

Impacts of mine-derived contaminants on Torres Strait environments and communities

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CONTENTS

Contents.....	i
List of Tables.....	iii
List of Figures.....	iv
Acronyms	vii
Abbreviations	viii
Acknowledgements	ix
Executive Summary	1
1. Introduction	4
2. Review of relevant studies on contaminants in the region	5
3. Field studies	10
3.1. Background.....	10
3.2 October 2016 survey details	10
3.3 Sample collection.....	13
3.3.1 Collection of water samples.....	13
3.3.2 Measurement of water physico-chemical parameters	13
3.3.3 Benthic sediment collection	14
3.4 Additional field work – Boigu and Saibai Islands	15
3.5 Water sample processing.....	18
4. Chemical analysis	20
4.1 Overview.....	20
4.2 General analytical procedures.....	20
4.3 Preparation of trace metal sample bottles	20
4.4 Analysis of metals in water samples.....	21
4.4.1 Dissolved cadmium, cobalt, copper, nickel, lead, and zinc.....	21
4.4.2 Dissolved arsenic	22
4.4.3 Total mercury in waters	22
4.4.4 Dissolved organic carbon (DOC)	22
4.4.5 Analytical methods for measuring metals in TSS and benthic sediments.....	22
5. Community survey: Boigu and Saibai	24
6. Results and discussion.....	25
6.1 October 2016 survey results	25
6.1.1. Water physico-chemical parameters.....	25
6.1.2 Metals in waters	27
6.1.3. October 2016 survey: total mercury concentrations	28

6.1.4 Metals in total suspended solids	34
6.1.5 Metals associated with benthic sediments	41
6.2 Boigu and Saibai survey June 2018 results.....	49
7. Water quality: Synthesis	53
7.1 Comparison of water quality data with other locations.....	53
7.2 Validity of the 99% species protection guideline value for cobalt.....	54
7.3 Spatial distributions and sources of trace metals.....	55
8. Community survey outcomes	60
8.1 Saibai Island	60
8.1.1 Involvement in the survey.....	60
8.1.2 State of the marine environment	60
8.1.3 Change of muddiness with weather and temporal conditions	61
8.1.4 Colour change in coastal waters	64
8.2 Boigu Island	65
8.2.1 Involvement in survey.....	65
8.2.2 State of the marine environment	66
8.2.3 Change of muddiness with weather and temporal conditions	67
8.2.4 Colour change in coastal waters	69
9. Conclusions.....	72
10. Recommendations.....	74
11. References.....	75
Appendix A: Analytical quality control data	78
Appendix B: Community survey questions.....	122

LIST OF TABLES

Table 1:	October 2016 survey: Sampling site locations	12
Table 2:	October 2016 survey: Summary of activities undertaken at each sampling location	15
Table 3:	October 2016 survey: Sediment sampling site details.....	17
Table 4:	June 2018 Survey sampling sites	18
Table 5:	October 2016 survey: Physico-chemical data measured on water samples	25
Table 6:	October 2016 survey: Concentrations of dissolved metals and total mercury in water samples.....	30
Table 7:	October 2016 survey: TSS-bound metal concentrations	35
Table 8:	October 2016 survey: Particulate metal concentrations in benthic sediments	44
Table 9:	June 2018 survey: general water quality parameters	50
Table 10:	June 2018 survey: dissolved metals data	51
Table 11:	June 2018 survey: particulate metals in suspended sediments data (µg/g)	51
Table 12:	Comparison of dissolved metal concentrations measured in the current study with other locations	53
Table 13:	Correlation coefficient matrix for dissolved metals, total mercury, TSS and salinity	55
Table 14:	Comparison of copper concentrations around Boigu/Saibai with those in the Fly River Estuary	57
Table 15:	Numbers and percentages of females and males on Saibai Island participating in the survey across the different categories of the time spent living in the community	60
Table 16:	Explanations provided by some participants about muddy waters extending around Saibai Island	63
Table 17:	Explanations provided by some participants around the change in the colour of their coastal waters around Saibai Island.....	65
Table 18:	Numbers and percentages of females and males on Boigu Island participating in the survey across the different categories of the time spent living in the community	66
Table 19:	Explanations provided by some participants about muddy waters extending around Boigu Island.....	69
Table 20:	Explanations provided by participants around the change in the colour of their coastal waters about Boigu Island	70

LIST OF FIGURES

Figure 1:	Dissolved copper versus salinity profiles in the Fly River Estuary. The units of salinity are parts per thousand (‰)	6
Figure 2:	Increases in particulate (total suspended solids (TSS)) copper concentrations in the Fly River Estuary in the low (0-10 ‰), mid (10-20 ‰) and high (20-30 ‰) salinity zones. The number of measurements in each salinity range is given in the inset Table. The units of salinity are parts per thousand (‰).....	7
Figure 3:	Maps showing the intrusion of the Fly River flood plume into the Torres Strait, indicated by the shaded area of low salinity (Wolanski et al., 1999). The units of salinity are parts per thousand (‰)	8
Figure 4:	Torres Strait Baseline Study pilot study sampling plan for sediment sampling (Dight & Gladstone, 1993). The approximate water depth in metres is indicated in parentheses.....	9
Figure 5:	Map showing the Location of sampling sites – main survey (October 2016)	11
Figure 6:	Location of sampling sites around Boigu and Saibai Islands (June 2018). The numbers refer to the depths (m) at each site.....	16
Figure 7:	October 2016 survey: summary of salinity, pH and dissolved oxygen data	26
Figure 8:	October 2016 survey: summary of turbidity and TSS data	27
Figure 9:	October 2016 survey: summary of the dissolved As, Cd and Co data.....	31
Figure 10:	October 2016 survey: summary of the dissolved Cu, Hg and Ni data	32
Figure 11:	October 2016 survey: summary of the dissolved Pb and Zn data	33
Figure 12:	Relationship between total mercury in waters and total suspended solids. The outliers to the trend are shown in blue	33
Figure 13:	October 2016 survey: TSS-bound As, Cd and Co.....	37
Figure 14:	October 2016 survey: TSS-bound Cu, Ni and Pb.....	38
Figure 15:	October 2016 survey: TSS-bound Zn	39
Figure 16:	Examples of the relationships between trace metals in TSS samples. Note the plots set also contain mean data from the 2018 survey.....	40
Figure 17:	Photographs (x20 magnification) of benthic sediment samples illustrating their heterogeneity	42
Figure 18:	Sediment core profiles: particulate copper at Site A and Site 8 Error bars are the standard deviation of mean core samples (n=3).	43
Figure 19:	Map showing the distribution of particulate copper concentrations (µg/g) in benthic sediments (October 2016)	46
Figure 20:	Maps showing the distribution of particulate cobalt, lead, nickel and zinc concentrations (µg/g) in benthic sediments (October 2016)	47
Figure 21:	Relationship between particulate copper and calcium in benthic sediments	47

Figure 22:	Comparison between the results for benthic particulate metals concentrations measured in this study with the 1993 Torres Strait baseline study.....	48
Figure 23:	Map showing the distributions of suspended sediments (TSS mg/L) around Boigu and Saibai Islands (June 2018).....	52
Figure 24:	Map showing the distributions of dissolved copper concentrations ($\mu\text{g/L}$) around Boigu and Saibai Islands (June 2018).....	52
Figure 25:	Map showing the distributions of particulate copper ($\mu\text{g/g}$) in suspended sediments around Boigu and Saibai Islands (June 2018)	52
Figure 26:	Species sensitivity distribution data upon which the marine cobalt guidelines were derived. Note the poor data fit and extremely large uncertainties around the derived guideline values (data supplied courtesy of G.Batley, CSIRO)	54
Figure 27:	Benthic, suspended and dissolved copper concentrations at the sampling sites	55
Figure 28:	October 2016 survey: the proportion of metals between dissolved and suspended solids (SS) forms at Saibai (left) and offshore (right) sites	58
Figure 29:	Elemental ratios for suspended sediment samples collected during the October 2016 survey. The bar in red is the mean ratio for the Fly River estuary based on data collected in 2013 by Angel et al. (2014)	59
Figure 30:	The proportion of participants in the Saibai Island community (Torres Strait, Australia) identifying their view on the condition of their local marine environment from a range of five different categories	60
Figure 31:	The number of participants in the Saibai Island community that have seen either less or more changes in their local environment and species.....	61
Figure 32:	The proportion of participants in the Saibai Island community that noticed their coastal waters becoming muddier after changes in weather conditions	61
Figure 33:	The proportion of participants in the Saibai Island community that have identified the most common length of time their coastal waters would be muddy.....	62
Figure 34:	The proportion of participants in the Saibai Island community identifying their view on changes in the level of muddiness in their coastal waters	62
Figure 35:	The proportion of participants in the Saibai community identifying their view on muddiness going around their island.....	63
Figure 36:	The proportion of participants in the Saibai Island community identifying their view on the muddiness of coastal water changing with season.....	64
Figure 37:	a) The proportion of the participants in the Saibai Island community indicating a change in the colour of their coastal waters b) The proportion of the participants in the Saibai Island community with views on the potential source of colour change in their coastal waters	64
Figure 38:	The proportion of the participants in the Saibai Island community noticing changes in the frequency of colour changes in their coastal waters.....	65

Figure 39:	The percentage of participants in the Boigu Island community identifying their view on the condition of their local marine environment from a range of five different categories	66
Figure 40:	The number of participants in the Boigu Island community that seen either less or more changes in their local environment and species	67
Figure 41:	The proportion of participants in the Boigu Island community that noticed their coastal waters becoming muddier after changes in weather conditions	67
Figure 42:	The proportion of participants in the Boigu Island community that have identified the most common length of time their coastal waters would be muddy.....	68
Figure 43:	The proportion of participants in the Boigu Island community identifying their view on changes in the level of muddiness in their coastal waters	68
Figure 44:	The proportion of participants in the Boigu Island community identifying their view on the muddiness of coastal water changing with season.....	69
Figure 45:	a) The proportion of the participants in the Boigu Island community indicating a change in the colour of their coastal waters. b) The proportion of the participants in the Boigu Island community with views on the potential source of colour change in their coastal waters	70
Figure 46:	The proportion of the participants in the Boigu Island community noticing changes in the frequency of colour changes in their coastal waters.....	71

ACRONYMS

ANZECC	Australian and New Zealand Environment and Conservation Council
CRM	Certified reference material
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DoEE	Department of the Environment & Energy
FEP	Fluorinated ethylene propylene
FLEP	Fluorinated high density polyethylene
GBR	Great Barrier Reef
JCU	James Cook University
LDPE	Low density polyethylene
LOD	Limit of detection
NESP	National Environmental Science Program
PNG	Papua New Guinea
QA/QC	Quality assurance/quality control
RRRC	Reef and Rainforest Research Centre Limited
SD	Standard deviation
SQGV	Sediment quality guideline value
TSRA	Torres Strait Regional Authority
TSS	Total suspended solids
TOC	Total organic carbon
TRM	Total recoverable metal
WQGV	Water quality guideline value
TWQ	Tropical Water Quality
UNSW	University of New South Wales
WQGV	Water Quality Guideline Values

ABBREVIATIONS

AEM	Dilute-acid extractable metal
As	Arsenic
ASW	Artificial seawater
BICON	Australian Biosecurity Import Conditions
Cd	Cadmium
Cu	Copper
Cr	Chromium
DGT	Diffusive gradients in thin films (passive metal samplers)
D.O	Dissolved oxygen
DOC	Dissolved organic carbon
Fe	Iron
HCl	Hydrochloric acid
Hg	Mercury
Milli-Q	High purity deionised water
Mt/y	Million tons per year
ng	Nanogram
Ni	Nickel
Pb	Lead
pM	Picomolar
Temp	Temperature
Zn	Zinc
µm	Micron
µg/g	Microgram per gram
‰	Parts per thousand

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EXECUTIVE SUMMARY

The Torres Strait is an area of Australia that has relatively few anthropogenic inputs of trace metals, however, concerns have been raised about the impacts of mining occurring in Papua New Guinea and the transboundary transport of metal contaminants into the Torres Strait.

The Ok Tedi copper mine in Papua New Guinea (PNG) has been operating since 1985 and discharges copper-contaminated sediments in the form of mine tailings and waste rock into the Fly River which ultimately flows into the Fly River estuary and Gulf of Papua. This has resulted in significant impacts on the river system including widespread contamination of the Fly River by copper (which is highly toxic to aquatic life), increased turbidity and changes to river geomorphology through widespread deposition of sediments. Estimates suggest that mining operations have increased sediment discharge from the whole of the Fly River by ~40% from 85 Mt/y to 120 Mt/y (Wolanski et al., 1995). Given the close proximity of the Torres Strait to the mouth of the Fly River, concerns have been raised since the start of mine operations that trans-boundary pollution may occur.

Under certain tidal and weather conditions, it has been observed that plumes of water from the Fly River estuary may extend into the north-east Torres Strait (Wolanski et al., 1999), thereby providing a means for transporting mine-derived sediments into this area. CSIRO has conducted various studies on the impacts of mine-associated contaminants in the Fly River system over the last 25 years, which have indicated an increase in the copper content of waters and sediments in the Fly River Estuary (Angel et al., 2010, 2014), thus giving rise to further concerns.

This National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub funded project was developed to address concerns regarding the impacts of mine-derived contaminants on the marine resources of the Torres Strait. The objectives of the project were:

- To generate high quality data on trace metal contaminants in waters and sediments (both benthic and suspended) across the Torres Strait;
- To determine if mine-derived contaminants are present/accumulating in the Torres Strait and influencing water and sediment quality; and
- To identify hotspots of mine-derived contamination.

The project involved a water quality survey of the region (conducted in October 2016) and follow-up event-driven sampling covering potentially impacted locations identified in the October 2016 water quality survey. Particular emphasis was placed on sites around the Warrior Reef, Bramble Cay and the eastern parts of the Torres Strait as these are the locations that are most likely to be subject to mine-derived contamination. In addition, community surveys were conducted on Saibai and Boigu islands in order to gain insights into local attitudes and perceptions of issues relating to water quality such as the turbidity of coastal water (muddiness) and how it has changed with time. This report details the findings of the two-year study.

A companion NESP TWQ Hub project (2.2.1) 'Identifying the water quality and ecosystem health threats to the high diversity Torres Strait and Far Northern GBR from runoff from the Fly

River' which focused on understanding various biophysical responses to inputs of freshwater was conducted in parallel and is reported separately (Waterhouse et al., 2019).

The findings of the study were:

1. Data on trace metal distributions in waters, suspended sediments and benthic sediments was generated for 29 sites across the Torres Strait. Trace element concentrations in waters were generally very low and consistent with uncontaminated marine waters from other regions of the world.
2. Trace metal concentrations in waters and sediments were highest in the northern Torres Strait, around Saibai and Boigu islands. The sources of higher concentrations of metals in the north remain to be fully identified. Correlations between suspended sediment and metals indicate that the most likely source of metals are inputs of sediments and waters from PNG. This may include some contributions from the Fly River, but inputs from runoff from the PNG mainland cannot be discounted. Contributions from mine-derived sediments are possible but not proven.
3. The concentrations of dissolved copper and cobalt were below the 95% species protection guideline values of the Australian and New Zealand water quality guidelines (ANZECC/ARMCANZ 2000) which are used by regulators in most areas of Australia as default regulatory benchmarks. Dissolved copper concentrations exceeded the 99% species protection guideline values in ten water samples collected in the vicinity of Boigu and Saibai Islands. Dissolved cobalt concentrations exceeded the 99% protection guideline value in five water samples collected in the vicinity of Boigu and Saibai islands. A subsequent investigation of the cobalt marine guidelines indicated that they are based on inappropriate data and overestimate the risks posed by cobalt in marine systems. Exceedance of the 99% protection guideline value can therefore be disregarded.
4. Total mercury concentrations in unfiltered water samples ranged from 0.11 to 0.88 ng/L (0.5 to 4.4 pM) with the highest concentrations being found around Saibai. To the best of our knowledge, this is the first data set generated for tropical Australian coastal waters, obtained using state-of-the-art analytical procedures. If the samples from around Saibai are not included on the grounds that their mercury concentrations are associated with the high suspended sediment load, the mean total mercury concentration for the Torres Strait was 0.31 ± 0.2 ng/L (1.5 ± 1.0 pM). This compares to typical open ocean concentrations for upper layer oceanic waters of 0.4 to 2.0 pM which is consistent with our data set. It should be noted that coastal waters will contain more suspended sediments than found in the open ocean and therefore, are more likely to support higher total mercury concentrations. Overall, this data set indicates that mercury concentrations in the waters of the Torres Strait are very low and are representative of uncontaminated marine waters.
5. Metal concentrations in sediments were generally very low. Metal concentrations in benthic sediments were below ANZECC/ARMCANZ guideline values, apart from particulate arsenic and nickel in two sediment cores collected close to Saibai Island. These higher arsenic and nickel concentrations are most likely due to natural background mineral enrichment in the area rather than any anthropogenic contamination.
6. Community members on Saibai and Boigu Island who participated in the survey identified that the muddiness of coastal waters changed with weather, temporal and spatial conditions. Similar comments were made from participants on both islands about

muddiness depending on the time of the year and spatial differences arising in the muddiness between the back and front of the island community.

7. Across all of the community survey participants, only two identified that the level of muddiness in the coastal waters had become less with more participants indicating muddiness had increased. One participant explained that when the water gets really brown it is hard to go fishing and swimming. Another participant also explained the change in the environment where freshwater country is now turning into saltwater country. Some differences occurred in the responses between Saibai and Boigu Island around changes in species abundance and the potential source of colour change in coastal waters. On Saibai, some participants identified less abundance of turtles and dugongs, whereas on Boigu, participants identified a greater abundance of turtles and dugongs. On Saibai, more participants identified that the potential source of the colour change in coastal waters was more likely from local creek runoff rather than an outside source, whereas on Boigu, colour change from an outside source was identified nearly as frequently as local creek runoff. This response is consistent with the presence of the mouth of a large river across from Boigu (Mai Kussa River) that drains the PNG mainland.
8. Most of the community interview questions were addressed by participants. The question that generated the highest 'unsure' response was in relation to whether the colour of coastal waters had changed in frequency over the years. This indicated that in future community interviews, there needs to be additional explanation about the frequency in change. Also, the survey question around the length of time that coastal waters would be muddy should be refined and modified to include percentage of time rather than categories of time as some participants preferred to state a percentage. Providing the community members with the opportunity to provide further details and comments, allowed more insight into the dynamics of the muddiness of coastal waters and the link this has with sea country, people, cultural practices and wellbeing.

1. INTRODUCTION

The Torres Strait is an area of Australia that has relatively few anthropogenic inputs of trace metals. However concerns have been raised about the impacts of mining occurring in Papua New Guinea and transboundary transport of metal contaminants into the Torres Strait.

The Ok Tedi copper mine in Papua New Guinea has been operating since 1985 and discharges copper-contaminated sediments in the form of mine tailings and waste rock into the Fly River which ultimately flow into the Fly River Estuary and Gulf of Papua. This has resulted in significant impacts on the river system including widespread contamination of the Fly River by copper (which is highly toxic to aquatic life), increased turbidity and changes to river geomorphology through widespread deposition of sediments (Bolton 2009). Estimates suggest that mining operations have increased sediment discharge from the whole of the Fly River by ~40% from 85 Mt/y to 120 Mt/y (Wolanski et al., 1995). Given the close proximity of the Torres Strait to the mouth of the Fly River, concerns have been raised since the start of mine operations that trans-boundary pollution may occur.

Under certain tidal and weather conditions it has been observed that plumes of water from the Fly River estuary may extend into the north-east Torres Strait (Wolanski et al., 1999), thereby providing a means for transporting mine sediments into this area. The CSIRO has conducted various studies on the impacts of mine contamination in the Fly River system over the last 25 years, which have indicated an increase in the copper content of waters and sediments in the Fly River estuary (Angel et al., 2010, 2014), thus giving rise to further concerns.

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- To identify hotspots of mine-derived contamination

The project involved a water quality survey of the region (conducted in October 2016) and follow-up event-driven sampling covering potentially impacted locations identified in the October 2016 water quality survey. Particular emphasis was placed on sites around the Warrior Reef, Bramble Cay and the eastern parts of the Torres Strait as these are the locations that are most likely to be subject to mine-derived contamination. In addition, community surveys were conducted with residents on Saibai and Boigu Islands in order to gain insights into local attitudes and perceptions of issues relating to water quality such as the turbidity of coastal water (muddiness) and how it has changed with time. This report details the findings of the two-year study.

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2. REVIEW OF RELEVANT STUDIES ON CONTAMINANTS IN THE REGION

This section provides a brief overview of studies conducted in the region that are relevant to understanding trace metal distributions and mine-related impacts.

CSIRO has conducted various studies on the impacts of mine pollution in the Fly River system over the last 25 years including the Fly River estuary. The dissolved copper versus salinity profiles measured in these surveys is shown in Figure 1. Snapshot surveys of this nature do not provide information on short term temporal variability, however, data collected over the last decade suggest an increase in the copper content of sediments in the Fly River estuary (Apte 2009; Angel et al., 2010, 2014) over the operating lifetime of the Ok Tedi mine in PNG. These trends are illustrated in Figure 2, which show how particulate copper in suspended sediment concentrations have increased with time in the mid- to outer-estuary. Based on a field survey conducted in 2013 (Angel et al., 2014), particulate copper concentrations in suspended sediments have increased from pre-mine levels of around 40 to 83 µg/g. This increase was caused by the mixing of copper-rich mine-derived sediments (i.e. mine tailings and waste rock) with natural fine sediments. For further information on the impacts of the Ok Tedi mine on the Fly River system, readers are referred to a monograph edited by Bolton (2009).

Previous work on the describing the biophysical environmental of the Torres Strait including modelling of water and sediment movement is reviewed in detail by Waterhouse et al. in their [Project 2.2.1 Final Report](#) (Waterhouse et al., 2019). A brief overview will be given here along with a review of past studies that looked at trace metal distributions in the region. Wolanski and co-workers have published a number of papers on modelling of currents and sediment transport in the Gulf of Papua and Torres Strait (Wolanski et al., 1995, 1999, 2013; Ayukai & Wolanski, 1997). Their publication on the patchiness of the Fly River discharge (Wolanski et al., 1999) is particularly noteworthy as it contains field measurements of a plume intrusion event into the Torres Strait (Figure 3). As is shown in Figure 3, under certain weather and flow conditions, the Fly River plume may extend as far west as Saibai Island where salinities as low as 29‰ were recorded during the event. Under these conditions, it is inevitable that there will be transport of mine-derived sediments and saline waters elevated in dissolved copper into the northern part of the Torres Strait. This will result in increased exposure of marine organisms to elevated metal concentrations both in dissolved and particulate forms.

There are only a few studies that have measured trace metal concentrations in waters and sediments in the Torres Strait or have studied water discharges from the Fly River Estuary. Brunkskill et al. (2009) developed a detailed mass balance for sediment and copper in the Gulf of Papua which included assessing contributions from the Fly River, but this study did not extend to the Torres Strait. As part of the Torres Strait Baseline Study (Dight & Gladstone, 1993) that was conducted in the early 1990s, metal concentrations were measured in sediment and biota samples collected at locations across the region. The sediment sampling program design consisted of diagonal transects running northeast to southwest, supplemented by one transect running north to south and one adjacent to the PNG coastline (Figure 4). Data were reported on the concentrations of a range of trace elements in benthic sediments including copper. The concentrations of trace metals were generally very low and indicative of uncontaminated environments. A comparison of data collected in this study versus the Torres Strait baseline data set is presented later in this report.

In February 2000, Hayne and Kwan (2002) collected benthic sediment samples along the proposed route of a gas pipeline running from PNG to Australia. The study included 16 sites in the Torres Strait. Particulate copper concentrations (a key tracer of mine-derived sediments) were below the detection limit of 8 $\mu\text{g/g}$ in most Torres Strait samples. The study demonstrated an inverse correlation between the concentrations of calcium carbonate and several trace elements which supports the notion that the major supply of trace elements to the region is runoff and sediment transport from terrestrial sources, predominantly the Papua New Guinea mainland. Marine waters and sediments did not contribute significantly to metal loadings.

Data on the concentrations of metals in waters of the Torres Strait are limited. Apte and Day (1998) conducted an ultratrace survey of dissolved trace metal concentrations in the Torres Strait and Gulf of Papua. The study measured dissolved copper, cadmium and nickel concentrations at 12 sites in the Torres Strait. The highest dissolved metal concentrations were detected at sites closest to the mouth of the Fly River estuary. Offshore metal concentrations declined rapidly and were consistent with trace metal concentrations measured in other coastal Australian waters. A recent study conducted by O'Brien et al. (2015) deployed *in situ* DGT trace metal samplers at eight locations across the Torres Strait. The concentrations of the metals detected in this study were generally low compared to the concentrations reported in other north Queensland studies. The highest copper concentrations were detected at Saibai Island and Bramble Cay with concentrations ranging from 0.06 – 0.6 $\mu\text{g/L}$ compared to 0.004 – 0.2 $\mu\text{g/L}$ across all other sites.

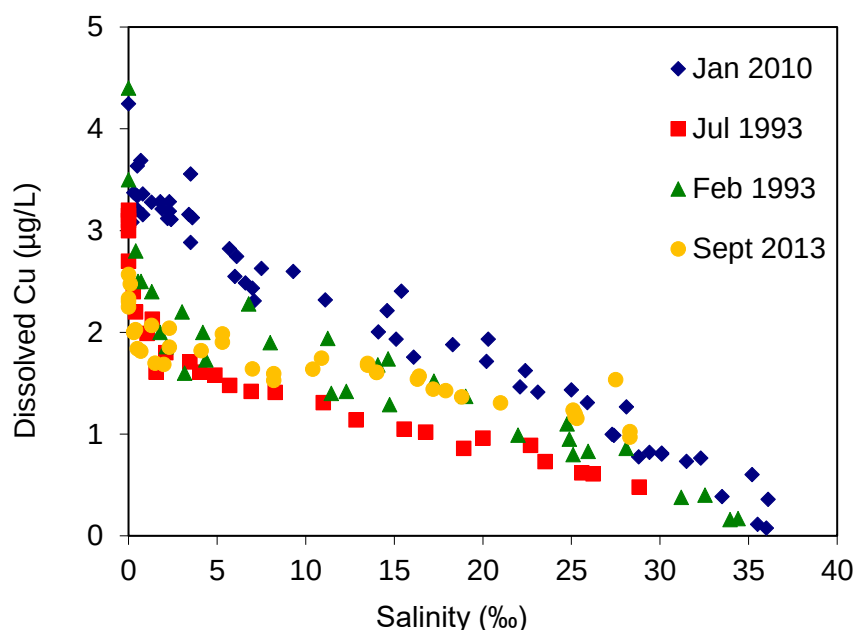


Figure 1: Dissolved copper versus salinity profiles in the Fly River Estuary. The units of salinity are parts per thousand (‰)

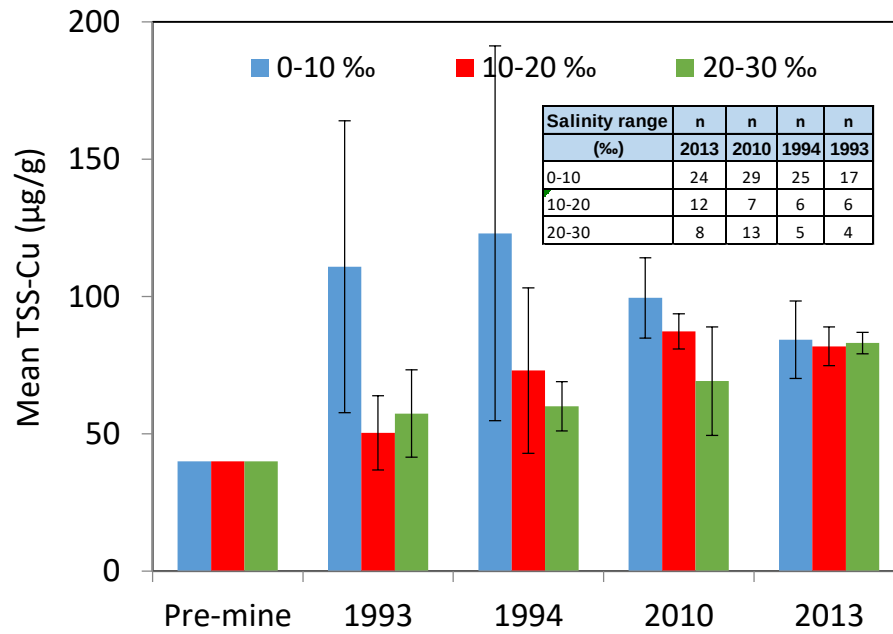


Figure 2: Increases in particulate (total suspended solids (TSS)) copper concentrations in the Fly River Estuary in the low (0-10 ‰), mid (10-20 ‰) and high (20-30 ‰) salinity zones. The number of measurements in each salinity range is given in the inset Table. The units of salinity are parts per thousand (‰)

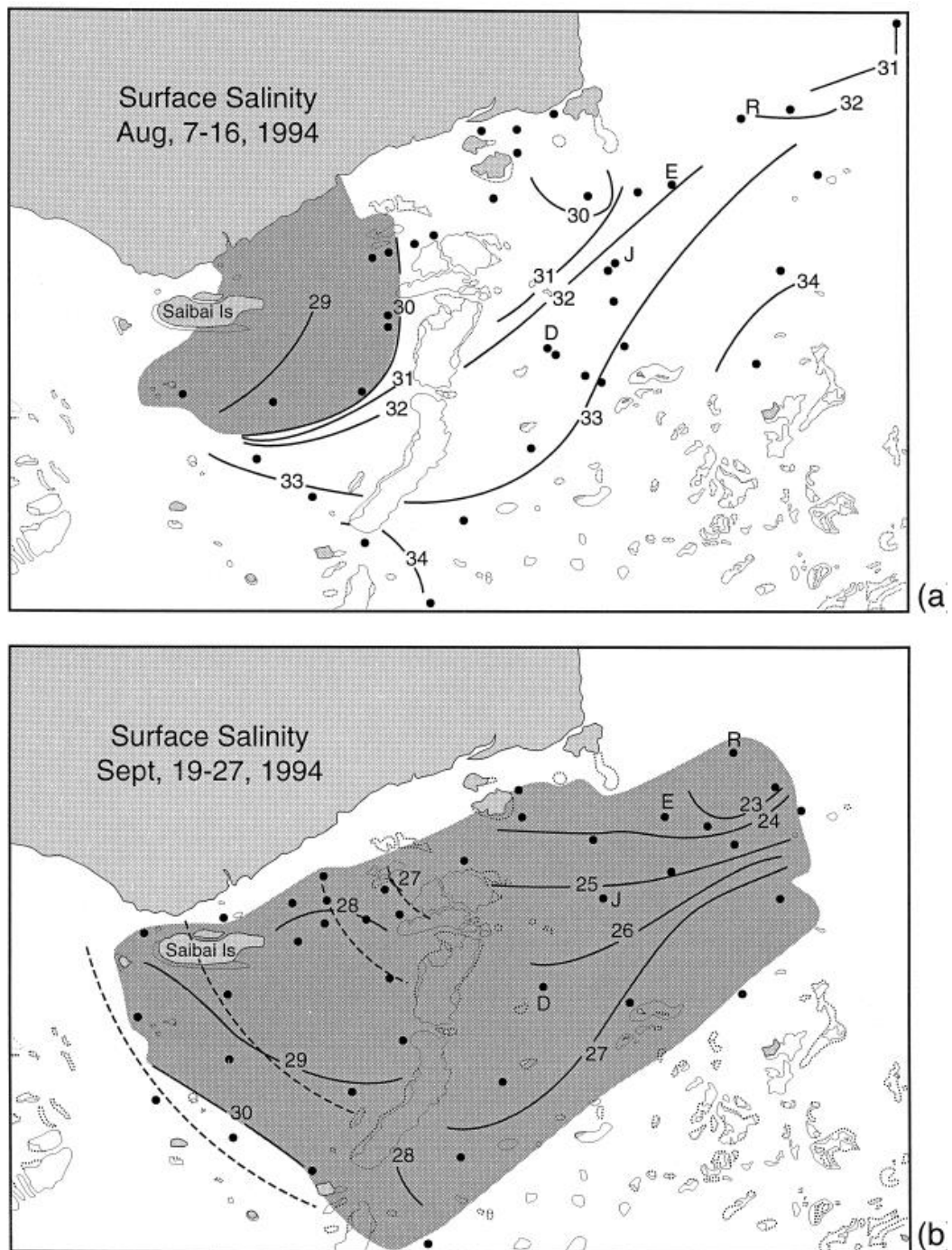


Figure 3: Maps showing the intrusion of the Fly River flood plume into the Torres Strait, indicated by the shaded area of low salinity (Wolanski et al., 1999). The units of salinity are parts per thousand (‰)

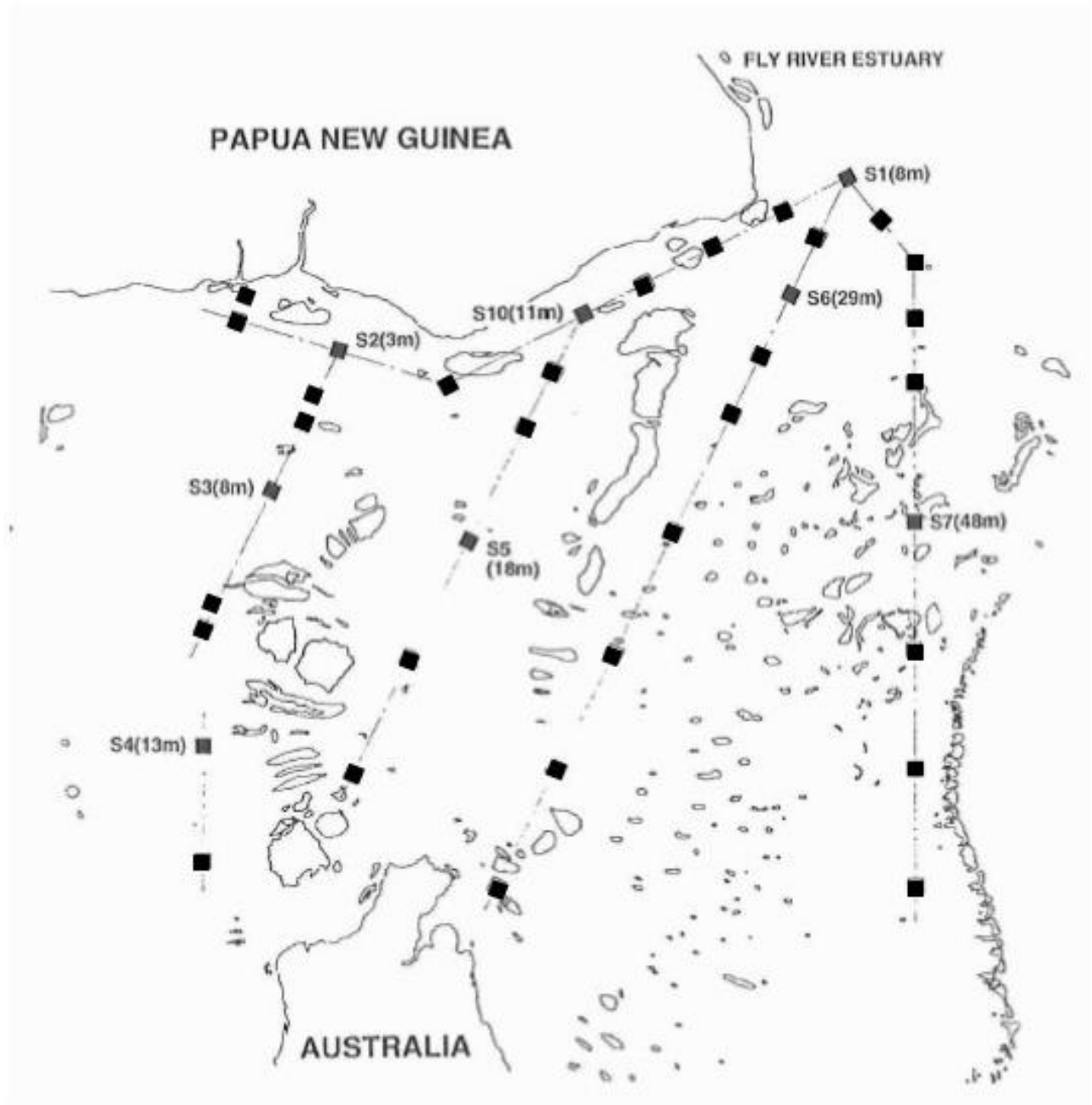


Figure 4: Torres Strait Baseline Study pilot study sampling plan for sediment sampling (Dight & Gladstone, 1993). The approximate water depth in metres is indicated in parentheses

3. FIELD STUDIES

3.1. Background

Two field sampling campaigns were conducted. The major field survey was conducted between the 3rd and 16th October, 2016 during which 29 sites across the Torres Strait were sampled for waters and sediments.

Prior to the execution of the field program, a detailed survey of the scientific literature relevant to the project was undertaken. This information was used to develop the field sampling plan. The sampling plan for the major survey was designed in stages. A 'straw-man' plan was initially developed and this was further refined by team members at a field-trip planning workshop at CSIRO Lucas Heights in July 2016. The following factors were taken into account in designing the sampling program:

- Adequate spatial coverage – one of the key goals of the project is to describe the current status of water and sediment quality across the Torres Strait
- Sampling of sites in the northern and eastern Torres Strait, in recognition of their exposure to mine-derived inputs emanating from the northeast of the Torres Strait
- Sufficient sample replication at selected sites to allow quantitation of variances associated with chemical analysis, sampling, spatial heterogeneity
- Insights from previous sampling program designs, e.g. Torres Strait baseline study.

The developed sampling design shown in Figure 5 was essentially a modified version of the Torres Strait baseline design (Dight & Gladstone, 1993). It comprised a series of north-south transects plus sampling at additional coastal locations. A special focus was placed on the eastern Torres Strait because of its proximity to the Fly River estuary. Key locations covered were Warrior Reef, Bramble Cay, Masig, Erub and Saibai islands.

This transect sampling approach formed a coarse grid which allowed the development of maps of measured parameter distributions.

A follow-up study which focussed on the coastal waters around Boigu and Saibai Islands was then conducted between the 18th and 21st June, 2018.

3.2 October 2016 survey details

The sampling program was carried out by the CSIRO team between the 3rd and 16th October 2016. The 21 sampling locations are listed in Table 1 and shown in Figure 5. The MV Eclipse, a charter vessel equipped for conducting scientific surveys in marine waters, was used for the sampling campaign. The sampling activities conducted at each site are summarised in Table 2.

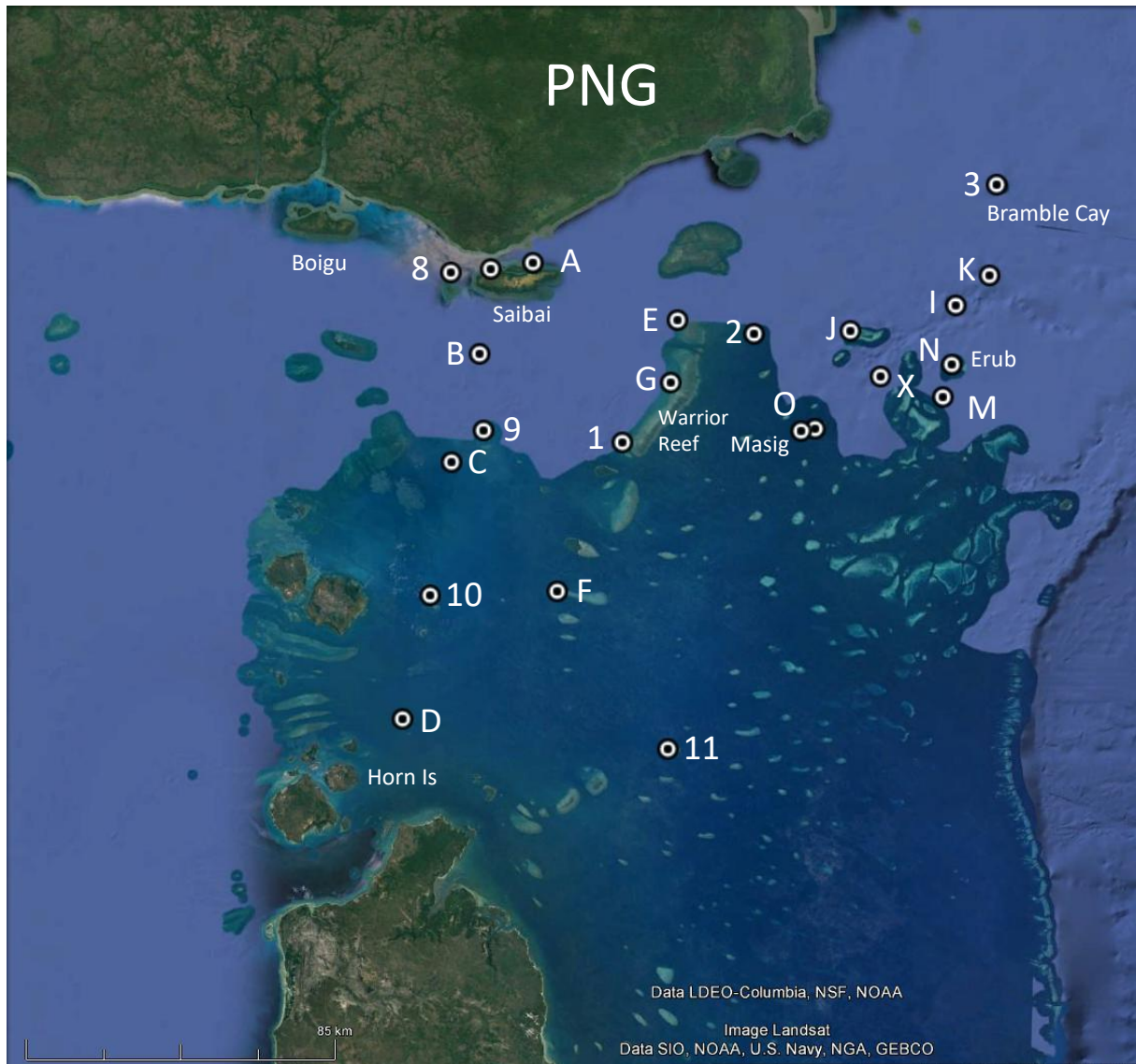


Figure 5: Map showing the Location of sampling sites – main survey (October 2016)

Table 1: October 2016 survey: Sampling site locations

¹ Site	Date	Time	Water depth	GPS coordinates		Location
			(m)	Eastings	Southings	
Site 1	3/10/2016	10:10	7.3	09°46.821'S	142°58.033'E	Warrior Reef, central Torres Strait
Site G	3/10/2016	14:50	8.5	09°36.026'S	143°05.000'E	Warrior Reef, central Torres Strait
Site 2	4/10/2016	8:50	16.7	09°30.748'S	143°17.117'E	North-east Torres Strait
Site J	4/10/2016	12:20	11.8	09°30.081'S	143°31.274'E	North-east Torres Strait
Site 3	5/10/2016	8:45	20.0	09°08.362'S	143°52.427'E	Bramble Cay, North-east Torres Strait
Site K	5/10/2016	12:15	2.0	09°21.612'S	143°51.594'E	North-east Torres Strait
Site I	5/10/2016	14:15	5.6	09°26.074'S	143°46.709'E	North-east Torres Strait
Site M	6/10/2016	11:20	8.0	09°39.419'S	143°45.041'E	North-east Torres Strait
Site N	6/10/2016	14:30	29.0	09°34.670'S	143°46.275'E	Erub (Darnley Island), north-east Torres Strait
Site X	7/10/2016	12:30	7.6	09°36.607'S	143°35.828'E	North-east Torres Strait
Site O	8/10/2016	7:15	21.8	09°44.735'S	143°24.281'E	Masig Island, north-east Torres Strait
Site E	10/10/2016	9:00	4.3	09°28.940'S	143°05.835'E	Warrior Reef, central Torres Strait
Site 8	11/10/2016	7:45	13.0	09°22.467'S	142°36.312'E	North-east Saibai Island
Site A	11/10/2016	15:41	7.8	09°20.909'S	142°44.401'E	North-west Saibai Island
Site B	12/10/2016	14:30	13.0	09°34.258'S	142°36.772'E	Central Torres Strait, south of Saibai Island
Site 9	13/10/2016	7:50	9.2	09°45.389'S	142°37.543'E	Central Torres Strait
Site C	13/10/2016	12:15	2.5	09°50.051'S	142°32.890'E	Central Torres Strait
Site 10	13/10/2016	16:10	5.3	10°09.438'S	142°30.028'E	Southern Torres Strait
Site F	14/10/2016	14:35	17.0	10°08.567'S	142°48.789'E	Southern Torres Strait
Site 11	15/10/2016	12:35	8.0	10°31.180'S	143°05.465'E	Southern Torres Strait
Site D	16/10/2016	12:45	10.0	10°27.469'S	142°26.181'E	Southern Torres Strait

¹The site codes are not sequential and, the chosen numbers/letters have no additional significance apart from denoting each site

3.3 Sample collection

3.3.1 Collection of water samples

Water sampling was conducted from an inflatable dinghy with low sides that allowed easy deployment of water sampling equipment. The dinghy was launched from the MV Eclipse and steered approximately 200 m into the prevailing current. This approach was adopted in order to minimise the likelihood of metal contamination from the main vessel.

Surface water samples were collected from the 21 sites shown in Table 1. All water samples were collected using strict sampling protocols that are designed to minimise contamination (USEPA, 1996; Angel et al., 2010b). This included the wearing of clean, powder-free vinyl gloves for the handling of all sample bottles and sampling equipment, and the collection of water samples before sediment samples at any given site. Acid-washed sampling bottles (0.5, 1, and 5 L), double-bagged in zip-lock bags and stored inside an Esky containing ice bricks was transported on the tender to each site. The 0.5 L bottle was used to collect a sample for total mercury analysis. The 1 L bottle was used for collecting a sample for total recoverable metals analyses other than mercury, and the 5 L bottle was used for collecting a sample for filterable (dissolved) and total suspended sediment (TSS)-bound metals analyses other than mercury. At every sampling site a 'clean hands', 'dirty hands' protocol was used for taking water samples. This involved the 'clean hands' person opening the esky, placing gloves on hands, withdrawing the 1 L sample bottle from pre-labelled zip-lock bags, placing it into an attachment on a purpose-built Perspex pole sampler, uncapping the bottle and holding onto the cap. The 'dirty hands' person then rapidly submerged the bottle in the pole sampler to a depth of approximately 50 cm to take the sample. Each sample bottle was rinsed twice with water from the sample site by filling each bottle, capping, shaking and emptying. The 1 L bottle was used to collect water samples that were decanted into the 0.5 and 5 L bottles until they were full of sample, after which the 1 L bottle was filled a final time. The 'clean hands' person capped each bottle once they were well filled and replaced them into the zip-lock bags in the Esky. The water samples were placed into a refrigerator on board the MV Eclipse prior to filtration. The samples were filtered within 6 hours of sample collection.

For quality control purposes, field blanks were collected at Sites M, O and 8 and duplicate samples were collected at Sites N, O and A. Field blanks for trace metals analysis were prepared at the designated sites by opening a 1 L bottle to the air for approximately 30 seconds followed by capping and returning to its zip-lock bag. On return to the MV Eclipse, the bottle was then filled with 1 L of deionised water.

3.3.2 Measurement of water physico-chemical parameters

Immediately after transferring the water samples from the tender onto the MV Eclipse, the unfiltered water samples were mixed by gentle agitation and subsampled for physico-chemical measurements.

Salinity, pH and dissolved oxygen were measured using an Orion Star A329 portable meter (Thermo Scientific). Sample pH was measured using a Thermo Scientific Orion Gel-Filled ROSS pH Ultra Triode Electrode (8107UWMMD) that was calibrated using pH 4.00, 7.00 and 10.00 buffers. Salinity was measured using a Thermo Scientific Orion Conductivity Cell

(013010MD) that was calibrated using KCl conductivity standards. Dissolved oxygen was measured using a Thermo Scientific Orion RDO optical dissolved oxygen sensor (087010MD) calibrated with water saturated air within its calibration sleeve. Turbidity was measured using an Orion AQ4500 (Thermo Scientific) that was calibrated with primary turbidity standards.

3.3.3 Benthic sediment collection

Sediment samples were collected from each site immediately after the water sampling (Table 3). A combination of techniques were employed to collect the sediment samples that depended on the local water current conditions and ability of the corer to penetrate the sediment. Firstly, a gravity core sampler was deployed from the MV Eclipse, which collected up to 12 cm deep sediment within pre-loaded plastic core tubes. If this was unsuccessful, divers took hand cores of up to 7 cm depth by diving to the sea bed. The core tubes were capped with plastic stoppers and wherever possible, returned to the surface in an upright position. If the substrate was too hard for hand coring, the divers took a grab of loose sediment samples by hand inside 250 mL polycarbonate vials.

The core tubes were withdrawn from the corer on-board the MV Eclipse, placed into zip-lock bags, and placed inside a freezer until frozen. The cores were then sectioned by allowing a core to partially thaw so that the sediment core could be extruded with a plastic plunger, before cutting into sections (typically 1-2 cm length) with a plastic blade. The core sections were placed into zip-lock bags and stored frozen for transport to the Lucas Heights laboratories. The contents of some of the shorter unconsolidated sediment cores became mixed, in which case the entire core was treated as a single sample rather than sub-sectioning. Triplicate cores were generally taken at each site in order to assess sampling heterogeneity. Mean analytical data for each sample/core slice were subsequently generated from the replicate samples.

Table 2: October 2016 survey: Summary of activities undertaken at each sampling location

Activity	Sampling equipment/procedure
1. Measurement of in situ physical and chemical parameters and acquisition of general site data.	Surface water sample taken using a polycarbonate pole sampler deployed from a tender and analysed for pH, temperature, salinity and other parameters using portable probes. Depth and weather conditions recorded at each site. Photographs and video footage taken at each sampling site.
2. Water sampling	Polycarbonate pole sampler deployed from a tender used for surface samples. Several water samples taken: (i) dissolved trace metals, (ii) total mercury (selected sites), (iii) general water quality measurements
3. Suspended sediment samples	Separated by filtration of waters using pre-weighed filter membranes. Filters stored for analysis of particulate metals. Filtrates retained for trace metals analysis
4. Sediment cores for trace metal analyses	Sediment gravity corer deployed from hand-held line or winch. At shallow locations, a hand corer was used by diver, as needed. Sediment cores were sliced into sections on-board boat and stored frozen.

3.4 Additional field work – Boigu and Saibai Islands

An additional, shorter survey of water quality was performed between the 18th and 21st June 2018, which focussed on the northern Torres Strait Islands of Boigu and Saibai. Water samples were collected from five sites around Saibai Island and five sites around Boigu Island (Table 4, Figure 6). Two of the sites (A and 8) had been sampled during the 2016 field survey.

Sampling was conducted by the CSIRO team with the assistance of TSRA staff from on-board the TSRA patrol vessels stationed at both islands. It was not possible to deploy a tender off the main boat, so water samples were collected from the back of the patrol vessel using 5 L acid-washed containers. Water samples were collected by immersing the container by hand to a depth of approximately 0.5 m. Powder free plastic gloves were worn during the sampling operation. The containers were filled and rinsed twice with water from the location prior to filling. It should be noted that this method of sampling is not recommended for the accurate determination of dissolved zinc in marine waters as many aluminium-hulled boats and outboard motors are equipped with zinc sacrificial anodes that release dissolved zinc into the solution.

For quality control purposes, a field blank was prepared during both the Saibai and Boigu legs of the field trip. Duplicate samples were collected at Sites S1, 8 and B1.

Salinity and pH were measured using an Orion Star A329 portable meter (Thermo Scientific). Sample pH was measured using a Thermo Scientific Orion Gel-Filled ROSS pH Ultra Triode Electrode (8107UWMMD) that was calibrated using pH 4.00, 7.00 and 10.00 buffers. Salinity was measured using a Thermo Scientific Orion Conductivity Cell (013010MD) that was calibrated using KCl conductivity standards.

Water samples were transported back to the field laboratory that was set up on each island and were processed within five hours of collection in a designated clean area free of dust and other conspicuous sources of metal contamination. As a precaution against sample contamination, surfaces coming into contact with sample containers or lab apparatus were covered with clean plastic. Pre-weighed 0.45 μm membrane filters were used for sample filtration and were retained for particulate metals analysis of suspended sediments. The water and sediment samples were stored chilled and 'hand carried' back to the CSIRO laboratories in Sydney for analysis of dissolved and TSS-bound metals.



Figure 6: Location of sampling sites around Boigu and Saibai Islands (June 2018). The numbers refer to the water column depths (m) at each site.

Table 3: October 2016 survey: Sediment sampling site details

Sample	Water column depth	Location	Sampling technique employed	Core length (range)
	(m)			(cm)
Site 1	7.3	Warrior Reef, central Torres Strait	Diver hand core	3-5
Site G	8.5	Warrior Reef, central Torres Strait	Diver hand core	6
Site 2	16.7	North-east Torres Strait	Diver hand core	3.5-7
Site J	11.8	North-east Torres Strait	Diver surface grab samples	-
Site 3	20.0	North-east Torres Strait	Diver hand core, surface grab samples	2.5-6.5
Site K	2.0	North-east Torres Strait	Diver hand core, surface grab samples	4-5
Site I	5.6	North-east Torres Strait	Diver surface grab samples	-
Site M	8.0	North-east Torres Strait	Diver surface grab samples	-
Site N	29.0	Darnley Island, north-east Torres Strait	Diver hand core, surface grab samples	3
Site X	7.6	North-east Torres Strait	Diver surface grab samples	-
Site O	21.8	Masig Island, north-east Torres Strait	Diver hand core, surface grab samples	5
Site E	4.3	Warrior Reef, central Torres Strait	Diver surface grab samples	-
Site 8	13.0	North-east Saibai Island	Gravity corer deployed from MV Eclipse	10
Site A	7.8	North-west Saibai Island	Gravity corer deployed from MV Eclipse	10-12
Site B	13.0	Central Torres Strait, south of Saibai Island	Diver surface grab samples	-
Site 9	9.2	Central Torres Strait	Diver surface grab samples	-
Site C	2.5	Central Torres Strait	Diver surface grab samples	-
Site 10	5.3	Southern Torres Strait	Diver surface grab samples	10
Site F	17.0	Southern Torres Strait	Gravity corer deployed from MV Eclipse	6-8
Site 11	8.0	Southern Torres Strait	Diver surface grab samples	-
Site D	10.0	Southern Torres Strait	Diver surface grab samples	-

Table 4: June 2018 Survey sampling sites

Site	Date	Time	Water column depth (m)	Southings	Eastings
A	18/06/2018	1050	10.3	9°20'54.54"S	142°44'24.84"E
S1	18/06/2018	1135	11.1	9°20'37.14"S	142°51'19.24"E
S2	18/06/2018	1250	7.6	9°28'33.58"S	142°41'28.86"E
8	18/06/2018	0928	3.6	9°22'27.66"S	142°36'19.38"E
S3	18/06/2018	1010	12.3	9°21'57.84"S	142°31'11.76"E
B3	18/06/2018	1100	10.8	9°12'29.94"S	142°07'52.56"E
B4	18/06/2018	1140	5.3	9°17'45.54"S	142° 4'06.54"E
B5	21/06/2018	1112	4.9	9°21'54.4"S	142°25'23.0"E
B2	21/06/2018	1200	5.3	9°20'50.8"S	142°12'15.7"E
B1	21/06/2018	1240	3.4	9°17'35.4"S	142°19'09.2"E

3.5 Water sample processing

Water samples for analysis of trace metals other than mercury were vacuum-filtered through acid-washed 0.45 µm Millipore membrane filters using an acid-washed polycarbonate filtration apparatus (Sartorius).

The filtration assemblies were further cleaned before processing each sample by first filtering a 100 mL volume of 10% v/v nitric acid solution followed by two 150 mL volumes of deionised water, and finally, a 50 mL volume of sample. For each volume of these solutions the filtration rig was held on an angle and rotated both before and after filtration so that the solutions came into contact with all surfaces of the top and bottom compartments of the apparatus to ensure rigorous rinsing / pre-treatment was achieved. The 50 mL aliquot of sample used to pre-clean the filtration rig was poured into the 1 L acid-washed Nalgene filtrate receiving bottle, shaken to pre-treat the bottle, and discarded to waste. The sample was then filtered and the filtrate transferred into the receiving bottle. Approximately 900 mL of each sample filtrate was retained for analysis. Filtrates were then preserved by addition of 2 mL/L of concentrated nitric acid (Merck Tracepur).

For the field blanks, approximately half of the 1 L sample was filtered and preserved. The remaining 500 mL was acidified and retained for subsequent analysis. The difference between the filtered and unfiltered field blanks gave an indication if filtration resulted in contamination.

Suspended sediment samples for TSS and TSS-bound metal analyses were acquired by filtering known volumes of water through pre-weighed 0.45 µm membrane filters (Millipore). The filters were rinsed with 10% nitric acid before use and each sample was filtered using the filtration procedure described above. Due to the low concentration of TSS in each sample, the volumes filtered were generally in the range 4 to 6 L. After the sample was filtered and the filtrate removed, the upper compartment of the filtration apparatus and the filter were rinsed with approximately 20 mL of deionised water to remove any salt. The filters were placed into acid-washed plastic Petri slides and stored frozen. The filters were transferred to the CSIRO Lucas Heights laboratories, after which they were oven-dried at 60°C, cooled to room

temperature in a desiccator, and weighed. This procedure was repeated three times to ensure the mass was consistent, after which, the filters were stored at room temperature until total recoverable (TR) metals analysis was performed. The TSS concentration (mg/L) of the water samples was calculated using the difference in the mass of the filter before and after filtration divided by the volume of sample filtered.

For mercury analysis, only the total concentration in the samples was measured. This was because filtration of mercury samples at remote field locations was not feasible as it requires specialist equipment in order to avoid contamination. Unfiltered samples were collected in acid washed fluorinated ethylene propylene (FEP) or fluorinated high density polyethylene (FLPE) bottles and were acidified without any further treatment with 1% HCl (Merck Tracepur).

4. CHEMICAL ANALYSIS

4.1 Overview

The CSIRO laboratories at Lucas Heights are accredited by the National Association of Testing Authorities (NATA) for all analyses performed for this project. The analysis of trace metals at sub- $\mu\text{g/L}$ concentrations is acknowledged to be technically challenging and necessitates the application of rigorous protocols for container preparation, sample collection and analysis (conducted in a clean room environment), in order to minimise the risk of sample contamination. Full details of the methods employed are given below.

Rigorous quality control procedures are employed in the laboratory. These comprise the following steps:

- Field blanks
- Replicate field samples
- Laboratory replicate (at least 10% of all samples in each batch)
- Laboratory blanks in each batch of samples (at least 3 in each batch)
- Analysis of a certified reference material – included in each batch of samples
- Spike recovery tests (at least 10% of all samples in each batch)

The limits of detection for the trace metal analyses are calculated based on the actual blank measurements made during the analyses (three times the standard deviation of the blank measurements). This provides a more realistic assessment of actual detection limits rather than the generalised detection limits based on historical data that are quoted by commercial laboratories.

4.2 General analytical procedures

High purity deionised water was obtained from a Milli-Q system (18 M Ω .cm conductivity, Millipore, Australia) and was used throughout the study. Plasticware used for metals analyses was acid-washed prior to use by soaking for a minimum of 24 h in 10% (v/v) analytical reagent (AR) or nitric acid (Merck Tracepur) followed by rinsing with copious quantities of deionised water.

4.3 Preparation of trace metal sample bottles

One-litre low-density polyethylene (Nalgene) bottles used for all metals analyses other than mercury were cleaned using a three-stage sequence in clean room laboratories at CSIRO Lucas Heights. First, the bottles and lids were submerged for a minimum of 2 h in 2% v/v Extran detergent solution, followed by rinsing the outside and inside at least five times with deionised water. The bottles were then soaked for a minimum of 24 h in 10% nitric acid (Merck, AR grade) contained in a covered plastic tank. They were then rinsed five times with deionised water and filled with 1% high purity nitric acid (Merck Tracepur), capped and left to stand for at least 48 h. After this time the bottles were rinsed five times with deionised water, 'double-bagged' in two polyethylene zip-lock bags, and stored in sealed containers to avoid contamination during transportation to the field.

For TSS-bound metals analyses, five-litre low-density polyethylene (Nalgene) bottles were used that underwent the same three-stage sequence washing procedure as used for the one-litre Nalgene bottles.

Fluorinated ethylene propylene (FEP) bottles were used for the collection of water samples for mercury analysis and were cleaned using the following four step procedure. Each bottle and lid was soaked for at least 2 h in 1% v/v Extran detergent solution, followed by rinsing the outside and inside at least five times with deionised water. The bottles and lids were then soaked in acidified (0.2% v/v nitric acid) seawater for at least one day, followed by rinsing the outside and inside at least five times with deionised water. Each bottle was then filled with 50% v/v AR grade nitric acid, capped and left to stand for at least 3 days in clean zip-lock bags. The outside and inside of each bottle were rinsed at least five times with deionised water, and the bottles filled with 10% v/v hydrochloric acid (Merck Tracepur) and left to stand for at least 3 days. Finally each bottle and lid was rinsed on the outside and inside at least five times with deionised water and placed inside two polyethylene zip-lock bags for transportation to the field.

4.4 Analysis of metals in water samples

4.4.1 Dissolved cadmium, cobalt, copper, nickel, lead, and zinc

Dissolved cadmium, cobalt, copper, nickel, lead and zinc (Cd, Co, Cu, Ni, Pb and Zn) in filtered samples were analysed by complexation and solvent extraction, followed by quantitation of the pre-concentrated metals by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The extraction procedure allowed the pre-concentration of metals by a factor of 25, thus allowing more accurate quantification. A dithiocarbamate complexation/solvent extraction method based on the procedure described by Magnusson and Westerlund (1981) was employed. The major differences were the use of a combined sodium bicarbonate buffer/ammonium pyrrolidine dithiocarbamate reagent (Apte & Gunn, 1987) and 1,1,1-trichloroethane as the extraction solvent in place of Freon. In brief, sample aliquots (250 mL) were buffered to pH 5 by the addition of the combined reagent and extracted into two 10 mL portions of triple-distilled trichloroethane. The extracts were combined and the metals back-extracted into 1 mL of concentrated nitric acid (Merck Tracepur). The back extracts were diluted to a final volume of 10 mL by addition of deionised water and analysed by ICP-MS (Agilent 8800) using the instrument operating conditions recommended by the manufacturer. For quality control purposes a portion of the certified reference seawater NASS-6 (National Research Council (NRC), Canada) CRM was analysed in every sample batch.

Dissolved aluminium and iron concentrations were measured directly on portions of acidified filtered waters by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) (Varian 730 ES) by the method of standard addition. The concentrations of dissolved chromium were measured directly by ICP-MS (Agilent 7500CE) following three-fold dilution with 0.2% v/v nitric acid and calibration against standards prepared from certified stocks (Choice Analytical).

4.4.2 Dissolved arsenic

The concentration of dissolved arsenic (As) in the filtered samples was measured by hydride generation atomic absorption spectrometry (HG-AAS), using procedures based on the standard methods described by APHA (2017). Samples were first digested by addition of potassium persulfate (1% m/v final concentration) and heating to 120°C for 30 min in an autoclave. Hydrochloric acid, (3 M final concentration) was then added to the samples. Pentavalent arsenic was then pre-reduced to arsenic (III) by addition of potassium iodide (1% m/v final concentration) and ascorbic acid (0.2% m/v final concentration) and left standing for at least 30 min at room temperature prior to analysis. Arsenic concentrations were then measured by HG-AAS using a Varian VGA system operated under standard conditions recommended by the manufacturer. Arsenic (III) in solution was reduced to arsine by reduction with sodium borohydride, which was stripped from solution with argon gas into a silica tube, electrically heated at 925°C. Heating converted arsine into arsenic vapour, which was quantified by atomic absorption spectrometry.

For quality control purposes a portion of the certified reference seawater NASS-6 (National Research Council (NRC), Canada) CRM was analysed in every sample batch.

4.4.3 Total mercury in waters

Total mercury (Hg) in unfiltered water samples was determined by cold-vapour atomic fluorescence spectrometry (AFS) (Liang & Bloom, 1993). A sample volume of 80 mL was dispensed into a Pyrex-glass purging vessel and a 0.4 mL aliquot of bromine monochloride (BrCl) (0.2 M) in hydrochloric acid added to allow oxidation of any organic mercury present to inorganic mercury. The mixture was allowed to stand for a minimum of 90 minutes followed by the addition of 100 µL of hydroxylamine solution (3 M) to destroy any residual BrCl. The vessel was connected to a custom-built purge trap system and 0.5 mL stannous chloride (20% m/v) in 20% hydrochloric acid was added to reduce the inorganic mercury to elemental mercury. The elemental mercury was purged from solution in a nitrogen stream (20 minutes purge time) and trapped on a gold-coated glass bead trap. The trap was transferred to a thermal desorption unit interfaced to a Brooks Rand atomic fluorescence spectrometer. The trap was connected to a mercury-free helium gas stream and rapidly heated to 320°C. The released mercury was quantified by the AFS. For quality control purposes, a portion of the certified reference coastal seawater BCR-579 (Institute for Reference Materials and Measurements, IRMM) was included in each batch.

4.4.4 Dissolved organic carbon (DOC)

DOC was measured on aliquots of filtered samples collected during the June 2018 survey using a Shimadzu TOC-LCSH Total Organic Carbon Analyser using the procedures recommended by the manufacturer.

4.4.5 Analytical methods for measuring metals in TSS and benthic sediments

The benthic sediment samples were freeze-dried (Christ Alpha 1-2 LD plus) before chemical analysis. The freeze-dried sediments were disaggregated by gentle grinding using an acid washed agate mortar and pestle.

TSS and benthic sediments were digested in pre-cleaned TFM™ fluoropolymer digestion vessels using aqua regia digestions in a microwave-assisted reaction system (MARS, CEM). The membrane filters containing the suspended sediments or aliquots of the benthic sediment samples (0.5 g) were transferred into the MARS digestion vessels and subjected to pressurised digestion. The method involved adding 9 mL of concentrated nitric acid (Merck Tracepur) and 3 mL of concentrated hydrochloric acid (Merck Tracepur) to each digestion vessel and heating at high pressure in a MARS digestion system for 4.5 minutes at 175°C. Once cool, the digest vessels were vented followed by dilution of the digest to a final volume of 40 mL using deionised water. The masses of the empty vessel, the vessel plus sample, and the vessel plus sample and acid mixture before and after heating were recorded to allow calculation of a dilution factor used in the determination of metal concentrations in the initial undiluted sample. For quality control purposes, portions of the certified reference sediments ERM-CC018 (IRMM) and PACS-3 (NRC Canada) were analysed in each sample batch. All particulate metals concentrations data is reported as dry sediment mass.

It should be noted that the analytical method applied does not measure all forms of particulate metals, rather the portion of metal that is released into solution (recoverable) during the acid-digestion procedure. Metals associated with silicates and refractory elements such as chromium are likely to be underestimated, however, for many metals (e.g. copper and zinc) near full recovery from particulates can be expected. For environmental studies which focus on the interactions of particulates with living organisms, the fraction of metals not mobilised by acid digestion is not likely to play a significant role and can be regarded as being inert. For the purposes of simplification, the term particulate metals is used in this report to denote the total recoverable metals.

5. COMMUNITY SURVEY: BOIGU AND SAIBAI

Community members on Saibai Island and Boigu Island in the Torres Strait were invited to participate in an interview to assist in providing information on their views of the frequency and potential consequences of muddy waters impacting upon their community. The community survey was carried out in Saibai and Boigu Islands during the respective dates of 18 to 19th and 20 to 21st June 2018. Permission to visit the community was granted by the Prescribed Body Corporates and Councillors on each island.

Taking part in this study was completely voluntary and participants could stop taking part in the study at any time without explanation or prejudice. Anonymity was safeguarded by using de-identified information that did not identify names. Participation was sought through a process involving informed consent and signed permission.

Before the interview commenced, background information about the project was discussed with the participants. This involved discussing the key aspects listed in the information sheet to help increase transparency and accountability. The consent form was signed by each participant before the interview began. The participants were asked 10 questions (see Appendix B for the community survey). The interview was facilitated by Dr Cass Hunter who is an Indigenous Researcher from CSIRO. Also, at least one Torres Strait Regional Authority (TSRA) Land and Sea Ranger was present to assist with explaining the project background to most participants, as well as, helping to seek the involvement of individuals across different age groups and genders. This involved visiting different locations and workplaces on the island.

6. RESULTS AND DISCUSSION

6.1 October 2016 survey results

6.1.1. Water physico-chemical parameters

The physico-chemical parameters measured in waters during the survey are shown in Table 5. To aid interpretation, the data was grouped into western, central and eastern categories and plotted in the form of approximate north to south transects (Figures 7 and 8). Note that for clarity, sites O, 2 J and X were not included in these plots as they did not align with a designated transect. Water pH ranged from 8.10 to 8.29 and was relatively constant throughout the region with no obvious trends (Table 5 and Figure 7). Salinity ranged from 30.4 to 35.7‰ and generally exhibited an increasing trend with distance south in the Torres Strait (Table 5 and Figure 7). This trend is consistent with the diluting effects of freshwater inputs from the PNG mainland which lower water salinity.

Turbidity ranged from 0.3 to 8.8 NTU, with the lowest levels measured in the south-eastern Torres Strait and the highest values measured at Sites A and 8, near the north of Saibai Island (Table 5 and Figure 8). Total suspended solids ranged from 0.6 to 12.0 mg/L and similar to turbidity generally exhibited a decreasing trend with distance south (Table 5 and Figure 8). The lowest salinity, highest turbidity and TSS all occurred at Sites A and 8, which were in close proximity to the north shore of Saibai Island (see locations in map on Figure 5).

Table 5: October 2016 survey: Physico-chemical data measured on water samples

Sample	Depth	pH	Salinity	Turbidity	TSS
	(m)		(‰)	(NTU)	(mg/L)
Site 1	7.3	8.15	32.95	0.84	1.65
Site G	8.5	8.20	33.16	1.33	1.93
Site 2	16.7	8.14	34.26	0.62	2.53
Site J	11.8	8.13	32.48	0.36	2.31
Site 3	20.0	8.10	32.81	0.33	0.72
Site K	2.0	8.29	33.94	0.58	5.01
Site I	5.6	8.21	34.49	0.41	1.61
Site M	8.0	8.17	34.90	0.82	0.75
Site N (Erub)	29.0	8.14	34.88	0.57	1.11
Site N (Erub) duplicate	29.0	8.17	34.46	0.55	1.02
Site X	7.6	8.15	34.87	0.93	3.54
Site O (Masig)	21.8	8.14	35.16	0.42	0.61
Site O (Masig) duplicate	21.8	8.14	35.16	0.42	0.77
Site E	4.3	8.23	34.10	2.71	7.31
Site 8	13.0	8.14	31.72	8.82	11.98
Site A	7.8	8.15	30.40	7.95	11.16
Site A duplicate	7.8	8.15	30.46	7.95	10.39
Site B	13.0	8.16	34.30	2.07	4.80
Site 9	9.2	8.17	35.27	1.96	2.98
Site C	2.5	8.15	35.49	0.78	1.00
Site 10	5.3	8.17	35.53	1.49	1.33

Site F	17.0	8.14	35.67	1.74	1.06
Site 11	8.0	8.16	35.51	1.53	1.77
Site D	10.0	8.14	35.72	6.98	5.12

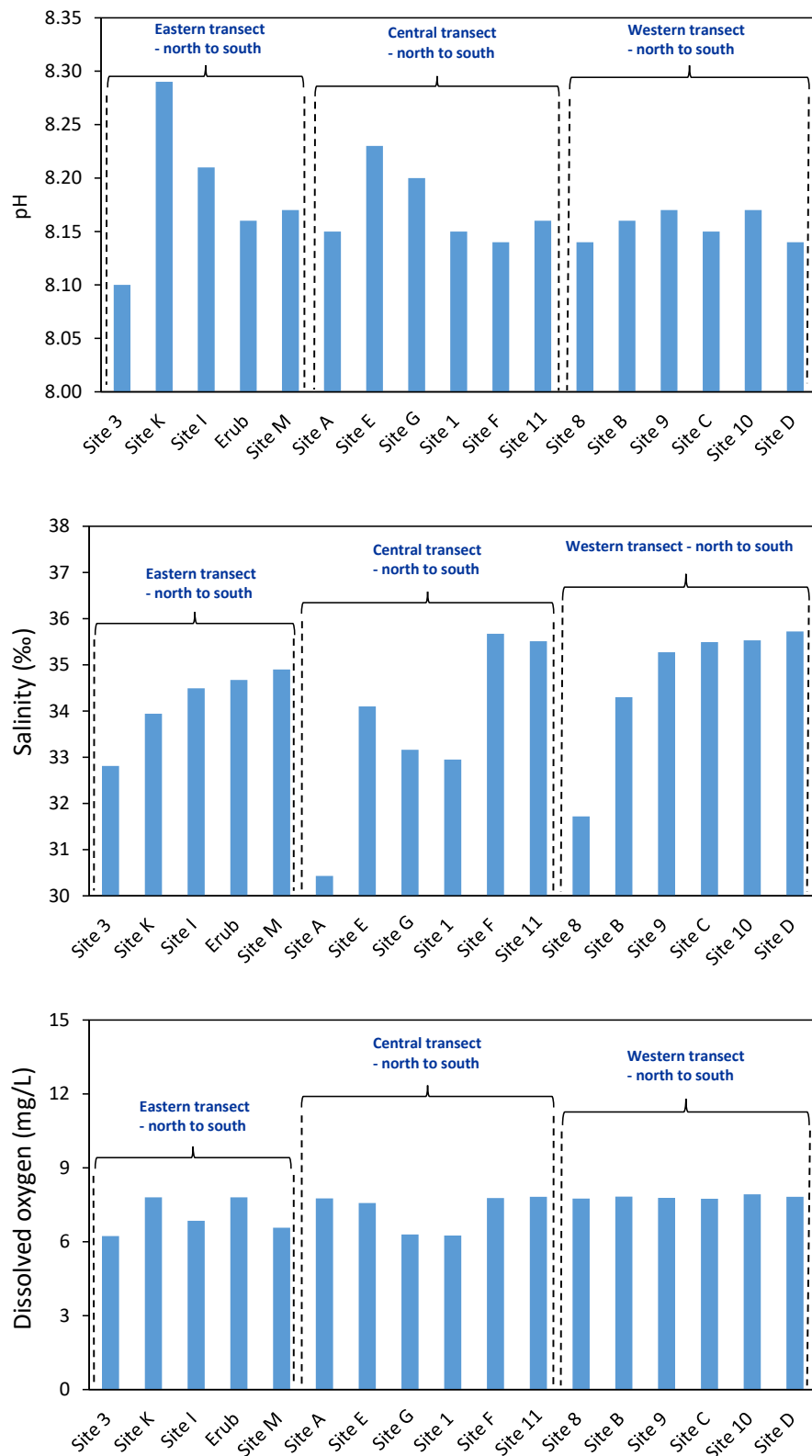


Figure 7: October 2016 survey: summary of salinity, pH and dissolved oxygen data

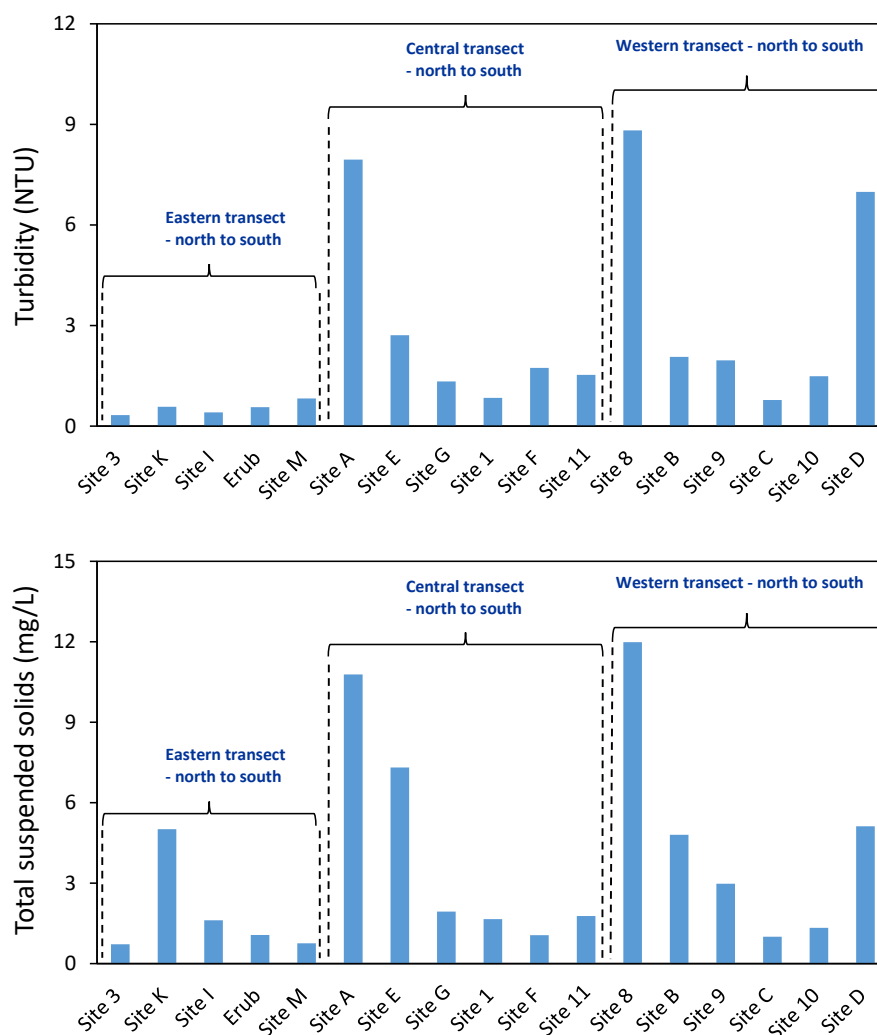


Figure 8: October 2016 survey: summary of turbidity and TSS data

6.1.2 Metals in waters

The quality control data for the water analyses are compiled in Appendix A and were generally excellent. The limits of detection (LOD) were in the low to sub-ng/L range for the metals analysed. Recoveries of metals in certified reference materials were in the range 83 to 106% (Appendix A1). Spike recoveries were in the range 80-110% (Appendix A1). Zinc is acknowledged to be an extremely difficult element to analyse in marine waters because of its low concentrations and the many sources of potential contamination during sampling and analysis. Some of the duplicate measurements for zinc which varied by up to a factor of two and elevated field blanks (Appendices A4 and A5) suggest some contamination in the ng/L range occurred at some sites (Sites M O, and 8). This should be taken into account when interpreting the field data for dissolved zinc.

The concentrations of dissolved arsenic, cadmium, cobalt, copper, nickel, lead and zinc and total mercury measured in the Torres Strait waters are shown in Table 6 and Figures 9, 10 and 11. The dissolved metal concentrations were all below ANZECC/ARMCANZ (2000) 95% species protection marine water quality guideline values (WQGVs), however, dissolved

copper exceeded the current 99% species protection marine WQGVs at Sites A and 8 (i.e. north Saibai Island sites). Issues surrounding the application of guideline values for dissolved cobalt in marine waters are covered in section 7.2.

Dissolved arsenic (As) concentrations ranged from 1.3 to 1.7 µg/L and generally exhibited an increasing trend with distance south in the Torres Strait (Figure 9). Dissolved arsenic was significantly correlated with salinity ($r = 0.63$), indicating that the seawater was the main source of dissolved arsenic relative to freshwater inputs (lower arsenic concentrations).

Dissolved cadmium, cobalt, copper and nickel (Cd, Co, Cu, Ni) generally exhibited decreasing trends with distance south in the Torres Strait and were measured in the range 1.0 to 6.8, 0.9 to 6.4, 45 to 629, and 116 to 184 ng/L, respectively. The concentrations of these metals were the highest at Sites A and 8 (the two sites on the north side of Saibai Island that also had the highest turbidity and TSS values – Figure 8).

Dissolved lead (Pb) and zinc (Zn) were measured in the range 2.0 to 10, and 19 to 136 ng/L, respectively. These metals were highest at the northern Saibai sites and generally lowest in the southern or Eastern Torres Strait. The concentrations of both of these metals were extremely low and, as indicated by field blank and duplicate data (Appendix A), may be subject to some contamination. This means that the lead and zinc concentrations at some sites may be overestimates.

6.1.3. October 2016 survey: total mercury concentrations

The total mercury (Hg) data (Table 6) obtained on unfiltered water samples, are worthy of special attention given the concerns over mercury as a global contaminant (Chen et al. 2016). To the best of our knowledge, this is the first data set generated for tropical Australian coastal waters, obtained using state-of-the-art analytical procedures. The relationship between total mercury concentration and total suspended solids is shown in Figure 12. In natural waters, mercury is known to be mainly associated with particulates (Balogh et al., 1997; Le Roux et al., 2001), and so, the two highest data points (Site 10 and Site O) which have low suspended sediment concentrations may be erroneous due to sample contamination. Ignoring the two outliers, the remaining data points show a good relationship with suspended sediments particularly considering the very low concentrations of mercury and suspended solids in the samples. Note that following outlier rejection, the highest mercury concentrations were found in the samples around Saibai Island which also contained the highest suspended sediment concentrations.

Total mercury concentrations (excluding sites 10 and O) ranged from 0.11 to 0.88 ng/L (0.5 to 4.4 pM). If the samples from around Saibai are not included on the grounds that their mercury concentrations are elevated because of the high suspended sediment load, the mean total mercury concentration for the Torres Strait was 0.31 ± 0.2 ng/L (1.5 ± 1.0 pM). Typical open Pacific Ocean total mercury concentrations have been summarised by Munson et al. (2015). Total mercury concentrations decrease with depth in the oceans, however, for upper layer oceanic waters, they typically range in concentration from 0.4 to 2.0 pM. This compares well with the lower end of our data set. Note that coastal waters will contain more suspended sediments than found in the open ocean and therefore, are more likely to support higher total mercury concentrations. Overall, this data set indicates that mercury concentrations in the

waters of the Torres Strait are very low and are representative of uncontaminated marine waters.

Table 6: October 2016 survey: Concentrations of dissolved metals and total mercury in water samples

Sample	Location	As	Cd	Co	Cu	Total Hg	Ni	Pb	Zn
		(µg/L)	(ng/L)						
Site 2	NE TS	1.37	2.1	2.8	195	0.37	137	3.4	47
Site 3	NE TS	1.28	2.4	2.6	188	0.31	116	2.4	36
Site K	NE TS	1.42	1.9	2.2	145	0.37	123	3.7	44
Site I	NE TS	1.49	1.6	1.5	113	0.11	128	2.4	19
Site M	NE TS	1.52	1.2	0.9	78	0.38	122	2.4	44
Site N (Erub)	NE TS	1.50	1.4	1.9	95	0.25	124	2.0	47
Site X	NE TS	1.32	1.6	1.6	102	0.12	128	2.1	39
Site J	NE TS	1.42	1.3	3.8	153	0.12	167	10.0	136
Site O (Masig)	NE TS	1.42	2.5	1.4	93	0.88	126	2.4	35
Site E	Warrior	1.34	3.6	4.8	287	0.36	146	3.8	51
Site G	Warrior	1.41	2.1	4.1	279	0.31	135	5.5	65
Site 1	Warrior	1.43	1.8	3.9	249	0.13	132	4.2	42
Site A	Saibai	1.30	6.8	5.8	629	0.88	184	7.8	46
Site 8	Saibai	1.34	6.6	6.4	560	0.78	183	7.7	65
Site B	South Saibai	1.54	2.2	3.0	153	0.19	129	8.6	26
Site 9	South Saibai	1.48	1.3	2.0	98	0.16	127	3.7	32
Site C	Southern TS	1.43	1.4	1.3	56	0.23	130	3.8	19
Site 10	Southern TS	1.55	1.0	1.5	46	1.26	131	2.8	23
Site F	Southern TS	1.66	2.5	2.7	47	0.19	145	2.2	35
Site 11	Southern TS	1.53	1.2	1.0	45	0.21	127	2.5	19
Site D	Southern TS	1.68	1.6	1.9	51	0.39	136	4.0	20
95% protection WQGV			5500	1000	1300	400	70000	4400	15000
99% protection WQGV			700	-	300	100	7000	2200	7000

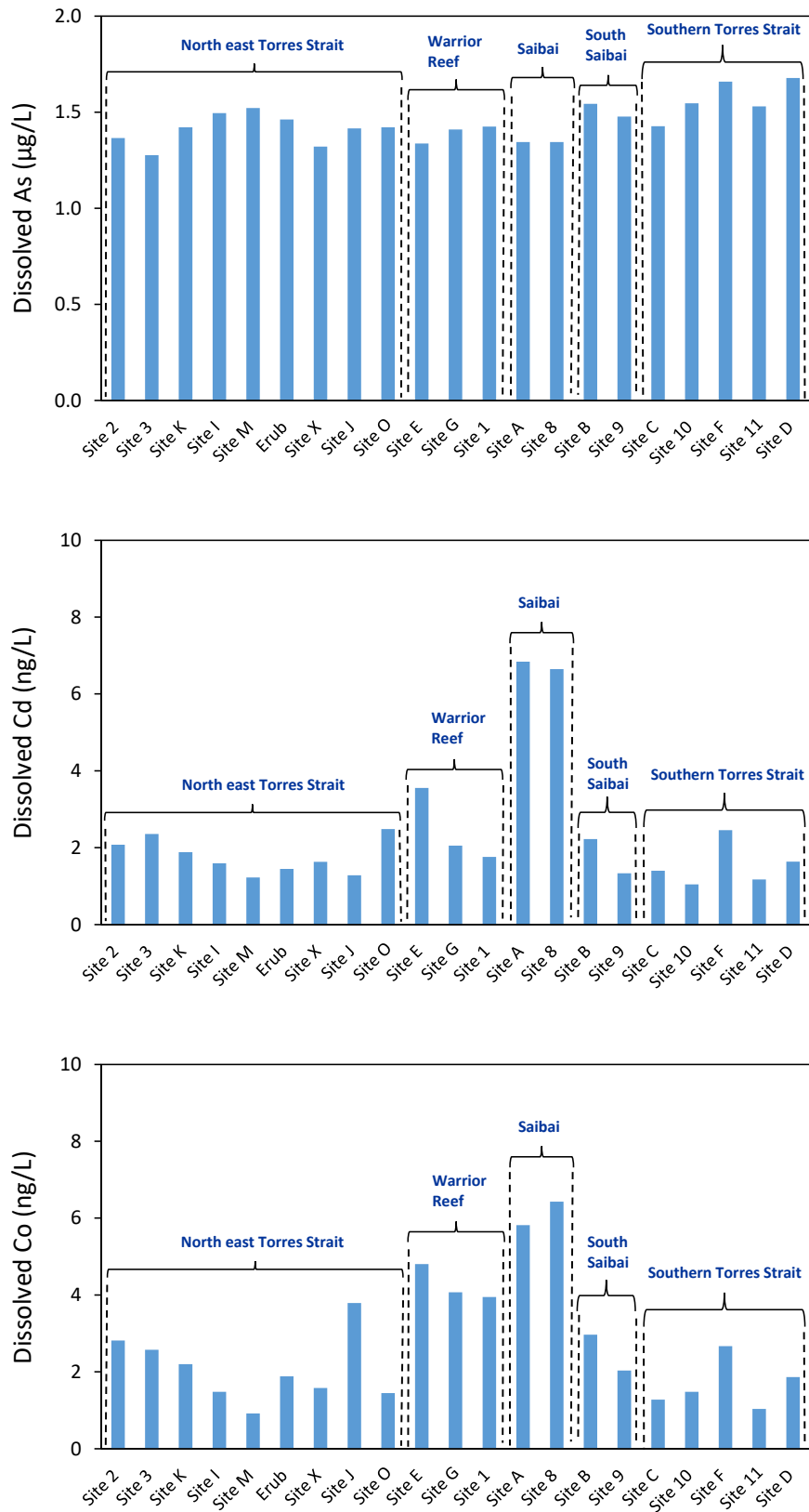


Figure 9: October 2016 survey: summary of the dissolved As, Cd and Co data

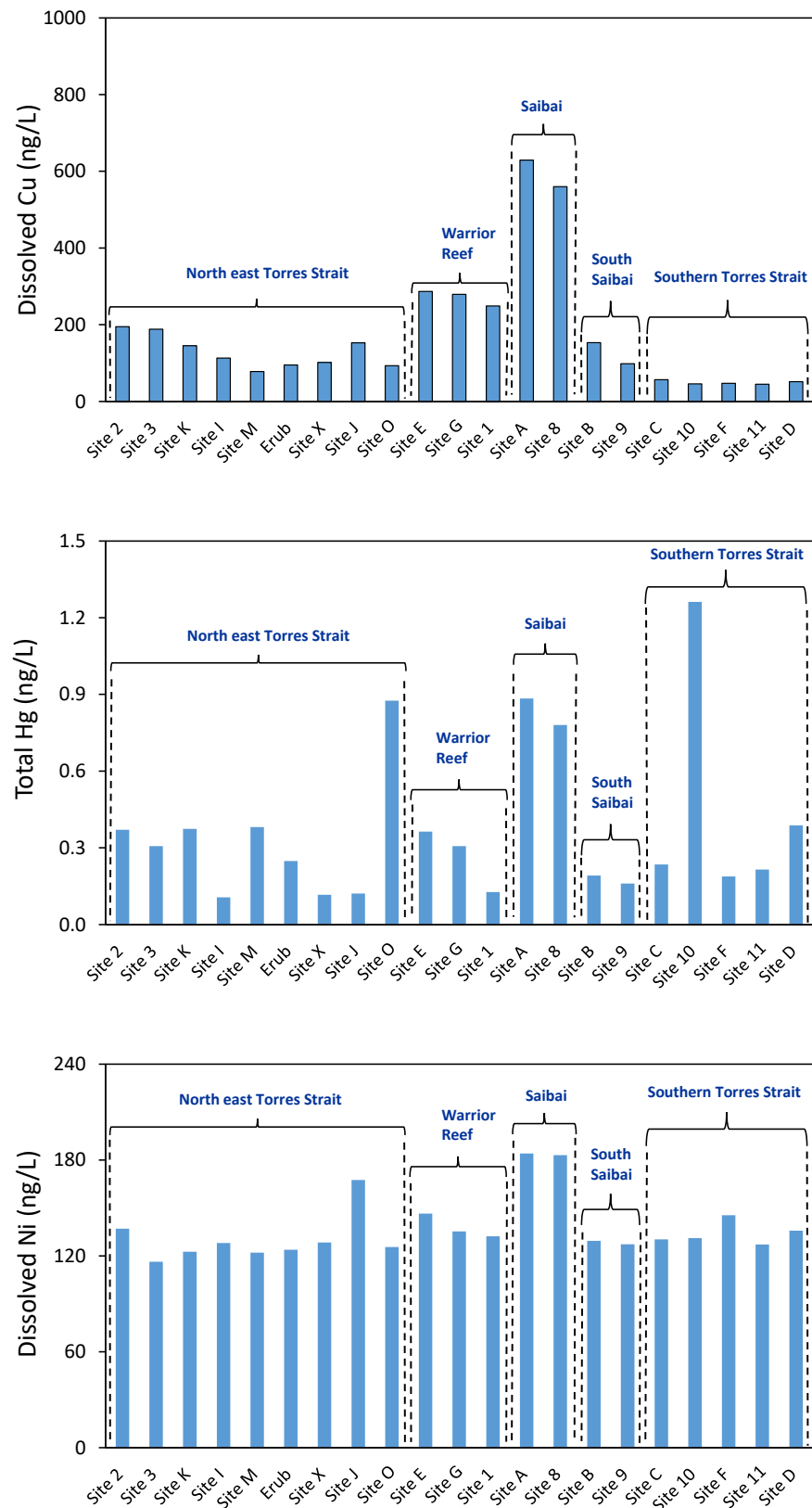


Figure 10: October 2016 survey: summary of the dissolved Cu, Hg and Ni data

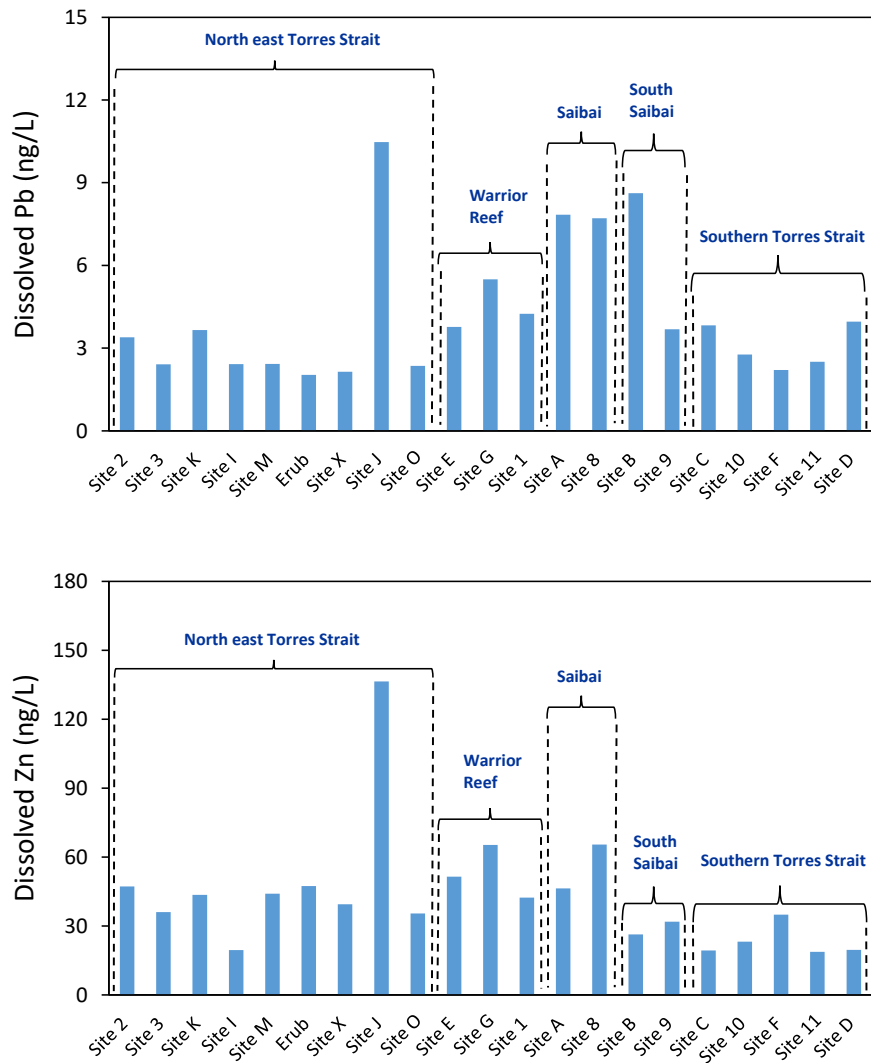


Figure 11: October 2016 survey: summary of the dissolved Pb and Zn data

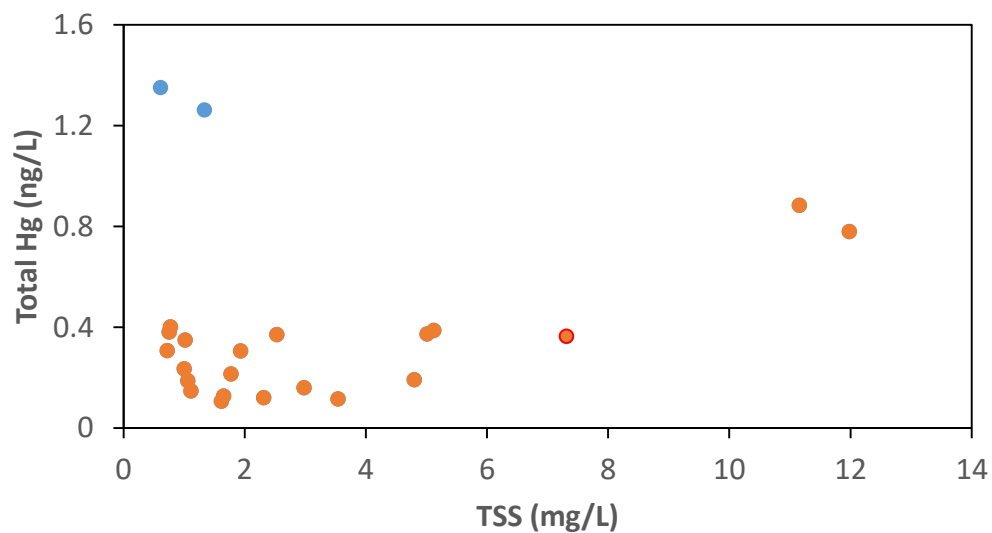


Figure 12: Relationship between total mercury in waters and total suspended solids. The outliers to the trend are shown in blue

6.1.4 Metals in total suspended solids

The quality control for TSS-bound metal analysis is shown in Appendices A8 and A9, and was generally excellent. The recoveries obtained for the certified reference sediment CC018 for As, Cd, Co, Cu, Ni, Pb, Zn were in the range of 84 to 99%. The recoveries obtained for certified reference sediment PACS-3 for As, Cd, Co, Cu, Ni, Pb, Zn were in the range of 105-111% of the CSIRO in-house reference values. Spike recoveries of As, Cd, Co, Cu, Ni, Pb, Zn were in the range 93-101%.

The concentrations of 54 trace elements were measured in the suspended sediment samples. The 13 most commonly monitored metals are shown in Table 7 and data for 7 of these metals are presented in Figures 13, 14 and 15. The concentration data for the remaining less common elements are compiled in Appendix A7.

The particulate Co, Cu, Ni, Pb and Zn concentrations in the TSS was generally much higher from the north Saibai Island (Sites A and 8) than elsewhere in the Torres Strait, which was similar to the trend observed for dissolved metals.

Interestingly the TSS-Cu concentration measured at site 3 (Bramble Cay), the site closest to the Fly River Estuary but further from the mainland than Saibai, was similar to the concentration measured at the Saibai sites. The concentration of arsenic was highest at the northern Saibai sites and Sites 2 and J.

Statistical analysis of the data set (Pearson correlation coefficients) indicated hundreds of very strong ($r > 0.85$) statistically significant correlations between many of the trace elements indicating a common source. The correlating elements included aluminium, copper, iron, manganese, nickel and zinc. A notable exception was calcium which showed an inverse relationship with most of the other trace elements. Uranium ($r = 0.89$) was the element that exhibited a strong positive correlation with calcium consistent with a common marine origin. Examples of the relationships between various trace elements in the suspended sediment samples are shown in Figure 16.

Table 7: October 2016 survey: TSS-bound metal concentrations

Sample	Location	Ag	As	Cd	Cr	Cu	Ni	Pb	Sb	Zn	Co	Se	U	Mo
		(µg/g)												
Site 2	NE TS	<0.23	15.9	<0.07	<5.27	4.96	3.84	0.83	<1.1	16.0	1.14	0.5	0.38	3.82
Site 3	NE TS	<0.86	8.63	0.25	<19.6	23.3	19.3	4.07	<4.2	<30.6	2.59	<1.13	0.77	6.09
Site K	NE TS	<0.17	4.43	0.08	<3.98	2.41	2.79	<0.4	<0.9	<6.21	0.28	<0.23	0.35	0.81
Site I	NE TS	<0.69	4.75	0.94	<15.8	6.21	6.78	<1.57	<3.4	<24.6	0.76	<0.91	1.29	6.24
Site M	NE TS	<1.09	4.22	<0.31	<24.9	5.46	5.40	<2.48	<5.4	<38.9	1.32	<1.44	1.21	18.8
Site N (Erub)	NE TS	<0.87	3.90	0.795	27.9	6.17	9.77	<1.98	<4.3	<31.0	1.13	<1.15	1.21	8.67
Site X	NE TS	<0.21	3.59	0.15	7.27	2.71	3.44	0.85	<1	13.8	0.63	<0.27	0.69	3.04
Site J	NE TS	<0.29	20.7	0.14	<6.75	2.93	1.60	<0.67	<1.5	<10.5	0.31	0.49	0.11	3.66
Site O (Masig)	NE TS	<0.81	4.93	1.59	26.9	7.82	12.7	<1.85	<4	<29.0	1.89	1.54	1.46	16.2
Site E	Warrior	<0.19	2.59	0.18	14.0	4.43	8.41	1.74	<0.9	8.53	2.03	<0.25	1.19	0.6
Site G	Warrior	<0.59	4.07	1.05	30.4	9.29	12.5	3.58	<2.9	27.1	4.37	<0.78	1.65	<1.3
Site 1	Warrior	<0.50	3.32	0.22	25.6	8.52	12.1	3.38	<2.5	27.5	3.65	<0.66	1.42	<1.1
Site A	Saibai	<0.17	14.3	0.16	35	27.1	31.8	19.1	<0.8	101	14.3	<0.22	0.913	0.678
Site 8	Saibai	<0.14	15.6	<0.04	44.7	24.3	32.0	19.2	<0.7	95.0	14.8	<0.19	1.02	0.72
Site B	South Saibai	<0.24	3.18	0.19	5.78	2.9	4.82	1.10	<1.2	10.5	1.53	<0.32	0.43	2.77
Site 9	South Saibai	<0.39	4.50	0.23	18.8	3.99	7.57	1.99	<1.9	23.5	2.37	<0.51	1.52	1.57
Site C	Southern TS	<0.80	5.19	1.21	<18.4	3.33	5.66	<1.83	<4	<28.7	1.55	<1.06	0.99	14.6
Site 10	Southern TS	<0.66	4.47	0.99	<15	3.44	4.45	1.51	<3.3	<23.5	1.70	<0.87	1.79	22.1
Site F	Southern TS	<0.66	2.66	0.26	22.2	<2.58	6.48	<1.51	<3.3	<23.6	1.98	<0.87	1.85	13.8
Site 11	Southern TS	<0.39	4.72	<0.11	26.4	2.61	4.49	2.00	<1.9	<14.0	1.98	<0.52	1.77	1.29
Site D	Southern TS	<0.18	3.68	<0.05	33	3.03	9.15	4.29	<0.9	13.1	2.64	<0.24	2.22	0.57

Table 7 (continued): October 2016 survey: TSS-bound metal concentrations

Sample name	Location	Al	Ca	Fe	K	Mg	Mn	P	S	Sr
		(µg/g)								
Site 2	NE TS	3030	36900	2850	10600	31400	46	893	21700	554
Site 3	NE TS	6760	137000	7010	2220	12000	134	2060	7530	1790
Site K	NE TS	881	46900	831	9130	28300	13	492	19900	606
Site I	NE TS	3320	176000	3420	2120	14500	48	1390	10500	2310
Site M	NE TS	2900	106000	3310	3120	12400	80	2360	12800	1460
Site N (Erub)	NE TS	5345	126500	5620	2790	12300	86	2160	10955	1660
Site X	NE TS	2800	70200	2430	8070	25700	38	687	17100	899
Site J	NE TS	223	11700	337	9770	28100	11	750	20900	445
Site O (Masig)	NE TS	6015	131500	6605	2330	12150	127	2950	9170	1765
Site E	Warrior	5430	91100	5300	7180	24500	67	699	14100	1080
Site G	Warrior	10700	161000	13300	2530	17500	179	1460	5510	1690
Site 1	Warrior	13000	144000	10600	4450	19700	164	1360	8590	1560
Site A	Saibai	21150	32700	31900	4805	14350	562	740	5165	337.5
Site 8	Saibai	35400	53100	35700	4980	12900	569	712	3836	518
Site B	South Saibai	2110	38000	3590	8840	27800	72	419	18200	452
Site 9	South Saibai	7750	207000	7760	2670	17200	125	932	6570	2170
Site C	Southern TS	5790	90600	6050	4180	16600	81	1080	10500	976
Site 10	Southern TS	8360	175000	7220	3580	17700	81	1430	8400	1900
Site F	Southern TS	4580	183000	6840	2530	16600	92	1470	7150	2050
Site 11	Southern TS	8720	205000	7430	2210	15000	87	1040	5660	2410
Site D	Southern TS	12100	243000	10500	1870	17200	141	732	3836	2560

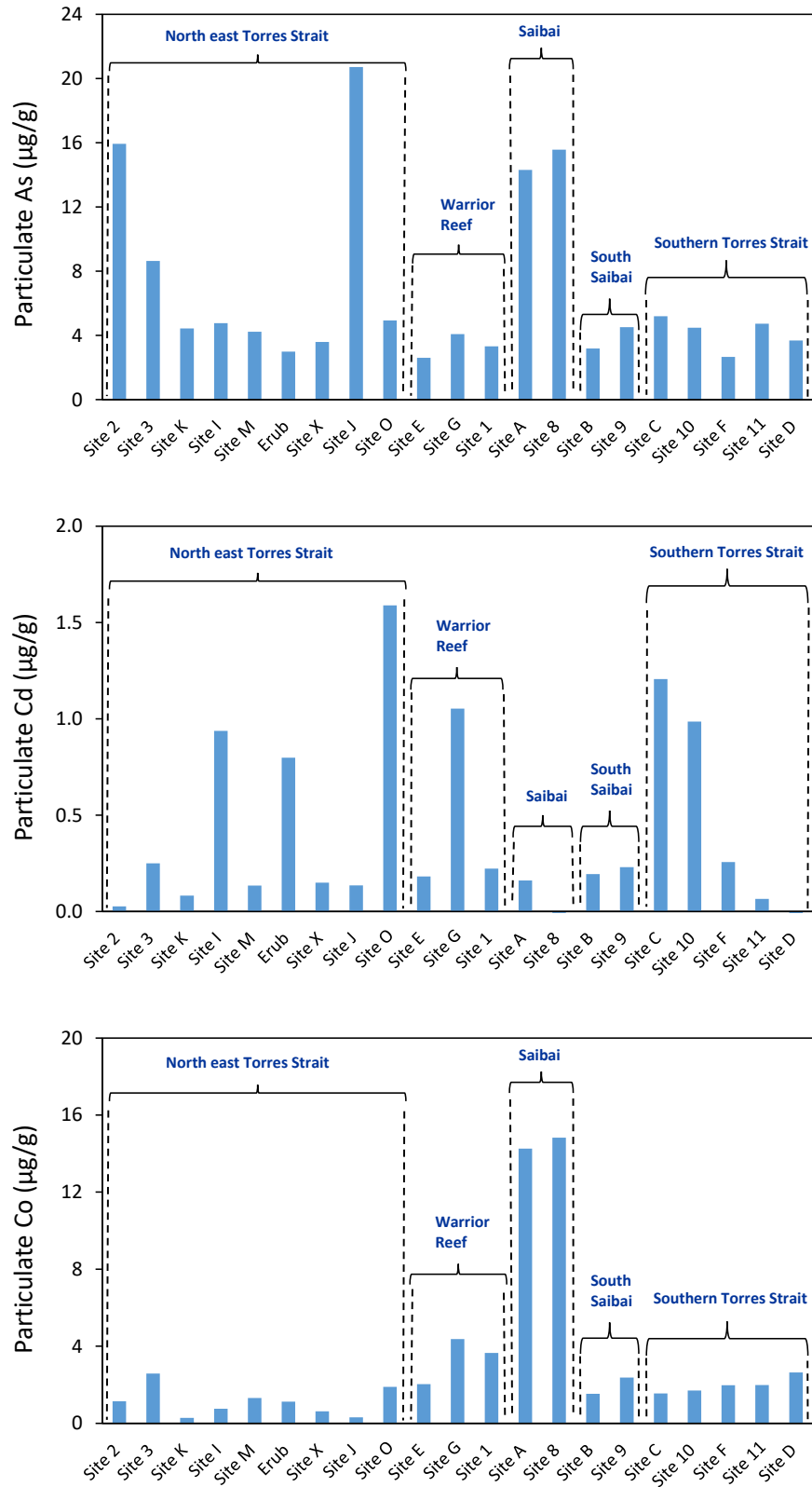


Figure 13: October 2016 survey: TSS-bound As, Cd and Co

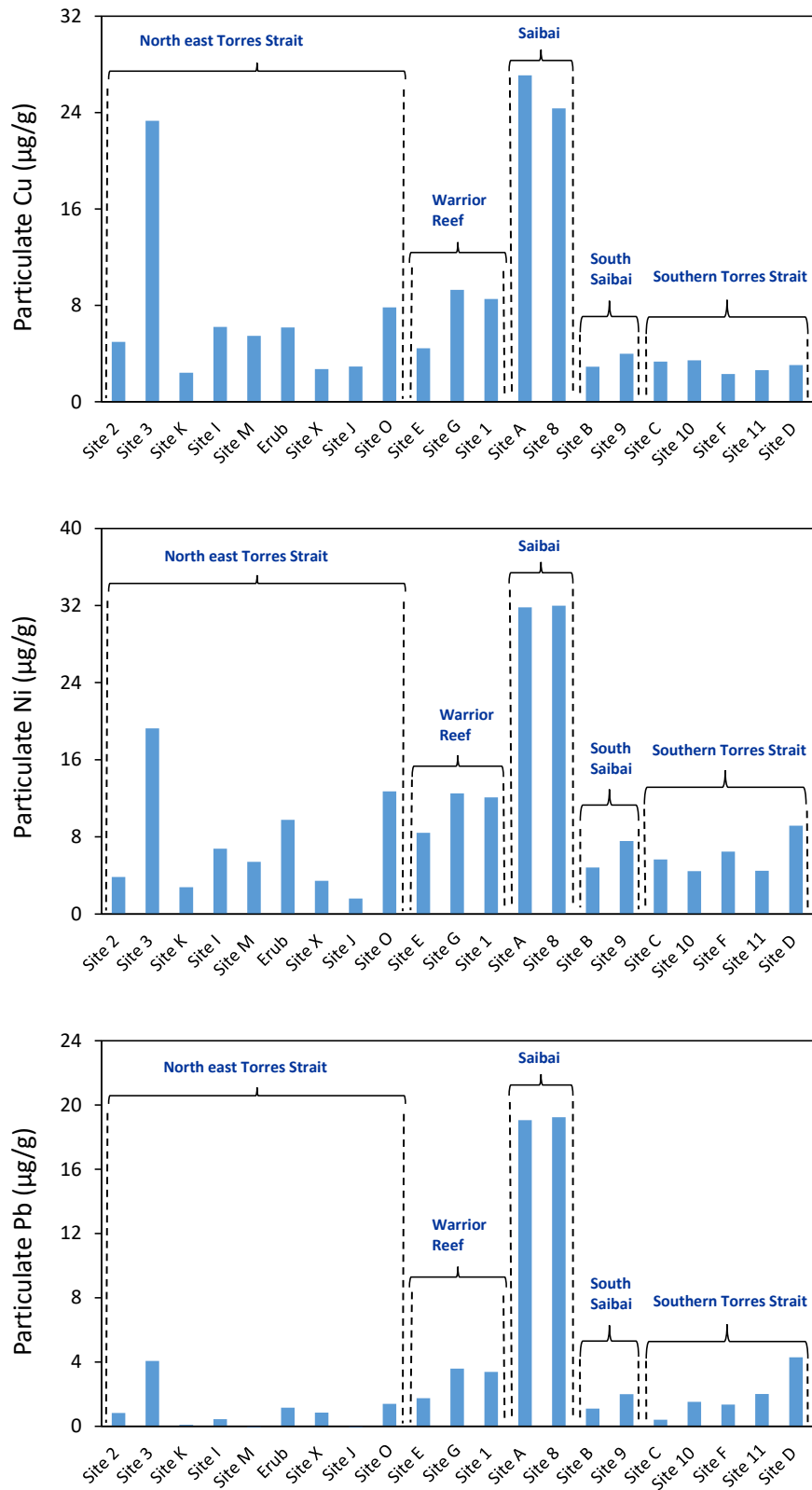


Figure 14: October 2016 survey: TSS-bound Cu, Ni and Pb

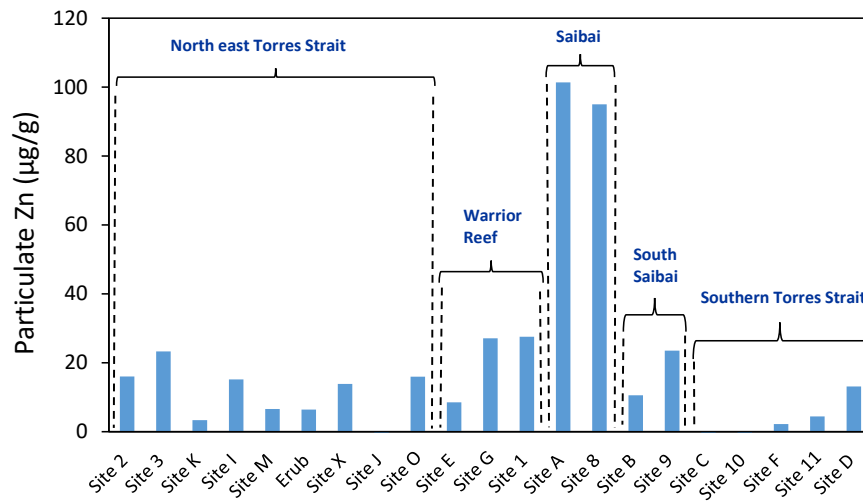


Figure 15: October 2016 survey: TSS-bound Zn

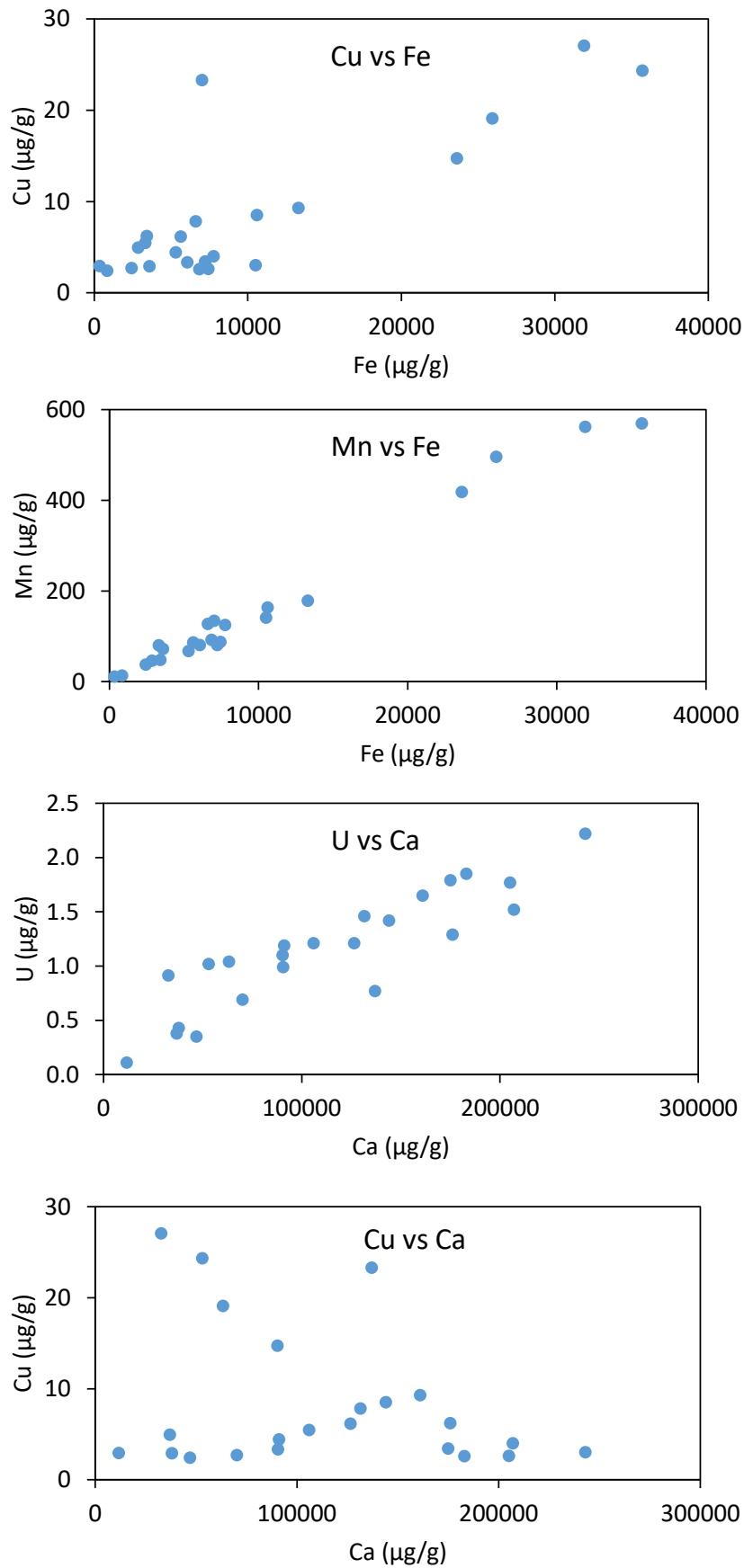


Figure 16: Examples of the relationships between trace metals in TSS samples. Note the plots set also contain mean data from the 2018 survey.

6.1.5 Metals associated with benthic sediments

The concentrations of 60 trace elements were measured in the benthic sediment samples. The 20 most commonly monitored metals are shown in Table 8 and the concentration data for the remaining less common elements are compiled in Appendix A10. The quality control data for the benthic sediment analysis are shown in Appendix A11, and was generally excellent. Sediment samples were analysed in triplicate and the mean data reported. Replicate analysis data may be found in Appendix A13. The recoveries obtained for the certified reference sediment CC018 for As, Cd, Co, Cu, Ni, Pb, Zn were in the range of 92 to 108%. The recoveries obtained for certified reference sediment PACS-3 for As, Cd, Co, Cu, Ni, Pb, Zn were in the range of 103-113% of the CSIRO in-house reference values. Spike recoveries of As, Cd, Co, Cu, Ni, Pb, Zn typically ranged from 85 to 105% (Appendix A12).

The concentrations of most trace elements were very low, reflecting uncontaminated environments (Table 8). None of the particulate metal concentrations exceeded the ANZECC/ARMCANZ (2000) SQGV-high guideline values which indicate a high likelihood of toxicity to sediment dwelling organisms. The only particulate metal concentrations that exceeded the ANZECC/ARMCANZ (2000) sediment quality guideline values were arsenic and nickel in core sections from sites A and 8 close to Saibai Island and a surface sediment sample taken at site B (Table 8). Given that the concentrations were fairly uniform throughout the core profiles at sites A and 8, it is most likely that the slightly elevated arsenic and nickel concentrations reflect natural background mineral enrichment in the area rather than point source contamination.

Photographs illustrating the differences in sediment morphology are shown in Figure 17. Sediment composition was quite varied, ranging from coarse coral rubble (e.g. Site 3) to fine muds (e.g. Site G). The sediment samples containing the highest fine sediments were from around Saibai Island. This is consistent with the build-up of fine terrigenous sediments over geological timescales.

Sediment core depth profiles of particulate copper at Sites A and 8 (the sites with the highest copper concentrations) are shown in Figure 18. Note there is little change in metal concentrations over the 12 cm depth of the core profile. Similar trends were observed in the other core samples taken at other sites (Table 8). There was no indication of any surface enrichment of copper which would be indicative of recent deposition of sediments containing elevated copper concentrations (i.e. mine-derived sediments).

The spatial trends in the distribution of particulate copper, cobalt, lead, nickel and zinc are shown in Figures 19 and 20. Similar to the trends observed for metals in waters and suspended sediments, the highest metal concentrations were found at the two sites around Saibai Island. Most of the 60 trace elements measured in the sediment samples displayed similar trends. This was clearly illustrated by correlation coefficient analysis which indicated hundreds of very strong ($r > 0.85$) statistically significant relationships between many of the trace elements indicating a common source. The most notable exception was calcium which showed a completely different relationship with most of the other trace elements (e.g. iron, aluminium and copper) with the lowest concentrations being found at the sites near Saibai Island. The inverse relationship between copper and calcium concentrations in the benthic sediment samples is shown in Figure 21. Particulate uranium and rhodium were the only two

elements that show strong correlations with calcium concentrations consistent with a common marine origin.

Clearly, the trends observed in particulate metal concentrations can be related to the relative amounts of marine-derived, calcium carbonate dominated sediments, and fine, terrigenous sediments containing far higher concentrations of trace elements. Not surprisingly, the sediments showing evidence of significant terrigenous contributions are found close to the PNG mainland.

Some of the sites sampled in the current study corresponded to or were close to the sites sampled during the Torres Strait baseline study conducted 26 years earlier (Dight & Gladstone, 1993). A comparison of the trace metal concentrations measured at these sites is shown in Figure 22. The concentrations of metals measured at the offshore sites (3, 9, K and M) were significantly higher in 1993 compared to the current data set. Whereas at Sites A and 8, metal concentrations were slightly higher in the current study. These differences could be associated with differences in sampling and analytical methodologies between the two studies.

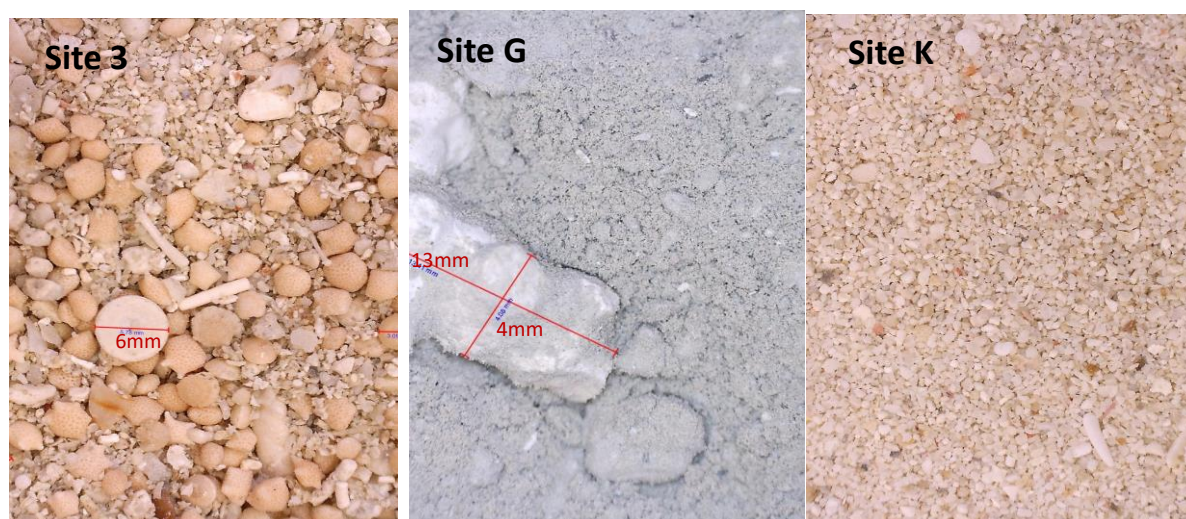


Figure 17: Photographs (x20 magnification) of benthic sediment samples illustrating their heterogeneity

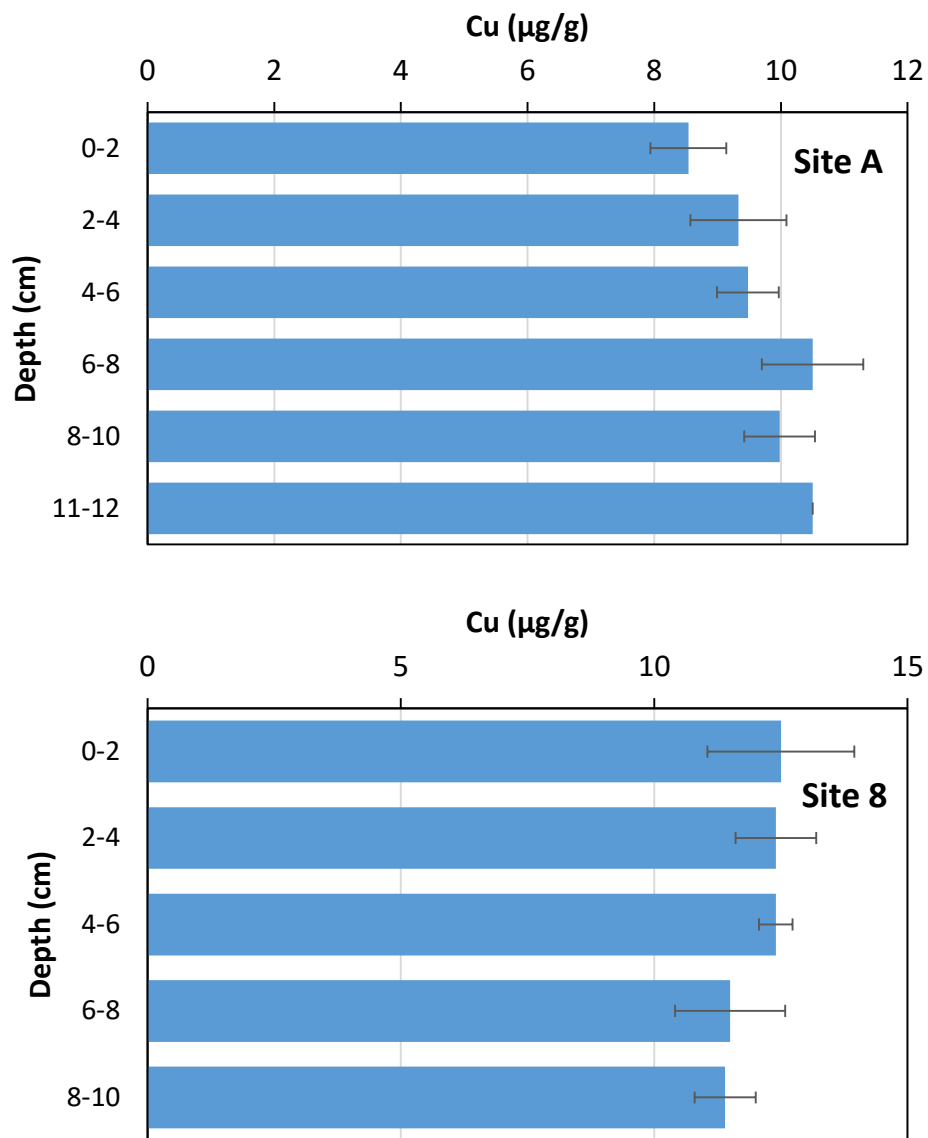


Figure 18: Sediment core profiles: particulate copper at Site A and Site 8 Error bars are the standard deviation of mean core samples (n=3).

Table 8: October 2016 survey: Particulate metal concentrations in benthic sediments

Sample	Location	Type	Core depth	Ag	As	Cd	Cr	Cu	Ni	Pb	Sb	Zn	Hg
			(cm)	(µg/g)									
Site 2	NE TS	C	0-0.3	0.017	1.64	0.042	10.4	1.99	3.64	1.68	0.078	7.53	<0.02
Site 2	NE TS	C	0-3.5	<0.01	1.12	0.03	5.36	0.722	1.43	1.07	0.059	2.65	<0.02
Site 3	NE TS	SS	---	<0.01	0.901	0.124	2.48	0.679	0.687	0.799	0.029	3.75	0.068
Site 3	NE TS	C	0-0.5	0.013	1.15	0.098	4.18	1.64	1.71	1.32	0.051	8.47	<0.02
Site 3	NE TS	C	0.3 - 4.5	<0.01	0.782	0.051	2.67	0.613	0.648	0.718	0.021	3.07	<0.02
Site K	NE TS	SS	---	<0.01	0.787	0.024	2.93	<0.3	0.377	0.309	0.028	<1	<0.02
Site K	NE TS	C	0-0.5	<0.01	0.9	0.018	2.81	0.314	0.45	0.352	0.024	<1	<0.02
Site I	NE TS	SS	---	<0.01	0.576	0.021	2.73	<0.3	0.318	0.347	0.022	<1	<0.02
Site M	NE TS	SS	---	<0.01	0.728	0.018	5.25	<0.3	0.389	0.412	0.032	<1	<0.02
Site N	NE TS	SS	---	0.014	1.83	0.033	8.61	0.791	2.57	0.656	0.032	3.32	<0.02
Site N	NE TS	C	0-3	<0.01	1.67	0.028	8.81	0.805	2.61	0.669	0.036	3.50	<0.02
Site X	NE TS	C	0-3	<0.01	1.86	0.201	6.53	0.853	2.08	0.981	0.084	3.57	0.062
Site J	NE TS	SS	---	<0.01	3.19	0.033	6.01	0.77	1.37	1.25	0.092	1.95	<0.02
Site O	NE TS	C	0-5	<0.01	1.66	0.109	8.64	1.25	2.80	1.29	0.072	5.15	<0.02
Site E	Warrior	SS	---	0.012	1.75	0.039	5.74	1.05	1.85	1.50	0.060	2.95	<0.02
Site G	Warrior	C	0-2	0.02	3.92	0.173	20.5	3.59	7.95	3.70	0.071	16.5	0.092
Site G	Warrior	C	2-4	0.022	3.98	0.042	20.2	3.6	7.67	3.79	0.072	16.1	<0.02
Site G	Warrior	C	4-6	0.019	3.67	0.039	19.8	3.38	7.40	3.66	0.071	15.2	<0.02
Site 1	Warrior	C	0-1	0.015	5.40	0.052	6.11	0.763	1.70	2.74	0.154	2.80	<0.02
Site 1	Warrior	C	1-3	0.013	6.64	0.052	6.89	0.758	1.74	2.96	0.171	2.66	<0.02
Site 1	Warrior	C	3-5	0.012	7.78	0.062	6.96	0.677	1.60	3.07	0.195	2.75	<0.02
Site A	Saibai	C	0-2	0.023	36.8	0.031	24.2	8.54	20.6	13.3	0.222	50.2	0.02
Site A	Saibai	C	2-4	0.024	31.8	0.033	31.5	9.33	22.4	15.1	0.203	54.8	0.017
Site A	Saibai	C	4-6	0.023	27.1	0.024	26.1	9.48	22.2	14.1	0.209	54.2	<0.02
Site A	Saibai	C	6-8	0.026	30.9	0.03	28.7	10.5	23.3	14.5	0.214	57.5	<0.02
Site A	Saibai	C	8-10	0.02	29.8	0.037	26.6	9.98	22.9	15.4	0.216	56.3	<0.02
Site A	Saibai	C	11-12	0.023	24.2	0.03	33.3	10.5	24.3	14.1	0.193	58.7	<0.02
Site 8	Saibai	C	0-2	0.027	10.1	0.052	32.4	12.5	24.2	11.8	0.099	63.2	0.03
Site 8	Saibai	C	2-4	0.023	9.02	0.036	31.8	12.4	23.4	12.0	0.097	61.6	<0.02
Site 8	Saibai	C	4-6	0.022	10.3	0.038	31.7	12.4	23.3	11.7	0.105	61.5	0.024
Site 8	Saibai	C	6-8	0.021	11.1	0.03	26.4	11.5	22.6	11.8	0.098	59.7	<0.02
Site 8	Saibai	C	8-10	0.017	12.0	0.031	31.1	11.4	22.8	12.0	0.115	59.9	<0.02
Site B	south Saibai	SS	---	0.012	32.9	0.075	10	1.79	3.92	8.89	0.514	7.61	<0.02
Site 9	south Saibai	SS	---	0.016	2.23	0.042	7.98	1.42	2.55	1.64	0.090	6.02	<0.02
Site C	SW TS	SS	---	<0.01	3.46	0.059	13.6	1.59	3.65	2.44	0.043	11.9	<0.02
Site C	SW TS	C	0-2	<0.01	3.91	0.166	17.5	2.09	4.81	3.04	0.071	24.7	0.066
Site C	SW TS	C	2-4	<0.01	3.72	0.099	15.3	1.84	4.03	2.88	0.063	11.6	0.053
Site C	SW TS	C	4-6	0.011	5.19	0.094	18.3	2.26	5.43	3.51	0.096	11.1	0.029
Site C	SW TS	C	6-8	<0.01	5.27	0.055	16.6	1.94	4.56	3.28	0.082	10.0	<0.02
Site C	SW TS	C	8-10	<0.01	6.55	0.078	16.4	2.28	4.66	4.01	0.110	19.9	<0.02
Site 10	SW TS	SS	---	<0.01	3.09	0.034	7.02	0.483	1.31	1.33	0.078	2.75	<0.02
Site 10	SW TS	Extra SS	---	<0.01	1.10	0.023	5.18	<0.3	0.83	0.843	0.030	<1	<0.02
Site F	SW TS	C	0-2	<0.01	3.40	0.227	13.9	1.05	3.16	1.77	0.073	4.70	0.12
Site F	SW TS	C	2-4	<0.01	2.86	0.184	15.7	1.19	3.38	1.87	0.071	5.41	0.11
Site F	SW TS	C	4-6	<0.01	2.83	0.15	17.6	1.37	3.77	2.02	0.063	6.13	0.045
Site F	SW TS	C	6-8	<0.01	2.94	0.126	18.6	1.42	4	2.08	0.062	6.54	0.039
Site 11	SW TS	SS	---	<0.01	1.59	0.088	9.31	0.657	2.04	1.39	0.034	3.78	0.026
Site D	SW TS	SS	---	<0.01	7.85	0.088	12.9	0.681	2.45	3.23	0.118	3.14	0.04
Cadel (Masig)	SW TS	SS	---	<0.01	3	0.071	10.6	1.18	3.25	2.27	0.063	7.69	0.028
SQGV				1	20	1.5	80	65	21	50	2	200	0.15
SQGV-high				3.7	70	10	370	270	52	220	25	410	1

Where, C = core, SS = surface scrape

Table 8 (continued): October 2016 survey: particulate metal concentrations in benthic sediments

Sample	Location	Type	Core depth (cm)	Al	Co	Fe	Mn	Mo	U	P	Se	Ca	Mg
(µg/g)													
Site 2	NE TS	C	0-0.3	2850	1.09	3100	54.2	0.129	2.23	305	<0.1	324000	11600
Site 2	NE TS	C	0-3.5	1120	0.382	1180	40.5	0.069	2.19	241	<0.1	363000	11000
Site 3	NE TS	SS	---	487	0.149	445	12.7	0.071	1.38	1140	0.132	333000	18700
Site 3	NE TS	C	0-0.5	1010	0.413	1060	23	0.171	1.99	1510	0.158	310000	17000
Site 3	NE TS	C	0.3 - 4.5	371	0.114	353	13.1	0.068	1.78	951	<0.1	353000	16300
Site K	NE TS	SS	---	189	0.051	167	11.3	0.068	2.69	172	<0.1	331000	9750
Site K	NE TS	C	0-0.5	162	0.05	174	13.6	0.054	2.63	190	<0.1	344000	10800
Site I	NE TS	SS	---	191	0.048	178	8.47	0.071	2.4	197	<0.1	332000	11600
Site M	NE TS	SS	---	167	0.04	211	7.37	0.06	3.75	299	<0.1	333000	11600
Site N	NE TS	SS	---	1360	0.503	1690	25	0.248	2.51	281	0.121	293000	9410
Site N	NE TS	C	0-3	1550	0.522	1710	25.4	0.275	2.58	288	0.126	307000	9430
Site X	NE TS	C	0-3	1520	0.498	1780	31.3	0.151	2.09	302	0.115	308000	10400
Site J	NE TS	SS	---	714	0.342	1510	52.7	0.196	1.69	297	<0.1	292000	14600
Site O	NE TS	C	0-5	2080	0.71	2460	50.5	0.161	2.4	344	<0.1	323000	14400
Site E	Warrior	SS	---	1220	0.449	1920	37.1	0.097	2.01	299	0.135	313000	13500
Site G	Warrior	C	0-2	6130	2.64	7540	123	0.297	2.26	475	0.167	295000	14200
Site G	Warrior	C	2-4	5890	2.6	7570	138	0.336	2.26	480	0.187	296000	14400
Site G	Warrior	C	4-6	6830	2.44	7400	119	0.355	2.23	464	0.154	298000	14600
Site 1	Warrior	C	0-1	1100	0.458	2600	86.4	0.148	1.77	367	0.153	373000	13900
Site 1	Warrior	C	1-3	1180	0.496	2960	91.6	0.153	1.73	364	0.107	370000	14900
Site 1	Warrior	C	3-5	701	0.462	3230	99.8	0.15	1.56	375	<0.1	372000	15300
Site A	Saibai	C	0-2	11800	10.5	33300	401	0.612	0.945	635	0.122	132000	9720
Site A	Saibai	C	2-4	14800	10.9	34400	372	0.524	1.02	621	0.128	115000	10500
Site A	Saibai	C	4-6	13400	10.9	32000	364	0.48	1.11	596	0.126	120000	10400
Site A	Saibai	C	6-8	16100	11.3	33700	362	0.596	1.31	637	0.147	119000	10500
Site A	Saibai	C	8-10	13700	12.7	35200	404	0.607	1.41	647	0.145	122000	10600
Site A	Saibai	C	11-12	23000	11.4	33500	360	0.454	1.14	599	0.128	118000	11100
Site 8	Saibai	C	0-2	19300	10.4	24800	327	0.47	1.08	499	0.155	99900	11300
Site 8	Saibai	C	2-4	17400	10.5	24300	311	0.475	1.24	492	0.171	103000	11400
Site 8	Saibai	C	4-6	18600	10.3	24600	309	0.44	1.35	471	0.149	102000	11000
Site 8	Saibai	C	6-8	12900	10.1	24100	315	0.446	1.28	469	0.149	105000	10900
Site 8	Saibai	C	8-10	18100	10.2	25600	317	0.418	1.36	481	0.164	104000	11300
Site B	South Saibai	SS	---	2080	2.34	10900	343	0.341	1.32	560	0.103	295000	20400
Site 9	South Saibai	SS	---	2140	0.662	2240	36.2	0.295	2.71	324	0.163	238000	9520
Site C	SW TS	SS	---	3750	1.24	4460	89.9	0.223	1.78	603	<0.1	231000	12300
Site C	SW TS	C	0-2	5170	1.58	5370	112	0.284	2.32	1830	0.197	276000	13400
Site C	SW TS	C	2-4	3270	1.38	5020	103	0.333	2.14	653	0.132	266000	13100
Site C	SW TS	C	4-6	4830	1.9	6590	127	0.965	2.32	679	0.135	277000	13100
Site C	SW TS	C	6-8	4210	1.59	5950	169	0.551	2.66	723	0.135	275000	13100
Site C	SW TS	C	8-10	4370	1.66	5940	127	0.57	2.71	1190	0.143	295000	12700
Site 10	SW TS	SS	---	1420	0.35	2410	32.3	0.124	2.07	281	<0.1	311000	9040
Site 10	SW TS	Extra SS	---	1050	0.194	797	16.8	0.063	3.77	254	<0.1	284000	9070
Site F	SW TS	C	0-2	3340	0.821	3710	61	0.685	2.62	643	0.15	291000	13200
Site F	SW TS	C	2-4	3560	0.896	3950	57.3	0.562	2.75	566	0.155	276000	13400
Site F	SW TS	C	4-6	4160	1.05	4170	60	0.581	2.63	463	0.147	276000	14000
Site F	SW TS	C	6-8	4890	1.14	4430	64.2	0.745	2.71	485	0.13	278000	14100
Site 11	SW TS	SS	---	2110	0.581	2450	42.6	0.172	2.25	289	<0.1	295000	9880
Site D	SW TS	SS	---	2990	0.771	4390	128	0.206	1.51	327	0.109	219000	12600
Cadel (Masig)	SW TS	SS	---	2340	0.991	4590	76.5	0.175	1.7	376	0.105	265000	17100

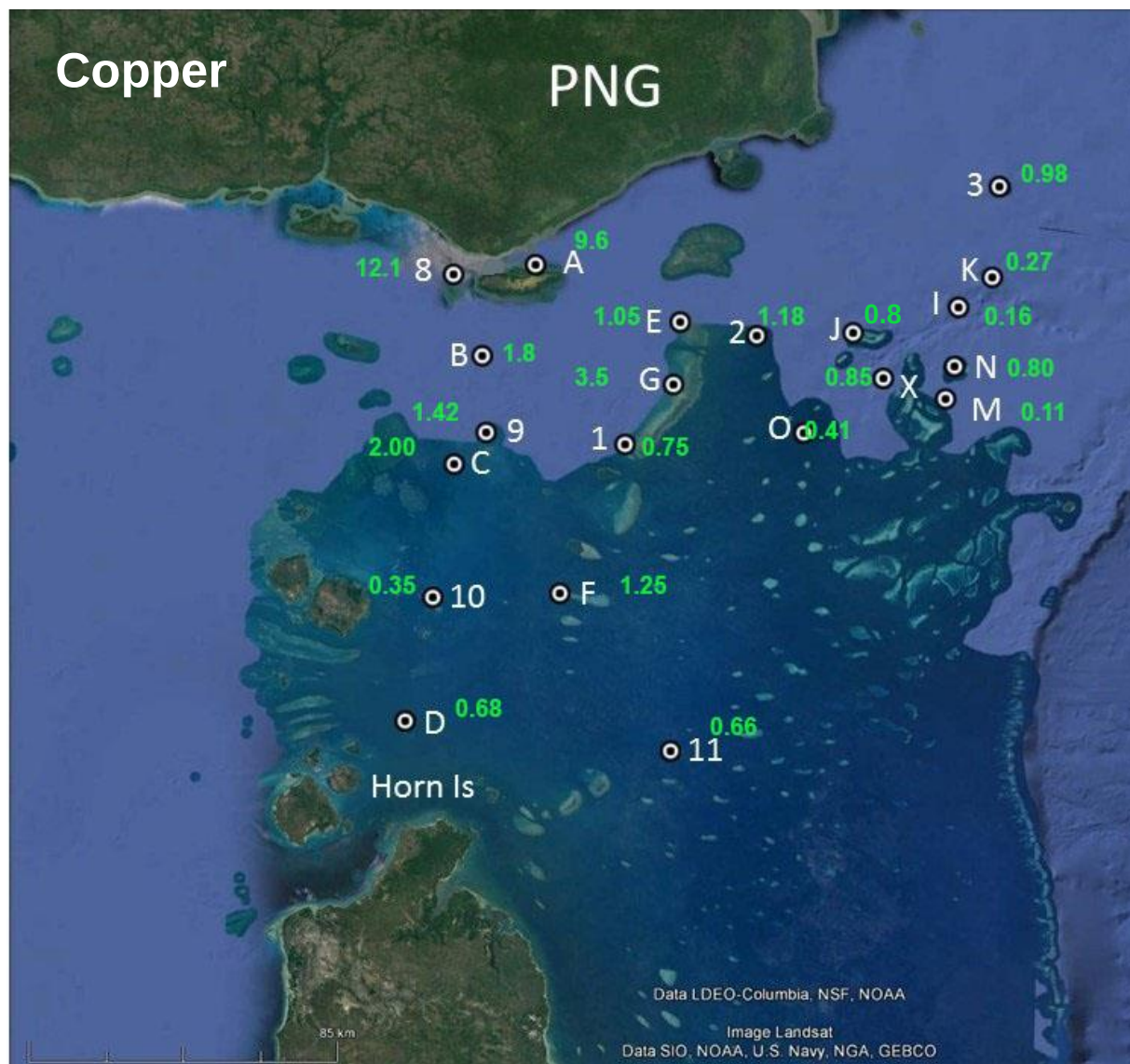


Figure 19: Map showing the distribution of particulate copper concentrations (µg/g) in benthic sediments (October 2016)

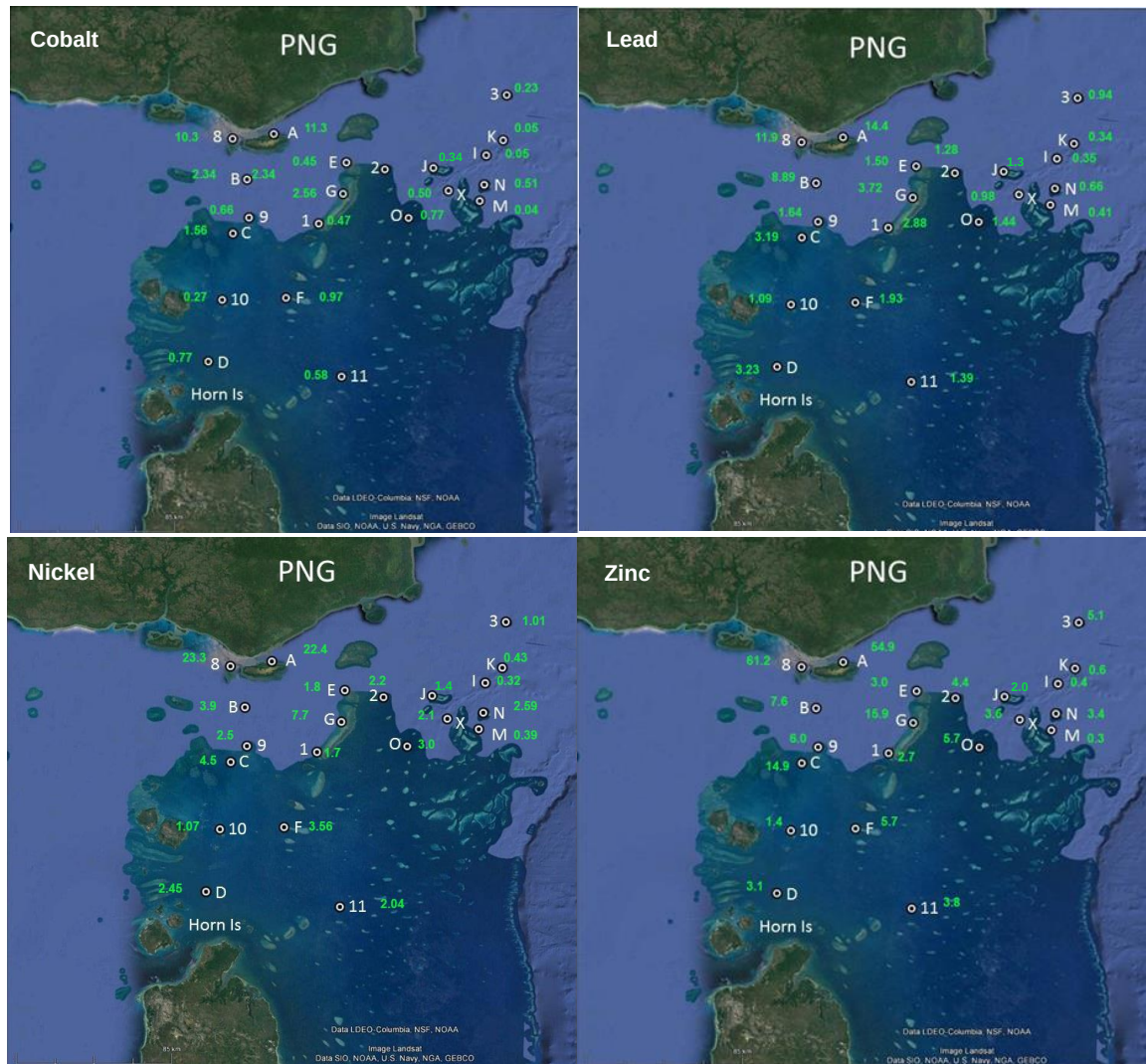


Figure 20: Maps showing the distribution of particulate cobalt, lead, nickel and zinc concentrations ($\mu\text{g/g}$) in benthic sediments (October 2016)

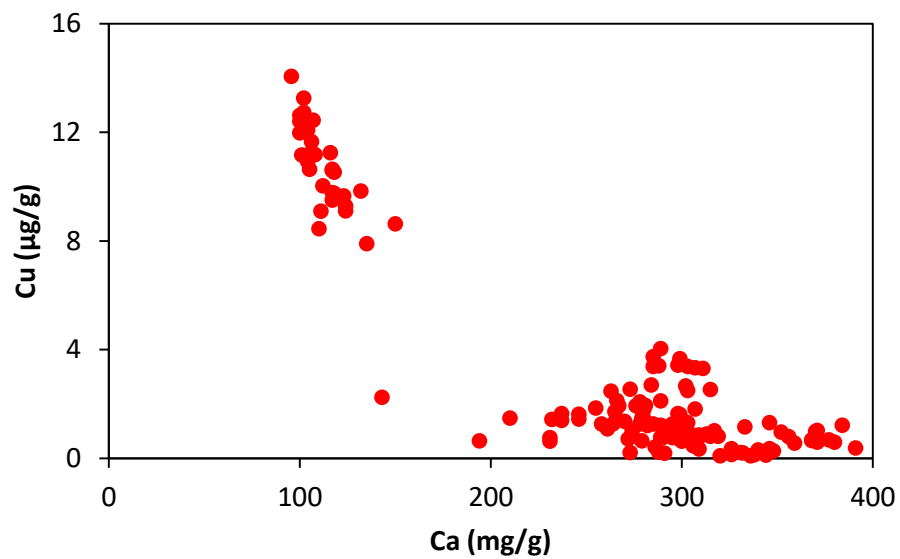


Figure 21: Relationship between particulate copper and calcium in benthic sediments

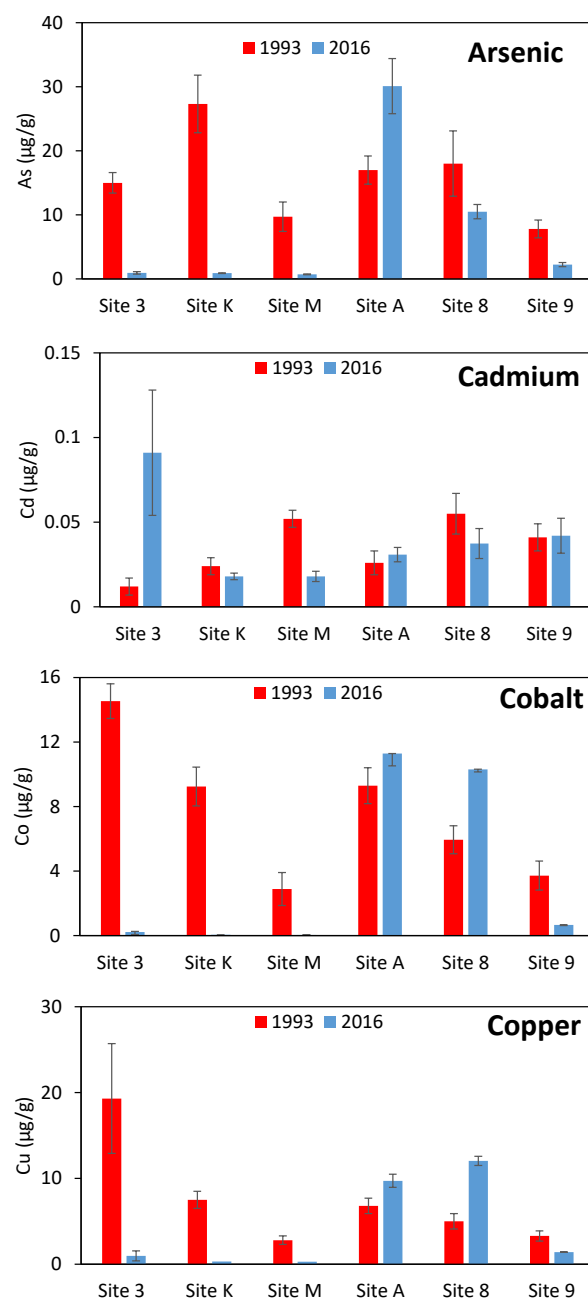


Figure 22: Comparison between the results for benthic particulate metals concentrations measured in this study with the 1993 Torres Strait baseline study

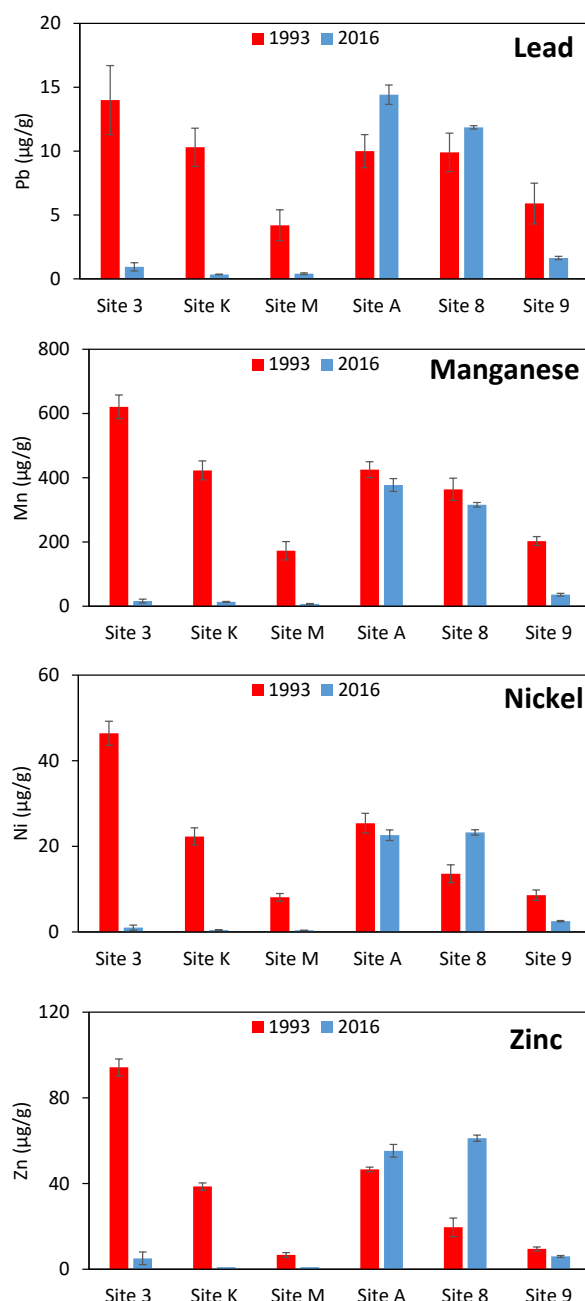


Figure 22 (Contd.): Comparison between the results for benthic particulate metals concentrations measured in this study with the 1993 Torres Strait baseline study

6.2 Boigu and Saibai survey June 2018 results

General water quality parameters are summarised in Table 9. Raw data and QC data for the survey may be found in Appendices 14 to 24. The quality control data were generally excellent. The limits of detection (LOD) were in the low to sub ng/L range for the dissolved metals analysed. Recoveries of metals (dissolved As, Cd, Co, Cu, Ni) in certified reference materials were in the range 83 to 117% (Appendix A18). Spike recoveries were in the range 91-101% (Appendix A19). The dissolved zinc data were subject to contamination (the most likely source was the sacrificial anodes on the patrol boats which are made of zinc) and is not reported. For

metals in suspended sediments, the recoveries of Cd, Co, Cr, Cu, Hg, Ni, Pb, V and Zn in the certified reference sediment CC018 ranged from 93 to 115% (Appendix A24).

Dissolved metal concentration data are summarised in Table 10 and particulate metal concentration data for key elements in Table 11. The data for less common elements in TSS are presented in Appendix A22. The data for TSS, dissolved copper and particulate copper in suspended sediments are also shown in map form in Figures 23, 24 and 25 respectively.

None of the dissolved metal concentrations exceeded the ANZECC/ARMCANZ (2000) 95% species protection WQGVs, however 8 out of the 10 samples collected exceeded the 99% species protection WQGV for copper.

The data from the survey confirmed the presence of elevated metal concentrations in this region. A point source of dissolved or particulate copper or an east to west concentration gradient (indicative of contribution from the Fly River) was not evident from the plots of the data (Figures 24 and 25). It is therefore likely that the elevated copper concentrations reflect a combination of inputs including broad-scale runoff from the PNG land mass and resuspension of terrigenous sediments deposited over geological timescales. Natural enrichment of trace metals (e.g. mineral deposits) in the region may also be possible. Contributions from the Fly River estuary plume, tracking down the coast of PNG cannot be discounted but were not unequivocally identified using conventional geochemical assessment techniques used in this study.

Table 9: June 2018 survey: general water quality parameters

Sample	Depth (m)	pH	Salinity (‰)	TSS (mg/L)	DOC (mg/L)
Saibai sites					
Site A	10.3	8.24	33.6	13.3	0.74
S1	11.1	8.27	33.0	4.0	0.74
S2	7.6	8.27	33.7	6.1	0.72
Site 8	3.6	8.22	33.5	6.9	0.77
S3	12.3	8.26	33.9	7.2	0.71
B3	10.8	8.25	34.4	16.9	1.64
Boigu sites					
B4	5.3	8.24	33.5	15.1	0.95
B5	4.9	8.27	34.2	11.5	0.73
B1	3.4	8.25	34.0	24.9	0.75
B2	5.3	8.25	34.0	14.5	0.69

Table 10: June 2018 survey: dissolved metals data

Location	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb
Saibai Sites	(µg/L)									
A	5.2	1.24	0.0056	0.003	0.16	0.44	0.5	0.19	0.19	0.004
S1	3	1.42	0.005	0.003	0.21	0.36 1	0.4	0.31	0.165	0.007
S2	3.4	1.27	0.0042	0.002	0.24	0.31	0.5	0.2	0.15	0.009
8	4.4	1.31	0.0059	0.006	0.28	0.45	0.5	0.34	0.19	0.005
S3	3.3	1.43	0.0039	0.002	0.27	0.31	0.1	0.16	0.15	0.008
Boigu Sites										
B3	3.5	1.27	0.0045	0.001	0.4	0.37	0.3	0.002	0.17	0.005
B4	3.3	1.35	0.0041	0.006	0.32	0.27	0.6	0.31	0.15	0.005
B5	2.9	1.49	0.0040	0.002	0.25	0.30	0.1	0.08	0.16	0.007
B1	4.7	1.33	0.005	0.013	0.28	0.39	0.4	0.47	0.18	0.018
B2	2.6	1.42	0.0034	0.001	0.27	0.28	0.1	0.04	0.14	0.006
Saibai mean	3.8 6	1.33	0.005	0.003	0.23	0.37	0.40	0.24	0.17	0.007
Boigu mean	3.4 0	1.37	0.004	0.005	0.30	0.32	0.30	0.18	0.16	0.008
Saibai/Boigu ratio	1.1	1.0	1.2	0.7	0.8	1.2	1.3	1.3	1.0	0.8

Table 11: June 2018 survey: particulate metals in suspended sediments data (µg/g)

Location	Al	Fe	Cr	Mn	Ni	Cu	Zn	As
	(µg/g)							
Saibai Sites								
A	211000	33100	32	606	31	25	85	12
S1	17400	25400	19	442	23	16	61	11
S2	14200	22800	39	490	29	18	67	11
8	19700	30600	27	547	28	23	114	13
S3	7600	17700	17	395	16	14	68	10
Boigu Sites								
B3	11600	23600	22	466	22	17	63	10
B4	17400	24600	33	389	24	15	79	11
B5	10600	21700	24	424	20	13	77	12
B1	16300	26300	30	445	24	15	63	12
B2	16200	21890	26	363	22	13	63	10
Saibai mean	16000	26000	27	496	25	19	79	11
Boigu mean	14400	23600	27	418	22	15	69	11
Saibai/Boigu ratio	1.1	1.1	1.0	1.2	1.1	1.3	1.2	1.0



Figure 23: Map showing the distributions of suspended sediments (TSS mg/L) around Boigu and Saibai Islands (June 2018).



Figure 24: Map showing the distributions of dissolved copper concentrations (µg/L) around Boigu and Saibai Islands (June 2018).



Figure 25: Map showing the distributions of particulate copper (µg/g) in suspended sediments around Boigu and Saibai Islands (June 2018)

7. WATER QUALITY: SYNTHESIS

7.1 Comparison of water quality data with other locations

The concentrations of key dissolved trace metals measured in this study are compared to typical concentrations at other locations in Table 12. The metal concentrations in the southern and eastern Torres Strait are consistent with uncontaminated locations. The concentrations of dissolved trace metals found around Boigu and Saibai are higher than that found in other Australian coastal environments, but are far lower than the concentrations observed in contaminated locations such as industrialised harbours.

Table 12: Comparison of dissolved metal concentrations measured in the current study with other locations

Location	Cadmium (ng/L)	Copper (ng/L)	Nickel (ng/L)	Lead (ng/L)	Zinc (ng/L)	References
Saibai/Boigu region (mean)	4.9	389	169	7	56	This study
Torres Strait – south and east (mean)	1.8	130	132	3.8	41	This study
Torres Strait	2.1	199	188	-	-	Apte & Day, 1998
Fly Estuary	18	800	180	10	120	Angel et al., 2014
Uncontaminated locations¹						
southern Great Barrier Reef QLD	<1.5	40	150	<10	40	Angel et al., 2010b
NSW coast (ng/L)	2.5	30	180	10	<22	Apte et al., 1998
Northern Australia coast	2.1	151	116	<2	18	Munksgaard & Parry, 2001
Contaminated locations						
Sydney Harbour	40	932	175	-	3270	Hatje et al., 2003
Humber estuary, UK	80	180	2500	-	3000	Comber et al., 1995
Scheldt estuary, Netherlands	15	750	1000	-	1000	Baeyens et al., 1998
San Francisco Bay estuary, USA	22	315	140	-	160	Sanudo-Wilhelmy et al., 1996

¹The reference location values are the typical dissolved metal concentrations found in waters with salinities >30‰

7.2 Validity of the 99% species protection guideline value for cobalt

A number of water samples collected from around Boigu and Saibai exceeded the ANZECC/ARMCANZ 99% species protection WQGV for cobalt of 5 ng/L. The guideline value, which is rarely used, seemed extremely low relative to other marine water quality guidelines and this triggered an investigation into the accuracy and appropriateness of this value.

The matter was referred to Dr Graeme Batley of CSIRO who was involved in the development of the ANZECC/ARMCANZ 2000 water quality guidelines. His subsequent investigations (G. Batley, personal communication) indicated that the cobalt guidelines are based on inappropriate data and both the 99% and 95% species protection WQGVs are subject to extremely large uncertainties and significantly overestimate the risks posed by cobalt in marine systems. These problems are illustrated in Figure 26, which shows the data set upon which the guideline values were derived. Note the poor model fit to the limited toxicity data and the extremely large uncertainties (which span several orders of magnitude) around the derived WQGVs. The lowest reported no observable effects concentration (NOEC) in the toxicity data set used to derive the Co guideline values was 9000 ng/L which is three orders of magnitude higher than the derived 99% guideline value of 5 ng/L. It was therefore concluded that the current cobalt GVs for marine waters are not fit for purpose. Consequently, exceedances of the stated 99% species protection GVs were disregarded and understanding the impacts of dissolved cobalt on marine ecosystems were not pursued any further in this study.

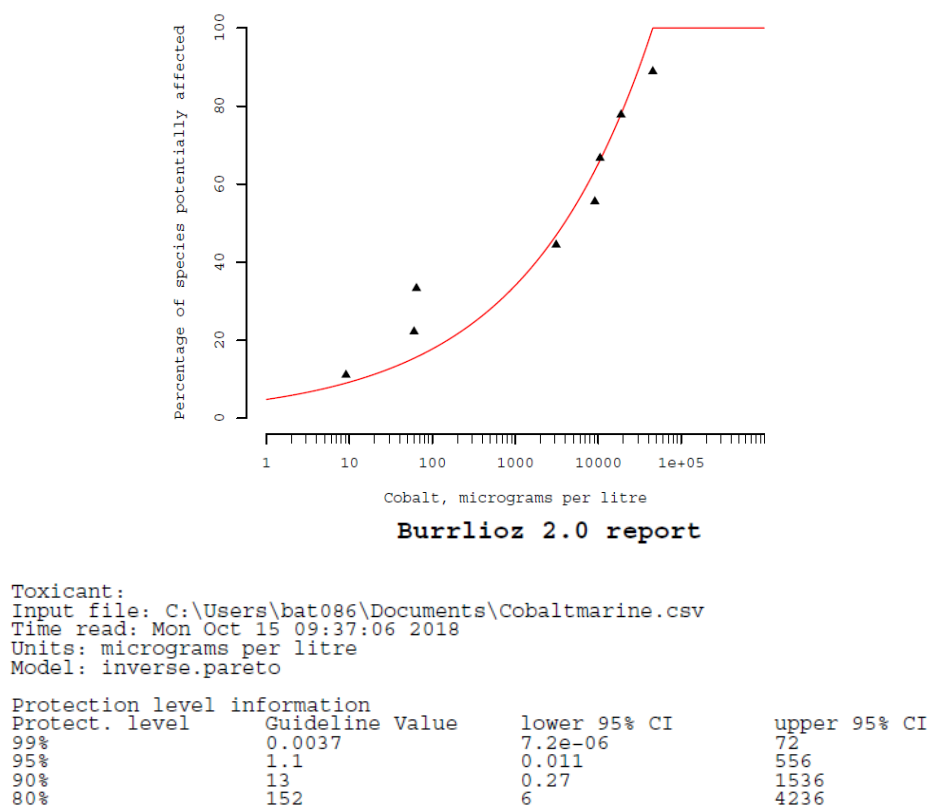


Figure 26: Species sensitivity distribution data upon which the marine cobalt guidelines were derived. Note the poor data fit and extremely large uncertainties around the derived guideline values (data supplied courtesy of G.Batley, CSIRO)

7.3 Spatial distributions and sources of trace metals

As indicated in previous sections of this report, metal concentrations in waters and sediments are generally low across most of the Torres Strait but appear elevated around the Boigu/Saibai region.

The concurrent elevation of metals in both waters, benthic sediments and suspended sediments is illustrated graphically in Figure 27. The relationship between suspended and benthic sediment concentrations is most likely a consequence of frequent sediment resuspension and settling events. The association between dissolved and particulate copper concentrations most likely reflects release of metals from the sediments into solution.

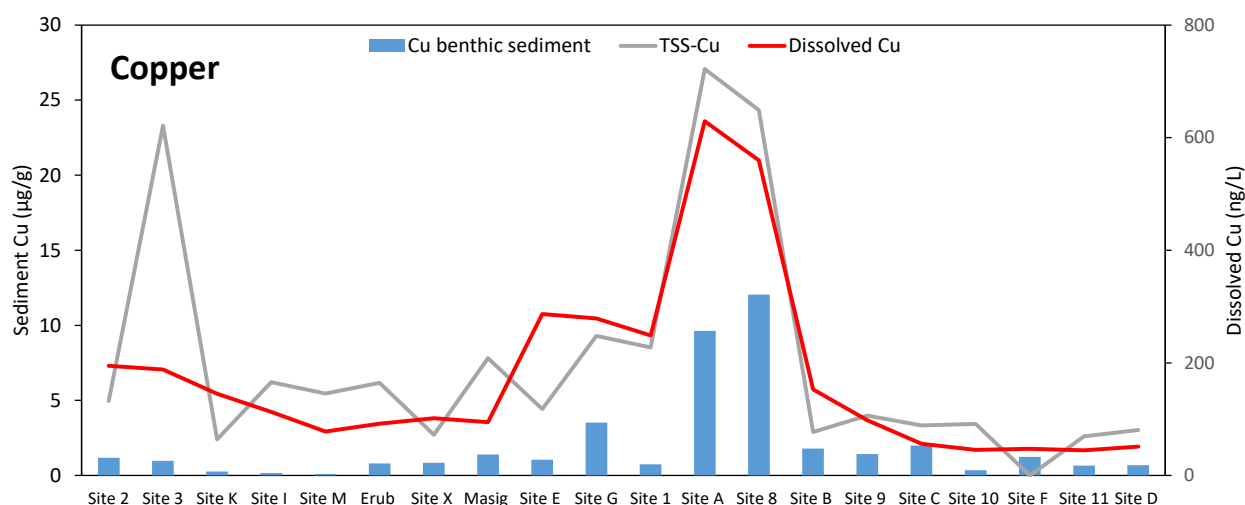


Figure 27: Benthic, suspended and dissolved copper concentrations at the sampling sites

A correlation coefficient matrix (Pearson *r* values) showing the correlations between dissolved metals, TSS, and salinity is shown in Table 13. Strong, statistically significant correlations were measured between dissolved Cu, Cd, Co, Ni and salinity or suspended solids. The results suggest a freshwater source of the metals, and is also consistent with the notion that metals are released into solution from the TSS.

Table 13: Correlation coefficient matrix for dissolved metals, total mercury, TSS and salinity

	TSS	Salinity	pH	Cu	Cd	Co	Ni	Pb	Zn	As
Salinity	-0.607									
pH	0.139	0.088								
Cu	0.820	-0.895	-0.023							
Cd	0.864	-0.727	-0.091	0.921						
Co	0.772	-0.837	-0.032	0.912	0.825					
Ni	0.761	-0.689	-0.185	0.780	0.795	0.824				
Pb	0.550	-0.660	-0.122	0.566	0.451	0.675	0.715			
Zn	0.170	-0.555	-0.086	0.331	0.165	0.505	0.538	0.638		
As	-0.293	0.628	0.011	-0.560	-0.411	-0.449	-0.218	-0.162	-0.360	
Total Hg	0.808	-0.631	-0.024	0.824	0.883	0.646	0.671	0.339	0.075	-0.293

Correlation coefficients >0.8 are marked in bold

In order to probe potential reasons for spatial variations in the concentrations of metals, the relationships between dissolved and particulate forms were investigated further. The mean proportions of metals in the dissolved and particulate forms is shown in Figure 28 for the areas of Saibai (data from sites A and 8, October 2016 survey) and other Torres Strait locations (offshore). At Saibai, which had the highest concentrations of TSS, cadmium and copper were predominantly in the dissolved form, nickel was predominantly bound to TSS, but had a large fraction in the dissolved form, while As, Co, Pb and Zn were almost entirely bound to TSS. For the offshore sites, Cd, Cu, Ni and Zn were predominantly in the dissolved form, cobalt and lead had similar fractions in the dissolved and particulate forms, and arsenic was predominantly bound to TSS.

There are various processes that may be occurring in the northern Torres Strait that may explain the trend in concentrations and partitioning observed in this study. Simple dilution of riverine dissolved and particulate metals by marine waters may result in different trends for different metals depending on the relative difference between concentrations in each end member. The higher concentrations of TSS and most TSS-bound metals at sites with lower salinities indicate that there is a freshwater source of particulates containing higher concentrations of metals than the marine particulates. These particulates undergo sedimentation to varying degrees depending on spatial and temporal variations in hydrodynamic forces, resulting in varying rates of particulate transport from the freshwater source(s) into and around the northern Torres Strait. Temporal variations in the hydrodynamic forces will also result in resuspension and transport of previously deposited particulates. The particulates contain concentrations of metals in both inert and reactive phases. The inert/mineralised fraction will remain in the particulate form, but the reactive metal phases may be released into the dissolved form from suspended particulates, with the rates of release varying for different metals. The extent and rate of metal release from particulates is influenced by factors such as the form of the metals in the particulate phases, the concentration of major anions (e.g. chloride complexation of cadmium), major cations, and dissolved organic carbon (DOC) that can displace metals from particulate forms or form water soluble complexes. Metal release from riverine particulates also counteracts the effects of dilution by seawater resulting in dissolved metal concentrations higher than expected by theoretical dilution calculations.

A key question arising from this work is: what are the main sources of the suspended sediments and how much sediment is derived from the Fly River? As noted earlier, sediments may be of marine origin (high in calcium carbonate, low in most trace metals) or terrigenous origin (high in iron, aluminium and associated trace elements). In addition, there is resuspension of sediments (coupling with benthic sediments) and bioturbation processes which result in the mixing of sediments from different sources. In an attempt to understand the potential contributions of suspended sediments derived from the Fly River estuary, the ratios of copper to various trace elements (Cu/Al, Cu/Fe and Cu/Mn) were examined and compared to data collected for suspended samples from the Fly River estuary (Angel et al., 2014). The data are presented in Figure 29. The ratios of copper to aluminium (Al), iron (Fe) and manganese (Mn) in samples from the Torres Strait are very different for the Fly River estuary sediments. This difference may be explained by mixing of sediments from other origins (e.g. sediment inputs from other rivers or deposited sediments), or release of copper into solution from the sediments which would lower the elemental ratios. Further work is needed to explore these possibilities. Assuming the data from the Fly River estuary is representative of long term

elemental ratios, the comparison suggest little deposition of recent Fly River sediments across the study sites.

A comparison of copper concentrations in the Fly River estuary, Boigu/Saibai and Bramble Cay is shown in Table 14. Note that the concentrations of copper in the Fly River estuary are far higher than observed in the samples from the current study. This indicates significant dilution of Fly River sediments/waters with sediments/water of much lower metal concentrations. This could be achieved by deposition and remobilisation processes which facilitate the mixing of new sediments with older deposits or mixing of the Fly River sediments with sediments introduced from other terrestrial sources.

Table 14: Comparison of copper concentrations around Boigu/Saibai with those in the Fly River Estuary

Site	Dissolved Cu	TSS-Cu	Benthic particulate Cu
	(ng/L)	µg/g	µg/g
Fly River Estuary	800	82	80
Boigu/Saibai	389	17	11
Bramble Cay	188	23.3	1

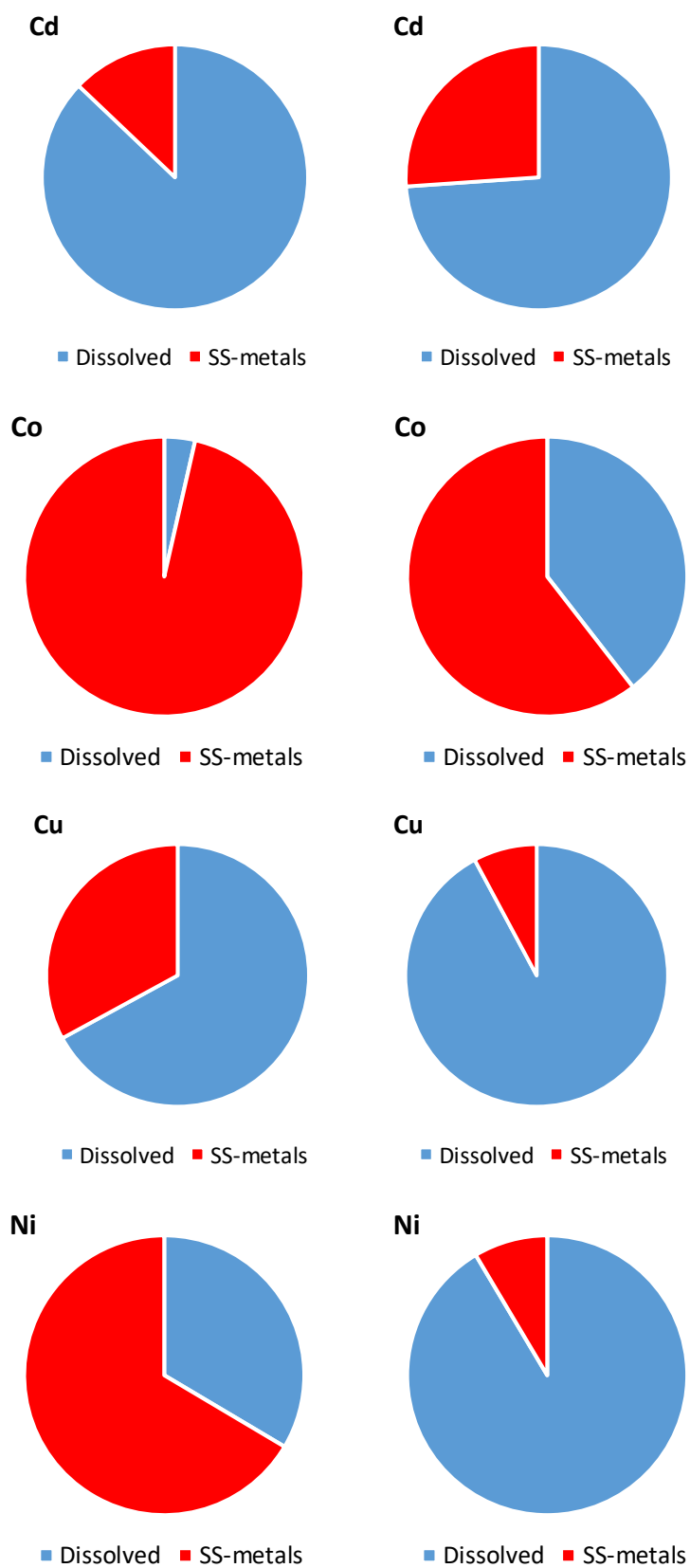


Figure 28: October 2016 survey: the proportion of metals between dissolved and suspended solids (SS) forms at Saibai (left) and offshore (right) sites

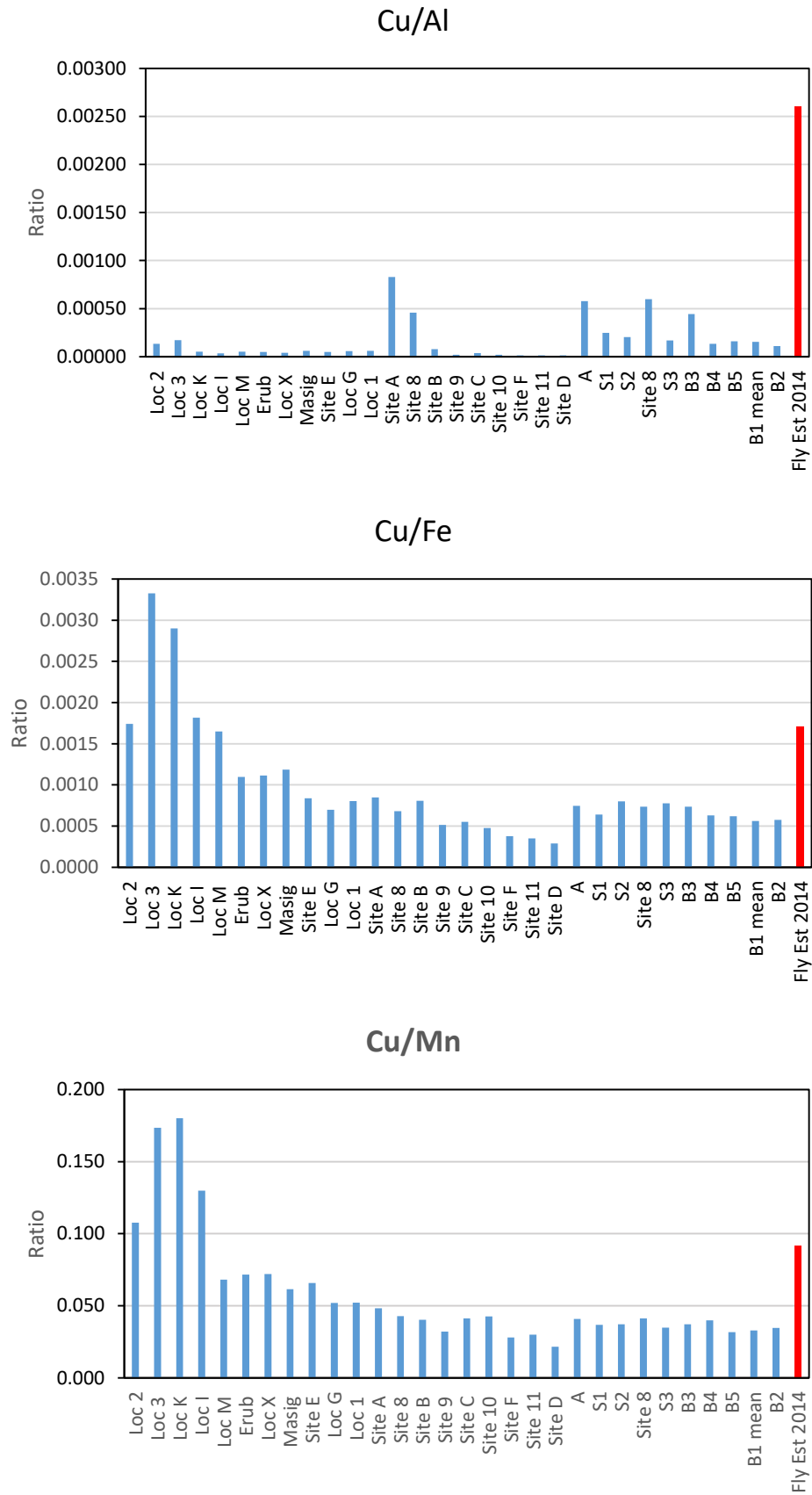


Figure 29: Elemental ratios for suspended sediment samples collected during the October 2016 survey. The bar in red is the mean ratio for the Fly River estuary based on data collected in 2013 by Angel et al. (2014)

8. COMMUNITY SURVEY OUTCOMES

8.1 Saibai Island

8.1.1 Involvement in the survey

In total, 32 community members participated in the survey with equal participation of females and males (Table 15). For females and males, there was representation across six of the eight length of residence categories. No participants had lived on the island for less than a year and some participants had lived on the island for more than 50 years.

Table 15: Numbers and percentages of females and males on Saibai Island participating in the survey across the different categories of the time spent living in the community

Length of residence category	Females		Males	
	Numbers	(%)	Numbers	(%)
Less than a year	0	0	0	0
1-5 years	1	3	0	0
5-10 years	2	6	3	9.5
10-20 years	4	13	2	6
20-30 years	5	16	3	9.5
30-40 years	0	0	3	9.5
40-50 years	2	6	2	6
More than 50 years	2	6	3	9.5
Total	16	50	16	50

8.1.2 State of the marine environment

In the Saibai Island community, the most common view across the participants was that the current condition of their local marine environment was good (Figure 30). The condition of very poor was indicated by one person living in the community for over 50 years. Eight people thought their local marine environment was in very good condition. Three people were not sure about the condition of their local marine environment.

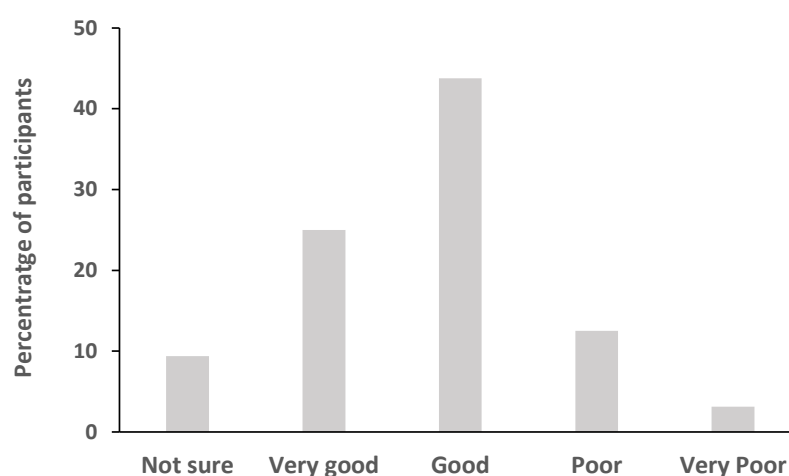


Figure 30: The proportion of participants in the Saibai Island community (Torres Strait, Australia) identifying their view on the condition of their local marine environment from a range of five different categories

Across the Saibai Island participants, the most commonly observed abundance change was that there was lower dugong abundance (Figure 31). Participants also noticed lower turtle abundance but this was not as frequent as lower dugong abundance. More participants saw less turtles and dugongs than more turtles and dugongs. This pattern changed with fish as more participants were likely to see more fish than less fish. Over 10 participants noticed more fish. With changes in the size of animals, there was twice as many participants that did not see any smaller size animals than those that did see smaller size animals. There were two occurrences of people noticing dead fish and four occurrences of people noticing algal blooms. No one listed any change in the colour of fish meat.

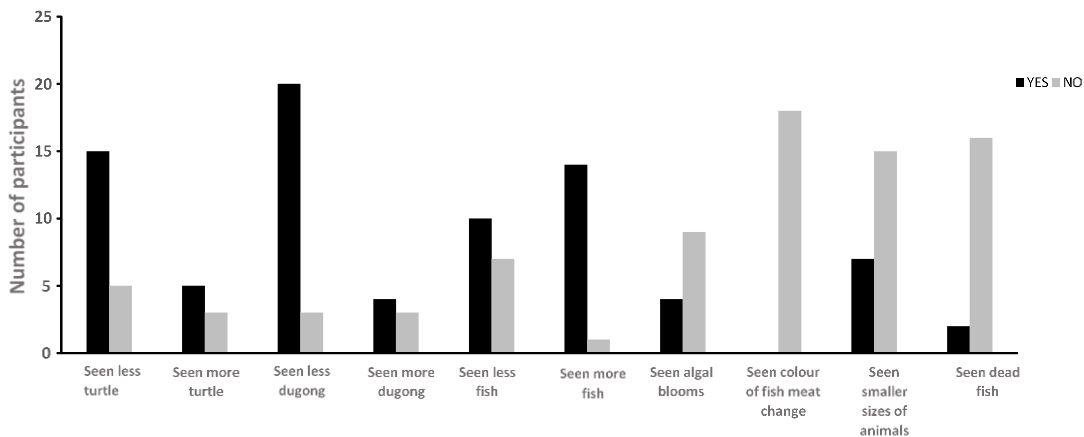


Figure 31: The number of participants in the Saibai Island community that have seen either less or more changes in their local environment and species

8.1.3 Change of muddiness with weather and temporal conditions

More than 75% of the participants indicated that their coastal waters become muddy after changes in weather conditions. Of these participants, more indicated that their coastal waters become muddy after both rainfall and wind (Figure 32).

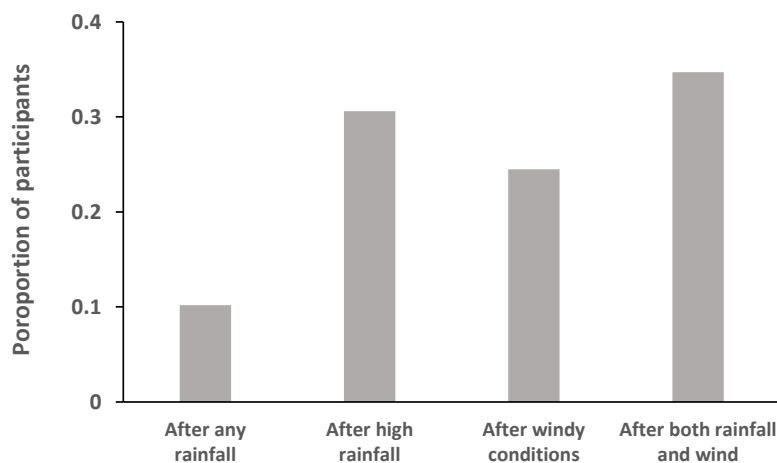


Figure 32: The proportion of participants in the Saibai Island community that noticed their coastal waters becoming muddier after changes in weather conditions

Across the Saibai Island participants, seven were unsure about the length of the time that the coastal waters would be muddy (Figure 33). More than one third of the total participants made comments in the 'other box'. Some commonly occurring comments were that muddiness depends on the time of the year and differences between the north and south of the island where statements were made that it is clear 'out the back of the island'. Fifteen participants indicated that it is always muddy without making any further comments about changes in muddiness.

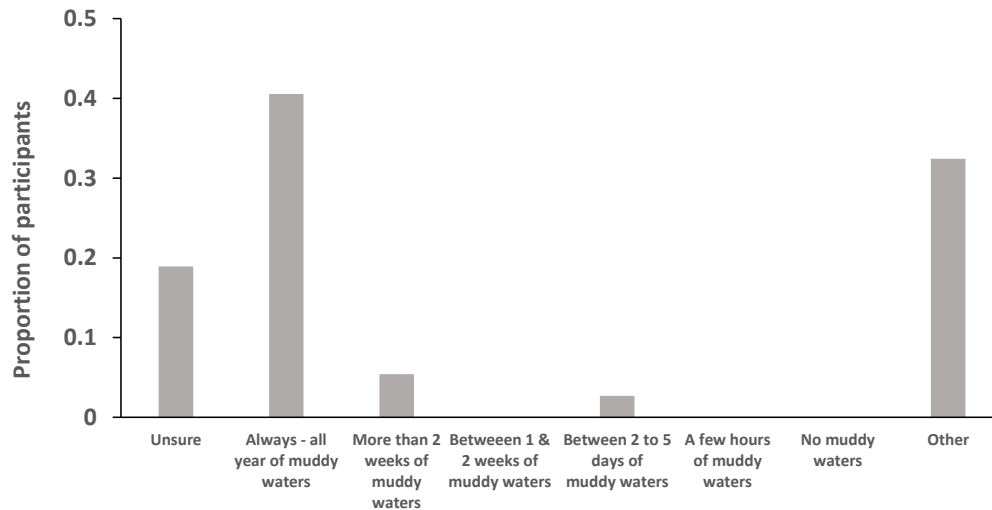


Figure 33: The proportion of participants in the Saibai Island community that have identified the most common length of time their coastal waters would be muddy

Only two people thought that the level of muddiness in the coastal waters around Saibai had become less over the last 5 years (Figure 34). There were equal numbers of participants that thought it stayed the same or had become more muddy.

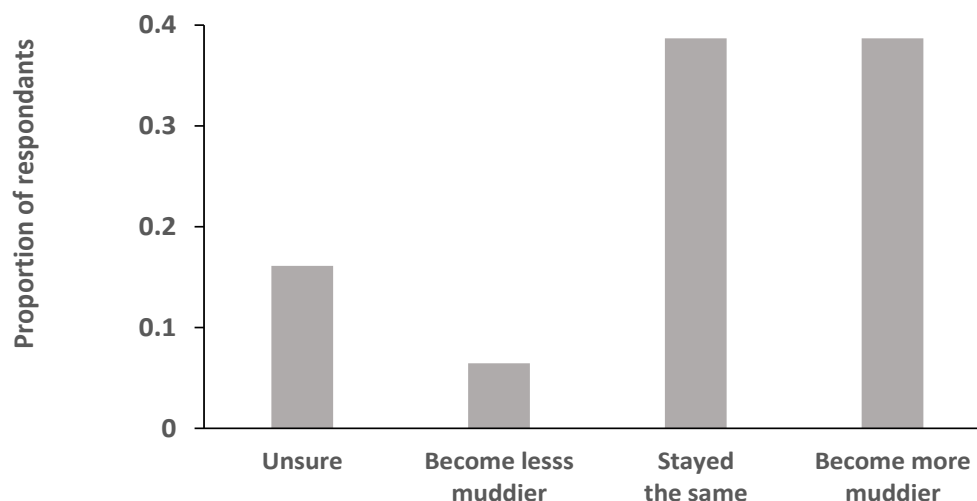


Figure 34: The proportion of participants in the Saibai Island community identifying their view on changes in the level of muddiness in their coastal waters

More participants have identified that they have not seen muddy waters all the way around the island compared to those who had (Figure 35). Some of the participant explanations are provided to give insight into the spread of muddy water around the island (Table 16).

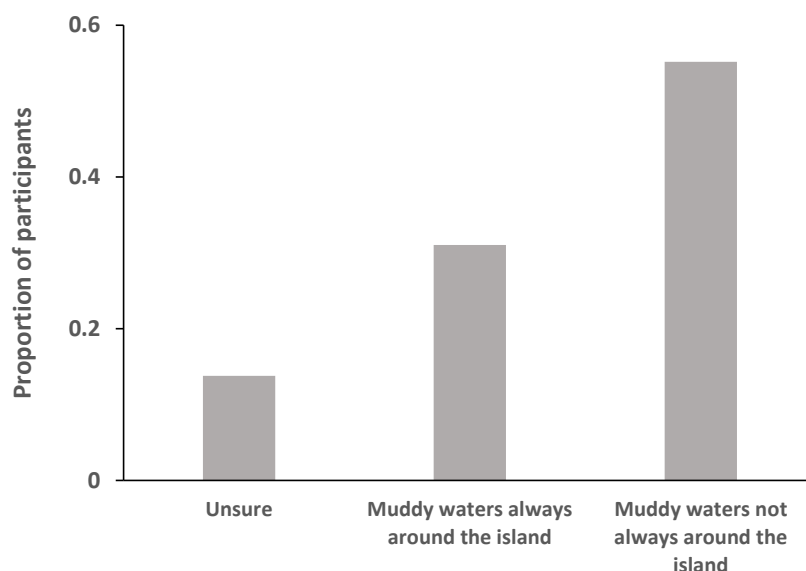


Figure 35: The proportion of participants in the Saibai community identifying their view on muddiness going around their island

Table 16: Explanations provided by some participants about muddy waters extending around Saibai Island

Views	Comment made
1.	"Depends on the weather circumstances. At the back, from my understanding, it always has been clear but muddy water all years around at the front of island"
2.	"The island part facing PNG and north side to the point is muddy. At the moment, April-June is murky at the back of the island as the water can't clear"
3.	"When the northerly wind blows then we don't see muddy waters"
4.	"May is dirty and September comes clear. A distinct line of muddy between PNG waters and Torres Strait waters"
5.	"Clear when its calm, no rain, and during nip tides and strong tides that pushes the muddy waters away"
6.	"Usually we have mud at the front of the village and sand beaches around the island. Lately most of the sand are washed away and huge mud have turn into the mangroves on upper land and towards the sea"

More than double the number of participants thought muddiness changed with season compared to those who thought muddiness was similar across the seasons (Figure 36).

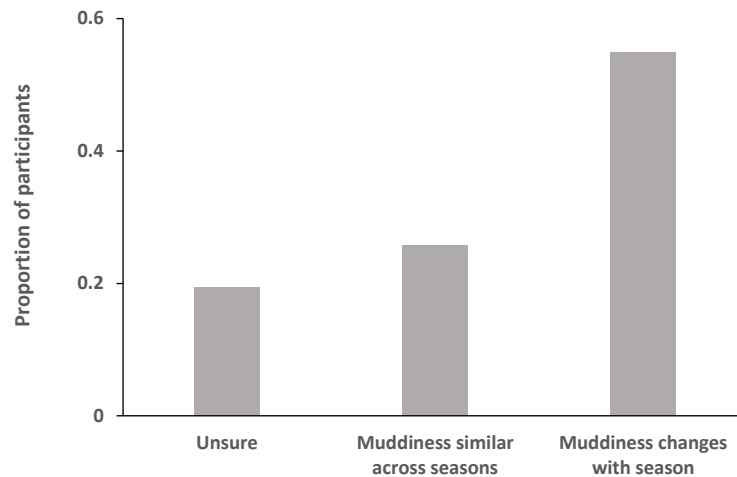


Figure 36: The proportion of participants in the Saibai Island community identifying their view on the muddiness of coastal water changing with season

8.1.4 Colour change in coastal waters

A higher number of participants had never seen colour change in the coastal waters compared to those who had seen colour changes (Figure 37a). Of those participants who had seen colour change, the potential source of the colour change was indicated to be more likely from local runoff from a creek (Figure 37b). Some comments were provided by participants to help explain the colour change (Table 17).

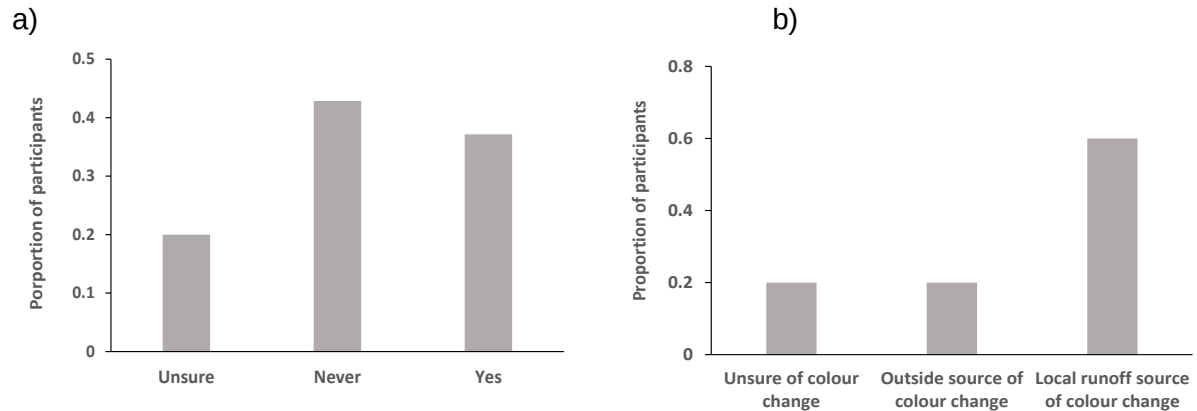
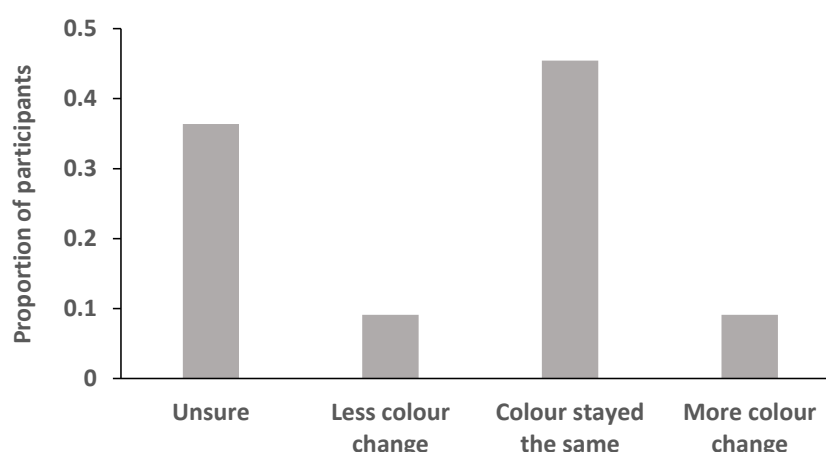


Figure 37: a) The proportion of the participants in the Saibai Island community indicating a change in the colour of their coastal waters b) The proportion of the participants in the Saibai Island community with views on the potential source of colour change in their coastal waters

Table 17: Explanations provided by some participants around the change in the colour of their coastal waters around Saibai Island

Views	Comment made
1.	“Very hard to detect colour change at the front part of the island. But at the back of the island the colour changes from potential creek and rainwater runoff. At the back of the community there is black colour and can notice black colour seawater mixing with freshwater”
2.	“It is kind of difficult to see due to our island having plenty of rivers that run out of the swamps”
3.	“There is rivers and creeks in Papua New Guinea that sometimes see their creek runoff come to the Saibai community”
4.	“Brown water from the culvert drain”
5.	“Colour of water is always the same, get runoff but it is the same colour”
6.	“There is a gradient change in colour. Colour change from swamps and local runoff”

A higher number of participants noticed the colour of their coastal waters had stayed the same since they have been living on the island. Twelve participants were unsure if the colour of their coastal waters had changed in frequency over the years (Figure 38). Three participants noticed more colour change in their coastal waters.

**Figure 38:** The proportion of the participants in the Saibai Island community noticing changes in the frequency of colour changes in their coastal waters

8.2 Boigu Island

8.2.1 Involvement in survey

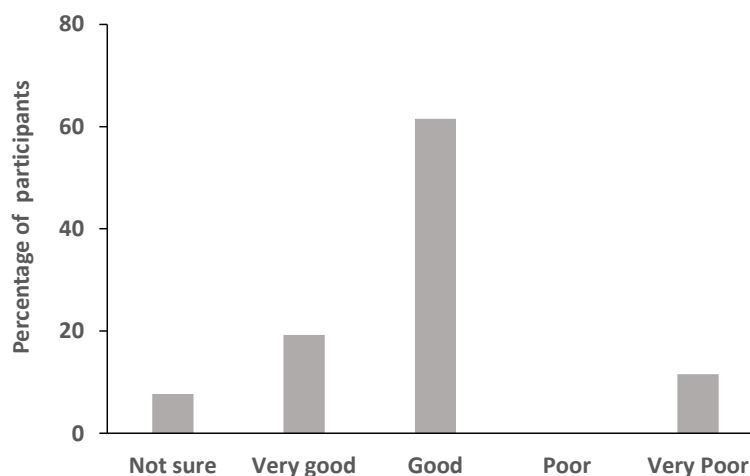
In total, 26 community members (9 females and 17 males) from Boigu Island participated in the survey (Table 18). For females, there was representation across four of the eight length of residence categories. For males, there was representation across six of the eight residence categories. One of the male participants had lived on the island for less than a year. The most frequent length of time living in the community for both female and male participants was more than 50 years.

Table 18: Numbers and percentages of females and males on Boigu Island participating in the survey across the different categories of the time spent living in the community

Time category	Females		Males	
	Numbers	(%)	Numbers	(%)
Less than a year	0	0	1	3.8
1-5 years	0	0	0	0
5-10 years	1	3.8	1	3.8
10-20 years	0	0	3	11.5
20-30 years	2	7.7	2	7.7
30-40 years	1	3.8	1	3.8
40-50 years	0	0	0	0
More than 50 years	5	19.3	9	34.8
Total	9	34.6	17	65.4

8.2.2 State of the marine environment

The most common view across the Boigu participants (16 people) was that the current condition of their local marine environment was good (Figure 39). A further five people living in the community for over 50 years identified their local marine environment was in very good condition. A very poor condition was indicated by only three people living in the community for over 50 years. Two people were not sure about the condition of their local marine environment.

**Figure 39:** The percentage of participants in the Boigu Island community identifying their view on the condition of their local marine environment from a range of five different categories

Across the Boigu Island participants, more had seen more turtle, dugong and fish than less numbers of these species (Figure 40). Algal blooms had been noticed by four participants. No participants had noticed any change in the colour of the fish meat. Two participants had noticed smaller sizes of animals. There were three occurrences of people noticing dead fish .

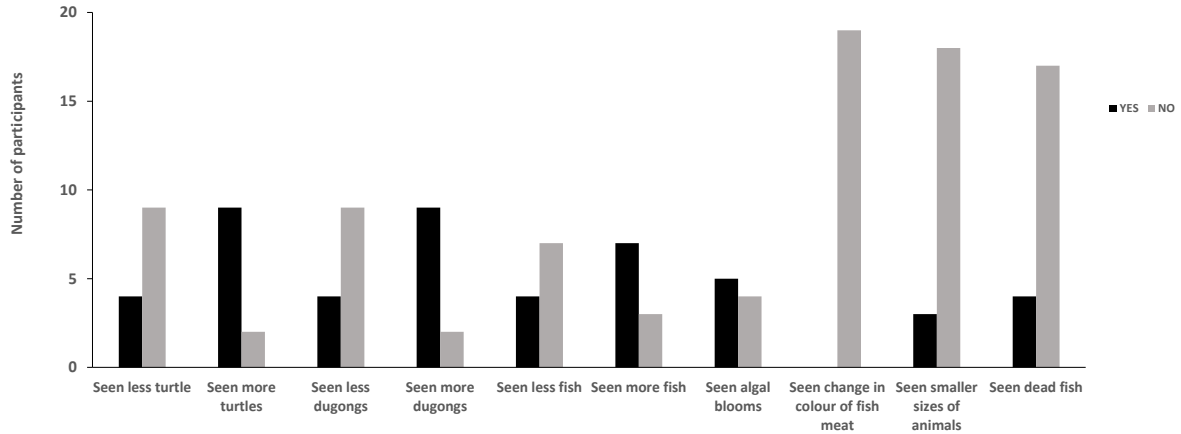


Figure 40: The number of participants in the Boigu Island community that seen either less or more changes in their local environment and species

8.2.3 Change of muddiness with weather and temporal conditions

All participants thought that the muddiness of coastal waters was affected by weather conditions. More than 85% of the participants indicated that their coastal waters become muddy after changes in weather conditions and the remaining 15% of participants were unsure. Of the participants that agreed muddiness is affected by weather condition, more indicated that their coastal waters become muddy after both rainfall and wind rather than solely rainfall and wind (Figure 41).

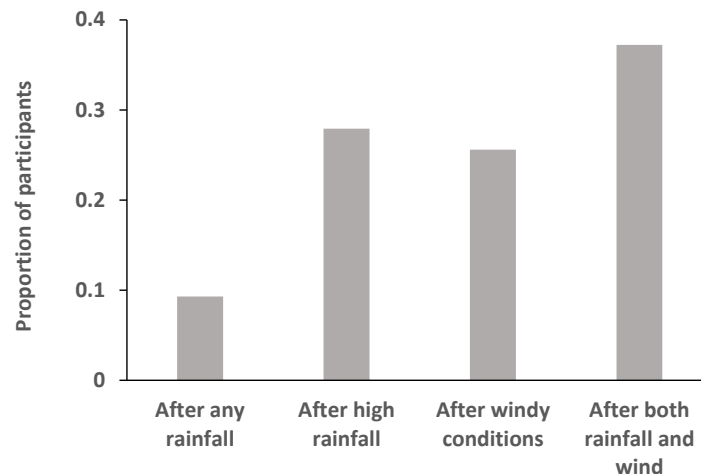


Figure 41: The proportion of participants in the Boigu Island community that noticed their coastal waters becoming muddier after changes in weather conditions

Across the Boigu Island participants, four were unsure about the common length of the time that the coastal waters would be muddy (Figure 42). The highest frequency occurred with participants noticing their coastal waters would always be muddy. One participant noticed only a few hours of muddy waters. More than one third of the total participants made comments in

the 'other box'. The most frequent comment was that participants preferred to write down a percentage rather than select from seven options.

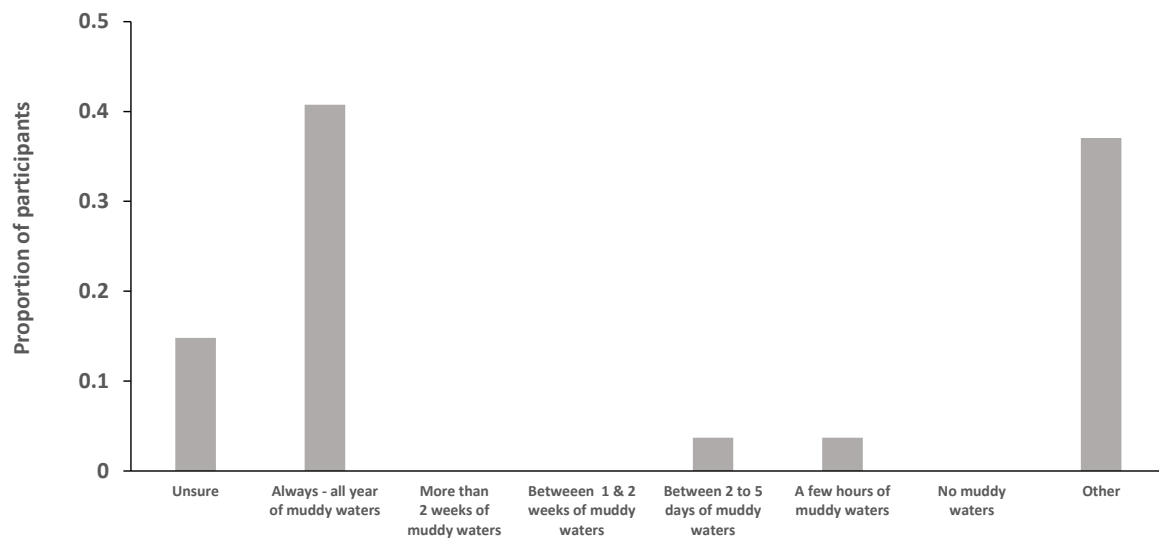


Figure 42: The proportion of participants in the Boigu Island community that have identified the most common length of time their coastal waters would be muddy

Across the Boigu participants, there was nobody who thought that the level of muddiness in the coastal waters around their island had become less (Figure 43). There were more participants that thought their coastal waters had become more muddier than stayed the same.

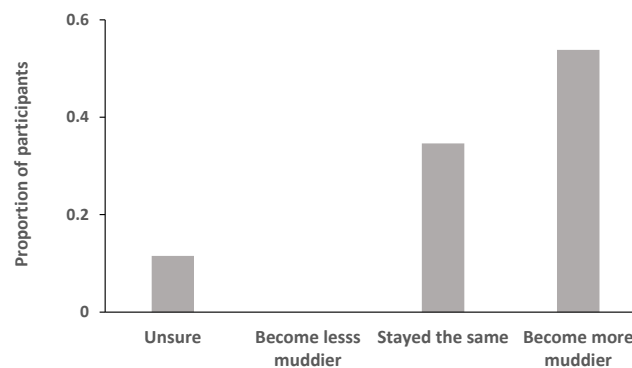


Figure 43: The proportion of participants in the Boigu Island community identifying their view on changes in the level of muddiness in their coastal waters

More participants identified that they have not seen muddy waters all the way around the island compared to those who had. Some of the participant explanations are provided to give insight into the spread of muddy water around the island (Table 19).

Table 19: Explanations provided by some participants about muddy waters extending around Boigu Island

Views	Comment made
1.	"Clearer out the back of the island and muddy out the front"
2.	"The whole island is clear during the doldrum time"
3.	"Muddiness not all the way around the island and depends on season"

More than 75% of participants thought muddiness changed with season compared to those who thought muddiness was similar across the seasons (Figure 44). Three participants were unsure about muddiness changing with season and three participants thought muddiness was similar across the seasons.

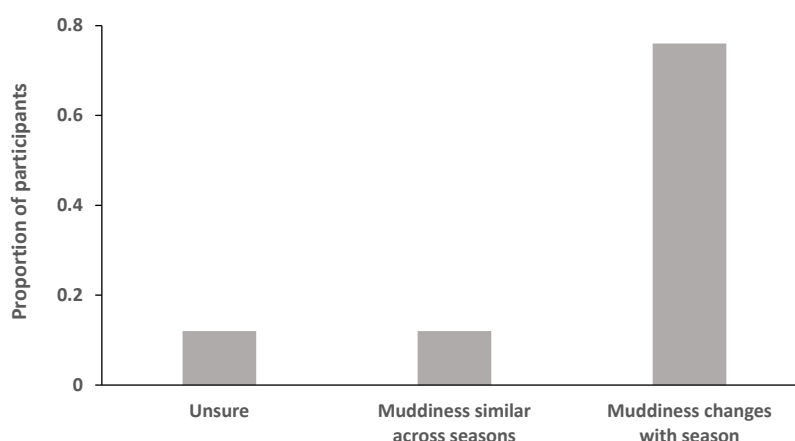


Figure 44: The proportion of participants in the Boigu Island community identifying their view on the muddiness of coastal water changing with season

8.2.4 Colour change in coastal waters

A higher number of participants had seen colour change in the coastal waters compared to those who had not seen colour changes (Figure 45a). Of those participants who had seen colour change, the potential source of the colour change was indicated to be from an outside source and local runoff from a creek (Figure 45b). Some comments were provided by participants to help explain the colour change (Table 20).

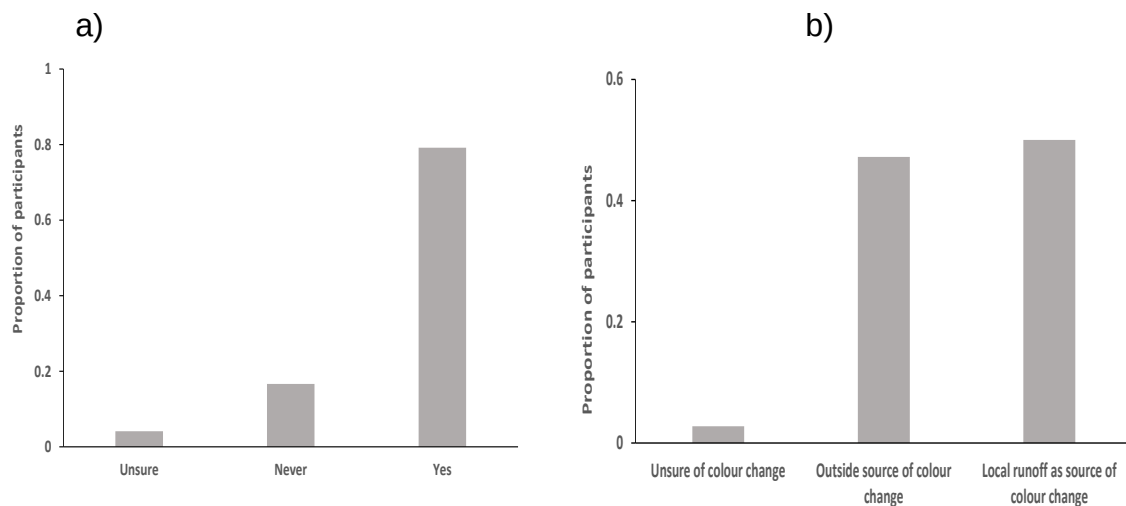


Figure 45: a) The proportion of the participants in the Boigu Island community indicating a change in the colour of their coastal waters. b) The proportion of the participants in the Boigu Island community with views on the potential source of colour change in their coastal waters

Table 20: Explanations provided by participants around the change in the colour of their coastal waters about Boigu Island

Views	Comment made
1.	"Mark between Papua New Guinea and Boigu is where their water and tides meet. This meeting of the tides and waters is the line that is drawn on the treaty map"
2.	"Colour change is from runoff from Papua New Guinea river. Freshwater is brown and during the rain it sits on top. The runoff from PNG doesn't always get across as currents are too strong to bring it across"
3.	"Runoff from PNG stays over on Papua New Guinea side"
4.	"Water from the island street brought in different colour waters"

A higher number of participants noticed the colour of their coastal waters had stayed the same since they have been living on the island (Figure 46). Seven participants were unsure if the colour of their coastal waters had changed in frequency over the years. Nine participants noticed more colour change in their coastal waters.

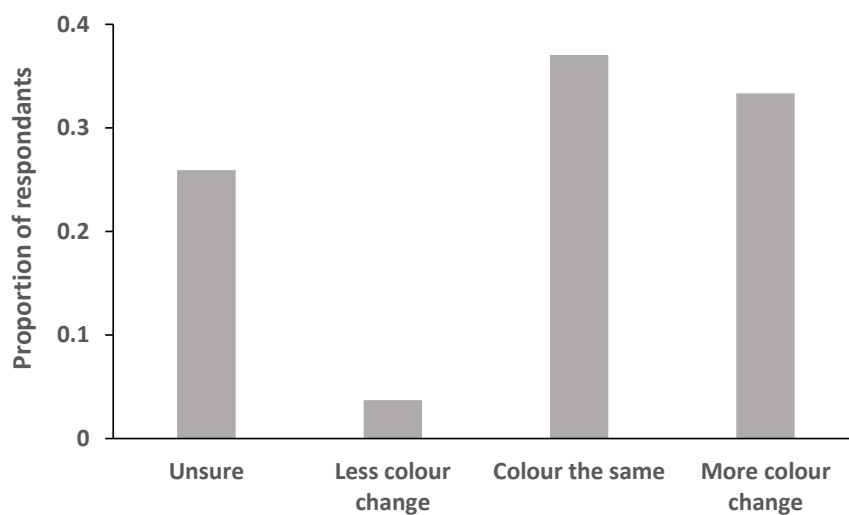


Figure 46: The proportion of the participants in the Boigu Island community noticing changes in the frequency of colour changes in their coastal waters.

9. CONCLUSIONS

1. Data on trace metal distributions in waters, suspended sediments and benthic sediments was generated for 29 sites across the Torres Strait. Trace element concentrations in waters were generally very low and consistent with uncontaminated marine waters from other regions of the world.
2. Trace metal concentrations in waters and sediments were highest in the northern Torres Strait, around Saibai and Boigu islands. The sources of higher concentrations of metals in the north remain to be fully identified. Correlations between suspended sediment and metals indicate that the most likely source of metals are inputs of sediments and waters from PNG. This may include some contributions from the Fly River, but inputs from runoff from other river systems on the PNG mainland cannot be discounted. Contributions from mine-derived sediments are possible but not proven.
3. The concentrations of dissolved copper and cobalt were below the 95% species protection guideline values of the Australian and New Zealand water quality guidelines (ANZECC/ARMCANZ 2000) which are used by regulators in most areas of Australia as default regulatory benchmarks. Dissolved copper concentrations exceeded the 99% species protection guideline values in ten water samples collected in the vicinity of Boigu and Saibai Islands. Dissolved cobalt concentrations exceeded the 99% protection guideline value in five water samples collected in the vicinity of Boigu and Saibai Islands. A subsequent investigation of the cobalt marine guidelines indicated that they are based on inappropriate data and overestimate the risks posed by cobalt in marine systems. Exceedance of the 99% protection guideline value for cobalt can therefore be disregarded.
4. Total mercury concentrations in unfiltered water samples ranged from 0.11 to 0.88 ng/L (0.5 to 4.4 pM) with the highest concentrations being found around Saibai Island. To the best of our knowledge, this is the first total mercury data set generated for tropical Australian coastal waters, obtained using state-of-the-art analytical procedures. If the samples from around Saibai Island are not included on the grounds that their mercury concentrations are associated with the high suspended sediment load, the mean total mercury concentration for the Torres Strait was 0.31 ± 0.2 ng/L (1.5 ± 1.0 pM). This compares to typical open ocean concentrations for upper layer oceanic waters of 0.4 to 2.0 pM which is consistent with our data set. It should be noted that coastal waters will contain more suspended sediments than found in the open ocean and therefore, are more likely to support higher total mercury concentrations. Overall, this data set indicates that mercury concentrations in the waters of the Torres Strait are very low and are representative of uncontaminated marine waters.
5. Metal concentrations in sediments were generally very low. Metal concentrations in benthic sediments were below ANZECC/ARMCANZ guideline values, apart from particulate arsenic and nickel in two sediment cores collected close to Saibai Island. These higher arsenic and nickel concentrations are most likely due to natural background mineral enrichment in the area rather than any anthropogenic contamination.
6. Community members on Saibai and Boigu islands who participated in the community survey identified that the muddiness of coastal waters changed with weather, temporal and spatial conditions. Similar comments were made from participants on both Islands about

muddiness depending on the time of the year and spatial differences arising in the muddiness between the back and front of the island communities.

7. Across all of the community survey participants, only two identified that the level of muddiness in the coastal waters had become less with more participants indicating muddiness had increased. Some differences occurred in the responses between Saibai and Boigu Islands around changes in species abundance and the potential source of colour change in coastal waters. On Saibai, some participants identified less abundance of turtles and dugongs, whereas on Boigu, participants identified a greater abundance of turtles and dugongs. On Saibai, more participants identified that the potential source of the colour change in coastal waters was more likely from local creek runoff rather than an outside source, whereas on Boigu, colour change from an outside source was identified nearly as frequently as local creek runoff. This response is consistent with the presence of the mouth of a large river across from Boigu (Mai Kussa River) that drains the PNG mainland.
8. Most of the community interview questions were addressed by participants. The question that generated the highest 'unsure' response was in relation to whether the colour of coastal waters had changed in frequency over the years. This indicated that in future community interviews, there needs to be additional explanation about the frequency in change. Also, the survey question around the length of time that coastal waters would be muddy should be refined and modified to include percentage of time rather than categories of time as some participants preferred to state a percentage. Providing the community members with the opportunity to provide further details and comments, allowed more insight into the dynamics of the muddiness of coastal waters and the link this has with sea country, people, cultural practices and wellbeing.

10. RECOMMENDATIONS

(a) Development of methods for tracing mine-derived sediments in the Torres Strait

A mine-derived sediment tracing technique should be developed which enables the detection of mine-derived sediments originating from the Ok Tedi mine in suspended and benthic sediments of the Torres Strait. This development may be possible through the application of a combination of particle separation, microscopic examination and elemental analysis techniques. The developed method should then be applied to both benthic and suspended sediment samples collected in the field campaigns described below. This information will allow us to gain an understanding of current mine-derived sediment transport across the Torres Strait. The method could also be applied to archived sediment cores collected during our first NESP TWQ Hub project in the Torres Strait.

(b) Understanding the factors governing trace metal distributions around Saibai and Boigu

Further work is required to understand the distributions of trace metals in the northern Torres Strait, particularly around Boigu and Saibai islands and how they vary with time. This is best achieved by regular monitoring to understand seasonal trends in metal concentrations supplemented by event-related sampling (e.g. when there are large freshwater flows from the Fly River Estuary).

(c) Characterising trace metal distributions in the northern Torres Strait

An intensive sampling campaign involving taking water and sediment samples along a transect running approximately from Daru in PNG (close to the mouth of the Fly River Estuary) to the NW edge of the Torres Strait should be undertaken. This would provide information on the sources of trace metals to the northern Torres Strait and the relative importance of mine-derived contributions.

(d) Characterising trace metal distributions in the Torres Strait region

Trace metal concentrations in waters and sediments are unlikely to change rapidly in the Torres Strait as a whole. It is therefore recommended that trace metals concentrations are measured at locations across the Torres Strait every 5 to 10 years. This should be sufficient for regulatory monitoring purposes.

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APPENDIX A: ANALYTICAL QUALITY CONTROL DATA

Appendix A1: 2016 survey – metals in waters QC data

Sample	As	Cd	Co	Cu	Total Hg	Ni	Pb	Zn
	(µg/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)
Limit of detection (3σ)	0.08	0.2	0.3	2.1	0.015	3.0	0.8	1.7
CRM analysis								
BCR-579	-	-	-	-	2.007	-	-	-
Certified Value (ng/kg)	-	-	-	-	1.9 ± 0.5	-	-	-
Recovery (%)	-	-	-	-	106	-	-	-
NASS-6	1.31	0.030	0.014	0.242	-	0.308	0.0050	0.242
Certified (µg/L)	1.43±0.12	0.0311 ± 0.0019	0.015	0.248 ± 0.025	-	0.301 ± 0.025	0.006 ± 0.002	0.257 ± 0.020
Recovery (%)	92	95	95	98	-	102	83	94
Spike recoveries (%)								
Site 5	-	-	-	-	105	-	-	-
Site B	-	-	-	-	103	-	-	-
Site D	-	-	-	-	103	-	-	-
Site 1	109	-	-	-	-	-	-	-
Site N duplicate	110	-	-	-	-	-	-	-
Site C	88	-	-	-	-	-	-	-
Site 1	-	105	101	102	-	101	110	100
Site N	-	96	97	97	-	97	98	93
Site O duplicate	-	98	97	88	-	95	98	93
Site 3	-	98	100	101	-	97	99	97
Site O duplicate	-	98	98	99	-	98	98	96
Site 8	-	96	95	95	-	94	97	96
Site B	-	103	100	101	-	100	109	91
Site 10	-	97	97	97	-	95	98	80

Appendix A2: 2016 survey TSS and total mercury in waters laboratory replicate measurements

Sample	TSS	Total Hg
	(mg/L)	(ng/L)
Site I	-	0.106
Site I replicate 2	-	0.121
Site I replicate 3	-	0.121
Site I mean	-	0.116
Site O	0.61	1.35
Site O replicate 2	0.77	1.31
Site O replicate 3	-	1.31
Site O mean	0.69	1.32
Site O site duplicate Hg	-	0.401
Site O site duplicate replicate 2	-	0.242
Site O site duplicate replicate 3	-	0.242
Site O site duplicate mean	-	0.295
Site 8	-	0.768
Site 8 replicate 2	-	0.793
Site 8 replicate 3	-	0.768
Site 8 replicate 4	-	0.793
Site 8 mean	-	0.780
Site A	11.4	1.21
Site A replicate 2	10.9	0.656
Site A replicate 3	-	1.21
Site A replicate 4	-	0.656
Site A mean	11.2	0.932
Site B	-	0.191
Site B replicate 2	-	0.191
Site B mean	-	0.191
Site 9	-	2.33
Site 9 replicate 2	-	0.164
Site 9 replicate 3	-	2.33
Site 9 replicate 4	-	0.164
Site 9 mean	-	1.25
Site C	-	0.235
Site C replicate 2	-	0.235
Site C mean	-	0.235
Site 10	-	1.26
Site 10 replicate 2	-	1.11
Site 10 replicate 3	-	1.26
Site 10 replicate 4	-	1.11
Site 10 mean	-	1.18
Site F	-	0.188
Site F replicate 2	-	0.188
Site F mean	-	0.188
Site 11	-	0.215
Site 11 replicate 2	-	0.215
Site 11 mean	-	0.215
Site D	-	0.388
Site D replicate 2	-	0.388
Site D mean	-	0.388

Appendix A3: 2016 survey - metals in waters laboratory duplicates

Sample	As (µg/L)	Cd (ng/L)	Co (ng/L)	Cu (ng/L)	Ni (ng/L)	Pb (ng/L)	Zn (ng/L)
Site 1	1.46	-	-	-	-	-	-
Site 1	1.39	-	-	-	-	-	-
Site 1 mean	1.43	-	-	-	-	-	-
Site N duplicate	1.50	-	-	-	-	-	-
Site N duplicate replicate	1.48	-	-	-	-	-	-
Site N duplicate mean	1.49	-	-	-	-	-	-
Site C	1.49	-	-	-	-	-	-
Site C	1.37	-	-	-	-	-	-
Site C mean	1.43	-	-	-	-	-	-
Site N	-	1.3	2.2	98	123	1.6	20
Site N duplicate	-	1.9	2.1	99	129	2.2	123
Site N duplicate mean	-	1.6	2.1	98	126	1.9	71
Site B	-	2.3	2.9	153	130	8.7	25.9
Site B duplicate	-	2.2	3.1	153	129	8.5	26.8
Site B mean	-	2.2	3.0	153	129	8.6	26.3
Site C	-	1.3	1.2	57	129	3.9	17
Site C duplicate	-	1.5	1.4	56	132	3.8	21
Site C mean	-	1.4	1.3	56	130	3.8	19
Site 11	-	1.2	1.2	45	128	2.5	20
Site 11 duplicate	-	1.2	0.9	44	126	2.6	18
Site 11 mean	-	1.2	1.0	45	127	2.5	19
Site 1	-	3.6	9.8	279	159	14.1	128
Site 1 duplicate	-	3.1	9.6	269	156	11.1	137
Site 1 mean	-	3.4	9.7	274	157	12.6	132
Site 9	-	1.8	8.7	111	147	9.7	50
Site 9 duplicate	-	1.9	7.5	106	149	9.8	49
Site 9 mean	-	1.8	8.1	108	148	9.8	49
Site C	-	1.6	3.1	64	138	5.5	24
Site C duplicate	-	1.7	3.0	60	142	5.6	89
Site C total mean	-	1.6	3.1	62	140	5.6	57

Appendix A4: 2016 survey - field blank data for metal in waters

Sample	As	Cd	Co	Cu	Total Hg	Ni	Pb	Zn
	(µg/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)
Field blank MQ water A	<0.08	<0.2	<0.3	<2.1	0.064	<3.0	<0.8	4.4
Field blank MQ water B	<0.08	<0.2	<0.3	<2.1	-	<3.0	<0.8	2.1
Field blank (Site M) filtered	<0.08	1.0	0.8	<2.1	-	3.1	3.1	108
Field blank (Site O) filtered	<0.08	<0.2	0.6	<2.1	<0.015	<3.0	<0.8	58
Field blank (Site 8) filtered	<0.08	<0.2	<0.3	<2.1	0.107	<3.0	<0.8	23
Field blank (Site O) unfiltered	<0.08	<0.2	<0.3	<2.1	0.089	<3.0	<0.8	4.7
Field blank (Site M) unfiltered	<0.08	<0.2	<0.3	<2.1	-	<3.0	<0.8	18
Field blank (Site 8) unfiltered	<0.08	<0.2	<0.3	<2.1	-	<3.0	<0.8	2.5

Appendix A5: 2016 survey - site duplicates for dissolved metals

Sample	As	Cd	Co	Cu	Ni	Pb	Zn
	(µg/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)
Site N	1.43	1.3	1.6	92	122	2.1	23
Site N duplicate	1.49	1.6	2.1	98	126	1.9	71
Site N Mean	1.46	1.5	1.9	95	124	2.0	47
Site O	1.47	0.9	1.3	95	125	2.1	34
Site O duplicate	1.37	4.1	1.6	91	126	2.7	37
Site O Mean	1.42	2.5	1.5	93	126	2.4	35
Site A	1.33	7.0	5.7	608	178	9.0	38
Site A site duplicate	1.36	6.7	5.9	650	190	6.6	54
Site A Mean	1.35	6.8	5.8	629	184	7.8	46

Appendix A6: 2016 survey - total mercury in waters: site duplicates

Sample	Hg
	(ng/L)
Site N	0.15
Site N, duplicate	0.35
Site N Mean	0.25
Site O	1.35
Site O, duplicate	0.40
Site O Mean	0.88
Site A	0.88
Site A, duplicate	1.21
Site A Mean	1.05

Appendix A7: 2016 survey - TSS metal concentrations (other elements)

Sample	Location	Bi	Cs	Dy	Er	Eu	Gd	Gd	Hf	Ho	In	Ir	La	Lu	Nb
		(µg/g)													
Site 2	NE TS	0.02	<1.06	0.17	0.06	0.06	0.23	0.23	<0.09	0.06	<0.01	<0.02	0.97	0.01	<3.8
Site 3	NE TS	0.07	<3.94	0.46	0.27	0.18	0.67	0.67	<0.35	0.09	<0.03	<0.09	1.88	<0.02	<14.3
Site K	NE TS	<0.01	<0.8	0.09	0.03	0.02	0.11	0.11	<0.07	0.03	<0.01	<0.02	0.29	0.01	<2.9
Site I	NE TS	<0.04	<3.17	0.33	0.19	0.1	0.44	0.44	<0.28	0.08	<0.02	<0.07	1.24	0.02	<11.5
Site M	NE TS	<0.07	<5	0.21	0.13	0.06	0.25	0.25	<0.45	<0.03	<0.03	<0.11	1	<0.03	<18.2
Site N	NE TS	<0.05	<3.99	0.37	0.205	0.15	0.475	0.475	<0.36	0.075	<0.03	<0.09	1.78	0.04	<14.5
Site X	NE TS	<0.01	<0.95	0.18	0.1	0.07	0.32	0.32	0.16	0.04	<0.01	<0.02	0.89	0.01	<3.5
Site J	NE TS	<0.02	<1.35	<0.01	<0.01	0.01	<0.03	<0.03	<0.12	<0.01	<0.01	<0.03	<0.07	<0.01	<4.9
Site O	NE TS	<0.05	<3.73	0.47	0.255	0.15	0.645	0.645	0.52	0.1	<0.02	<0.08	2.44	0.03	<13.6
Site E	Warrior	0.04	<0.87	0.43	0.22	0.13	0.63	0.63	<0.08	0.08	<0.01	<0.02	1.96	0.03	<3.2
Site G	Warrior	0.07	<2.7	0.97	0.46	0.35	1.18	1.18	0.6	0.19	<0.02	<0.06	4.12	0.06	<9.8
Site 1	Warrior	0.07	<2.3	0.76	0.36	0.29	1.21	1.21	0.3	0.15	<0.02	<0.05	3.6	0.04	<8.4
Site A	Saibai	0.365	3.64	2	0.815	0.805	3.03	3.03	0.34	0.33	0.038	<0.02	8.4	0.073	<2.8
Site 8	Saibai	0.32	4.57	2.07	0.86	0.84	3.28	3.28	0.41	0.38	0.03	<0.01	10	0.09	<2.4
Site B	South Saibai	0.02	<1.11	0.28	0.12	0.11	0.33	0.33	<0.1	0.04	<0.01	<0.02	1.07	0.01	<4
Site 9	South Saibai	0.03	<1.77	0.66	0.19	0.21	0.77	0.77	<0.16	0.13	<0.01	<0.04	3.49	0.02	<6.4
Site C	Southern TS	<0.05	<3.69	0.49	0.22	0.12	0.35	0.35	0.47	0.08	<0.02	<0.08	2.1	<0.02	<13.4
Site 10	Southern TS	<0.04	<3.02	0.46	1.46	0.21	1.04	1.04	<0.27	0.1	<0.02	<0.07	3.85	0.03	<11
Site F	Southern TS	<0.04	<3.03	0.63	0.27	0.19	0.91	0.91	<0.27	0.1	<0.02	<0.07	3.46	0.04	<11
Site 11	Southern TS	0.03	<1.8	0.42	0.3	0.22	0.92	0.92	<0.16	0.09	<0.01	<0.04	4.68	0.03	<6.5
Site D	Southern TS	0.07	1.49	1.11	0.52	0.28	1.35	1.35	0.17	0.15	<0.01	<0.02	7.4	0.05	<3

Sample	Location	Nd	Os	Pr	Rb	Re	Rh	Ru	Sc	Sm	Ta	Tb	Te	Th	Tl	Tm
		(µg/g)														
Site 2	NE TS	1	<0.5	0.24	5.7	<0.01	<0.01	<0.09	<1.51	0.3	<17.8	0.04	0.45	0.33	<0.22	0.01
Site 3	NE TS	2.76	<2	0.43	7.1	<0.05	<0.05	<0.35	<5.65	0.56	<66.2	0.08	<1.52	0.65	<0.81	0.03
Site K	NE TS	0.33	<0.4	0.08	3.1	<0.01	<0.01	<0.07	<1.14	0.13	<13.4	0.01	0.59	0.08	<0.17	<0
Site I	NE TS	1.69	<1.6	0.24	3.8	<0.04	<0.04	<0.28	<4.54	0.43	<53.3	0.06	<1.23	0.36	<0.66	<0.02
Site M	NE TS	1.29	<2.5	0.24	3.4	<0.06	<0.06	<0.44	<7.17	0.38	<84.1	0.03	<1.93	0.34	<1.03	<0.03
Site N	NE TS	2.14	<2	0.49	5.3	<0.05	<0.05	1.57	<5.72	0.465	<67.1	0.08	2.6	0.56	<0.83	0.025
Site X	NE TS	1.08	<0.5	0.23	5.2	<0.01	<0.01	<0.08	<1.37	0.25	<16	0.04	0.49	0.29	<0.2	0.01
Site J	NE TS	0.1	<0.7	<0.02	2.7	<0.02	<0.02	<0.12	<1.94	<0.03	<22.8	<0	0.63	<0.03	<0.28	<0.01
Site O	NE TS	2.93	<1.9	0.735	8	<0.05	<0.05	<0.33	<5.35	0.75	<62.7	0.075	2.04	1.01	<0.77	0.04
Site E	Warrior	2.23	<0.4	0.55	9.2	<0.01	<0.01	<0.08	1.51	0.58	<14.7	0.09	0.34	0.71	<0.18	0.02
Site G	Warrior	5.64	<1.3	1.14	13	<0.03	<0.03	<0.24	4.88	1.22	<45.4	0.18	<1.04	1.57	<0.56	0.06
Site 1	Warrior	3.88	<1.1	0.97	14	<0.03	0.03	<0.2	<3.3	0.91	<38.7	0.14	<0.89	1.38	<0.48	0.05
Site A	Saibai	11.3	<0.4	2.63	29	<0.01	<0.01	<0.07	8.03	3.08	<13	0.448	<0.3	4.01	<0.16	0.115
Site 8	Saibai	12.9	<0.3	2.95	42	<0.01	<0.01	<0.06	9.1	3.05	<10.9	0.45	<0.25	4.03	<0.13	0.12
Site B	South Saibai	1.61	<0.5	0.32	6	<0.01	<0.01	<0.1	<1.59	0.4	<18.6	0.07	<0.43	0.47	<0.23	0.02
Site 9	South Saibai	3.95	<0.9	0.91	9.7	<0.02	<0.02	<0.16	<2.54	0.9	<29.8	0.12	<0.68	1.01	<0.37	0.03
Site C	Southern TS	2.64	<1.8	0.53	8	<0.05	<0.05	<0.33	<5.29	0.36	<62.1	0.05	2.31	1.02	<0.76	<0.02
Site 10	Southern TS	3.61	<1.5	1.54	11	<0.04	<0.04	<0.27	<4.32	0.77	<50.7	0.09	<1.17	1.52	<0.62	0.03
Site F	Southern TS	4.16	<1.5	0.87	7.8	<0.04	<0.04	<0.27	<4.35	0.81	<51	0.1	<1.17	1.42	<0.63	0.03
Site 11	Southern TS	4.16	<0.9	1.13	12	<0.02	<0.02	<0.16	<2.58	0.8	<30.2	0.1	<0.69	1.75	<0.37	0.04
Site D	Southern TS	6.83	<0.4	1.82	17	<0.01	<0.01	<0.07	1.73	1.45	<13.9	0.18	0.47	3.32	<0.17	0.06

Sample	Location	Au	Ba	Be	Ce	V	W	Li	Y	Yb	Sn	Zr	Ga
		(µg/g)											
Site 2	NE TS	<1.4	21.4	0.07	1.86	8.2	<0.28	9.03	1.01	0.09	0.62	1.32	0.68
Site 3	NE TS	<5.3	37.3	<0.16	7.1	18	<1.05	8.85	2.79	<0.14	0.4	2.6	1.6
Site K	NE TS	<1.1	9.2	<0.03	0.44	2.2	<0.21	4.37	0.63	<0.03	0.18	0.5	0.17
Site I	NE TS	<4.3	42	<0.13	1.69	12	<0.85	5.82	2.1	0.13	<0.29	1.95	0.65
Site M	NE TS	<6.8	39.5	<0.2	<2.06	20	<1.34	6.7	1.49	<0.18	1.02	<1.92	0.74
Site N	NE TS	9.97	44.3	0.24	3.18	15	<1.07	9.88	2.6	<0.15	1.2	3.66	1.27
Site X	NE TS	<1.3	13.5	0.08	1.59	8.5	<0.25	8.81	1.22	0.04	0.99	1.06	0.71
Site J	NE TS	<1.8	26.3	<0.05	<0.56	6.2	<0.36	6.1	0.07	<0.05	0.27	0.72	<0.09
Site O	NE TS	<5.1	44.9	0.315	5.21	19	<1	12.4	3.18	<0.14	1.3	3.49	1.42
Site E	Warrior	<1.2	9.35	0.22	3.89	13	<0.23	13.6	2.4	0.17	0.59	1.78	1.48
Site G	Warrior	<3.7	12.3	0.22	8.51	17	<0.72	23	5.66	0.29	<0.25	6.28	2.59
Site 1	Warrior	<3.1	16.4	0.51	7.54	22	<0.61	22.8	3.88	0.15	1.02	5.11	3.2
Site A	Saibai	<1	31.9	0.953	20.3	59	<0.21	40.6	8.28	0.685	1.39	10.7	6.16
Site 8	Saibai	<0.9	60.2	1.1	22.9	91	<0.17	50.9	8.8	0.62	1.29	13.7	9.53
Site B	South Saibai	<1.5	6.39	0.19	2.62	2.5	<0.3	9.79	1.49	0.09	1.14	1.27	0.65
Site 9	South Saibai	<2.4	12.5	0.22	8.44	8	<0.47	13.7	3.75	0.19	1.49	2.64	2.06
Site C	Southern TS	<5	9.79	<0.15	3.94	<7.47	<0.99	12	2.09	<0.14	2.73	2.38	1.48
Site 10	Southern TS	<4.1	11.6	0.47	7.8	10	<0.81	16.9	3.19	0.15	2.09	3.01	1.78
Site F	Southern TS	<4.1	20.8	0.19	7.25	9.2	<0.81	12.1	3.65	0.17	2.39	3.11	1.25
Site 11	Southern TS	<2.4	35.5	0.28	9.06	12	<0.48	17.5	4.28	0.22	1.53	3.26	2.06
Site D	Southern TS	<1.1	19.6	0.46	15.7	14	<0.22	25.5	5.04	0.32	0.65	4.21	3.05

Appendix A8: 2016 survey - TSS-bound metals analysis QC data

Sample	As	Cd	Co	Cu	Ni	Pb	Zn
CRM Analysis							
ERM-CC018 (µg/g)	20.4	5.1	4.9	72.8	23.9	287	303
Certified value (µg/g)	22.9	5.40	5.90	80.0	25.8	289	313
Recovery (%)	89	94	84	91	93	99	97
PACS-3 (µg/g)	26.2	2.1	8.7	305	31.6	171	369
In-house value (µg/g)	23.8	1.99	8.20	289	28.4	170	343
Recovery (%)	110	105	106	105	111	100	108
Spike recoveries (%)							
Site G	101	99	105	103	105	100	112
Site N, site replicate 2	113	106	108	107	105	99	104
Site A, site replicate 2	97	101	101	99	97	98	93

Appendix A9: 2016 survey - method and site duplicates for TSS-bound metals analysis

Sample	As	Cd	Co	Cu	Ni	Pb	Zn
	(µg/g)						
Method duplicates							
Site A, site duplicate 1, lab replicate 1	15.2	0.27	14.5	27.1	31.7	19.0	103
Site A, site duplicate 1, lab replicate 2	12.4	0.25	13.3	25.7	30.9	17.3	91
Site A Mean	13.8	0.26	13.9	26.4	31.3	18.1	97
Site duplicates							
Site N, site replicate 1	<2.94	0.85	0.84	4.98	5.45	<1.90	<29.7
Site N, site replicate 2	3.90	0.74	1.41	7.35	14.1	<1.98	<31.1
Site N Mean	3.90	0.80	1.13	6.17	9.77	<1.98	<31.1
Site O, site replicate 1	3.92	1.93	1.84	7.59	15.3	<2.31	<36.2
Site O, site replicate 2	5.93	1.25	1.94	8.05	10.1	<1.85	<29.0
Site O Mean	4.93	1.59	1.89	7.82	12.7	<1.85	<29.0
Site A, site replicate 1	13.8	0.26	13.9	26.4	31.3	18.1	97
Site A, site replicate 2	14.8	0.06	14.6	27.7	32.4	20.0	106
Site A Mean	14.3	0.16	14.3	27.1	31.8	19.1	101

Appendix A10: 2016 survey: metals in benthic sediments (other elements)

Sample	Location	Type	Core depth (cm)	Bi	Cs	Dy	Er	Eu	Gd	Hf	Ho	In
(µg/g)												
Site 2	NE TS	C	0-0.3	0.017	0.34	0.415	0.212	0.132	0.54	0.035	0.081	<0.01
Site 2	NE TS	C	0-3.5	0.009	0.12	0.277	0.148	0.08	0.327	0.017	0.056	<0.01
Site 3	NE TS	SS	---	0.007	0.057	0.204	0.105	0.058	0.23	0.008	0.04	<0.01
Site 3	NE TS	C	0-0.5	0.006	0.142	0.267	0.138	0.086	0.348	0.019	0.051	<0.01
Site 3	NE TS	C	0.3 - 4.5	<0.01	0.041	0.194	0.106	0.056	0.231	0.007	0.039	<0.01
Site K	NE TS	SS	---	<0.01	0.012	0.12	0.068	0.042	0.15	0.003	0.024	<0.01
Site K	NE TS	C	0-0.5	<0.01	0.012	0.138	0.076	0.043	0.164	0.002	0.027	<0.01
Site I	NE TS	SS	---	<0.01	0.013	0.115	0.068	0.029	0.124	0.005	0.023	<0.01
Site M	NE TS	SS	---	<0.01	0.009	0.153	0.093	0.04	0.156	0.004	0.033	<0.01
Site N	NE TS	SS	---	0.007	0.121	0.266	0.144	0.086	0.328	0.019	0.053	<0.01
Site N	NE TS	C	0-3	0.01	0.131	0.267	0.142	0.085	0.335	0.02	0.054	<0.01
Site X	NE TS	C	0-3	0.01	0.162	0.239	0.13	0.075	0.304	0.019	0.045	<0.01
Site J	NE TS	SS	---	0.008	0.073	0.256	0.144	0.074	0.306	0.016	0.051	<0.01
Site O	NE TS	C	0-5	0.011	0.227	0.299	0.157	0.094	0.373	0.024	0.057	<0.01
Site E	Warrior	SS	---	0.015	0.132	0.243	0.136	0.072	0.297	0.017	0.048	<0.01
Site G	Warrior	C	0-2	0.047	0.745	0.895	0.441	0.296	1.19	0.05	0.169	0.013
Site G	Warrior	C	2-4	0.048	0.706	0.916	0.445	0.303	1.2	0.054	0.171	0.013
Site G	Warrior	C	4-6	0.044	0.77	0.844	0.423	0.28	1.14	0.063	0.158	0.011
Site 1	Warrior	C	0-1	0.036	0.119	0.432	0.224	0.135	0.539	0.022	0.083	<0.01
Site 1	Warrior	C	1-3	0.038	0.123	0.468	0.242	0.144	0.581	0.023	0.091	<0.01
Site 1	Warrior	C	3-5	0.04	0.07	0.514	0.275	0.154	0.627	0.018	0.1	<0.01
Site A	Saibai	C	0-2	0.184	1.23	1.87	0.828	0.672	2.64	0.134	0.325	0.034
Site A	Saibai	C	2-4	0.201	1.47	1.98	0.856	0.719	2.83	0.171	0.339	0.034
Site A	Saibai	C	4-6	0.202	1.39	1.9	0.822	0.688	2.71	0.155	0.328	0.032
Site A	Saibai	C	6-8	0.217	1.72	2.02	0.886	0.74	2.91	0.184	0.348	0.037
Site A	Saibai	C	8-10	0.218	1.5	2.06	0.905	0.749	2.94	0.158	0.36	0.032
Site A	Saibai	C	11-12	0.219	2.15	2.02	0.877	0.761	2.94	0.25	0.347	0.036
Site 8	Saibai	C	0-2	0.194	2.1	1.67	0.699	0.623	2.43	0.151	0.283	0.033
Site 8	Saibai	C	2-4	0.199	2.02	1.7	0.717	0.632	2.5	0.157	0.289	0.034
Site 8	Saibai	C	4-6	0.19	2.04	1.68	0.711	0.618	2.47	0.169	0.285	0.034
Site 8	Saibai	C	6-8	0.188	1.54	1.68	0.706	0.615	2.45	0.112	0.284	0.032
Site 8	Saibai	C	8-10	0.198	2.02	1.71	0.734	0.633	2.5	0.167	0.291	0.034
Site B	South Saibai	SS	---	0.113	0.194	1.34	0.65	0.429	1.7	0.039	0.246	<0.01
Site 9	South Saibai	SS	---	0.026	0.237	0.456	0.241	0.13	0.59	0.027	0.088	<0.01
Site C	SW TS	SS	---	0.026	0.41	0.648	0.328	0.212	0.848	0.035	0.123	<0.01
Site C	SW TS	C	0-2	0.035	0.572	0.862	0.441	0.285	1.17	0.039	0.163	<0.01
Site C	SW TS	C	2-4	0.039	0.397	0.778	0.388	0.257	1.05	0.037	0.146	<0.01
Site C	SW TS	C	4-6	0.05	0.551	0.918	0.46	0.31	1.24	0.043	0.174	<0.01
Site C	SW TS	C	6-8	0.047	0.482	0.916	0.459	0.307	1.27	0.04	0.173	<0.01
Site C	SW TS	C	8-10	0.051	0.46	1.1	0.562	0.373	1.5	0.042	0.208	<0.01
Site 10	SW TS	SS	---	0.015	0.16	0.23	0.131	0.068	0.293	0.021	0.045	<0.01
Site 10	SW TS	Extra SS	---	0.008	0.12	0.333	0.194	0.079	0.416	0.031	0.066	<0.01
Site F	SW TS	C	0-2	0.021	0.375	0.434	0.233	0.131	0.552	0.029	0.083	<0.01
Site F	SW TS	C	2-4	0.02	0.412	0.489	0.258	0.148	0.64	0.036	0.092	<0.01
Site F	SW TS	C	4-6	0.022	0.485	0.536	0.279	0.162	0.681	0.037	0.101	<0.01
Site F	SW TS	C	6-8	0.023	0.553	0.536	0.277	0.161	0.689	0.037	0.101	<0.01
Site 11	SW TS	SS	---	0.015	0.268	0.38	0.198	0.111	0.48	0.027	0.073	<0.01
Site D	SW TS	SS	---	0.049	0.348	1.04	0.545	0.283	1.35	0.042	0.199	<0.01
Cadel (Masig)	SW TS	SS	---	0.016	0.229	0.75	0.365	0.244	0.966	0.031	0.139	<0.01

Sample	Location	Type	Core depth (cm)	Rb	Re	Rh	Ru	Sc	Sm	Tb	Te	Th
				(µg/g)								
Site 2	NE TS	C	0-0.3	3.23	<0.01	0.064	0.011	1	0.489	0.077	0.185	0.467
Site 2	NE TS	C	0-3.5	1.29	<0.01	0.07	0.012	0.534	0.28	0.049	0.207	0.191
Site 3	NE TS	SS	---	0.678	<0.01	0.045	<0.01	0.306	0.179	0.036	0.178	0.083
Site 3	NE TS	C	0-0.5	1.45	<0.01	0.055	0.011	0.406	0.283	0.049	0.198	0.157
Site 3	NE TS	C	0.3 - 4.5	0.489	<0.01	0.063	0.012	0.269	0.181	0.033	0.204	0.074
Site K	NE TS	SS	---	0.294	<0.01	0.08	0.012	0.15	0.126	0.021	0.24	0.048
Site K	NE TS	C	0-0.5	0.243	<0.01	0.076	0.012	0.156	0.143	0.025	0.255	0.047
Site I	NE TS	SS	---	0.297	<0.01	0.066	<0.01	0.161	0.093	0.019	0.286	0.039
Site M	NE TS	SS	---	0.224	<0.01	0.076	<0.01	0.197	0.12	0.025	0.294	0.051
Site N	NE TS	SS	---	1.24	<0.01	0.068	0.012	0.567	0.295	0.051	0.192	0.24
Site N	NE TS	C	0-3	1.42	<0.01	0.069	0.012	0.579	0.304	0.051	0.214	0.237
Site X	NE TS	C	0-3	1.65	<0.01	0.071	<0.01	0.55	0.259	0.046	0.181	0.209
Site J	NE TS	SS	---	0.85	<0.01	0.049	<0.01	0.491	0.251	0.047	0.177	0.144
Site O	NE TS	C	0-5	2.55	<0.01	0.071	<0.01	0.741	0.331	0.055	<0.1	0.311
Site E	Warrior	SS	---	1.33	<0.01	0.069	<0.01	0.515	0.254	0.044	0.206	0.174
Site G	Warrior	C	0-2	6.99	<0.01	0.037	<0.01	2.22	1.1	0.172	0.139	1.17
Site G	Warrior	C	2-4	6.61	<0.01	0.039	<0.01	2.1	1.12	0.174	0.176	1.18
Site G	Warrior	C	4-6	7.71	<0.01	0.037	<0.01	2.12	1.08	0.167	0.141	1.13
Site 1	Warrior	C	0-1	1.3	<0.01	0.051	<0.01	0.645	0.462	0.079	0.214	0.233
Site 1	Warrior	C	1-3	1.36	<0.01	0.049	<0.01	0.73	0.511	0.085	0.192	0.237
Site 1	Warrior	C	3-5	0.734	<0.01	0.047	<0.01	0.705	0.538	0.09	0.226	0.235
Site A	Saibai	C	0-2	9.74	<0.01	0.01	<0.01	5.25	2.5	0.381	0.139	2.39
Site A	Saibai	C	2-4	12.8	<0.01	0.011	<0.01	5.74	2.74	0.402	0.126	2.7
Site A	Saibai	C	4-6	11.7	<0.01	<0.01	<0.01	5.58	2.59	0.385	0.13	2.59
Site A	Saibai	C	6-8	14.9	<0.01	0.011	0.017	6.16	2.79	0.415	0.11	2.78
Site A	Saibai	C	8-10	12	<0.01	0.01	<0.01	5.97	2.78	0.42	0.108	2.73
Site A	Saibai	C	11-12	22.2	<0.01	0.009	<0.01	6.95	2.94	0.414	0.122	2.94
Site 8	Saibai	C	0-2	18.8	<0.01	0.01	<0.01	5.69	2.36	0.343	<0.1	2.78
Site 8	Saibai	C	2-4	17.6	<0.01	0.011	<0.01	5.49	2.43	0.355	0.108	2.91
Site 8	Saibai	C	4-6	18.1	<0.01	<0.01	<0.01	5.56	2.42	0.343	<0.1	2.9
Site 8	Saibai	C	6-8	11.7	<0.01	0.01	<0.01	4.81	2.32	0.342	0.111	2.59
Site 8	Saibai	C	8-10	17.4	<0.01	<0.01	<0.01	5.64	2.42	0.349	0.115	2.95
Site B	South Saibai	SS	---	1.97	<0.01	0.035	<0.01	1.96	1.49	0.253	0.156	0.5
Site 9	South Saibai	SS	---	2.59	<0.01	0.048	<0.01	0.752	0.603	0.089	0.162	0.858
Site C	SW TS	SS	---	4.49	<0.01	0.038	<0.01	1.33	0.833	0.123	0.102	0.811
Site C	SW TS	C	0-2	6.44	<0.01	0.042	<0.01	1.76	1.13	0.167	0.134	0.991
Site C	SW TS	C	2-4	4.13	<0.01	0.04	<0.01	1.37	1	0.148	0.165	0.829
Site C	SW TS	C	4-6	6.03	<0.01	0.037	<0.01	1.89	1.23	0.177	0.135	1.04
Site C	SW TS	C	6-8	5.14	<0.01	0.041	<0.01	1.7	1.22	0.176	0.128	0.939
Site C	SW TS	C	8-10	5.21	<0.01	0.041	<0.01	1.84	1.42	0.209	0.136	0.939
Site 10	SW TS	SS	---	1.86	<0.01	0.06	<0.01	0.464	0.29	0.042	0.187	0.345
Site 10	SW TS	Extra SS	---	1.53	<0.01	0.056	<0.01	0.432	0.447	0.059	0.232	1.14
Site F	SW TS	C	0-2	4.04	<0.01	0.039	<0.01	1.03	0.538	0.079	0.161	0.666
Site F	SW TS	C	2-4	4.31	<0.01	0.04	<0.01	1.11	0.606	0.09	0.146	0.774
Site F	SW TS	C	4-6	5.08	<0.01	0.039	<0.01	1.23	0.671	0.098	0.157	0.875
Site F	SW TS	C	6-8	5.89	<0.01	0.039	<0.01	1.36	0.682	0.1	0.157	0.936
Site 11	SW TS	SS	---	2.81	<0.01	0.05	<0.01	0.686	0.494	0.069	0.181	0.718
Site D	SW TS	SS	---	3.54	<0.01	0.026	<0.01	1.26	1.29	0.19	0.122	1.45
Cadel (Masig)	SW TS	SS	---	2.35	<0.01	0.034	<0.01	1.14	0.852	0.143	0.141	0.502

Sample	Location	Type	Core depth	Li	Sn	V	Ba	Be	Ce
			(cm)	(µg/g)					
Site 2	NE TS	C	0-0.3	7.2	0.08	7.27	9.84	0.125	3.16
Site 2	NE TS	C	0-3.5	3.28	0.032	3.48	8.53	0.055	1.7
Site 3	NE TS	SS	---	2.68	0.028	1.66	5.66	0.023	0.799
Site 3	NE TS	C	0-0.5	3.47	0.028	4.39	7.25	0.038	1.32
Site 3	NE TS	C	0.3 - 4.5	2.16	0.012	1.74	5.91	0.02	0.764
Site K	NE TS	SS	---	1.29	<0.01	1.3	6.6	0.009	0.556
Site K	NE TS	C	0-0.5	1.41	0.01	1.09	6.62	0.009	0.616
Site I	NE TS	SS	---	1.46	<0.01	1.43	5.56	0.012	0.383
Site M	NE TS	SS	---	1.34	0.011	3.13	4.86	0.012	0.566
Site N	NE TS	SS	---	3.91	0.041	3.78	6.43	0.057	1.82
Site N	NE TS	C	0-3	4.12	0.045	4.14	6.83	0.059	1.87
Site X	NE TS	C	0-3	4.17	0.055	4.95	7.73	0.058	1.69
Site J	NE TS	SS	---	3.21	0.034	4.57	6.13	0.039	1.36
Site O	NE TS	C	0-5	5.95	0.068	5.52	9.15	0.083	2.25
Site E	Warrior	SS	---	4.29	0.036	3.47	8.39	0.063	1.64
Site G	Warrior	C	0-2	15.8	0.191	14	10.6	0.287	7.65
Site G	Warrior	C	2-4	15.3	0.184	13.4	10.7	0.276	7.69
Site G	Warrior	C	4-6	15.7	0.199	14.8	13.2	0.29	7.43
Site 1	Warrior	C	0-1	3.63	0.046	8.3	10.6	0.071	3.22
Site 1	Warrior	C	1-3	3.6	0.049	9.66	9.69	0.075	3.52
Site 1	Warrior	C	3-5	3.05	0.036	10.6	10.2	0.066	3.67
Site A	Saibai	C	0-2	21.2	0.335	54.4	10.7	0.588	16.3
Site A	Saibai	C	2-4	24	0.411	59.8	16.3	0.667	18.3
Site A	Saibai	C	4-6	23.3	0.38	52.1	13.7	0.64	16.9
Site A	Saibai	C	6-8	26.7	0.44	62.4	18.1	0.706	18.8
Site A	Saibai	C	8-10	25	0.39	57.5	12.6	0.684	19.8
Site A	Saibai	C	11-12	30	0.568	73	36.4	0.816	20
Site 8	Saibai	C	0-2	30.5	0.528	53.4	25	0.725	16.7
Site 8	Saibai	C	2-4	31.3	0.507	48.8	19.9	0.705	17.1
Site 8	Saibai	C	4-6	31.2	0.522	51.1	22	0.707	17
Site 8	Saibai	C	6-8	27.1	0.398	39.3	10.7	0.588	15.3
Site 8	Saibai	C	8-10	32.2	0.517	49.5	20.3	0.697	16.9
Site B	South Saibai	SS	---	4.27	0.067	28.3	7.26	0.188	8.74
Site 9	South Saibai	SS	---	5.32	0.091	5.29	7.23	0.126	6.33
Site C	SW TS	SS	---	9.34	0.12	9.46	7.63	0.182	6.56
Site C	SW TS	C	0-2	11.9	0.17	12.3	10.2	0.256	8.93
Site C	SW TS	C	2-4	9.42	0.12	8.7	7.94	0.191	7.64
Site C	SW TS	C	4-6	11.7	0.173	14.2	8.44	0.258	9.78
Site C	SW TS	C	6-8	10.6	0.139	11.5	9	0.213	9.92
Site C	SW TS	C	8-10	10.1	0.137	14	9.27	0.231	10.9
Site 10	SW TS	SS	---	4.66	0.062	5.15	13.7	0.082	2.74
Site 10	SW TS	Extra SS	---	3	0.045	2.89	6.28	0.075	4.22
Site F	SW TS	C	0-2	9.34	0.12	7.13	8.45	0.165	4.66
Site F	SW TS	C	2-4	10.1	0.139	7.26	8.87	0.18	5.3
Site F	SW TS	C	4-6	11.3	0.155	8.05	8.72	0.211	5.78
Site F	SW TS	C	6-8	12.4	0.268	9.08	9.72	0.223	6.01
Site 11	SW TS	SS	---	6.61	0.096	3.72	8.46	0.12	4.85
Site D	SW TS	SS	---	7.72	0.147	10.5	6.94	0.181	12.4
Cadel (Masig)	SW TS	SS	---	8.54	0.087	6.52	6.42	0.129	5.8

Sample	Location	Type	Core depth	Ir	La	Lu	Nb	Nd	Pr	Pt	Ga
			(cm)	(µg/g)							
Site 2	NE TS	C	0-0.3	<0.003	1.49	0.024	0.054	1.94	0.429	<0.02	0.05
Site 2	NE TS	C	0-3.5	<0.003	0.834	0.017	0.033	1.1	0.237	<0.02	0.054
Site 3	NE TS	SS	---	<0.003	0.477	0.013	0.021	0.676	0.136	<0.02	0.047
Site 3	NE TS	C	0-0.5	<0.003	0.747	0.014	0.04	1.02	0.217	<0.02	0.389
Site 3	NE TS	C	0.3 - 4.5	<0.003	0.468	0.012	0.021	0.66	0.133	<0.02	0.44
Site K	NE TS	SS	---	<0.003	0.392	0.006	0.014	0.531	0.109	<0.02	0.383
Site K	NE TS	C	0-0.5	<0.003	0.423	0.007	0.012	0.571	0.118	<0.02	0.214
Site I	NE TS	SS	---	<0.003	0.245	0.008	0.016	0.336	0.066	<0.02	0.547
Site M	NE TS	SS	---	<0.003	0.307	0.01	0.016	0.428	0.088	<0.02	0.352
Site N	NE TS	SS	---	<0.003	0.881	0.014	0.1	1.18	0.259	<0.02	1.75
Site N	NE TS	C	0-3	<0.003	0.899	0.015	0.103	1.2	0.263	<0.02	1.68
Site X	NE TS	C	0-3	<0.003	0.825	0.013	0.038	1.08	0.238	<0.02	1.89
Site J	NE TS	SS	---	<0.003	0.677	0.016	0.029	0.968	0.202	<0.02	0.313
Site O	NE TS	C	0-5	<0.003	1.03	0.016	0.047	1.32	0.295	<0.02	0.332
Site E	Warrior	SS	---	<0.003	0.731	0.015	0.028	0.964	0.212	<0.02	0.214
Site G	Warrior	C	0-2	<0.003	3.29	0.046	0.058	4.42	0.991	<0.02	3.38
Site G	Warrior	C	2-4	<0.003	3.3	0.048	0.064	4.44	0.995	<0.02	4.23
Site G	Warrior	C	4-6	<0.003	3.24	0.043	0.077	4.23	0.957	<0.02	3.84
Site 1	Warrior	C	0-1	<0.003	1.32	0.026	0.04	1.81	0.4	<0.02	4.57
Site 1	Warrior	C	1-3	<0.003	1.43	0.027	0.042	1.96	0.433	<0.02	3.92
Site 1	Warrior	C	3-5	<0.003	1.46	0.03	0.036	2.06	0.45	<0.02	6
Site A	Saibai	C	0-2	<0.003	6.76	0.088	0.107	9.71	2.15	<0.02	5.36
Site A	Saibai	C	2-4	<0.003	7.65	0.087	0.112	10.7	2.4	<0.02	5.06
Site A	Saibai	C	4-6	<0.003	6.8	0.086	0.109	9.96	2.2	<0.02	5.27
Site A	Saibai	C	6-8	<0.003	7.87	0.09	0.118	11.1	2.48	<0.02	3.79
Site A	Saibai	C	8-10	<0.003	7.36	0.097	0.112	10.7	2.38	<0.02	5.1
Site A	Saibai	C	11-12	<0.003	8.55	0.088	0.096	11.5	2.6	<0.02	0.571
Site 8	Saibai	C	0-2	<0.003	6.99	0.07	0.157	9.41	2.13	<0.02	0.601
Site 8	Saibai	C	2-4	<0.003	7.22	0.072	0.136	9.65	2.2	<0.02	1.07
Site 8	Saibai	C	4-6	<0.003	7.28	0.069	0.132	9.56	2.18	<0.02	1.44
Site 8	Saibai	C	6-8	<0.003	6.25	0.069	0.131	8.96	1.99	<0.02	0.999
Site 8	Saibai	C	8-10	<0.003	7.22	0.072	0.15	9.64	2.18	<0.02	1.44
Site B	South Saibai	SS	---	<0.003	3.77	0.07	0.068	5.62	1.22	<0.02	1.25
Site 9	South Saibai	SS	---	<0.003	2.56	0.026	0.075	2.82	0.697	<0.02	1.31
Site C	SW TS	SS	---	<0.003	2.88	0.036	0.062	3.53	0.825	<0.02	0.403
Site C	SW TS	C	0-2	<0.003	3.99	0.045	0.079	4.9	1.12	<0.02	0.296
Site C	SW TS	C	2-4	<0.003	3.29	0.04	0.046	4.26	0.975	<0.02	0.936
Site C	SW TS	C	4-6	<0.003	4.36	0.048	0.073	5.32	1.23	<0.02	1.02
Site C	SW TS	C	6-8	<0.003	4.49	0.048	0.062	5.36	1.25	<0.02	1.18
Site C	SW TS	C	8-10	<0.003	4.8	0.058	0.069	6.15	1.4	<0.02	1.37
Site 10	SW TS	SS	---	<0.003	1.29	0.014	0.037	1.36	0.331	<0.02	0.606
Site 10	SW TS	Extra SS	---	<0.003	1.99	0.024	0.055	2.13	0.521	<0.02	0.977
Site F	SW TS	C	0-2	<0.003	2.13	0.026	0.068	2.42	0.568	<0.02	0.701
Site F	SW TS	C	2-4	<0.003	2.37	0.028	0.062	2.74	0.645	<0.02	0.05
Site F	SW TS	C	4-6	<0.003	2.64	0.03	0.074	2.99	0.715	<0.02	0.054
Site F	SW TS	C	6-8	<0.003	2.76	0.03	0.087	3.04	0.741	<0.02	0.047
Site 11	SW TS	SS	---	<0.003	2.11	0.021	0.054	2.31	0.567	<0.02	0.389
Site D	SW TS	SS	---	<0.003	5.44	0.057	0.094	5.95	1.45	<0.02	0.44
Cadel (Masig)	SW TS	SS	---	<0.003	2.23	0.036	0.048	3.3	0.717	<0.02	0.383

Sample	Location	Type	Core depth	Ti	Tl	Tm	V	W	Y	Yb	Zr
			(cm)	(µg/g)							
Site 2	NE TS	C	0-0.3	18.3	<0.03	0.026	7.27	0.043	2.71	0.159	0.859
Site 2	NE TS	C	0-3.5	9.7	<0.03	0.019	3.48	0.011	2.09	0.111	0.406
Site 3	NE TS	SS	---	5.47	<0.03	0.014	1.66	0.007	1.53	0.081	0.234
Site 3	NE TS	C	0-0.5	12.7	<0.03	0.016	4.39	0.016	1.93	0.098	0.421
Site 3	NE TS	C	0.3 - 4.5	4.15	<0.03	0.013	1.74	0.009	1.48	0.076	0.19
Site K	NE TS	SS	---	2.52	<0.03	0.008	1.3	0.003	1.03	0.053	0.101
Site K	NE TS	C	0-0.5	1.9	<0.03	0.009	1.09	0.005	1.13	0.052	0.092
Site I	NE TS	SS	---	2.3	<0.03	0.009	1.43	<0.004	1.05	0.049	0.108
Site M	NE TS	SS	---	2.22	<0.03	0.012	3.13	0.01	1.48	0.067	0.087
Site N	NE TS	SS	---	31.1	0.046	0.017	3.78	0.016	1.89	0.1	0.697
Site N	NE TS	C	0-3	33.1	0.046	0.017	4.14	0.019	1.9	0.103	0.793
Site X	NE TS	C	0-3	12.5	<0.03	0.016	4.95	0.015	1.69	0.088	0.503
Site J	NE TS	SS	---	8.64	<0.03	0.019	4.57	0.018	2	0.109	0.355
Site O	NE TS	C	0-5	17.3	<0.03	0.019	5.52	0.017	1.99	0.114	0.623
Site E	Warrior	SS	---	6.54	0.039	0.017	3.47	0.011	1.78	0.103	0.473
Site G	Warrior	C	0-2	24.4	0.06	0.056	14	0.03	5.23	0.324	1.53
Site G	Warrior	C	2-4	28.2	0.077	0.055	13.4	0.033	5.32	0.324	1.52
Site G	Warrior	C	4-6	39	0.062	0.052	14.8	0.029	4.99	0.311	1.89
Site 1	Warrior	C	0-1	11.9	<0.03	0.028	8.3	0.03	2.89	0.17	0.673
Site 1	Warrior	C	1-3	12.5	0.03	0.031	9.66	0.033	3.14	0.186	0.702
Site 1	Warrior	C	3-5	9.59	<0.03	0.035	10.6	0.037	3.4	0.213	0.547
Site A	Saibai	C	0-2	74.6	0.049	0.101	54.4	0.06	8.36	0.629	5.39
Site A	Saibai	C	2-4	109	0.045	0.105	59.8	0.036	8.66	0.627	6.42
Site A	Saibai	C	4-6	88.1	0.062	0.101	52.1	0.044	8.34	0.611	5.94
Site A	Saibai	C	6-8	111	0.06	0.108	62.4	0.03	8.9	0.647	6.95
Site A	Saibai	C	8-10	73.5	0.045	0.111	57.5	0.045	9.16	0.67	6.2
Site A	Saibai	C	11-12	195	0.086	0.108	73	0.018	8.82	0.635	8.28
Site 8	Saibai	C	0-2	123	0.079	0.085	53.4	0.023	7.14	0.498	5.27
Site 8	Saibai	C	2-4	96.7	0.054	0.087	48.8	0.024	7.3	0.514	5.28
Site 8	Saibai	C	4-6	114	0.058	0.085	51.1	0.021	7.14	0.497	5.85
Site 8	Saibai	C	6-8	59.8	0.03	0.086	39.3	0.027	7.18	0.504	3.98
Site 8	Saibai	C	8-10	104	0.061	0.089	49.5	0.023	7.3	0.519	6
Site B	South Saibai	SS	---	18.7	<0.03	0.08	28.3	0.086	7.43	0.474	1.97
Site 9	South Saibai	SS	---	13.9	0.038	0.032	5.29	0.023	2.74	0.19	0.729
Site C	SW TS	SS	---	23.2	0.041	0.04	9.46	0.02	3.95	0.248	1
Site C	SW TS	C	0-2	30.3	0.054	0.053	12.3	0.026	5.43	0.325	1.47
Site C	SW TS	C	2-4	15.6	0.053	0.049	8.7	0.025	4.96	0.29	0.904
Site C	SW TS	C	4-6	25.7	0.066	0.057	14.2	0.031	5.82	0.349	1.35
Site C	SW TS	C	6-8	20.8	0.073	0.057	11.5	0.022	5.8	0.338	1.19
Site C	SW TS	C	8-10	26	0.089	0.071	14	0.024	7.08	0.414	1.48
Site 10	SW TS	SS	---	8.95	<0.03	0.016	5.15	0.015	1.66	0.103	0.468
Site 10	SW TS	Extra SS	---	8.8	<0.03	0.027	2.89	0.009	2.34	0.168	0.828
Site F	SW TS	C	0-2	21.7	0.064	0.03	7.13	0.022	2.97	0.18	0.837
Site F	SW TS	C	2-4	21.8	0.064	0.033	7.26	0.02	3.25	0.2	0.856
Site F	SW TS	C	4-6	25	0.053	0.034	8.05	0.019	3.41	0.213	1
Site F	SW TS	C	6-8	33	0.056	0.036	9.08	0.017	3.43	0.213	1.11
Site 11	SW TS	SS	---	15.9	<0.03	0.024	3.72	0.01	2.34	0.153	0.582
Site D	SW TS	SS	---	25.8	0.045	0.069	10.5	0.031	6.09	0.41	1.19
Cadel (Masig)	SW TS	SS	---	20.7	0.049	0.044	6.52	0.015	4.37	0.256	0.747

Where, C = Core, SS = Surface scrape

Appendix A11: 2016 survey - benthic sediment metals analysis QC data

Sample	Al	Ag	As	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cu	Cs	Dy
Limit of detection (µg/g)	70	0.01	0.03	4	0.1	0.01	0.01	50	0.01	0.002	0.01	0.2	0.3	0.02	0.001
CRM analysis															
ERM-CC018 (µg/g)	5990	2.09	21.1	13	403	0.57	1.11	18100	5.49	18.6	5.21	127	77.6	0.96	0.98
Certified value (µg/g)	---	---	22.9	---	---	---	---	---	5.40	---	5.90	129	80.0	---	---
Recovery (%)	---	---	92	---	---	---	---	---	102	---	88	99	97	---	---
PACS-3 (µg/g)	19500	1.20	26.5	63	431	0.46	0.39	7380	2.22	24.2	8.76	52.7	307	1.68	2.14
In-house value (µg/g)	16334	1.13	23.8	63	433	0.46	0.39	7439	1.99	24.2	8.20	48.0	289	1.68	2.14
Recovery (%)	119	107	111	99	100	100	100	99	112	100	107	110	106	100	100

Sample	Er	Eu	Fe	Ga	Gd	Hf	Hg	Ho	In	Ir	La	Li	Lu	Mg	Mn
Limit of detection (µg/g)	0.001	0.001	1	0.004	0.01	0.001	0.02	0.0003	0.01	0.003	0.001	0.03	0.001	5	0.3
CRM analysis															
ERM-CC018 (µg/g)	0.51	0.30	10400	2.88	1.35	0.26	1.40	0.18	<0.01	<0.003	8.80	7.45	0.06	1270	201
Certified value (µg/g)	---	---	---	---	---	---	1.38	---	---	---	---	---	---	---	---
Recovery (%)	---	---	---	---	---	---	101	---	---	---	---	---	---	---	---
PACS-3 (µg/g)	1.09	0.69	30000	6.46	2.71	0.54	3.01	0.40	0.41	<0.003	11.4	27.2	0.12	9640	250
In-house value (µg/g)	1.09	0.69	30442	6.46	2.71	0.54	3.01	0.40	0.41	---	11.4	27.2	0.12	9656	240
Recovery (%)	100	100	99	100	100	100	100	100	100	---	100	100	100	100	104

Sample	Mo	Nb	Nd	Ni	P	Pb	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc	Se
Limit of detection (µg/g)	0.01	0.004	0.001	0.1	10	0.02	0.001	0.02	0.02	0.01	0.01	0.01	0.01	0.1	0.1
CRM analysis															
ERM-CC018 (µg/g)	12.7	0.80	7.85	25.0	856	311	2.05	<0.02	8.16	0.01	0.01	<0.01	3.12	1.58	0.53
Certified value (µg/g)	---	---	---	25.8	---	289	---	---	---	---	---	---	---	---	---
Recovery (%)	---	---	---	97	---	108	---	---	---	---	---	---		---	
PACS-3 (µg/g)	5.25	0.64	12.9	32.2	844	192	3.10	<0.02	18.5	<0.01	<0.01	<0.01	11.1	6.89	1.03
In-house value (µg/g)	5.20	0.64	12.9	28.4	845	170	3.10	---	18.5	---	---	---	10.6	6.89	1.00
Recovery (%)	101	100	100	113	100	113	100	---	100	---	---	---	105	100	103

Sample	Sm	Sn	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Limit of detection (µg/g)	0.001	0.01	0.0002	0.1	0.001	0.1	0.03	0.0001	0.001	0.1	0.004	0.0004	0.001	1	0.02
CRM analysis															
ERM-CC018 (µg/g)	1.50	13.7	0.19	0.03	2.50	202	0.20	0.07	1.18	16.7	1.91	6.92	0.43	302	19.4
Certified value (µg/g)	---	---	---	---	---	---	---	---	---	19.4	---	---	---	313	---
Recovery (%)	---	---	---	---	---	---	---	---	---	86	---	---	---	96	---
PACS-3 (µg/g)	2.80	22.5	0.39	0.04	3.13	1190	0.47	0.14	1.93	77.1	0.21	10.4	0.87	353	17.0
In-house value (µg/g)	2.80	19.8	0.39	---	3.13	---	0.47	---	1.93	72.7	0.21	10.4	0.87	343	17.0
Recovery (%)	100	114	100	---	100	---	100	---	100	106	100	100	100	103	100

Appendix A12: 2016 survey - metal spike/recovery tests conducted on benthic sediment samples

Sample	Core section	Al	Ag	As	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cu	Cs	Dy
		(%)														
Site-1, replicate 3	0-1 cm	---	99	101	---	---	107	101	---	106	107	101	106	100	109	112
Site G, replicate 2	4-6 cm	---	97	108	94	88	107	99	---	102	99	109	124	109	104	107
Site 2, replicate 1	top-7 cm	95	98	104	94	87	107	100	---	104	104	103	103	101	105	109
Site 3, scrape 2	Surface scrape	91	91	99	95	89	100	96	---	97	101	97	104	96	102	104
Site I, replicate 3	Surface scrape	89	91	98	96	89	100	96	---	99	101	101	108	99	103	106
Site N , replicate 3	Entire core	---	94	94	98	90	102	97	---	98	100	94	88	91	103	106
Site O, replicate 3	Entire core	---	97	106	97	90	105	97	---	102	100	104	110	101	104	107
Site A, replicate 2	4-6 cm	---	88	---	97	90	101	97	---	97	102	123	---	112	100	101
Site A, replicate 3	11-12 cm	---	85	---	101	93	99	95	---	93	95	113	---	101	97	100
Site C, replicate 2	0-2 cm	---	91	96	97	88	108	97	---	100	101	99	88	96	105	105
Site C, replicate 3	4-6 cm	104	90	97	97	88	108	97	---	99	104	96	99	98	105	106
Site F, replicate 1	0-2 cm	88	89	98	98	88	106	95	---	97	101	96	104	93	102	104
Site F, replicate 2	6-8 cm	---	89	92	99	89	105	95	---	98	101	97	95	92	102	105
Site 8, replicate 1	6-8 cm	---	91	105	93	89	105	94	---	95	90	107	107	100	97	102
Site 8, replicate 3	0-2 cm	98	92	---	92	97	105	95	---	98	92	109	---	100	99	102

Sample	Core section	Er	Eu	Fe	Ga	Gd	Hf	Hg	Ho	In	Ir	La	Li	Lu	Mg	Mn
		(%)														
Site-1, replicate 3	0-1 cm	111	110	---	102	109	112	99	111	109	105	108	106	110	---	---
Site G, replicate 2	4-6 cm	108	107	---	105	106	108	101	108	105	103	103	102	108	---	86
Site 2, replicate 1	top-7 cm	109	108	---	103	107	106	102	109	105	103	105	107	108	---	85
Site 3, scrape 2	Surface scrape	104	102	---	100	102	97	103	105	102	99	101	100	104	---	86
Site I, replicate 3	Surface scrape	106	103	---	102	102	102	103	105	102	99	102	103	105	---	85
Site N , replicate 3	Entire core	105	104	93	95	105	104	100	105	103	101	103	101	104	---	89
Site O, replicate 3	Entire core	107	103	96	101	105	106	100	107	104	99	102	103	105	106	88
Site A, replicate 2	4-6 cm	102	100	---	96	101	103	106	102	99	98	98	101	102	---	97
Site A, replicate 3	11-12 cm	100	98	---	92	100	100	100	100	97	97	96	85	101	---	91
Site C, replicate 2	0-2 cm	107	106	103	97	105	108	105	106	104	102	103	117	106	94	86
Site C, replicate 3	4-6 cm	106	105	102	97	106	107	101	106	103	102	105	106	104	---	87
Site F, replicate 1	0-2 cm	103	102	94	99	103	104	102	103	100	98	101	107	102	---	86
Site F, replicate 2	6-8 cm	104	102	105	99	101	105	102	104	101	99	101	98	103	112	87
Site 8, replicate 1	6-8 cm	101	98	---	104	98	102	100	102	98	96	94	---	103	---	---
Site 8, replicate 3	0-2 cm	103	101	---	102	101	102	101	103	100	98	97	---	103	---	98

Sample	Core section	Mo	Nb	Nd	Ni	P	Pb	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc	Se
		(%)														
Site-1, replicate 3	0-1 cm	112	113	107	100	---	99	107	102	108	107	105	105	107	109	100
Site G, replicate 2	4-6 cm	110	109	102	108	95	96	104	100	104	103	101	105	102	111	104
Site 2, replicate 1	top-7 cm	109	92	106	98	92	100	105	101	107	104	102	104	105	109	102
Site 3, scrape 2	Surface scrape	105	100	101	97	89	96	102	97	102	101	97	97	100	99	98
Site I, replicate 3	Surface scrape	108	102	102	100	93	97	102	97	103	102	98	99	102	103	100
Site N , replicate 3	Entire core	103	107	103	88	96	97	103	99	102	103	98	99	101	103	93
Site O, replicate 3	Entire core	110	108	101	100	98	98	102	97	103	103	100	102	102	107	103
Site A, replicate 2	4-6 cm	108	99	100	---	100	91	99	97	96	99	96	98	99	106	97
Site A, replicate 3	11-12 cm	104	95	96	---	98	90	97	95	90	97	94	96	96	101	91
Site C, replicate 2	0-2 cm	105	108	100	97	92	97	103	102	100	105	99	102	104	100	94
Site C, replicate 3	4-6 cm	104	106	103	98	112	99	103	101	108	102	99	103	102	102	93
Site F, replicate 1	0-2 cm	103	104	100	93	94	96	102	96	99	102	97	100	99	108	98
Site F, replicate 2	6-8 cm	102	104	101	97	102	96	101	97	104	102	96	100	99	109	99
Site 8, replicate 1	6-8 cm	110	102	90	104	84	90	97	95	89	98	96	98	98	103	100
Site 8, replicate 3	0-2 cm	108	103	93	108	95	89	99	95	93	100	98	100	98	108	101

Sample	Core section	Sm	Sn	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
		(%)														
Site-1, replicate 3	0-1 cm	109	109	111	103	108	---	104	112	106	105	109	109	110	101	111
Site G, replicate 2	4-6 cm	104	105	107	100	105	91	103	109	104	126	107	107	106	118	108
Site 2, replicate 1	top-7 cm	105	104	108	102	106	91	103	109	106	119	106	108	107	91	107
Site 3, scrape 2	Surface scrape	102	101	104	100	99	90	100	104	100	105	101	102	102	88	101
Site I, replicate 3	Surface scrape	102	102	104	100	101	90	100	105	101	105	103	104	104	102	105
Site N , replicate 3	Entire core	102	101	105	99	104	92	100	104	99	101	104	102	105	89	103
Site O, replicate 3	Entire core	103	101	106	94	103	93	100	106	102	111	105	105	106	107	105
Site A, replicate 2	4-6 cm	100	99	102	93	99	---	98	103	101	243	100	100	102	---	103
Site A, replicate 3	11-12 cm	97	97	100	89	98	96	97	100	98	143	98	98	100	---	97
Site C, replicate 2	0-2 cm	105	101	105	97	106	91	102	107	105	102	106	102	108	92	105
Site C, replicate 3	4-6 cm	104	101	105	103	104	91	101	106	103	106	105	107	105	99	106
Site F, replicate 1	0-2 cm	101	101	103	96	103	91	97	102	103	103	103	101	102	99	102
Site F, replicate 2	6-8 cm	101	100	104	95	103	92	98	102	102	102	104	102	103	102	104
Site 8, replicate 1	6-8 cm	95	98	103	99	100	90	97	102	100	---	100	97	102	---	99
Site 8, replicate 3	0-2 cm	97	100	103	101	101	96	98	103	102	---	102	98	102	---	101

Appendix A13: 2016 survey - laboratory duplicates for sediment-bound metals analysis

Sample	Sample type	Core section	Al	Ag	As	B	Ba	Be	Bi	Ca	Cd	Ce
			(µg/g)									
Site G, replicate 1	Core	0-2 cm	7300	0.02	5.89	37	13	0.30	0.04	308000	0.04	7.48
Site G, replicate 1 (duplicate)	Core	0-2 cm	4450	0.02	5.08	35	8.7	0.27	0.04	305000	0.04	6.85
Site G, replicate 1 mean	Core	0-2 cm	5880	0.02	5.48	36	11	0.28	0.04	306500	0.04	7.16
Site 2, replicate 1	Core	top-7 cm	2040	0.01	1.33	33	10	0.08	0.01	334000	0.03	2.21
Site 2, replicate 1 (duplicate)	Core	top-7 cm	1110	0.01	1.22	31	7.7	0.07	0.01	369000	0.03	1.99
Site 2, replicate 1 mean	Core	top-7 cm	1580	0.01	1.27	32	9.1	0.07	0.01	351500	0.03	2.10
Site K, replicate 1	Core	0-4 cm	192	<0.01	0.99	44	6.6	0.01	<0.01	331000	0.03	0.63
Site K, replicate 1 (duplicate)	Core	0-4 cm	204	<0.01	0.87	43	6.4	0.01	<0.01	365000	0.02	0.59
Site K, replicate 1 mean	Core	0-4 cm	198	<0.01	0.93	43	6.5	0.01	<0.01	348000	0.02	0.61
Site N , replicate 1	Core	0-3 cm	1390	<0.01	1.55	35	6.4	0.06	<0.01	282000	0.01	1.66
Site N , replicate 1 (duplicate)	Core	0-3 cm	1570	<0.01	1.60	38	6.9	0.06	<0.01	314000	0.02	1.85
Site N , replicate 1 mean	Core	0-3 cm	1480	<0.01	1.58	37	6.7	0.06	<0.01	298000	0.02	1.75
Site O, replicate 3	Core	Entire core	1360	<0.01	1.25	38	9.0	0.05	0.01	316000	0.23	1.53
Site O, replicate 3 (duplicate)	Core	Entire core	2000	<0.01	1.35	37	8.6	0.08	0.01	313000	0.23	1.94
Site O, replicate 3 mean	Core	Entire core	1680	<0.01	1.30	37	8.8	0.06	0.01	314500	0.23	1.73
Site A, replicate 2	Core	2-4 cm	10100	0.02	24.8	39	8.5	0.51	0.18	109000	0.03	14.3
Site A, replicate 2 (duplicate)	Core	2-4 cm	16600	0.03	23.2	53	20	0.67	0.18	111000	0.03	19.1
Site A, replicate 2 mean	Core	2-4 cm	13400	0.02	24.0	46	14	0.59	0.18	110000	0.03	16.7
Site 9, replicate 1	Surface scrape	---	1740	0.01	2.14	38	5.6	0.13	0.02	222000	0.06	6.56
Site 9, replicate 1 (duplicate)	Surface scrape	---	2760	0.02	2.55	43	7.1	0.14	0.04	242000	0.05	7.20
Site 9, replicate 1 mean	Surface scrape	---	2300	0.02	2.34	41	6.4	0.13	0.03	232000	0.05	6.88
Site C, replicate 2	Core	6-8 cm	2640	<0.01	5.21	31	7.3	0.19	0.04	264000	0.05	9.8
Site C, replicate 2 (duplicate)	Core	6-8 cm	3730	<0.01	4.71	31	9.3	0.20	0.04	294000	0.05	9.9
Site C, replicate 2 mean	Core	6-8 cm	3190	<0.01	4.96	31	8.3	0.19	0.04	279000	0.05	9.87
Site C, replicate 3	Surface scrape	---	3260	<0.01	3.42	29	6.6	0.17	0.02	207000	0.07	6.30
Site C, replicate 3 (duplicate)	Surface scrape	---	3460	<0.01	3.29	28	7.1	0.17	0.02	213000	0.08	6.72

Sample	Sample type	Core section	Al	Ag	As	B	Ba	Be	Bi	Ca	Cd	Ce
			(µg/g)									
Site C, replicate 3 mean	Surface scrape	---	3360	<0.01	3.35	29	6.9	0.17	0.02	210000	0.08	6.51
Site F, replicate 1	Core	6-8 cm	4350	<0.01	3.26	40	9.1	0.21	0.02	260000	0.18	5.57
Site F, replicate 1 (duplicate)	Core	6-8 cm	4800	<0.01	3.25	40	9.6	0.21	0.02	298000	0.19	5.85
Site F, replicate 1 mean	Core	6-8 cm	4580	<0.01	3.26	40	9.3	0.21	0.02	279000	0.19	5.71

Sample	Sample type	Core section	Co	Cr	Cu	Cs	Dy	Er	Eu	Fe	Ga	Gd
			(µg/g)									
Site G, replicate 1	Core	0-2 cm	2.56	20	3.4	0.84	0.82	0.42	0.28	7310	2.09	1.12
Site G, replicate 1 (duplicate)	Core	0-2 cm	2.44	18	3.3	0.56	0.83	0.41	0.28	7280	1.33	1.11
Site G, replicate 1 mean	Core	0-2 cm	2.50	19	3.3	0.70	0.83	0.41	0.28	7295	1.71	1.11
Site 2, replicate 1	Core	top-7 cm	0.54	6.8	1.0	0.21	0.32	0.17	0.10	1660	0.54	0.38
Site 2, replicate 1 (duplicate)	Core	top-7 cm	0.56	6.8	1.0	0.13	0.31	0.17	0.10	1620	0.30	0.39
Site 2, replicate 1 mean	Core	top-7 cm	0.55	6.8	1.0	0.17	0.32	0.17	0.10	1640	0.42	0.39
Site K, replicate 1	Core	0-4 cm	0.05	2.9	0.3	0.02	0.14	0.08	0.04	182	0.06	0.17
Site K, replicate 1 (duplicate)	Core	0-4 cm	0.05	3.0	<0.3	0.02	0.15	0.08	0.04	179	0.06	0.16
Site K, replicate 1 mean	Core	0-4 cm	0.05	3.0	<0.3	0.02	0.14	0.08	0.04	181	0.06	0.17
Site N , replicate 1	Core	0-3 cm	0.46	7.9	0.7	0.11	0.25	0.13	0.08	1580	0.38	0.30
Site N , replicate 1 (duplicate)	Core	0-3 cm	0.53	9.0	0.8	0.13	0.26	0.14	0.08	1730	0.44	0.34
Site N , replicate 1 mean	Core	0-3 cm	0.49	8.5	0.7	0.12	0.25	0.14	0.08	1655	0.41	0.32
Site O, replicate 3	Core	Entire core	0.45	5.8	0.7	0.15	0.20	0.11	0.06	1620	0.36	0.26
Site O, replicate 3 (duplicate)	Core	Entire core	0.58	7.1	0.9	0.22	0.25	0.13	0.08	1900	0.53	0.30
Site O, replicate 3 mean	Core	Entire core	0.51	6.5	0.8	0.18	0.23	0.12	0.07	1760	0.45	0.28
Site A, replicate 2	Core	2-4 cm	10.2	21	8.2	1.07	1.67	0.73	0.61	29800	2.91	2.40
Site A, replicate 2 (duplicate)	Core	2-4 cm	10.4	28	8.7	1.60	1.90	0.81	0.68	31500	4.55	2.81
Site A, replicate 2 mean	Core	2-4 cm	10.3	24	8.5	1.33	1.78	0.77	0.65	30650	3.73	2.60
Site 9, replicate 1	Surface scrape	---	0.59	7.6	1.3	0.19	0.47	0.26	0.13	2020	0.49	0.61
Site 9, replicate 1 (duplicate)	Surface scrape	---	0.78	8.8	1.5	0.30	0.51	0.27	0.15	2580	0.75	0.68
Site 9, replicate 1 mean	Surface scrape	---	0.68	8.2	1.4	0.24	0.49	0.26	0.14	2300	0.62	0.64
Site C, replicate 2	Core	6-8 cm	1.46	16	1.8	0.28	1.02	0.53	0.35	5300	0.85	1.41
Site C, replicate 2 (duplicate)	Core	6-8 cm	1.42	16	1.8	0.41	0.97	0.49	0.33	5030	1.13	1.34
Site C, replicate 2 mean	Core	6-8 cm	1.44	16	1.8	0.34	1.00	0.51	0.34	5165	0.99	1.37
Site C, replicate 3	Surface scrape	---	1.16	12	1.4	0.37	0.62	0.31	0.20	4070	0.90	0.82
Site C, replicate 3 (duplicate)	Surface scrape	---	1.14	13	1.6	0.39	0.64	0.33	0.22	4190	0.98	0.87

Sample	Sample type	Core section	Co	Cr	Cu	Cs	Dy	Er	Eu	Fe	Ga	Gd
			(µg/g)									
Site C, replicate 3 mean	Surface scrape	---	1.15	13	1.5	0.38	0.63	0.32	0.21	4130	0.94	0.85
Site F, replicate 1	Core	6-8 cm	1.10	18	1.4	0.49	0.50	0.26	0.15	4340	1.23	0.65
Site F, replicate 1 (duplicate)	Core	6-8 cm	1.13	19	1.4	0.55	0.50	0.27	0.15	4500	1.34	0.66
Site F, replicate 1 mean	Core	6-8 cm	1.12	19	1.4	0.52	0.50	0.26	0.15	4420	1.28	0.65

Sample	Sample type	Core section	Hf	Hg	Ho	In	Ir	La	Li	Lu	Mg	Mn
			(µg/g)									
Site G, replicate 1	Core	0-2 cm	0.058	<0.02	0.16	0.01	<0.003	3.33	16.3	0.043	14200	112
Site G, replicate 1 (duplicate)	Core	0-2 cm	0.046	<0.02	0.16	<0.01	<0.003	2.90	13.6	0.043	13900	120
Site G, replicate 1 mean	Core	0-2 cm	0.052	<0.02	0.16	<0.01	<0.003	3.11	15.0	0.043	14050	116
Site 2, replicate 1	Core	top-7 cm	0.031	<0.02	0.06	<0.01	<0.003	1.08	4.66	0.019	10700	44.4
Site 2, replicate 1 (duplicate)	Core	top-7 cm	0.014	<0.02	0.07	<0.01	<0.003	0.94	3.80	0.020	11300	53.0
Site 2, replicate 1 mean	Core	top-7 cm	0.02	<0.02	0.06	<0.01	<0.003	1.01	4.23	0.019	11000	48.7
Site K, replicate 1	Core	0-4 cm	0.004	<0.02	0.03	<0.01	<0.003	0.43	1.47	0.008	11200	14.4
Site K, replicate 1 (duplicate)	Core	0-4 cm	0.003	<0.02	0.03	<0.01	<0.003	0.41	1.53	0.009	11900	14.6
Site K, replicate 1 mean	Core	0-4 cm	0.003	<0.02	0.03	<0.01	<0.003	0.42	1.50	0.008	11550	14.5
Site N , replicate 1	Core	0-3 cm	0.016	<0.02	0.05	<0.01	<0.003	0.81	3.67	0.014	8900	24.0
Site N , replicate 1 (duplicate)	Core	0-3 cm	0.018	<0.02	0.06	<0.01	<0.003	0.88	4.05	0.017	9630	25.9
Site N , replicate 1 mean	Core	0-3 cm	0.02	<0.02	0.05	<0.01	<0.003	0.85	3.86	0.015	9265	24.9
Site O, replicate 3	Core	Entire core	0.018	0.05	0.04	<0.01	<0.003	0.72	4.14	0.012	11200	61.7
Site O, replicate 3 (duplicate)	Core	Entire core	0.022	0.05	0.05	<0.01	<0.003	0.92	5.08	0.014	11300	38.8
Site O, replicate 3 mean	Core	Entire core	0.02	0.05	0.04	<0.01	<0.003	0.82	4.61	0.013	11250	50.2
Site A, replicate 2	Core	2-4 cm	0.102	<0.02	0.29	0.03	<0.003	5.87	20.3	0.076	10100	362
Site A, replicate 2 (duplicate)	Core	2-4 cm	0.195	<0.02	0.33	0.04	<0.003	8.14	25.3	0.084	10500	365
Site A, replicate 2 mean	Core	2-4 cm	0.148	<0.02	0.31	0.04	<0.003	7.01	22.8	0.080	10300	364
Site 9, replicate 1	Surface scrape	---	0.023	<0.02	0.09	<0.01	<0.003	2.59	4.31	0.025	9450	36.9
Site 9, replicate 1 (duplicate)	Surface scrape	---	0.033	<0.02	0.09	<0.01	<0.003	3.02	6.41	0.031	10200	41.1
Site 9, replicate 1 mean	Surface scrape	---	0.03	<0.02	0.09	<0.01	<0.003	2.81	5.36	0.028	9825	39.0
Site C, replicate 2	Core	6-8 cm	0.031	<0.02	0.19	<0.01	<0.003	4.21	7.77	0.052	12700	155
Site C, replicate 2 (duplicate)	Core	6-8 cm	0.037	<0.02	0.19	<0.01	<0.003	4.39	9.50	0.053	12900	135
Site C, replicate 2 mean	Core	6-8 cm	0.03	<0.02	0.19	<0.01	<0.003	4.30	8.63	0.052	12800	145
Site C, replicate 3	Surface scrape	---	0.036	<0.02	0.12	<0.01	<0.003	2.70	8.56	0.033	11700	90.6
Site C, replicate 3 (duplicate)	Surface scrape	---	0.032	<0.02	0.12	<0.01	<0.003	2.90	9.00	0.036	11800	85.9
Site C, replicate 3 mean	Surface scrape	---	0.03	<0.02	0.12	<0.01	<0.003	2.80	8.78	0.034	11750	88.3
Site F, replicate 1	Core	6-8 cm	0.038	0.03	0.09	<0.01	<0.003	2.56	11.6	0.030	14200	59.6

Sample	Sample type	Core section	Hf	Hg	Ho	In	Ir	La	Li	Lu	Mg	Mn
			(µg/g)									
Site F, replicate 1 (duplicate)	Core	6-8 cm	0.039	0.03	0.10	<0.01	<0.003	2.67	12.2	0.030	14200	63.5
Site F, replicate 1 mean	Core	6-8 cm	0.04	0.03	0.09	<0.01	<0.003	2.61	11.9	0.030	14200	61.6

Sample	Sample type	Core section	Mo	Nb	Nd	Ni	P	Pb	Pr	Pt	Rb	Re
			(µg/g)									
Site G, replicate 1	Core	0-2 cm	0.34	0.08	4.26	7.91	480	3.58	0.97	<0.02	8.40	<0.01
Site G, replicate 1 (duplicate)	Core	0-2 cm	0.42	0.05	3.99	7.32	456	3.60	0.90	<0.02	4.94	<0.01
Site G, replicate 1 mean	Core	0-2 cm	0.38	0.06	4.13	7.62	468	3.59	0.93	<0.02	6.67	<0.01
Site 2, replicate 1	Core	top-7 cm	0.08	0.05	1.35	2.05	261	1.24	0.30	<0.02	2.46	<0.01
Site 2, replicate 1 (duplicate)	Core	top-7 cm	0.08	0.03	1.31	1.97	262	1.27	0.28	<0.02	1.24	<0.01
Site 2, replicate 1 mean	Core	top-7 cm	0.08	0.04	1.33	2.01	261	1.25	0.29	<0.02	1.85	<0.01
Site K, replicate 1	Core	0-4 cm	0.06	0.01	0.59	0.49	186	0.38	0.12	<0.02	0.28	<0.01
Site K, replicate 1 (duplicate)	Core	0-4 cm	0.05	0.01	0.56	0.49	225	0.36	0.11	<0.02	0.29	<0.01
Site K, replicate 1 mean	Core	0-4 cm	0.06	0.01	0.58	0.49	206	0.37	0.12	<0.02	0.29	<0.01
Site N , replicate 1	Core	0-3 cm	0.25	0.09	1.10	2.29	260	0.60	0.24	<0.02	1.27	<0.01
Site N , replicate 1 (duplicate)	Core	0-3 cm	0.21	0.10	1.16	2.70	298	0.63	0.25	<0.02	1.42	<0.01
Site N , replicate 1 mean	Core	0-3 cm	0.23	0.10	1.13	2.49	279	0.62	0.25	<0.02	1.34	<0.01
Site O, replicate 3	Core	Entire core	0.09	0.03	0.90	1.74	287	0.89	0.20	<0.02	1.56	<0.01
Site O, replicate 3 (duplicate)	Core	Entire core	0.12	0.05	1.15	2.26	292	0.99	0.25	<0.02	2.36	<0.01
Site O, replicate 3 mean	Core	Entire core	0.11	0.04	1.02	2.00	289	0.94	0.23	<0.02	1.96	<0.02
Site A, replicate 2	Core	2-4 cm	0.41	0.11	8.74	20.7	577	12.6	1.90	<0.02	8.11	<0.01
Site A, replicate 2 (duplicate)	Core	2-4 cm	0.43	0.13	11.0	22.1	571	13.0	2.48	<0.02	14.8	<0.01
Site A, replicate 2 mean	Core	2-4 cm	0.42	0.12	9.86	21.4	574	12.8	2.19	<0.02	11.5	<0.01
Site 9, replicate 1	Surface scrape	---	0.25	0.06	2.87	2.32	317	1.46	0.71	<0.02	2.00	<0.01
Site 9, replicate 1 (duplicate)	Surface scrape	---	0.36	0.10	3.30	2.84	369	1.84	0.82	<0.02	3.34	<0.01
Site 9, replicate 1 mean	Surface scrape	---	0.31	0.08	3.08	2.58	343	1.65	0.77	<0.02	2.67	<0.01

Sample	Sample type	Core section	Mo	Nb	Nd	Ni	P	Pb	Pr	Pt	Rb	Re
			(µg/g)									
Site C, replicate 2	Core	6-8 cm	0.46	0.04	5.73	4.06	902	3.09	1.30	<0.02	2.90	<0.01
Site C, replicate 2 (duplicate)	Core	6-8 cm	0.41	0.06	5.50	3.99	916	3.13	1.28	<0.02	4.24	<0.01
Site C, replicate 2 mean	Core	6-8 cm	0.44	0.05	5.61	4.03	909	3.11	1.29	<0.02	3.57	<0.01
Site C, replicate 3	Surface scrape	---	0.26	0.06	3.35	3.37	431	2.31	0.78	<0.02	4.03	<0.01
Site C, replicate 3 (duplicate)	Surface scrape	---	0.21	0.06	3.59	3.54	602	2.38	0.83	<0.02	4.29	<0.01
Site C, replicate 3 mean	Surface scrape	---	0.23	0.06	3.47	3.45	517	2.34	0.81	<0.02	4.16	<0.01
Site F, replicate 1	Core	6-8 cm	0.65	0.07	2.84	3.86	447	1.94	0.70	<0.02	5.18	<0.01
Site F, replicate 1 (duplicate)	Core	6-8 cm	0.62	0.09	2.92	4.18	472	2.04	0.70	<0.02	5.78	<0.01
Site F, replicate 1 mean	Core	6-8 cm	0.63	0.08	2.88	4.02	459	1.99	0.70	<0.02	5.48	<0.01

Sample	Sample type	Core section	Rh	Ru	Sb	Sc	Se	Sm	Sn	Tb	Te	Th
			(µg/g)									
Site G, replicate 1	Core	0-2 cm	0.04	<0.01	0.08	2.3	0.2	1.04	0.21	0.16	0.1	1.17
Site G, replicate 1 (duplicate)	Core	0-2 cm	0.04	<0.01	0.08	1.9	0.2	1.02	0.15	0.16	0.2	1.05
Site G, replicate 1 mean	Core	0-2 cm	0.04	<0.01	0.08	2.1	0.2	1.03	0.18	0.16	0.1	1.11
Site 2, replicate 1	Core	top-7 cm	0.07	0.01	0.06	0.7	<0.1	0.34	0.06	0.057	0.2	0.27
Site 2, replicate 1 (duplicate)	Core	top-7 cm	0.07	0.01	0.07	0.6	<0.1	0.34	0.03	0.059	0.2	0.23
Site 2, replicate 1 mean	Core	top-7 cm	0.07	0.01	0.07	0.7	<0.1	0.34	0.04	0.058	0.2	0.25
Site K, replicate 1	Core	0-4 cm	0.07	<0.01	0.03	0.2	<0.1	0.15	0.01	0.027	0.3	0.05
Site K, replicate 1 (duplicate)	Core	0-4 cm	0.07	<0.01	0.02	0.2	<0.1	0.13	0.01	0.025	0.2	0.05
Site K, replicate 1 mean	Core	0-4 cm	0.07	<0.01	0.03	0.2	<0.1	0.14	0.01	0.026	0.2	0.05
Site N , replicate 1	Core	0-3 cm	0.06	<0.01	0.03	0.5	0.1	0.27	0.04	0.046	0.2	0.21
Site N , replicate 1 (duplicate)	Core	0-3 cm	0.07	<0.01	0.03	0.6	0.1	0.30	0.04	0.047	0.2	0.24
Site N , replicate 1 mean	Core	0-3 cm	0.06	<0.01	0.03	0.6	0.1	0.28	0.04	0.046	0.2	0.23
Site O, replicate 3	Core	Entire core	0.07	0.01	0.06	0.5	<0.1	0.22	0.04	0.039	0.2	0.21
Site O, replicate 3 (duplicate)	Core	Entire core	0.07	0.01	0.06	0.7	<0.1	0.29	0.06	0.046	0.1	0.28
Site O, replicate 3 mean	Core	Entire core	0.07	0.01	0.06	0.6	<0.1	0.25	0.05	0.042	0.2	0.25
Site A, replicate 2	Core	2-4 cm	<0.01	<0.01	0.16	4.6	0.1	2.30	0.30	0.34	0.1	2.14
Site A, replicate 2 (duplicate)	Core	2-4 cm	<0.01	<0.01	0.16	5.6	0.1	2.71	0.44	0.39	0.1	3.04
Site A, replicate 2 mean	Core	2-4 cm	<0.01	<0.01	0.16	5.1	0.1	2.50	0.37	0.36	0.1	2.59
Site 9, replicate 1	Surface scrape	---	0.05	<0.01	0.07	0.8	0.1	0.64	0.08	0.09	0.2	0.77
Site 9, replicate 1 (duplicate)	Surface scrape	---	0.05	<0.01	0.12	0.9	0.2	0.70	0.12	0.10	0.2	0.92
Site 9, replicate 1 mean	Surface scrape	---	0.05	<0.01	0.10	0.8	0.2	0.67	0.10	0.09	0.2	0.85
Site C, replicate 2	Core	6-8 cm	0.04	<0.01	0.09	1.5	0.1	1.33	0.09	0.20	0.1	0.70
Site C, replicate 2 (duplicate)	Core	6-8 cm	0.04	<0.01	0.08	1.8	0.1	1.29	0.12	0.19	0.2	0.81
Site C, replicate 2 mean	Core	6-8 cm	0.04	<0.01	0.09	1.7	0.1	1.31	0.11	0.19	0.2	0.75
Site C, replicate 3	Surface scrape	---	0.04	<0.01	0.04	1.2	<0.1	0.83	0.11	0.12	0.1	0.76
Site C, replicate 3 (duplicate)	Surface scrape	---	0.04	<0.01	0.04	1.3	<0.1	0.86	0.09	0.12	0.1	0.79
Site C, replicate 3 mean	Surface scrape	---	0.04	<0.01	0.04	1.2	<0.1	0.84	0.10	0.12	0.1	0.78

Sample	Sample type	Core section	Rh	Ru	Sb	Sc	Se	Sm	Sn	Tb	Te	Th
			(µg/g)									
Site F, replicate 1	Core	6-8 cm	0.04	<0.01	0.06	1.3	0.1	0.63	0.16	0.09	0.2	0.87
Site F, replicate 1 (duplicate)	Core	6-8 cm	0.04	<0.01	0.06	1.4	0.1	0.66	0.72	0.09	0.2	0.92
Site F, replicate 1 mean	Core	6-8 cm	0.04	<0.01	0.06	1.3	0.1	0.64	0.44	0.09	0.2	0.89

Sample	Sample type	Core section	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
			(µg/g)									
Site G, replicate 1	Core	0-2 cm	39	0.09	0.051	2.11	17	0.023	4.80	0.30	16	2.0
Site G, replicate 1 (duplicate)	Core	0-2 cm	19	0.06	0.054	2.32	11	0.031	4.94	0.31	15	1.1
Site G, replicate 1 mean	Core	0-2 cm	29	0.07	0.053	2.21	14	0.027	4.87	0.30	16	1.6
Site 2, replicate 1	Core	top-7 cm	20	<0.03	0.022	2.19	5.4	0.015	2.27	0.12	4	0.72
Site 2, replicate 1 (duplicate)	Core	top-7 cm	7.6	<0.03	0.022	2.24	4.0	0.011	2.40	0.12	4	0.35
Site 2, replicate 1 mean	Core	top-7 cm	14	<0.03	0.022	2.22	4.7	0.013	2.33	0.12	4	0.53
Site K, replicate 1	Core	0-4 cm	2.2	<0.03	0.009	2.65	1.2	0.007	1.16	0.053	1	0.11
Site K, replicate 1 (duplicate)	Core	0-4 cm	2.4	<0.03	0.010	2.53	1.2	0.004	1.19	0.058	<1	0.11
Site K, replicate 1 mean	Core	0-4 cm	2.3	<0.03	0.010	2.59	1.2	0.005	1.18	0.056	<1	0.11
Site N , replicate 1	Core	0-3 cm	30	0.05	0.015	2.41	3.7	0.016	1.71	0.09	3	0.73
Site N , replicate 1 (duplicate)	Core	0-3 cm	34	0.04	0.018	2.43	4.3	0.014	1.86	0.10	3	0.77
Site N , replicate 1 mean	Core	0-3 cm	32	0.04	0.016	2.42	4.0	0.015	1.79	0.10	3	0.75
Site O, replicate 3	Core	Entire core	11	<0.03	0.013	2.23	3.8	0.012	1.48	0.084	3	0.47
Site O, replicate 3 (duplicate)	Core	Entire core	18	<0.03	0.016	2.23	5.2	0.013	1.68	0.091	4	0.66
Site O, replicate 3 mean	Core	Entire core	15	<0.03	0.014	2.23	4.5	0.013	1.58	0.088	4	0.56
Site A, replicate 2	Core	2-4 cm	72	0.03	0.091	0.85	43	0.048	7.60	0.54	51	4.2
Site A, replicate 2 (duplicate)	Core	2-4 cm	159	0.06	0.098	0.92	56	0.029	8.33	0.61	54	6.7
Site A, replicate 2 mean	Core	2-4 cm	116	0.04	0.095	0.89	49	0.039	7.97	0.58	52	5.4
Site 9, replicate 1	Surface scrape	---	10	0.03	0.031	2.46	4.7	0.021	2.80	0.19	6	0.62
Site 9, replicate 1 (duplicate)	Surface scrape	---	20	0.05	0.037	2.65	6.3	0.027	3.03	0.21	6	1.0
Site 9, replicate 1 mean	Surface scrape	---	15	0.04	0.034	2.56	5.5	0.024	2.91	0.20	6	0.81
Site C, replicate 2	Core	6-8 cm	14	0.06	0.066	2.65	11	0.022	6.50	0.40	11	0.79
Site C, replicate 2 (duplicate)	Core	6-8 cm	20	0.07	0.063	2.36	11	0.019	6.19	0.37	10	1.1
Site C, replicate 2 mean	Core	6-8 cm	17	0.07	0.064	2.51	11	0.021	6.34	0.38	10	0.96
Site C, replicate 3	Surface scrape	---	19	0.04	0.039	1.74	7.9	0.018	3.88	0.23	7	0.91
Site C, replicate 3 (duplicate)	Surface scrape	---	21	0.03	0.040	1.75	8.6	0.019	4.03	0.26	13	0.94
Site C, replicate 3 mean	Surface scrape	---	20	0.04	0.040	1.75	8.3	0.018	3.96	0.25	10	0.92
Site F, replicate 1	Core	6-8 cm	25	0.06	0.032	2.79	9.1	0.018	3.23	0.19	6	0.98

Sample	Sample type	Core section	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
			(µg/g)									
Site F, replicate 1 (duplicate)	Core	6-8 cm	31	0.06	0.033	2.87	9.4	0.018	3.31	0.20	7	1.10
Site F, replicate 1 mean	Core	6-8 cm	28	0.06	0.032	2.83	9.3	0.018	3.27	0.19	6	1.04

Appendix A14: June 2018 Saibai and Boigu samples: dissolved metals data

Sample	Cd	Co	Cu	Ni
	(µg/L)			
A	0.0056	0.003	0.44	0.19
S1 mean	0.005	0.003	0.36	0.165
S2	0.0042	0.002	0.31	0.15
8	0.0061	0.006	0.46	0.19
8 Site duplicate	0.0058	0.007	0.44	0.19
8 mean	0.0059	0.006	0.45	0.19
S3	0.0039	0.002	0.31	0.15
B3	0.0045	0.001	0.37	0.17
B4	0.0041	0.006	0.27	0.15
B5	0.0040	0.002	0.30	0.16
B1	0.0047	0.005	0.35	0.17
B1 site duplicate	0.0053	0.022	0.43	0.20
B1 site mean	0.005	0.013	0.39	0.18
B2	0.0034	0.001	0.28	0.14

Appendix A15: June 2018 Saibai and Boigu samples: blanks & limits of detection

Sample	Date	Cd	Co	Cu	Ni
		(µg/L)			
Method blank 1	3.07.18	0.0002	0.0005	0.002	0.010
Method blank 2	3.07.18	-0.0002	-0.0006	0.000	-0.002
Method blank 3	3.07.18	-0.0002	0.0004	-0.001	-0.005
Method blank 4	3.07.18	0.0002	-0.0004	-0.001	-0.003
Method blank 1	4.07.18	-0.0001	0.0004	0.001	0.000
Method blank 2	4.07.18	0.0001	0.0000	0.001	0.001
Method blank 3	4.07.18	0.0000	-0.0001	0.000	0.000
Method blank 4	4.07.18	-0.0001	-0.0003	-0.002	-0.001
LOD (3σ)		0.0005	0.0013	0.004	0.014

Appendix A16: June 2018 Saibai and Boigu samples - certified reference materials analysis

Sample	Cd	Co	Cu	Ni
	(µg/L)	(µg/L)	(µg/L)	(µg/L)
NASS-5 3.07.18	0.0217	0.0100	0.306	0.241
Certified value	0.023±0.003	0.011±0.003	0.297±0.046	0.253±0.028
% recovery	94	91	103	95
NASS-5 04.07.18	0.0224	0.0091	0.304	0.2494
Certified value	0.023±0.003	0.011±0.003	0.297±0.046	0.253±0.028
% recovery	97	83	102	99
CASS-6 3.07.18	0.0255	0.0631	0.516	0.386
Certified value	0.0217±0.0018	0.0672±0.0052	0.530±0.032	0.418±0.040
% recovery	117	94	97	92

Appendix A17: June 2018 Saibai and Boigu samples - duplicates

Sample	Cd	Co	Cu	Ni
	(µg/L)	(µg/L)	(µg/L)	(µg/L)
S1	0.0051	0.003	0.36	0.17
S1 duplicate	0.0048	0.002	0.36	0.16
8	0.0061	0.006	0.46	0.19
8 Site duplicate	0.0058	0.007	0.44	0.19
B1 site duplicate	0.0053	0.022	0.43	0.20
B1 site mean	0.0050	0.013	0.39	0.18

Appendix A18: June 2018 Saibai and Boigu samples - field blanks

Site	As	Cd	Co	Cu	Ni	Zn
	(µg/L)					
Saibai field blank	<0.05	0.08	<0.001	0.02	-0.02	0.12
Boigu field blank	<0.05	0.11	<0.001	<0.01	<0.03	<0.08
MQ Filter blank	<0.05	0.07	<0.001	<0.01	<0.03	0.29
MQ water	<0.05	0.03	<0.001	<0.01	<0.03	<0.08

Appendix A19: June 2018 Saibai and Boigu samples - spike recovery data

Spike recovery (%)	Co	Ni	Cu	Zn	Cd
S2	98	99	101	91	98

Appendix A20: June 2018 Saibai and Boigu samples - dissolved As certified reference material analysis

Sample	As (µg/L)
CASS-6	0.95
CASS-6 duplicate	1.09
CASS-6 mean n=2	1.02
Certified value	1.02±0.10
% recovery	100
NASS-6	1.30
NASS-6 duplicate	1.23
NASS-6 mean n=2	1.26
Certified value	1.40±0.12
% recovery	90

Appendix A21: June 2018 Saibai and Boigu samples - dissolved As duplicates and blanks

Sample	As (µg/L)
S1	1.12
S1 duplicate	1.36
S1 mean	1.24
Site 8	1.12
Site 8 Site duplicate	1.29
Site 8 mean	1.20
B1	1.18
B1 Site duplicate	1.32
B1 mean	1.25
Site 8 (field blank)	<0.05
Boigu filter blank	<0.05
MQ filter blank	<0.05
MQ water	<0.05

Appendix A22: June 2018 Saibai and Boigu samples - TSS trace element data

Site	Ag	Al	As	Au	Ba	Be	Bi	Ca	Cd	Ce	Co
	(µg/g)										
A	<0.16	21100	12.0	<9.6	21.8	0.95	<0.41	42800	<0.35	22.9	14.2
S1	<0.16	17400	10.7	<9.6	21.6	0.66	<0.41	65300	<0.35	17.4	9.9
S2	<0.16	14200	11.0	<9.6	16.2	0.72	<0.41	89300	<0.35	19.0	12.2
Site 8	<0.16	19700	13.3	<9.6	30.7	0.9	<0.41	37800	<0.35	18.4	12.8
S3	<0.16	7600	10.4	<9.6	8.4	0.36	<0.41	81300	<0.35	11.9	8.4
B3	<0.16	11600	10.4	<9.6	10.7	0.56	<0.41	38900	<0.35	12.6	10.2
B4	<0.16	17400	10.7	<9.6	17.7	0.77	<0.41	117000	<0.35	17.7	10.2
B5	<0.16	10600	11.8	<9.6	9.2	0.57	<0.41	84400	<0.35	17.2	9.7
B1	<0.16	16200	11.6	<9.6	16.5	0.75	<0.41	97000	<0.35	18.0	10.2
B1	<0.16	16300	11.8	<9.6	16.2	0.80	<0.41	95200	<0.35	17.7	10.2
B2	<0.16	16200	10.2	<9.6	15.6	0.72	<0.41	115000	<0.35	16.0	9.1
LOD	0.16	504	0.20	9.6	3.9	0.03	0.41	478	0.35	1.25	0.3

Site	Cr	Cs	Cu	Dy	Er	Eu	Fe	Ga	Gd	Hf	Hg
	(µg/g)										
A	32.4	2.42	24.7	2.24	0.80	0.80	33100	5.8	3.19	<0.27	<0.68
S1	18.7	1.00	16.2	1.58	0.69	0.68	25500	4.6	2.50	<0.27	<0.68
S2	39.2	1.17	18.2	1.89	0.91	0.76	22800	4.2	2.80	<0.27	<0.68
Site 8	27.2	2.0	22.5	1.9	0.78	0.8	30600	5.1	2.90	<0.27	<0.68
S3	17.5	8.68	13.8	1.76	0.75	0.61	17700	1.8	2.33	<0.27	<0.68
B3	21.7	4.24	17.3	1.61	0.60	0.58	23600	3.1	2.36	<0.27	<0.68
B4	33.0	6.10	15.5	1.59	0.66	0.66	24600	4.5	2.44	0.29	<0.68
B5	23.8	2.65	13.5	1.53	0.66	0.58	21700	3.0	2.42	<0.27	<0.68
B1	31.8	2.47	14.9	1.88	0.74	0.72	26400	4.4	2.81	<0.27	<0.68
B1	30.1	2.2	14.6	1.8	0.74	0.7	26300	4.4	2.8	<0.27	<0.68
B2	26.3	2.77	12.6	1.58	0.65	0.54	21900	4.2	2.17	<0.27	<0.68
LOD	3.5	1.70	4.1	0.02	0.01	0.01	42	0.3	0.03	0.27	0.68

Site	Ho	In	Ir	La	Li	Lu	Mg	Mn	Mo	Nb	Nd
	(µg/g)										
A	0.32	<0.19	<0.22	8.38	40.2	<0.18	11900	606	0.87	<0.85	11.9
S1	<0.19	<0.19	<0.22	6.84	34.4	<0.18	13500	442	0.78	<0.85	10.3
S2	0.30	<0.19	<0.22	6.86	33.0	<0.18	14600	490	0.33	<0.85	10.4
Site 8	0.27	<0.19	<0.22	7.40	38.2	<0.18	12900	547	0.80	<0.85	10.4
S3	0.22	<0.19	<0.22	4.50	18.9	<0.18	12700	395	0.66	<0.85	7.32
B3	0.24	<0.19	<0.22	4.83	25.5	<0.18	9460	466	0.44	<0.85	7.62
B4	0.25	<0.19	<0.22	7.31	32.9	<0.18	15700	389	0.91	<0.85	8.93
B5	0.20	<0.19	<0.22	5.39	25.4	<0.18	15500	424	0.27	<0.85	8.16
B1	0.29	<0.19	<0.22	7.68	32.7	<0.18	13400	454	0.57	<0.85	10.3
B1	0.28	<0.19	<0.22	7.60	32.5	<0.18	13900	445	0.50	<0.85	10.3
B2	0.22	<0.19	<0.22	6.94	31.3	<0.18	15500	363	0.46	<0.85	9.05
LOD	0.19	0.19	0.22	0.09	0.2	0.18	71	3.4	0.50	0.85	0.14

Site	Ni	Os	P	Pb	Pd	Pr	Rb	Re	Rh	Ru	S
	(µg/g)										
A	31.4	<1.3	694	19.5	<0.51	2.66	24.1	<0.11	<0.85	<0.19	1650
S1	22.5	<1.3	861	12.3	<0.51	2.02	22.0	<0.11	<0.85	<0.19	1970
S2	28.6	<1.3	638	12.1	<0.51	2.33	19.9	<0.11	<0.85	<0.19	1770
Site 8	28.4	<1.3	816	17.2	<0.51	2.30	22.6	<0.11	<0.85	<0.19	2590
S3	16.0	<1.3	615	10.2	<0.51	1.55	11.1	<0.11	<0.85	<0.19	1700
B3	22.1	<1.3	465	13.9	<0.51	1.68	13.3	<0.11	<0.85	<0.19	1330
B4	24.5	<1.3	694	13.0	<0.51	2.18	20.5	<0.11	<0.85	<0.19	2330
B5	20.2	<1.3	636	10.7	<0.51	1.83	14.8	<0.11	<0.85	<0.19	3120
B1	25.0	<1.3	629	13.7	<0.51	2.37	19.6	<0.11	<0.85	<0.19	1530
B1	24.0	<1.3	640	13.4	<0.51	2.30	19.4	<0.11	<0.85	<0.19	1920
B2	21.8	<1.3	723	10.0	<0.51	2.07	20.4	<0.11	<0.85	<0.19	1610
LOD	2.3	1.3	259	0.6	0.51	0.03	0.5	0.11	0.85	0.19	819

Site	Sb	Sc	Se	Sm	Sn	Sr	Ta	Tb	Te	Th	Tl
	(µg/g)										
A	<0.57	7.44	0.23	3.09	<1.61	414	<0.81	0.42	<1.1	3.93	<0.74
S1	1.15	5.29	<0.19	2.41	<1.61	640	<0.81	0.34	<1.1	3.27	<0.74
S2	<0.57	6.10	0.29	2.99	<1.61	1140	<0.81	0.46	<1.1	3.11	<0.74
Site 8	0.90	4.70	0.40	2.80	<1.61	386	<0.81	0.40	<1.1	3.50	<0.74
S3	0.87	<2.09	0.23	2.12	<1.61	808	<0.81	0.31	<1.1	1.92	<0.74
B3	<0.57	4.01	<0.19	2.13	<1.61	385	<0.81	0.32	<1.1	2.50	<0.74
B4	0.62	4.09	0.26	2.44	<1.61	117	<0.81	0.34	<1.1	2.90	<0.74
B5	0.62	2.51	<0.19	2.11	<1.61	886	<0.81	0.31	<1.1	2.42	<0.74
B1	<0.57	4.88	0.24	2.57	<1.61	944	<0.81	0.38	<1.1	3.24	<0.74
B1	<0.57	4.90	0.20	2.60	<1.61	936	<0.81	0.40	<1.1	3.20	<0.74
B2	0.72	3.02	<0.19	2.29	<1.61	1150	<0.81	0.33	<1.1	2.92	<0.74
LOD	0.57	2.09	0.19	0.04	1.61	1	0.81	0.01	1.10	0.13	0.74

Site	Tm	U	V	W	Y	Yb	Zn	Zr
	(µg/g)							
A	0.11	0.93	56.2	<0.19	8.37	0.55	85.4	10.5
S1	0.08	0.96	45.8	<0.19	7.33	0.40	61.5	9.0
S2	0.10	1.42	44.0	<0.19	9.17	0.55	67.0	6.1
Site 8	0.10	0.93	52.7	<0.19	7.84	0.60	114	10.1
S3	0.08	0.96	27.3	<0.19	7.45	0.43	67.9	3.1
B3	0.08	0.69	37.0	<0.19	6.40	0.44	62.7	5.7
B4	0.09	1.37	45.0	<0.19	7.42	0.50	78.7	7.4
B5	0.09	1.07	32.8	<0.19	6.96	0.49	76.7	3.5
B1	0.11	1.16	46.6	<0.19	7.98	0.55	63.8	6.9
B1	0.1	1.15	45.4	<0.19	7.81	0.50	62.9	7.2
B2	0.09	1.22	41.5	<0.19	6.90	0.50	62.8	7.8
LOD	0.04	0.01	0.3	0.19	0.05	0.01	22.5	2.0

Appendix A23: June 2018 Saibai and Boigu samples - TSS trace elements duplicate measurements

Sample	Site 8	Site 8 duplicate	B1	B1 duplicate	LOD
	(µg/g)				
Ag	<0.16	<0.16	<0.16	<0.16	0.16
Al	19507	19887	16199	16480	504
As	13.3	13.2	11.6	12.1	0.2
Au	<9.55	<9.55	<9.55	<9.55	9.55
Ba	42.3	19.1	16.5	15.9	3.9
Be	0.97	0.86	0.75	0.76	0.03
Bi	<0.41	<0.41	<0.41	<0.41	0.41
Ca	36100	39400	97000	94000	478
Cd	<0.35	<0.35	<0.35	<0.35	0.35
Ce	19.1	17.6	18.0	17.3	1.2
Co	12.8	12.7	10.2	10.3	0.3
Cr	21.9	32.5	31.8	28.4	3.5
Cs	1.82	2.19	2.47	1.98	1.70
Cu	22.2	22.9	14.9	14.4	4.1
Dy	1.84	1.88	1.88	1.80	0.02
Er	0.75	0.80	0.74	0.75	0.01
Eu	0.74	0.78	0.72	0.66	0.01
Fe	30200	31000	26400	26200	42
Ga	5.3	4.9	4.4	4.4	0.3
Gd	2.82	2.88	2.81	2.73	0.03
Hf	<0.27	<0.27	<0.27	<0.27	0.27
Hg	<0.68	<0.68	<0.68	<0.68	0.68
Ho	0.29	0.26	0.29	0.28	0.19
In	<0.19	<0.19	<0.19	<0.19	0.19
Ir	<0.22	<0.22	<0.22	<0.22	0.22
La	8.11	6.62	7.68	7.49	0.09
Li	38.3	38.1	32.7	32.3	0.2
Lu	<0.18	<0.18	<0.18	<0.18	0.18
Mg	12700	13100	13400	14300	71
Mn	543	552	454	436	3
Mo	0.89	0.70	0.57	0.51	0.50
Nb	<0.85	<0.85	<0.85	<0.85	0.85
Nd	11.1	9.64	10.3	10.3	0.1
Ni	29.0	27.8	25.0	23.0	2.3
Os	<1.3	<0.85	<0.85	<0.85	1.3
P	886	746	629	652	259
Pb	17.7	16.8	13.7	13.1	0.6
Pd	<0.51	<0.51	<0.51	<0.51	0.51
Pr	2.54	2.14	2.37	2.16	0.03
Rb	23.5	21.6	19.6	19.3	0.5
Re	<0.1	<0.1	<0.1	<0.1	0.11
Rh	<0.85	<0.85	<0.85	<0.85	0.85

Sample	Site 8	Site 8 duplicate	B1	B1 duplicate	LOD
	(µg/g)				
Ru	<0.19	<0.19	<0.19	<0.19	0.19
S	2780	2400	1530	2300	819
Sb	1.02	0.75	0.46	0.40	0.57
Sc	5.78	3.64	4.88	4.96	2.09
Se	0.45	0.34	0.24	0.25	0.19
Sm	2.74	2.84	2.57	2.54	0.04
Sn	<1.6	<1.6	<1.6	<1.6	1.6
Sr	384	389	944	928	1
Ta	<0.81	<0.81	<0.81	<0.81	0.81
Tb	0.38	0.40	0.38	0.36	0.01
Te	<1.1	<1.1	<1.1	<1.1	1.1
Th	3.62	3.34	3.24	3.25	0.13
Tl	<0.74	<0.74	<0.74	<0.74	0.74
Tm	0.09	0.09	0.11	0.10	0.04
U	0.88	0.97	1.16	1.14	0.01
V	52.7	52.8	46.6	44.2	0.3
W	<0.19	<0.19	<0.19	<0.19	0.19
Y	7.84	7.84	7.98	7.64	0.05
Yb	0.61	0.49	0.55	0.54	0.01
Zn	145	83.7	63.8	62.0	23
Zr	9.8	10.4	6.9	7.5	2.0

Appendix A24: June 2018 Saibai and Boigu samples - TSS metals certified reference material analysis

Sample	Cd	Co	Cr	Cu	Hg	Ni	Pb	V	Zn
	(µg/g)								
ERM-CC018 replicate-1	5.96	5.79	139	84.2	1.80	27.7	313	18.7	328.2
ERM-CC018 replicate-2	6.00	5.47	143	84.4	1.33	26.0	310	17.2	341.7
ERM-CC018 replicate-3	5.92	5.73	142	82.4	1.61	27.0	315	18.4	341.4
ERM-CC018 Mean	5.96	5.66	141	83.7	1.58	26.9	313	18.1	337.1
Certified value	5.4	5.90	129	80.0	1.38	25.8	289±10	19.4	313.0
% Recovery	110	96	109	105	115	104	108	93	108

APPENDIX B: COMMUNITY SURVEY QUESTIONS

OCEANS AND ATMOSPHERE

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Local survey of coastal water quality

Date:

Time:

Community:

How long have you been living in the community:

- ☐ Less than a year
- ☐ 1-5 years
- ☐ 5-10 years
- ☐ 10-20 years
- ☐ 20-30 years
- ☐ 30-40 years
- ☐ 40-50 years
- ☐ More than 50 years

Gender: ☐ Male ☐ Female

Before we begin the survey, there is some background material to show you about the concepts used in this survey

Question 1: Select the option that you think describes the current condition of your local marine environment?

- ☐ NOT SURE
- ☐ VERY GOOD
- ☐ GOOD
- ☐ POOR
- ☐ VERY POOR

Question 2: Since you have been living on the island, have you seen any changes to your local sea country and marine environment?

- ☐ NOT SURE
- ☐ NO
- ☐ YES MARINE ENVIRONMENT

If your answer is yes, please describe:

Have you noticed:

- | | | |
|--------------|-----------------------------|------------------------------|
| Less turtles | ☐ NO | ☐ YES |
| More turtles | ☐ NO | ☐ YES |
| Less dugong | ☐ NO | ☐ YES |
| More dugong | ☐ NO | ☐ YES |
| Less fish | ☐ NO | ☐ YES |
| More fish | ☐ NO | ☐ YES |
| Algal blooms | ☐ NO | ☐ YES |

Comments:

CHANGES IN THE APPEARANCE OF ANIMALS:

- | | | |
|--------------------------|-----------------------------|------------------------------|
| Colour of fish meat | ☐ NO | ☐ YES |
| Smaller sizes of animals | ☐ NO | ☐ YES |
| Dead fish | ☐ NO | ☐ YES |

Comments:

Are there any further comments you would like to make about changes to your marine environment?

Comments:

Question 3: Do your coastal waters become muddier after changes in weather conditions?

- ☐ UNSURE
- ☐ NO ☐ Unpredictable
- ☐ YES ☐ After any rainfall
- ☐ After high rainfall
- ☐ After windy conditions
- ☐ After both rainfall and wind
- ☐ Other...

Question 4: What is the most common length of time your coastal waters would be muddy?

- ☐ UNSURE
- ☐ ALWAYS - ALL YEAR OF MUDDY WATERS
- ☐ MORE THAN 2 WEEKS OF MUDDY WATERS
- ☐ BETWEEN 1 AND 2 WEEKS OF MUDDY WATERS
- ☐ BETWEEN 2 to 5 DAYS OF MUDDY WATERS
- ☐ A FEW HOURS OF MUDDY WATERS
- ☐ NO MUDDY WATERS
- ☐ Other...

Question 5: Since you have been living on the island, do you think the level of muddiness in the coastal waters around your island community has changed?

- ☐ UNSURE
- ☐ BECOME LESS MUDDIER
- ☐ STAYED THE SAME
- ☐ BECOME MORE MUDDIER

Question 6: While you have lived on the island, have you ever not seen muddy waters all the way around your island?

- ☐ UNSURE
- ☐ NO Muddy water always surround the island
- ☐ YES Please explain when you have not seen muddy waters

Comment:

Question 7: Do you think the level of muddiness in the coastal waters around your island community changes across the seasons?

- ☐ UNSURE
- ☐ NO ☐ Muddy level similar across all seasons
- ☐ YES ☐ Muddy level changes with seasons

Comment:

Question 8: Have you noticed any colour changes to the coastal waters around your island community?

- ☐ UNSURE
- ☐ NEVER
- ☐ YES Did you notice what contributed to the colour change?

Select from one or more options or provide your own explanation

- ☐ Unsure of the colour change
- ☐ Currents brought in different colour of coastal waters from outside source
- ☐ Local runoff from a creek on the island brought in different colour waters
- ☐ Others....

Question 9: Since you have been living on the island, have you noticed any changes in the frequency of colour changes to the coastal waters around your island community?

- ☐ UNSURE
- ☐ LESS COLOUR CHANGES IN YOUR COASTAL WATERS
- ☐ COLOUR OF YOUR COASTAL WATER HAS STAYED THE SAME
- ☐ MORE COLOUR CHANGES IN YOUR COASTAL WATERS

Question 10: Are there any further comments you would like to make about your local seawater quality?

