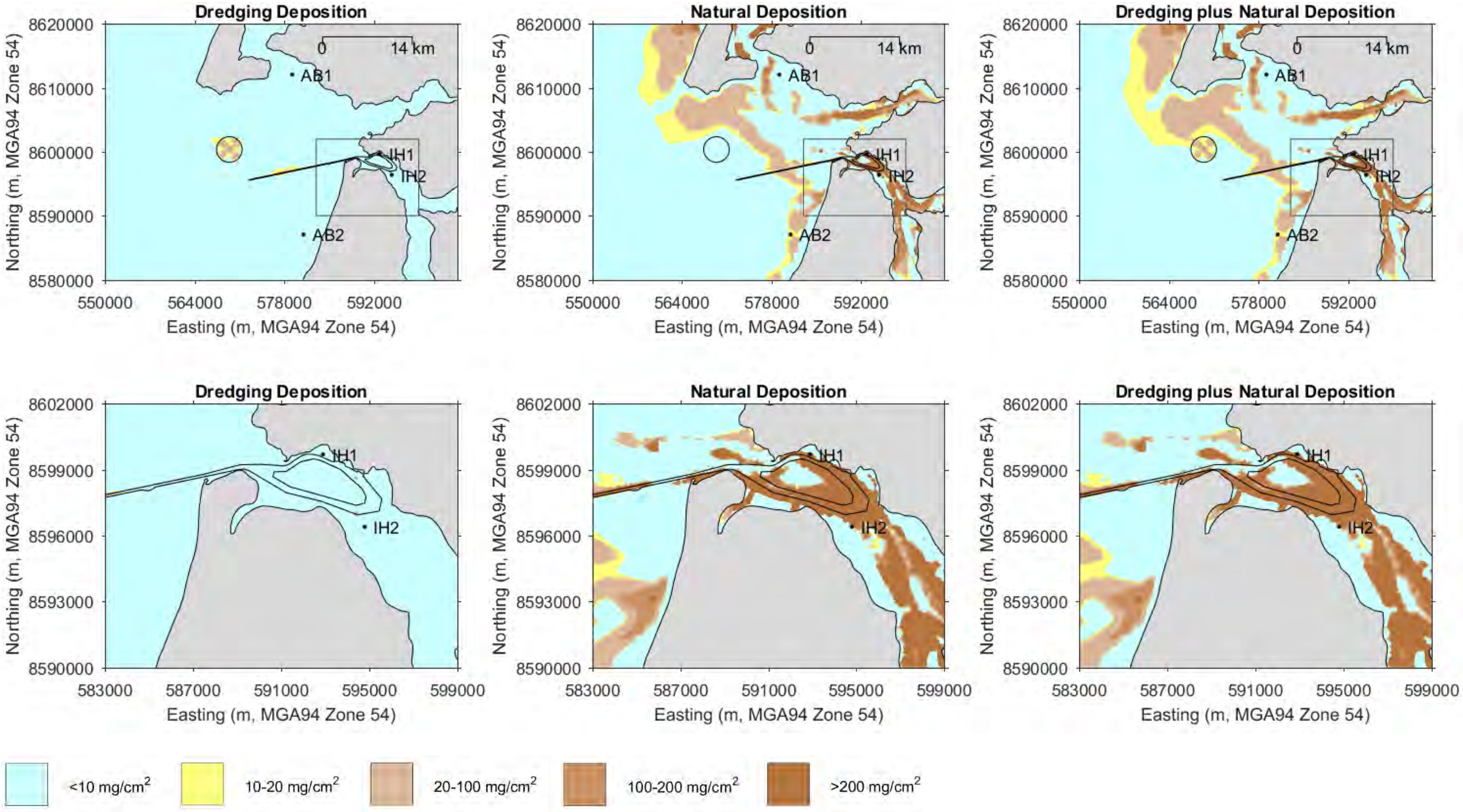


Figure C2. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

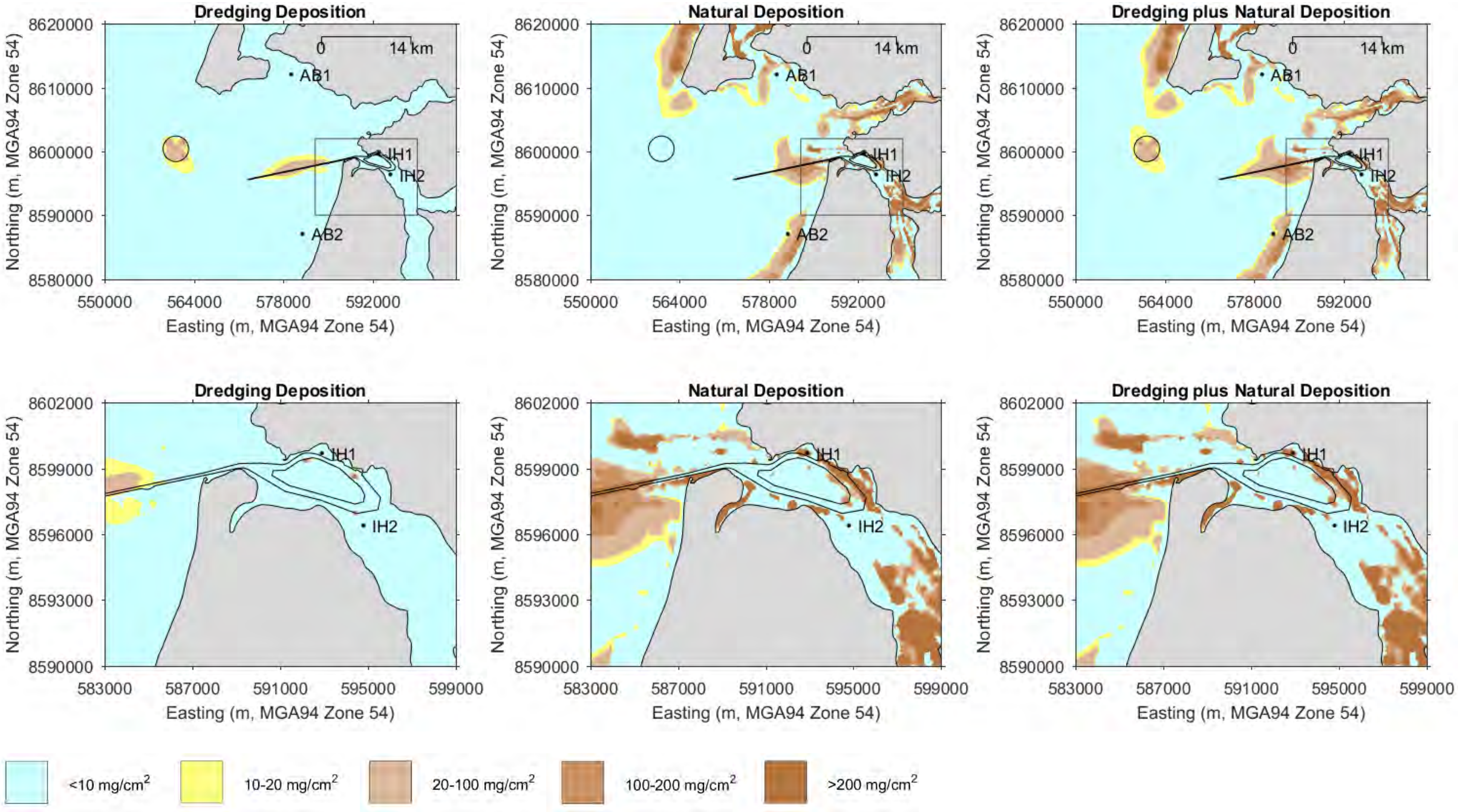


Figure C3. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

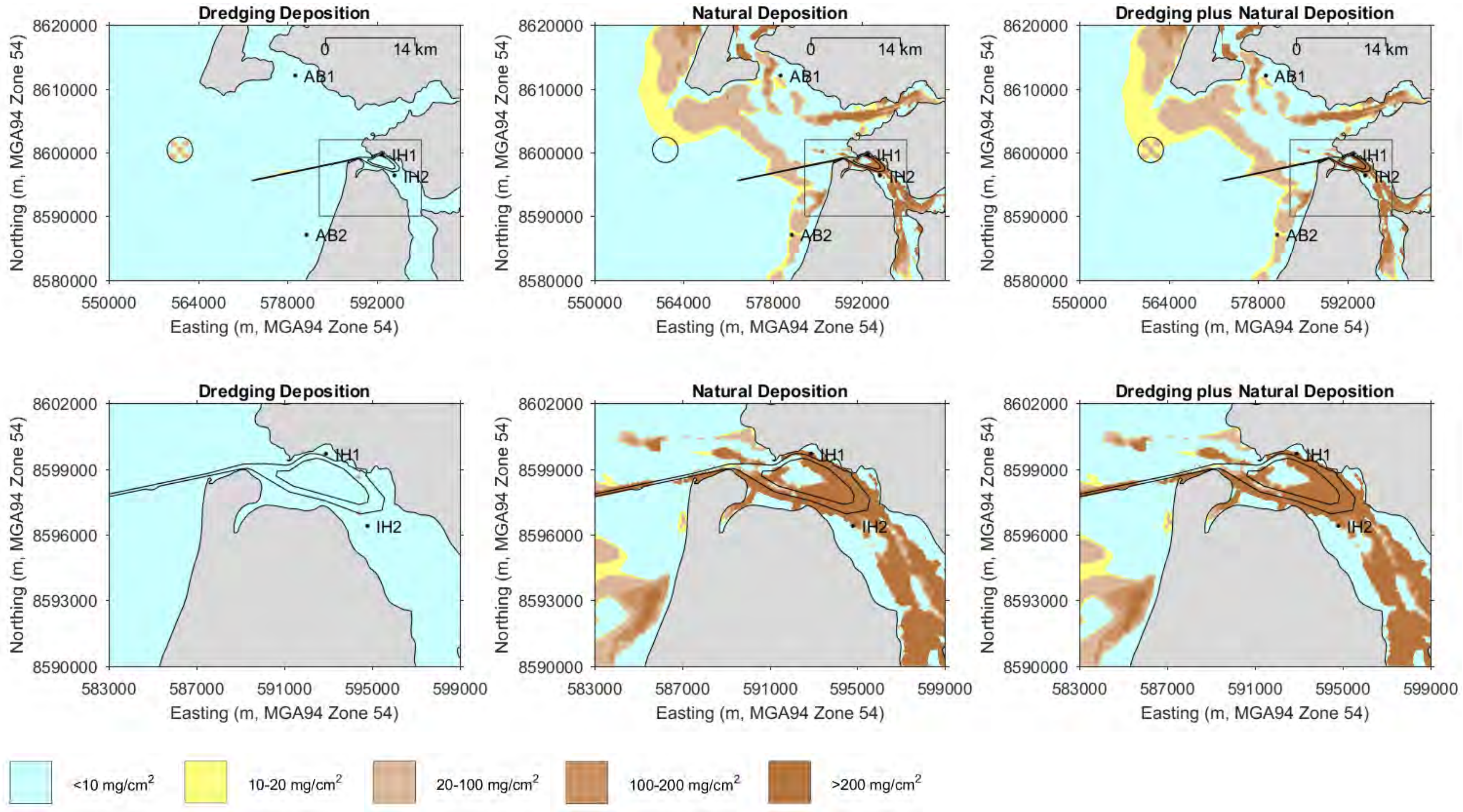


Figure C4. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

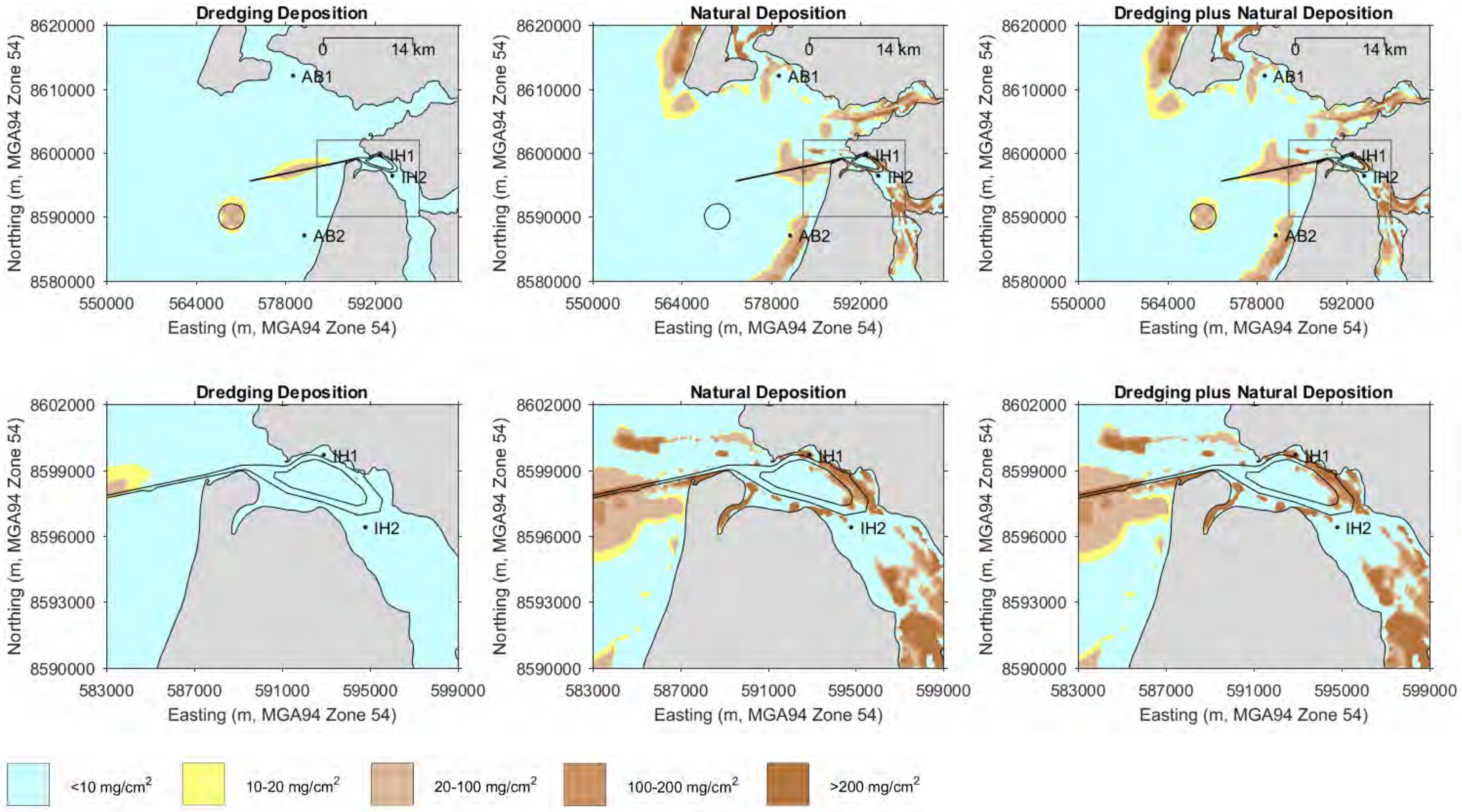


Figure C5. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

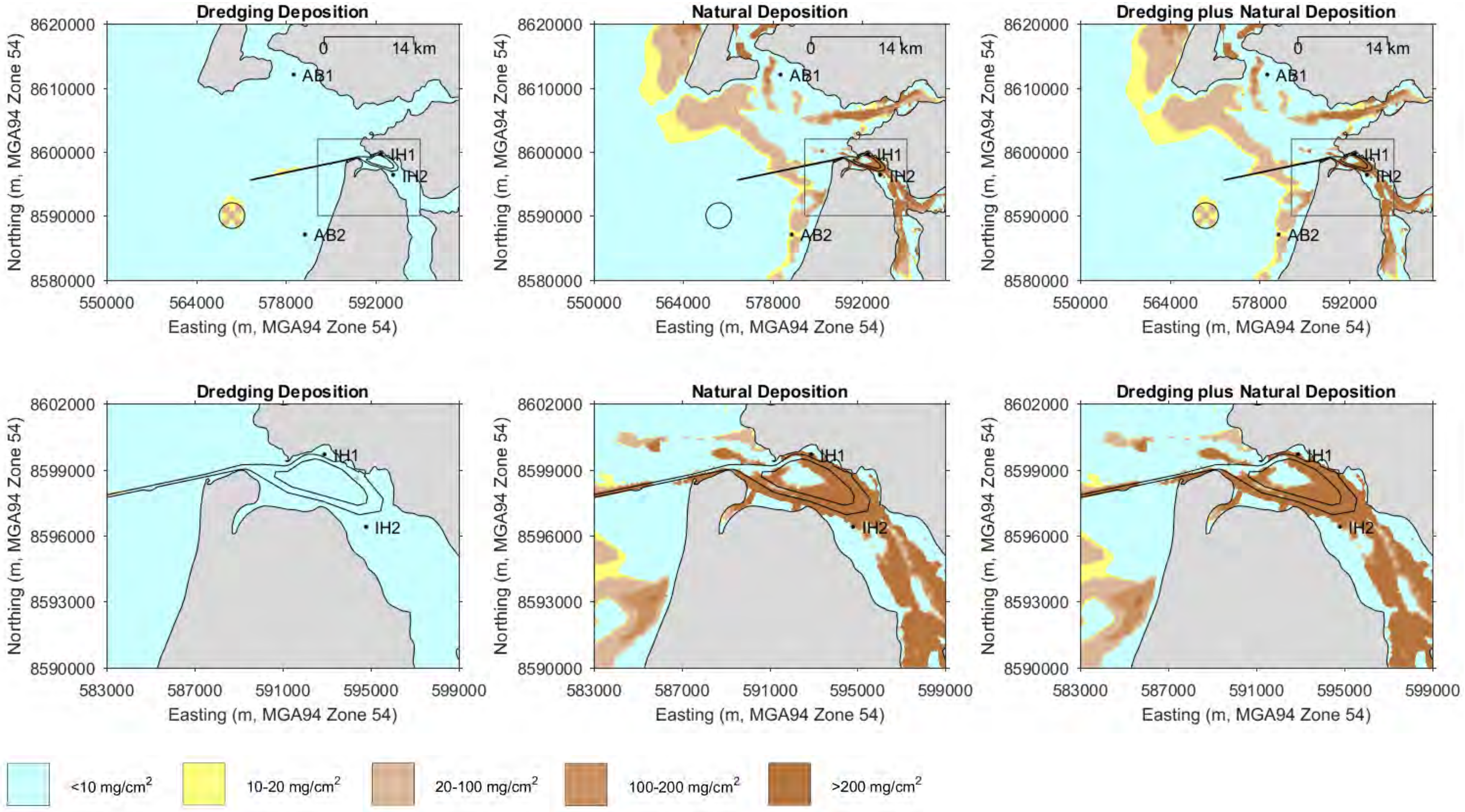


Figure C6. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

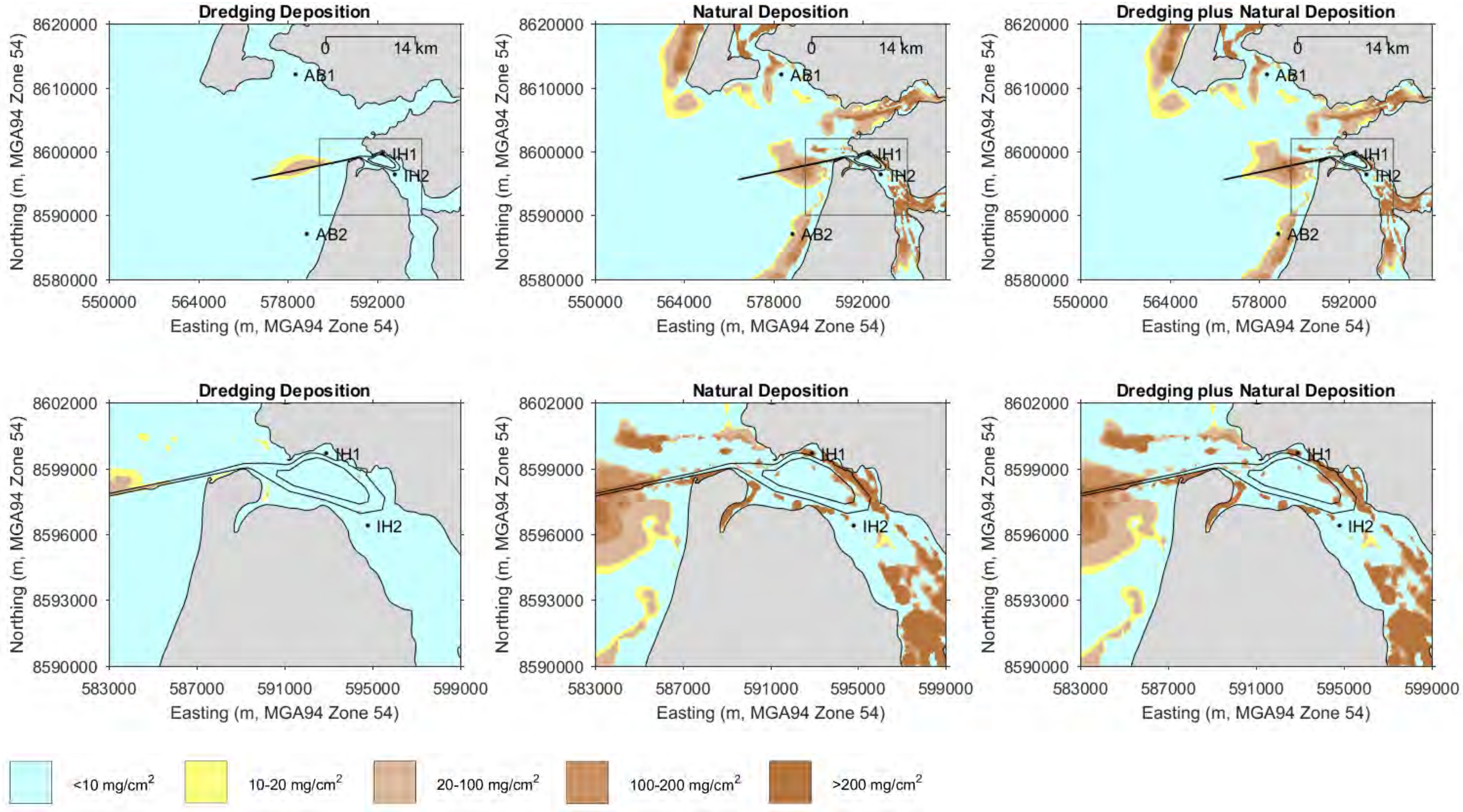


Figure C7. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

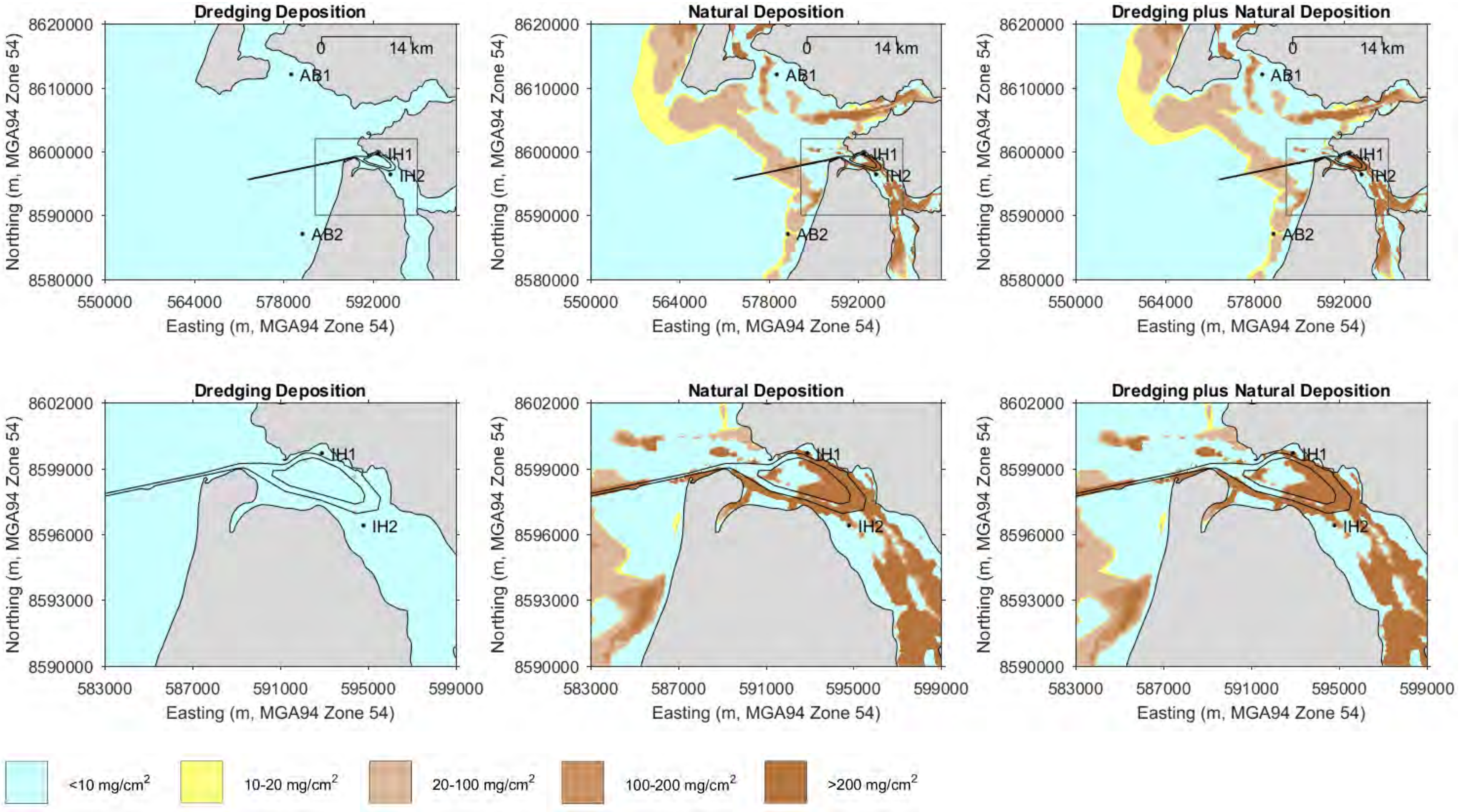


Figure C8. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.

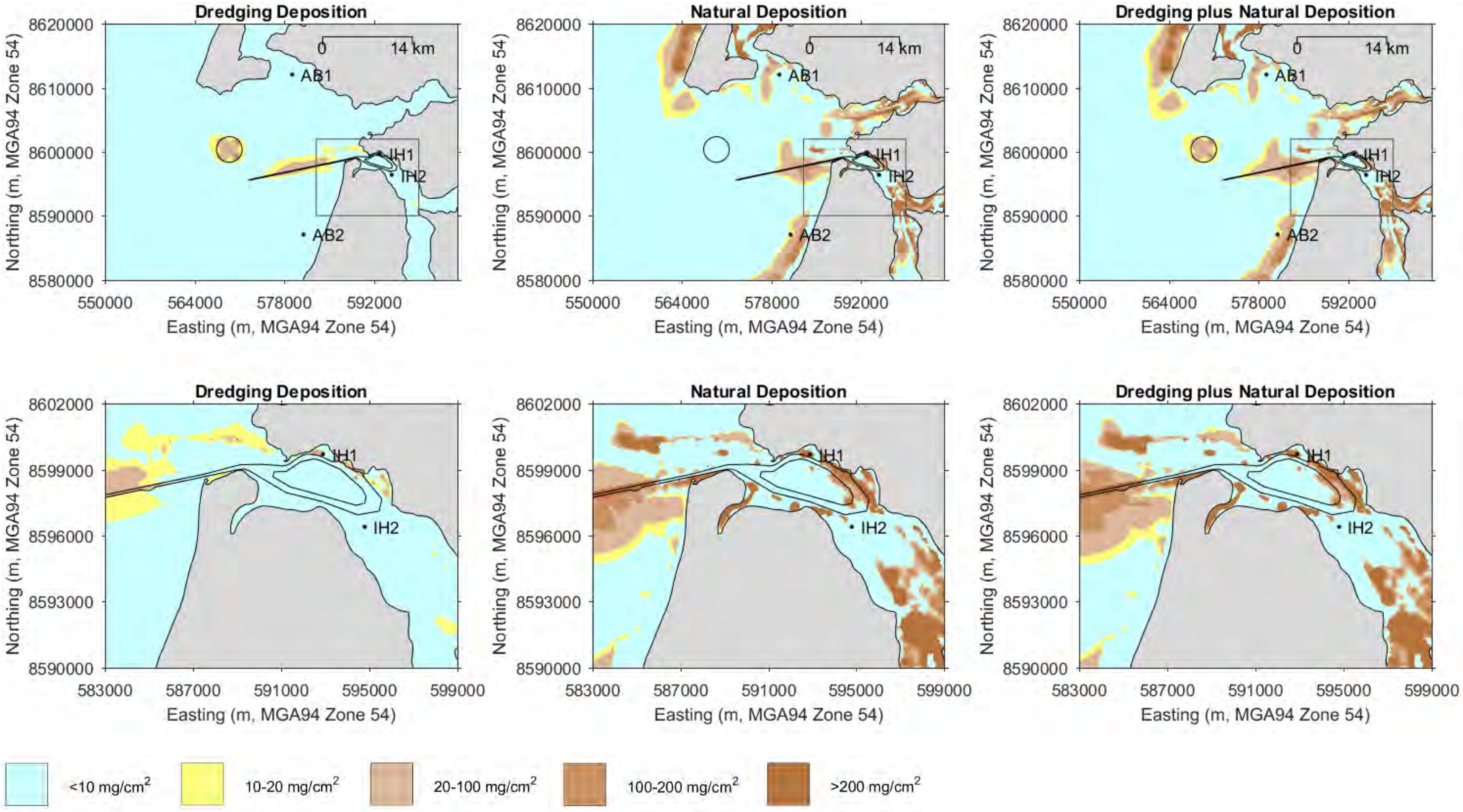


Figure C9. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the ambient dry season.

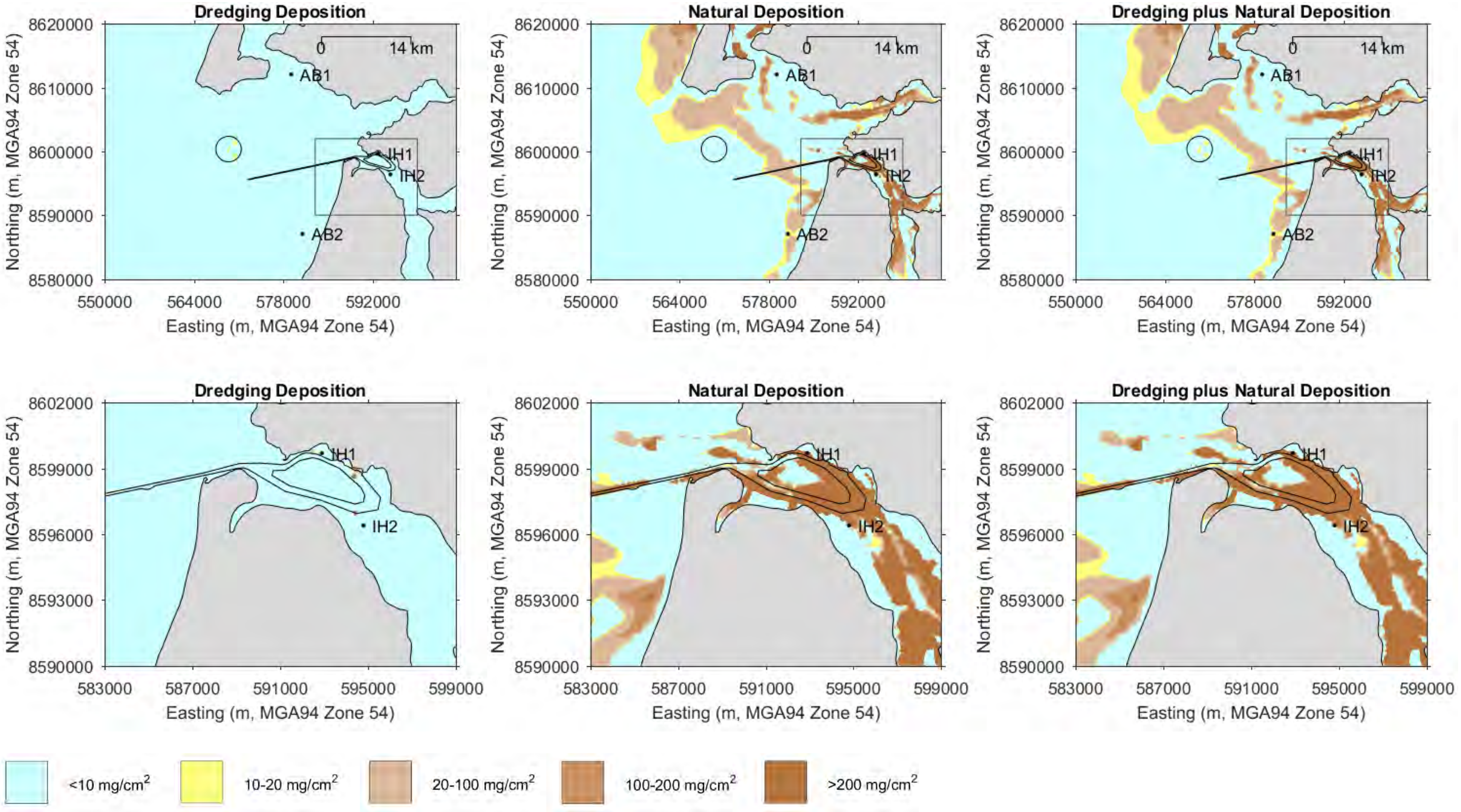


Figure C10. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material placed at the reclamation site in the energetic dry season.

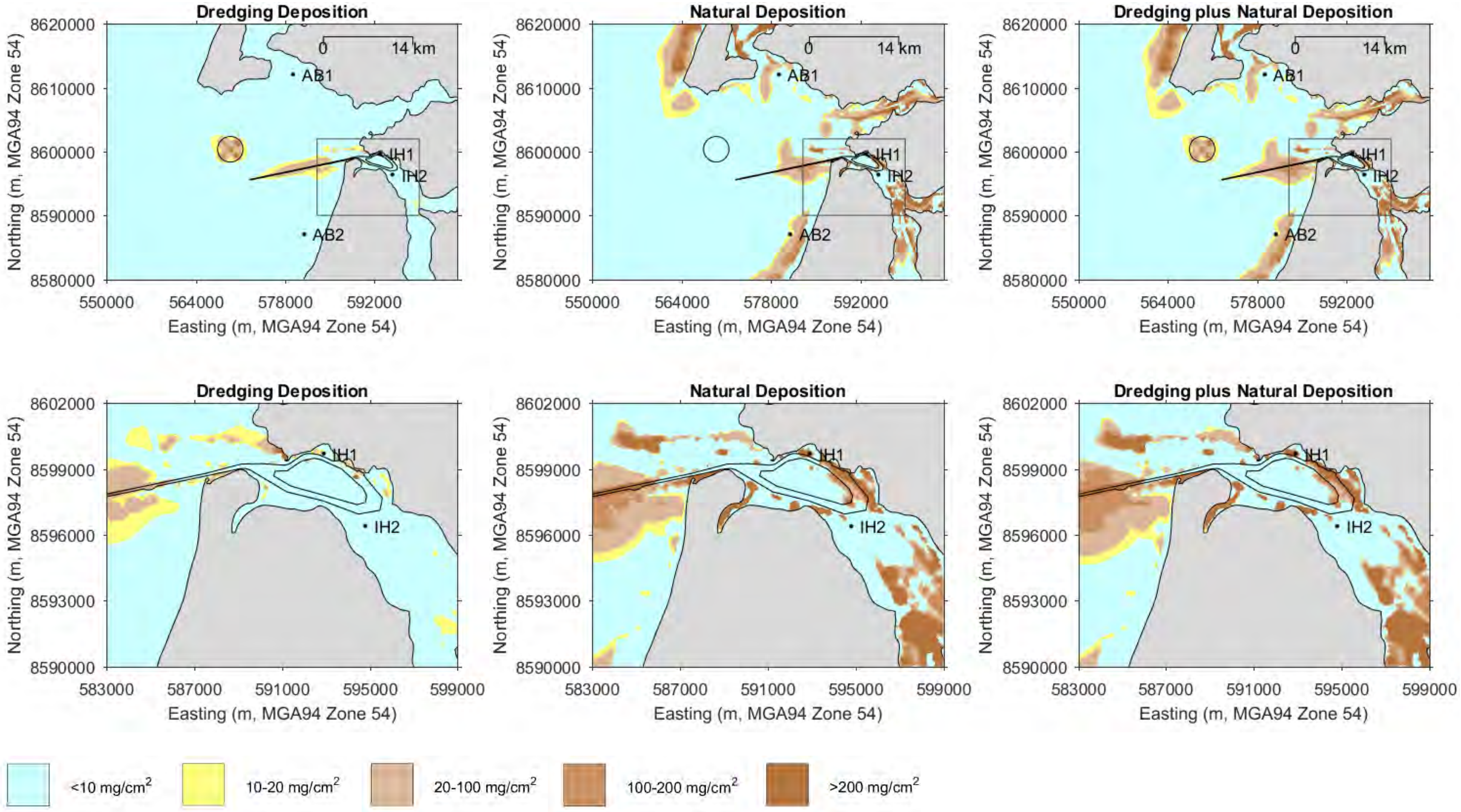


Figure C11. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the ambient dry season.

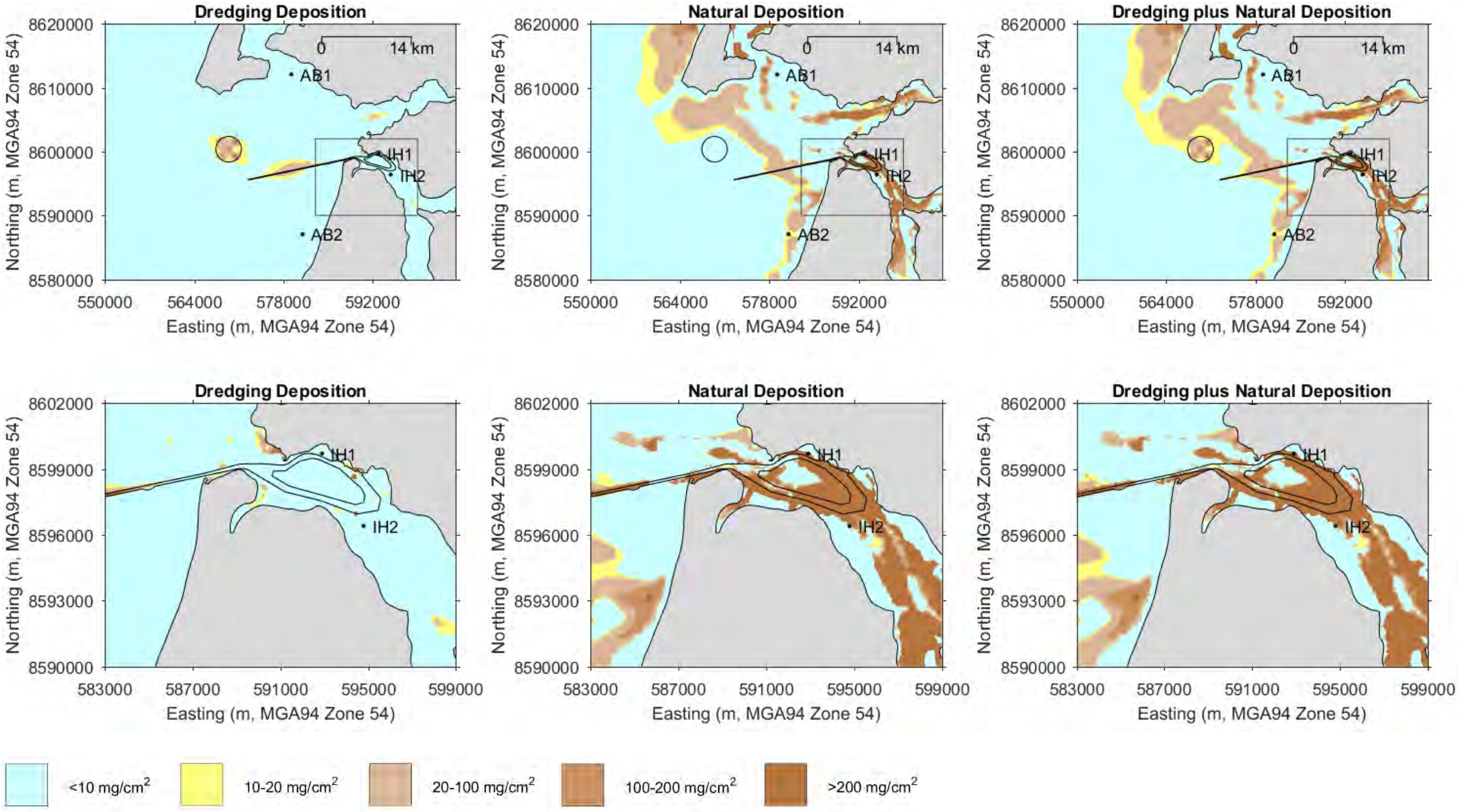


Figure C12. Deposition for dredging, natural and natural plus dredging for 400,000 m^3 of sediment with material used for beach nourishment in the energetic dry season.

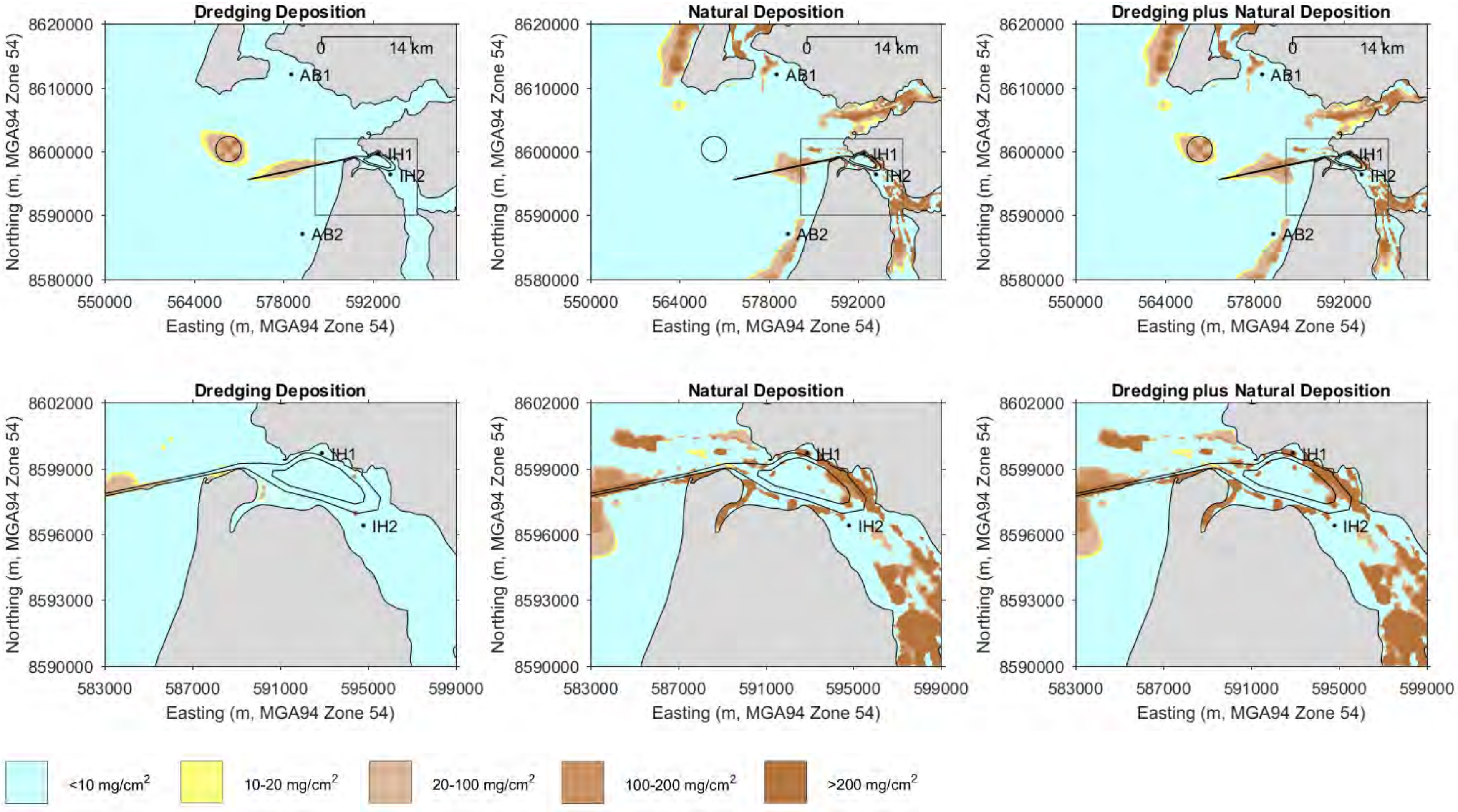


Figure C13. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

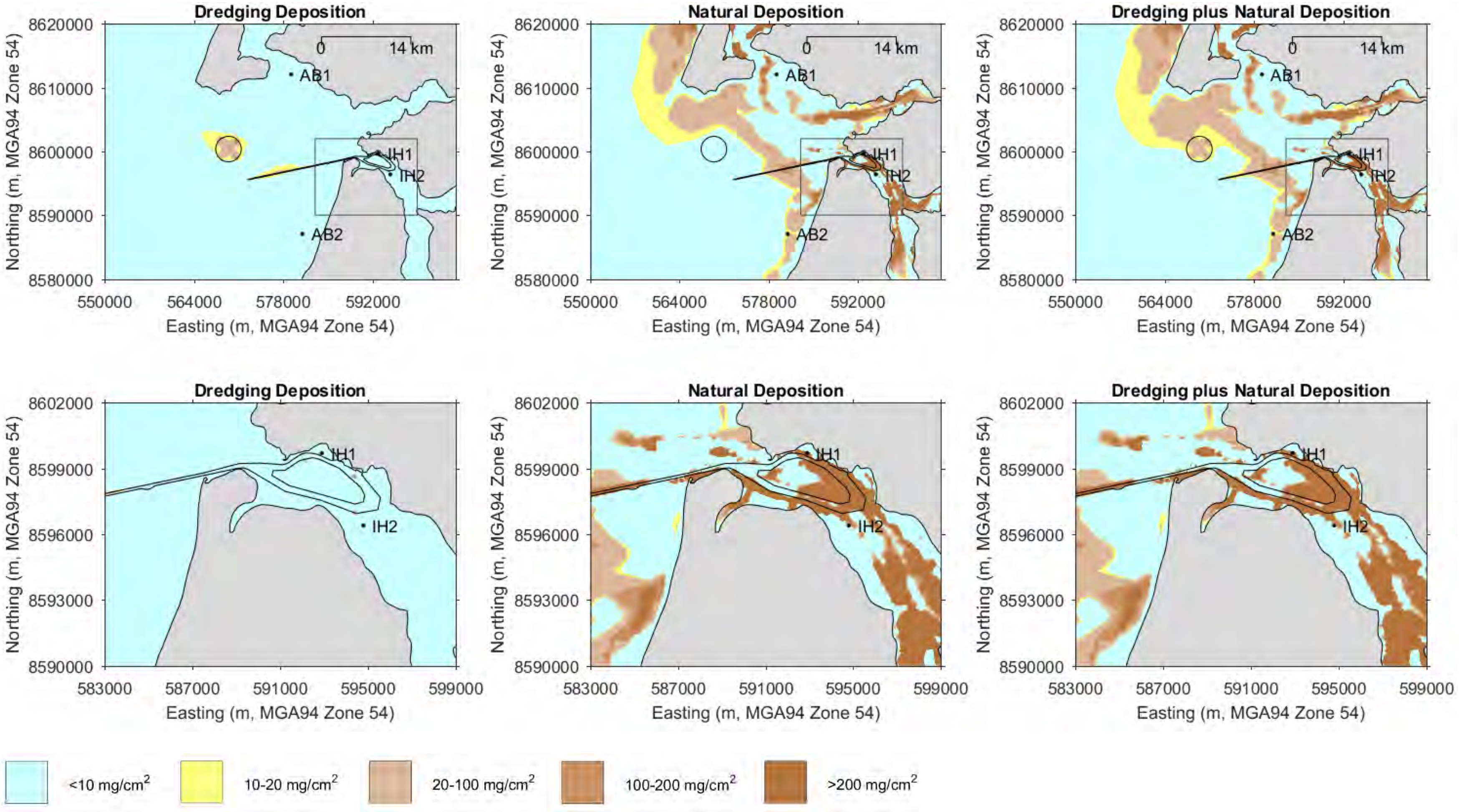


Figure C14. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

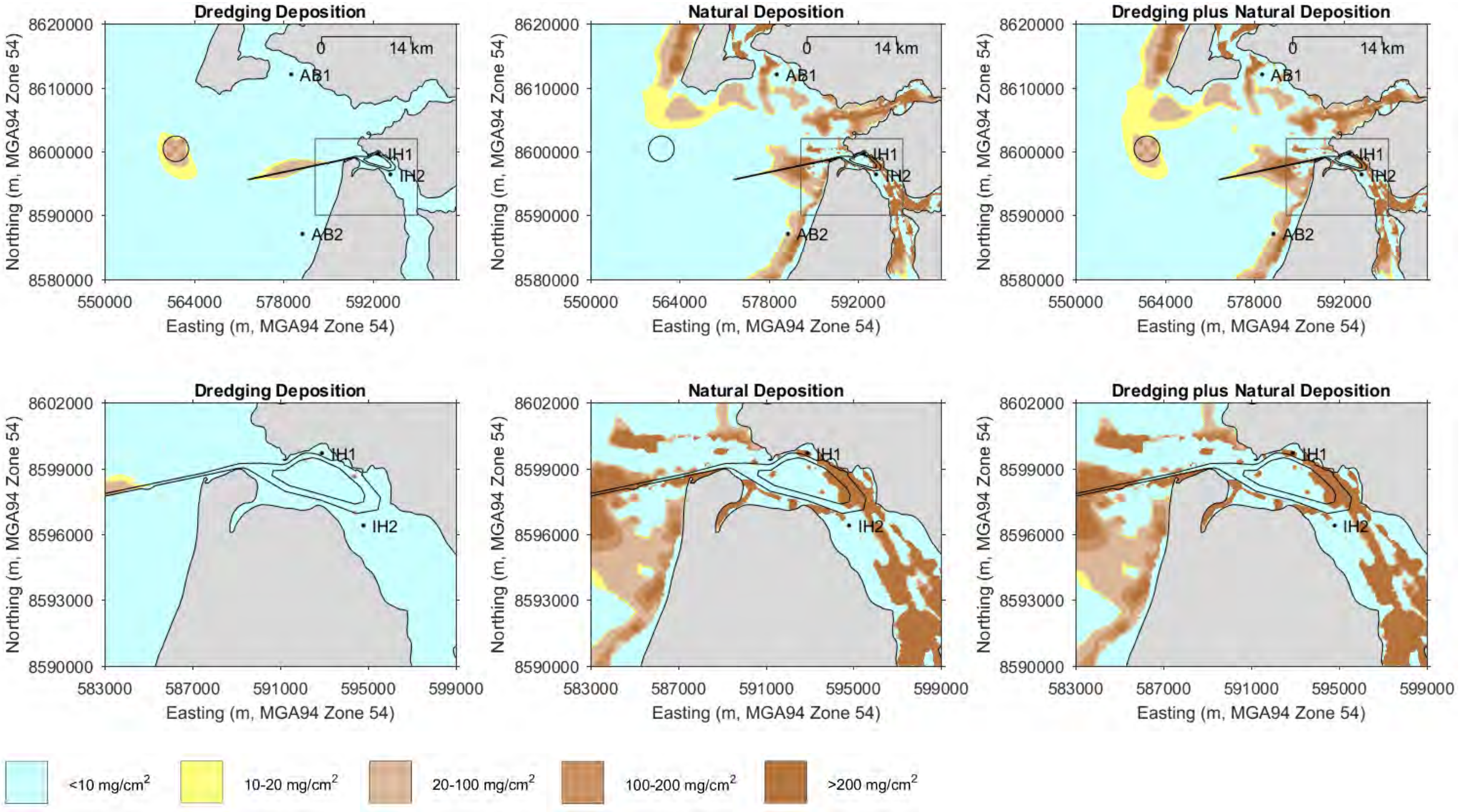


Figure C15. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.

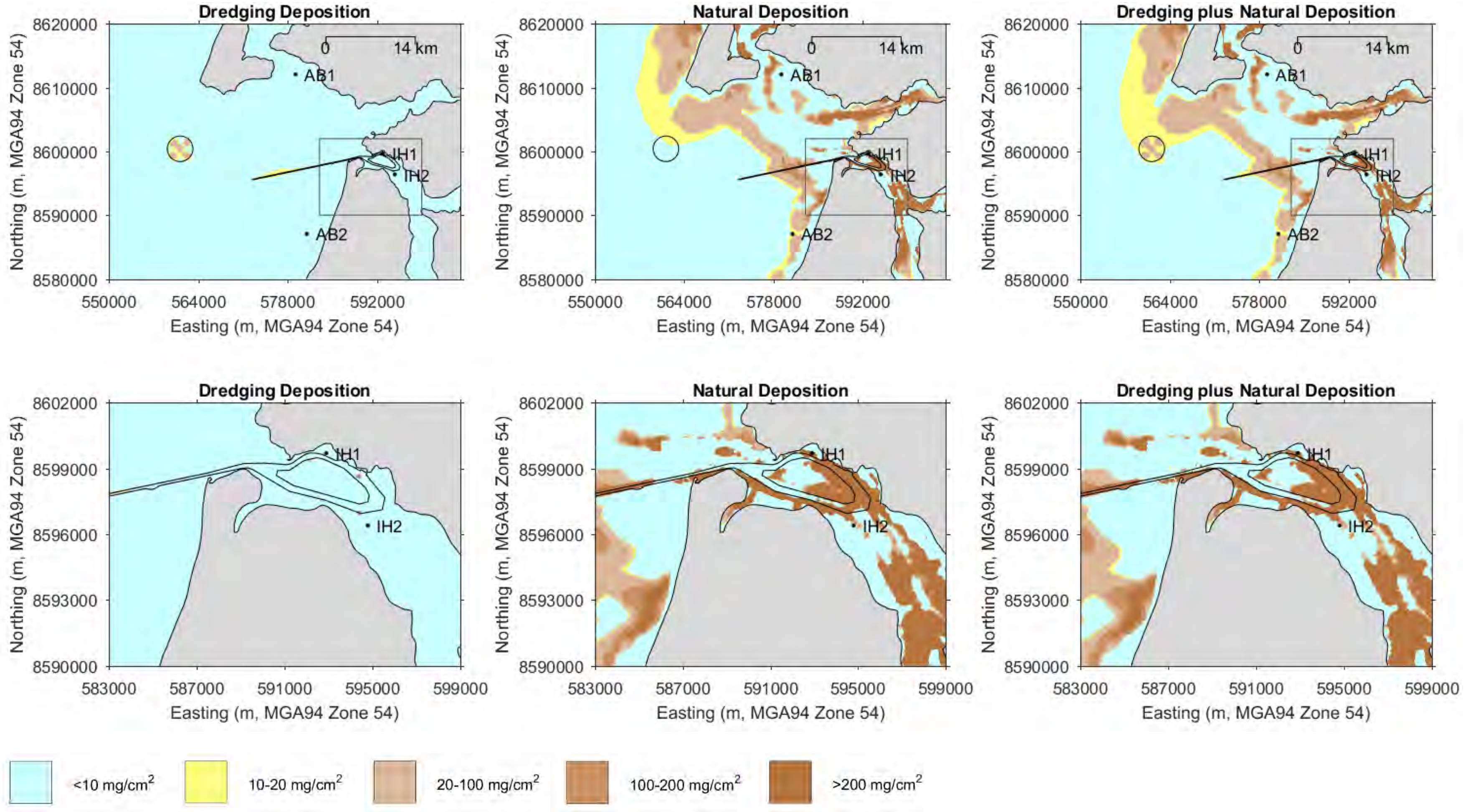


Figure C16. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

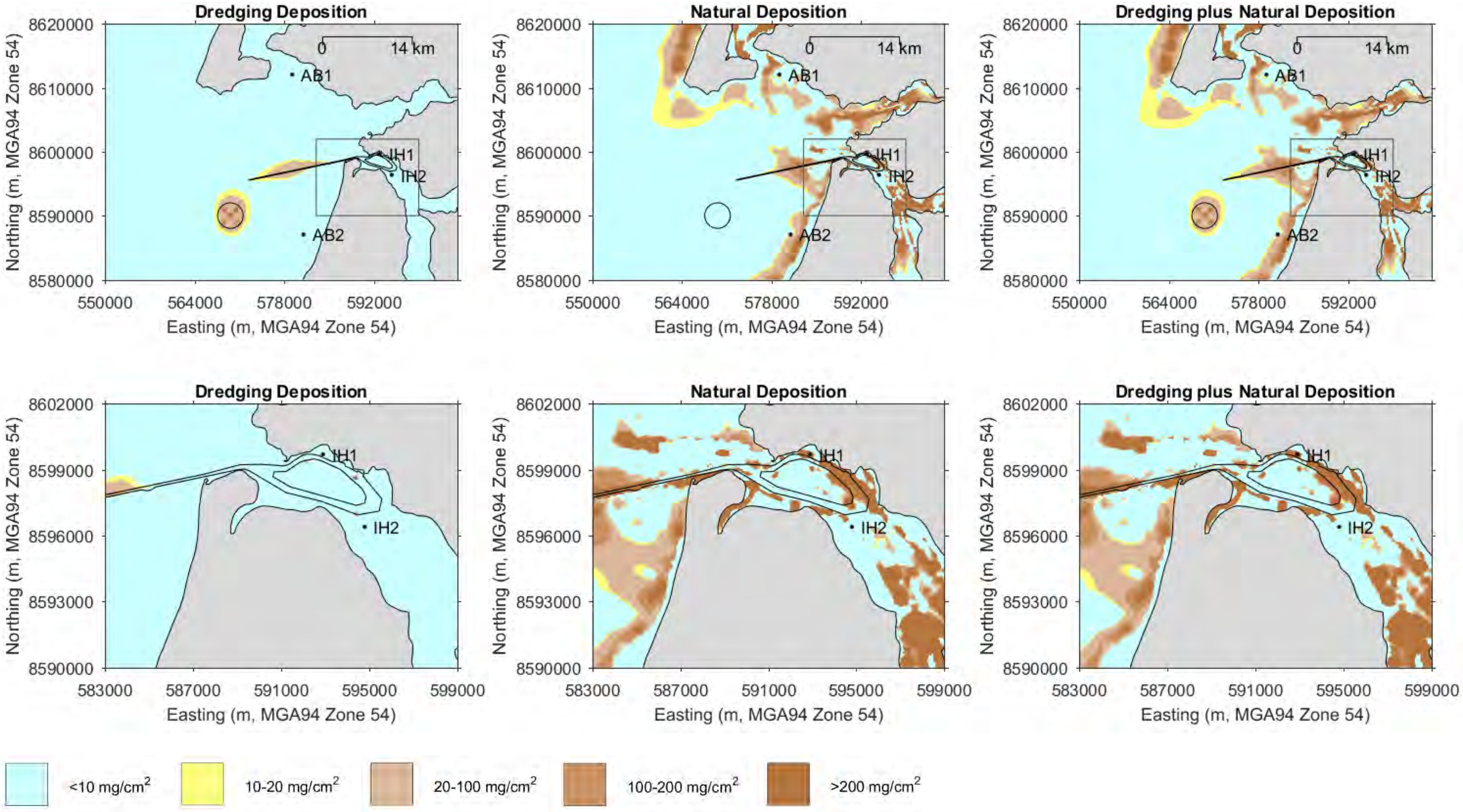


Figure C17. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

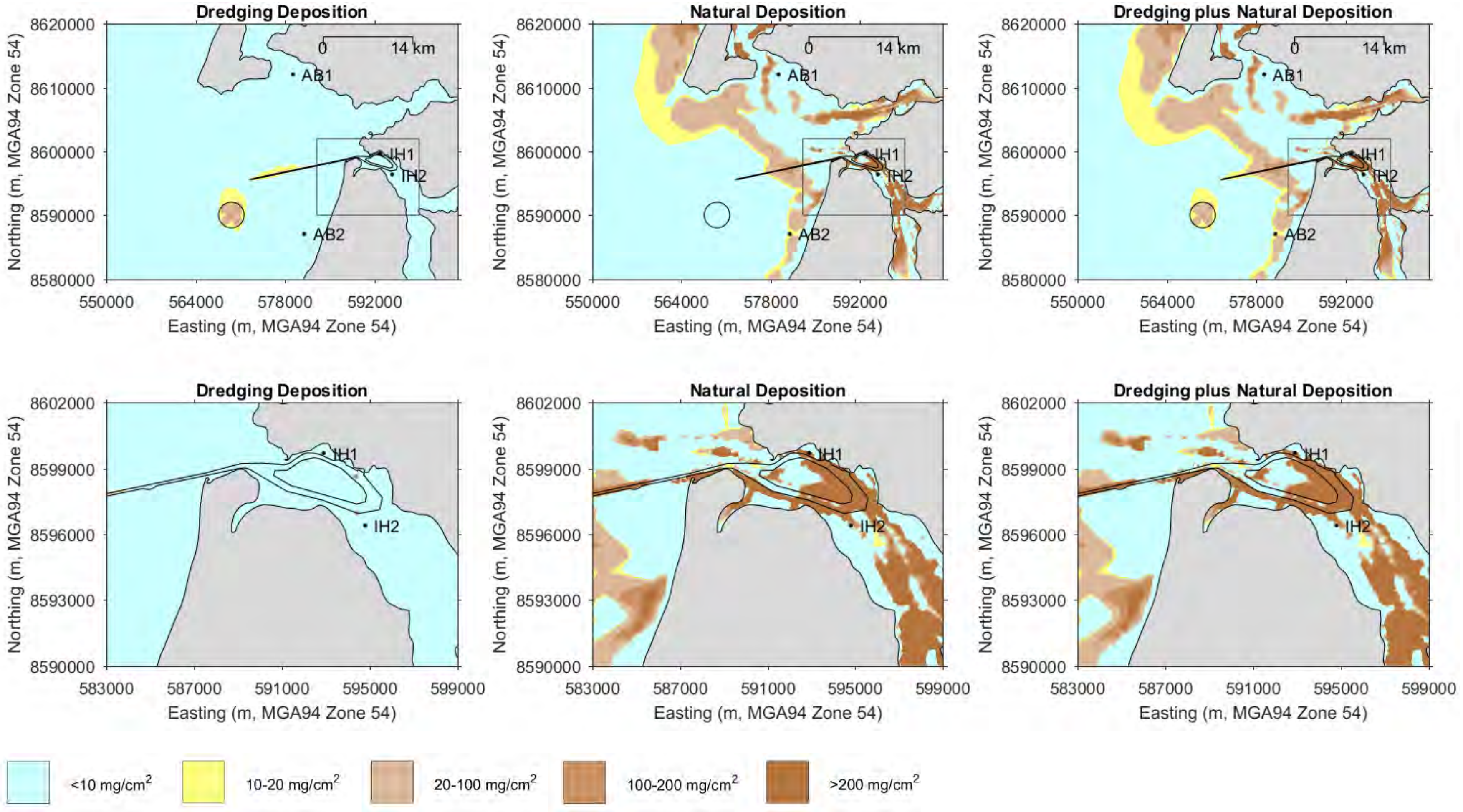


Figure C18. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.

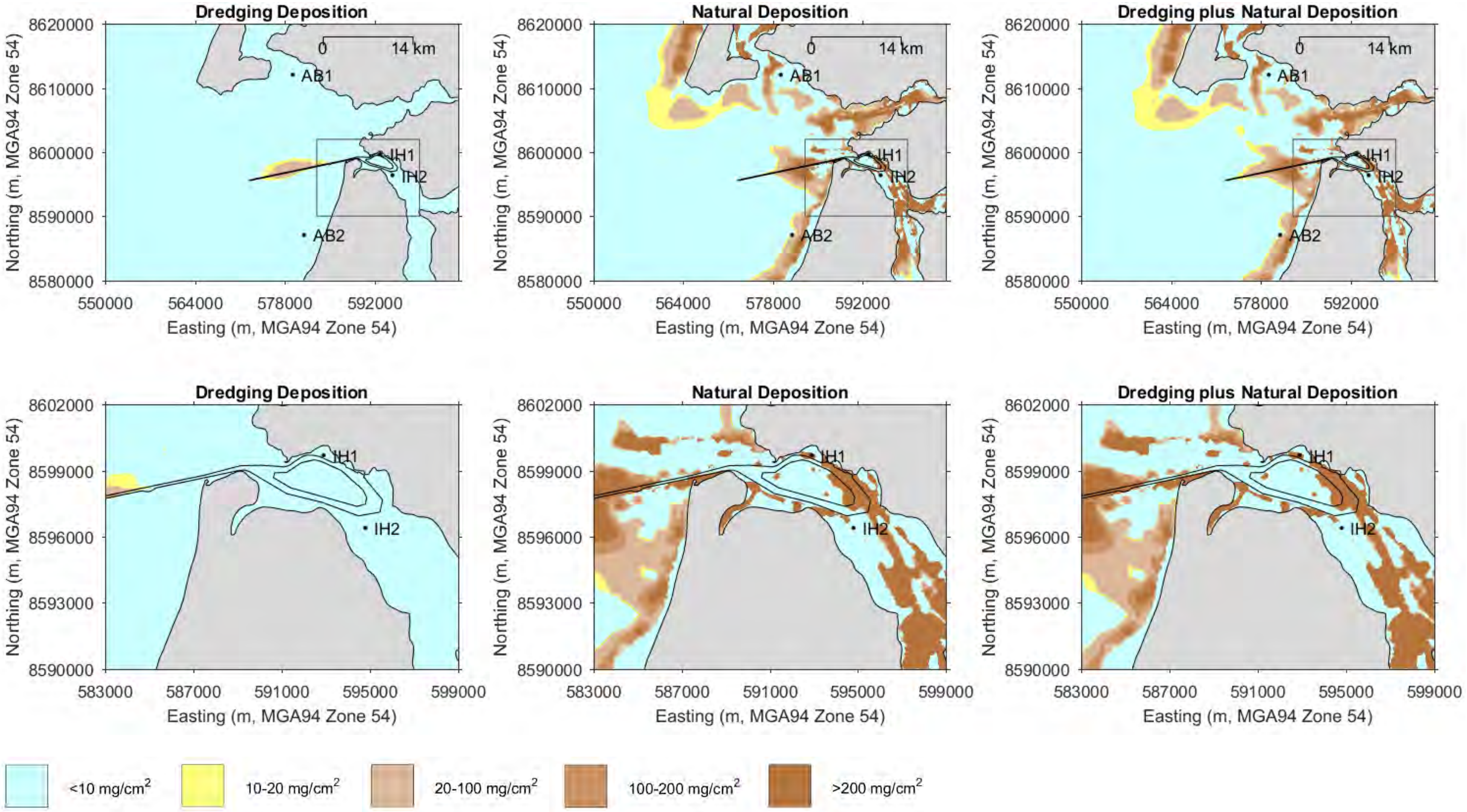


Figure C19. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the ambient dry season.

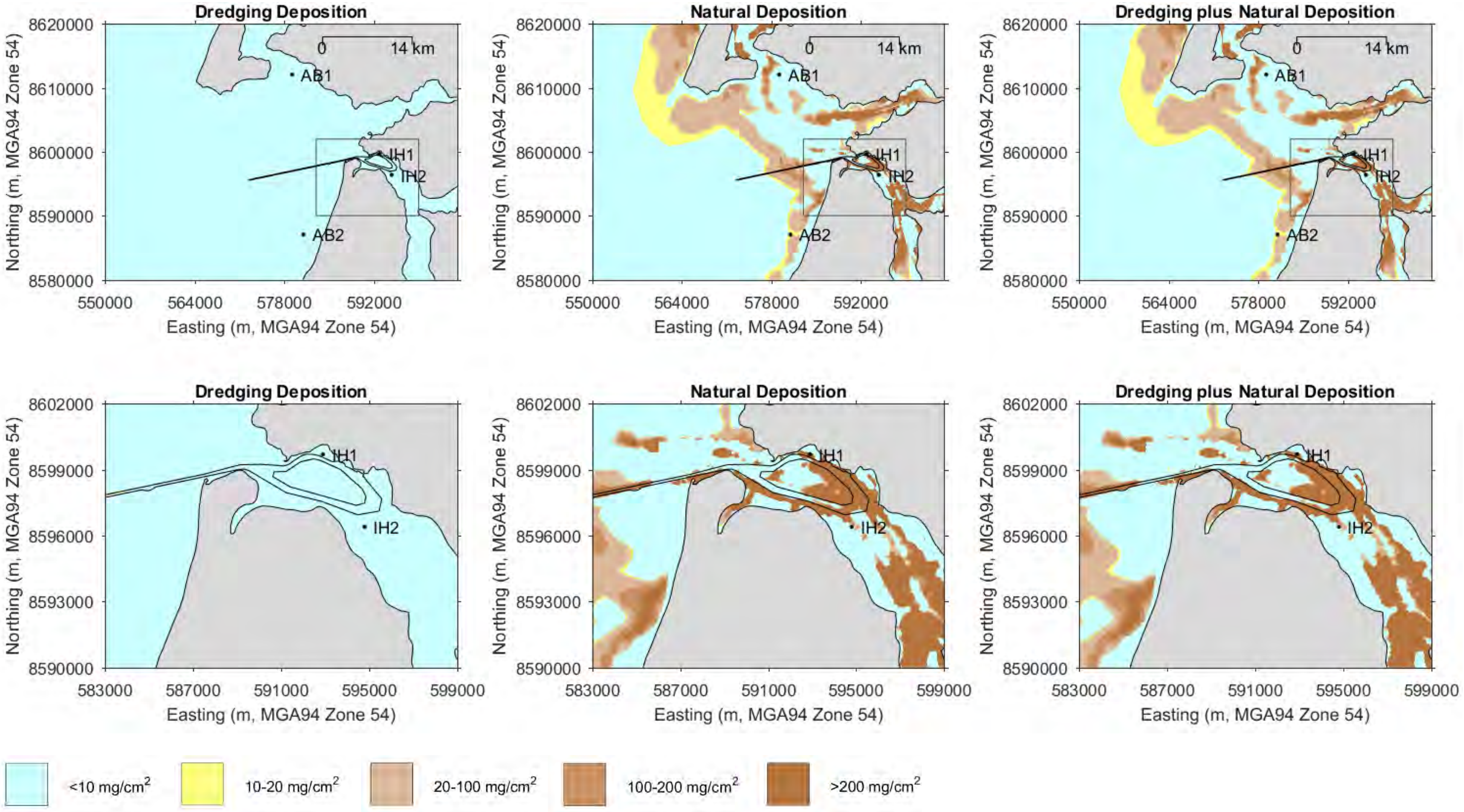


Figure C20. Deposition for dredging, natural and natural plus dredging for 800,000 m^3 of sediment with material placed at the onshore pond in the energetic dry season.

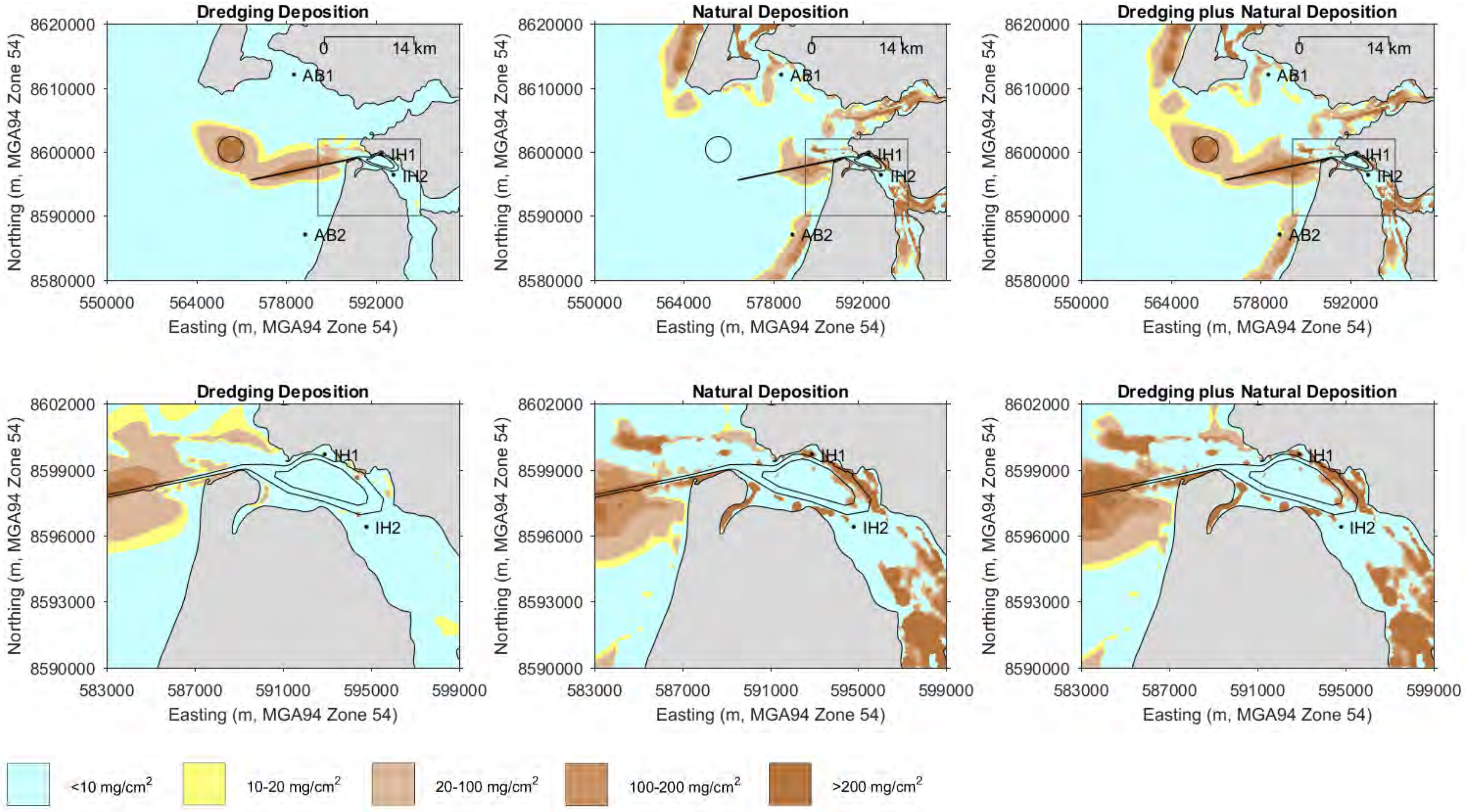


Figure C21. Deposition for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the ambient dry season.

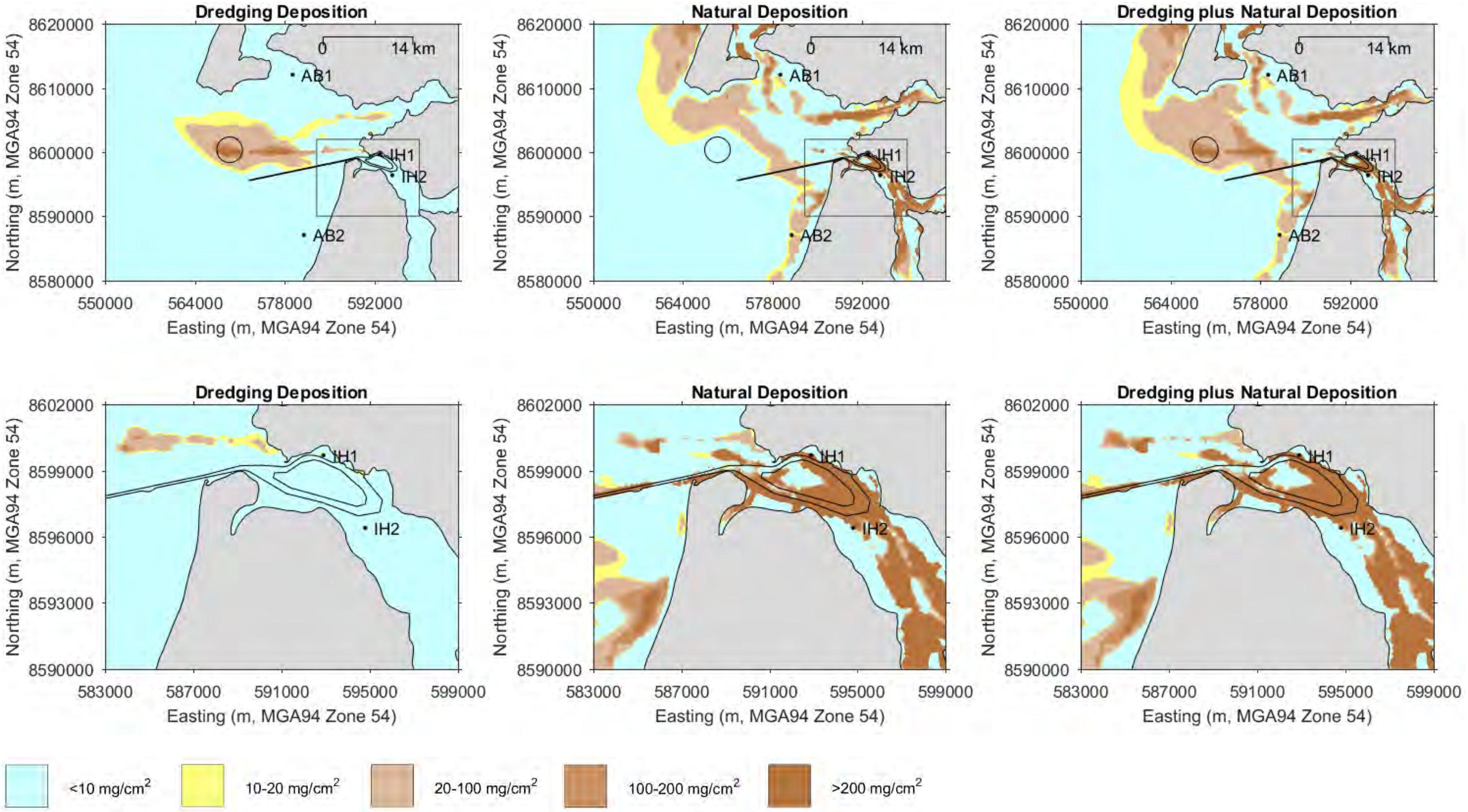


Figure C22. Deposition for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the existing Albatross DMPA in the energetic dry season.

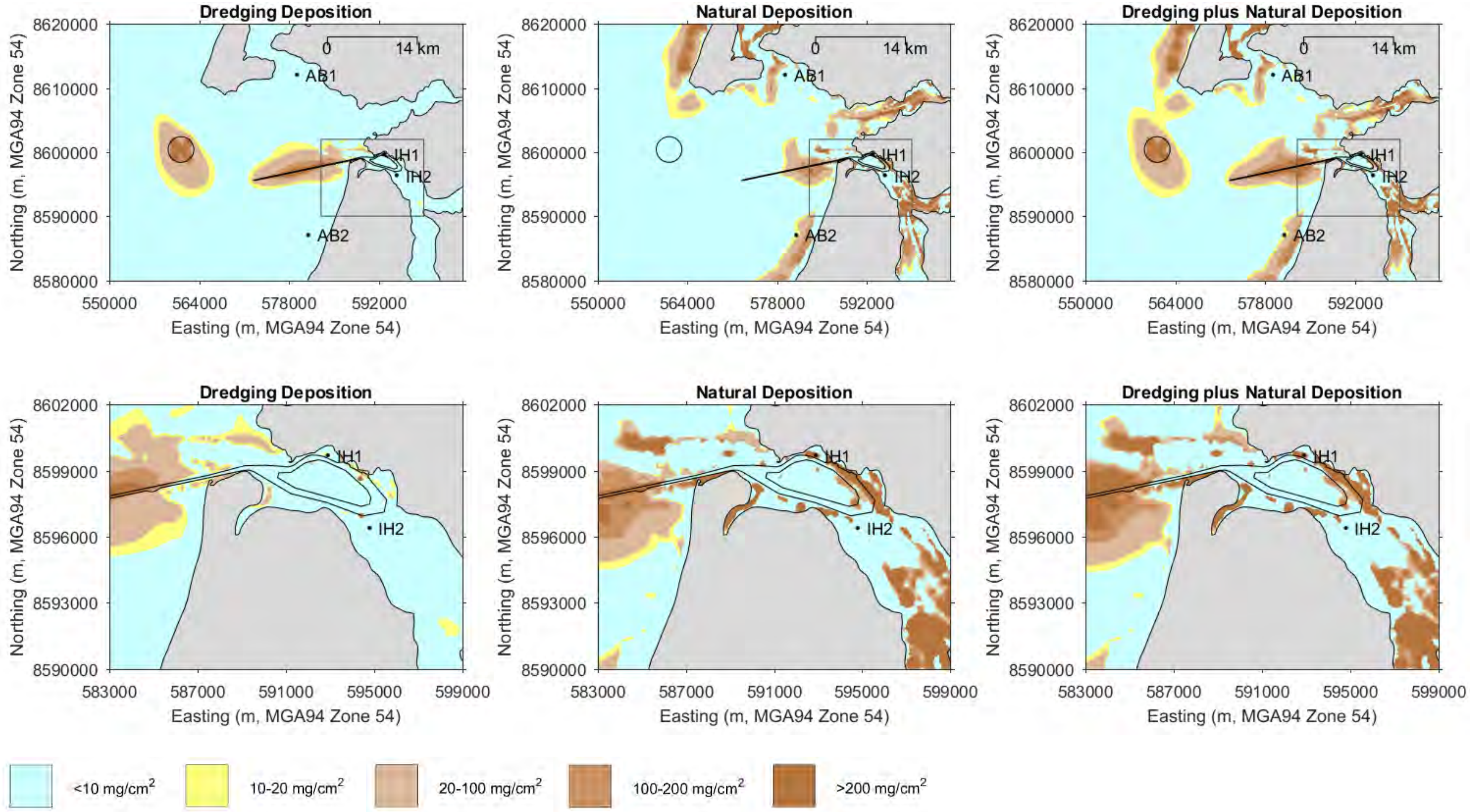
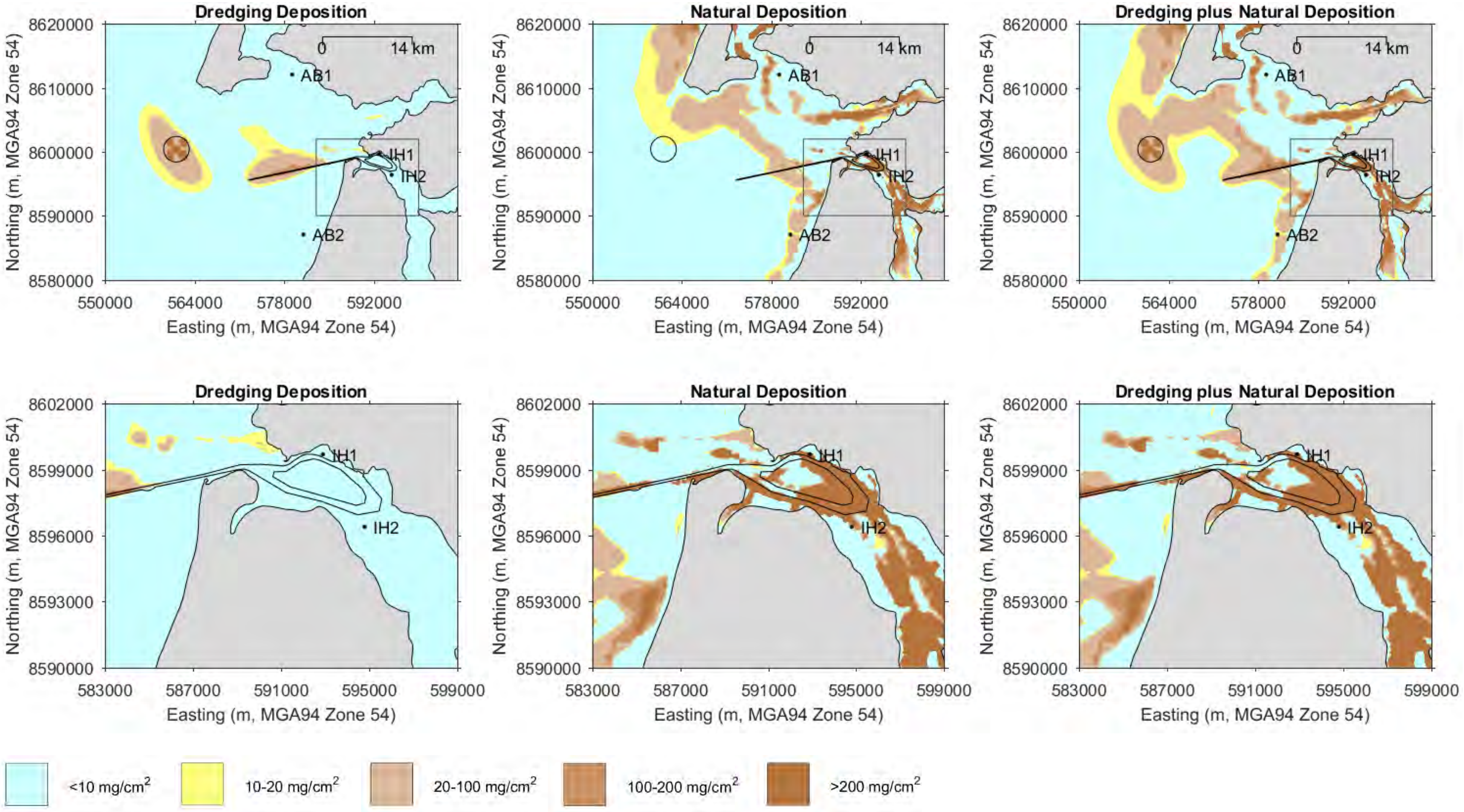


Figure C23. Deposition for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the ambient dry season.



Dredging Deposition

Natural Deposition

Dredging plus Natural Deposition

Figure C24. Deposition for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross West DMPA in the energetic dry season.

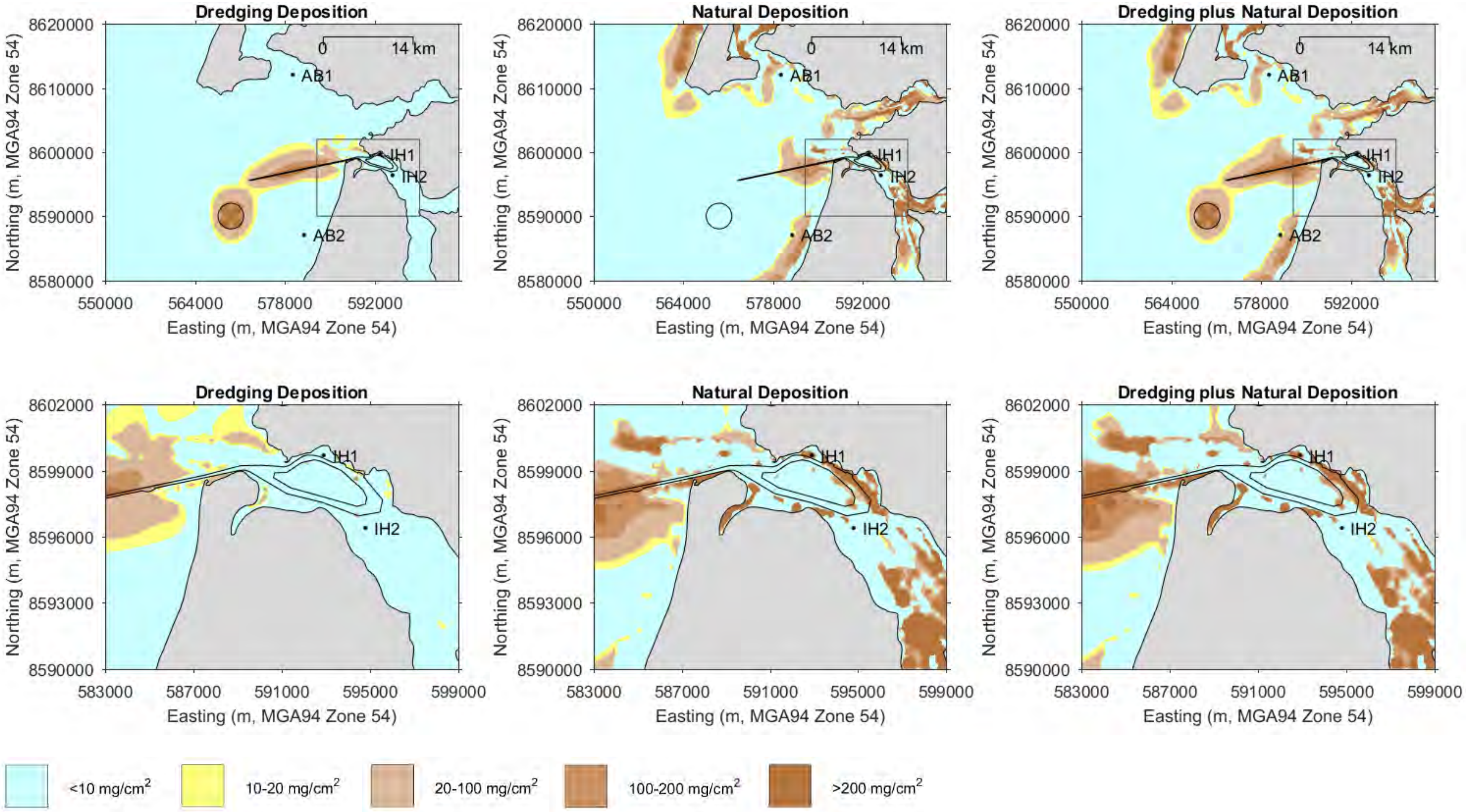


Figure C25. Deposition for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the ambient dry season.

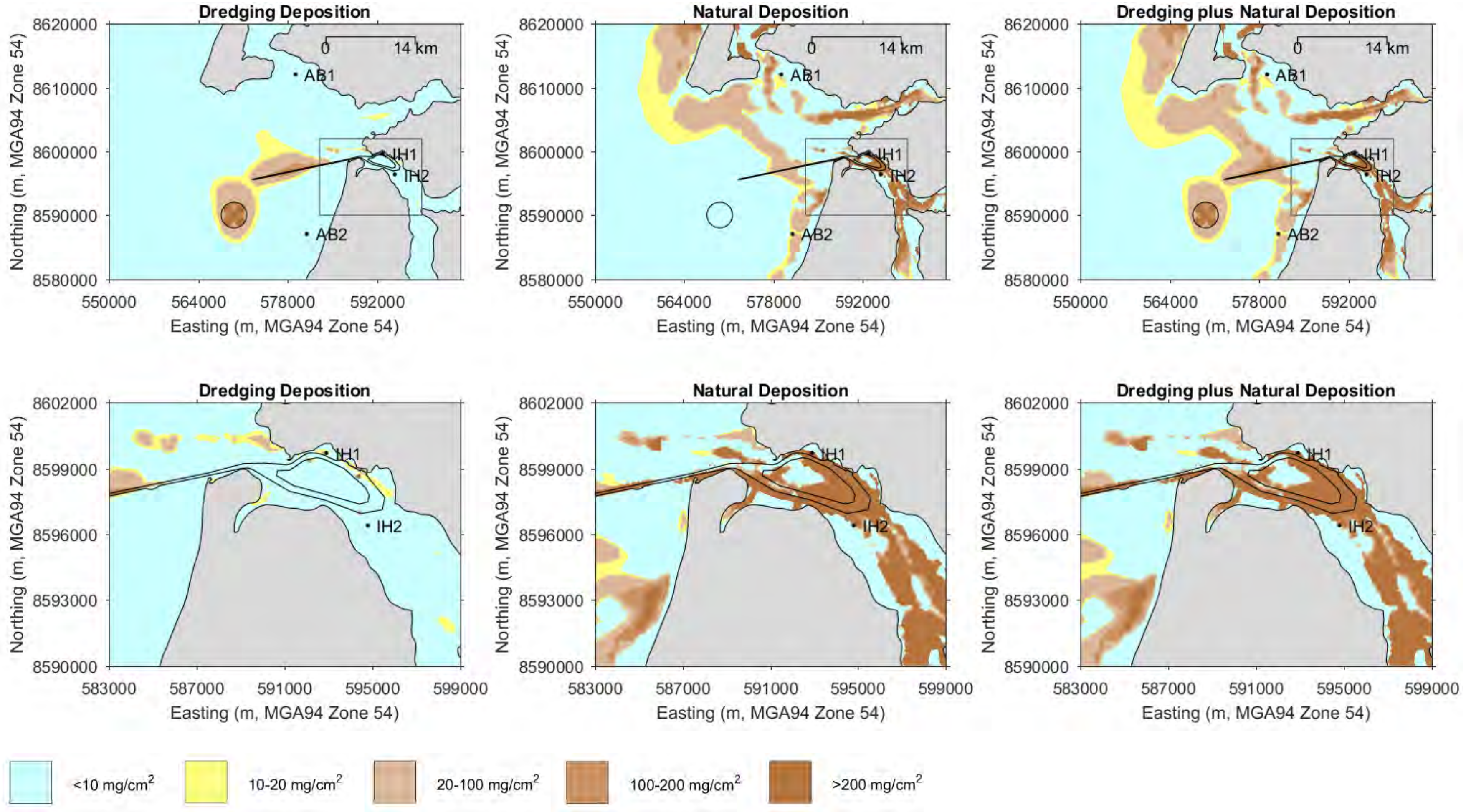


Figure C26. Deposition for dredging, natural and natural plus dredging for 2,500,000 m^3 of sediment using the Albatross South DMPA in the energetic dry season.