Stantec

EX-HMAS ADELAIDE ENVIRONMENTAL MONITORING 2023

Sediment Quality, Bioaccumulation and Invasive Pests

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Executive Summary

Background

The Department of Planning and Environment – Crown Lands commissioned Stantec (previously Cardno) to carry out monitoring of the Ex-HMAS Adelaide Artificial Reef and Dive Site according to the Ex-HMAS Adelaide Long Term Management and Monitoring Plan as per the requirement of the sea dumping permit No.SD2008/1062. The monitoring plan outlines environmental and structural monitoring requirements over the operational life of the vessel as a dive site and prescribes pest species surveys, bioaccumulation, and sediment quality studies be completed in 2023. The ship is located on the seabed approximately 1.87 km offshore from Avoca Beach, NSW, and is made of steel and aluminium alloy. Prior to scuttling in 2011, it was prepared according to the Department of Sustainability, Environment, Water, Population and Communities' standards, including removal of potential contaminants.

The overall aim of this study is to ensure that there are no environmental risks around biosecurity (introduced marine pests) and contamination from corrosion of metals or paints. The study was comprised of three main components, each with specific aims:

1. Pest species and biosecurity – to determine if the ship has provided settlement surface for any introduced marine pests.
2. Bioaccumulation – to determine if there has been uptake of zinc chromate paint into tissues of resident biota.
3. Sediment quality – to determine if metal corrosion and degradation of protective paint layers have impacted the surrounding marine environment.

This study continues from a succession of previous baseline and monitoring surveys that have been conducted since 2011.

Methodology

1. Introduced Marine Pest Survey

Visual surveys were conducted by a team of two divers recording video along 16 line transects across the exterior of the ship. Photos were also taken at 12 fixed-photo locations on the exterior of the ship, as well as of any other incidental sightings of potential marine pests or threatened/protected species. All fish species observed were recorded. Samples of all potential marine pests observed were collected. Seven 0.4 m^2 surface scrapings were collected from the exterior of the ship and samples were sorted into major taxonomic groups in the laboratory. Video/photo footage and scraping samples were reviewed and marine pest species identified and validated by NSW Fisheries or the Australian Museum Marine Invertebrates Section.

2. Bioaccumulation Survey

Approximately 30 ascidian individuals (*Herdmania momus*) were collected from three sites within each of three monitoring and two reference locations. The tissue from 15–20 of the ascidians from

each site were combined to form a composite sample of adequate size for chemical tissue analysis (~100 g). Samples were sent to National Measurement Institute for analyses of trace metals chromium and zinc. Results were analysed to determine any spatial differences in concentrations of trace metals in invertebrate tissues between monitoring and reference locations.

3. Sediment Quality Survey

Sediment samples were collected from monitoring and reference locations by deploying benthic grabs from a boat. Samples were sent to Australian Laboratory Services for analyses of trace metals Aluminium, Iron, Chromium, Copper, Lead, Nickel, and Zinc. Results were averaged and compared to determine temporal and spatial differences in concentrations of trace metals in sediments between monitoring and reference locations over time since scuttling.

Findings

1. Introduced Marine Pest Survey

No species listed by NSW Department of Primary Industries as marine pests likely to occur in NSW were identified during visual surveys or in surface scrapings in 2023.

2. Bioaccumulation Survey

Mean concentration of chromium in *H. momus* was generally similar at impact and control locations. Mean concentration of zinc in *H. momus* fluctuated slightly among impact locations but were similar to the range recorded at control locations.

3. Sediment Quality Survey

Mean heavy metal concentrations in samples collected 147 months post-scuttling (July 2023) were generally similar to those collected one month (May 2011) and 62 months (June 2016) post-scuttling, with the exception of substantially lower levels of aluminium in 2023 compared with 2016. Mean heavy metal concentrations in samples collected 147 months post-scuttling at impact locations were generally similar to or lower than at control locations, apart from copper which was higher at impact locations. Concentrations of all metals were well below the ANZECC/ARMCANZ (2000) interim sediment quality guidelines lower trigger values where available.

Conclusions

Since no marine pests were identified during surveys in 2023, it is not considered likely that the Ex-HMAS Adelaide has provided a settlement surface for any invasive species. Similar ranges of zinc and chromium levels recorded in the tissues of ascidians on the vessel and reference locations indicate no uptake of metals potentially leached by zinc chromate paint by resident biota. Concentrations of all metals in sediments were below guideline values. Overall, it was considered that the Ex-HMAS Adelaide presents no risk to the marine environment.

Acronyms / Abbreviations

ANZECC/ARMCANZ	Australian and New Zealand Environment and Conservation Council/ Agriculture and Resource Management Council of Australia and New Zealand
APMPL	Australian Priority Marine Pest List
DGV	Default Guideline Value
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities
EC50	Median effective concentration
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectrometry
ICP-MS	Coupled Plasma-Mass Spectrometry
ICPMS	Inductively Coupled Plasma Mass Spectrometry
IMP	Introduced Marine Pest
ISQG	Interim Sediment Quality Guidelines
LAT	Lowest Astronomical Tide
LOEC	Lowest Observed Effect Concentration
LTMMP	Long Term Management and Monitoring Plan
NAGD	National Assessment Guidelines for Dredging
NATA	National Association of Testing Authorities
NODG	National Ocean Disposal Guideline for dredged material
NOEC	No Observed Effects Concentrations
PCBs	Polychlorinated Biphenols
QA/QC	Quality Assurance / Quality Control

Glossary

Bioaccumulation	Accumulation of a substance in an organism or ecosystem over time
Bioavailable	Describing a substance that has the potential for uptake by a living organism
Biofouling	Accumulation of organisms on a structure
Biomagnify	Increasing concentration of a substance in a food chain
Biosecurity	Measures aimed at preventing introduction or spread of harmful organisms
Contaminants	A polluting substance
Dissolution	Process of mixing a solute and solvent to form a solution
Ecological niche	The role or space an organism fills in an ecosystem
Nauplii	The first larval stage of many crustaceans
Sentinel organism	Non-resident organism used to detect accumulation of toxicants in tissues
Toxicants	Substances from an external source than can damage an organism
Toxicity	Degree to which a substance can damage an organism

1 INTRODUCTION

1.1 BACKGROUND

Stantec Australia Pty Ltd (formerly Cardno (NSW/ACT) trading as Cardno Ecology Lab Pty Ltd) was commissioned by the NSW Department of Planning and Environment – Crown Lands (the Department), to carry out monitoring of sediment quality, bioaccumulation and invasive pests associated with the Ex-HMAS Adelaide Artificial Reef and Dive Site as per the requirement of the sea dumping permit No.SD2008/1062. The permit requires that monitoring is undertaken according to the Ex-HMAS Adelaide Long Term Management and Monitoring Plan (LTMMP) (Advisian 2018).

The Ex-HMAS Adelaide (the vessel) was gifted from the Australian Government to the NSW Government for the specific purpose of creating an artificial dive reef. Following a rigorous assessment and approvals process, the ship was subsequently scuttled offshore from Avoca Beach on the Central Coast of NSW, Australia on 13 April 2011 (Figure 1-1). Prior to approval being granted for the project, a comprehensive environmental assessment was undertaken in accordance with state and federal environmental legislation. This included approval under the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) and obtaining a Permit issued under the Environment Protection (Sea Dumping) Act 1981 from the commonwealth Department of the Environment (DoE), formerly the Department for Sustainability, Environment, Water, Population and Communities (DSEWPaC).

A condition of the Permit was that NSW DPI – Lands must implement the proposed Long-Term Monitoring and Management Plan (LTMMP), which was prepared in March 2011 (Worley Parsons 2011a) and updated in 2018 (Advisian 2018 – the current 'Plan'). The current Plan outlines environmental and structural monitoring requirements over the operational life of the vessel as a dive site, estimated to be 40 years. The focus of the monitoring is to inform management actions and contingency measures to minimise potential risks to users of the artificial reef and the marine environment.

The current Plan considers the results of all monitoring undertaken to date and recommendations made following the first five years of post-scuttling monitoring. Consistent with the current Plan, pest species survey, bioaccumulation and sediment quality studies are due to be completed in 2023. All survey methodology must align with the requirements described in the current Plan.

1.2 STUDY AREA

The Ex-HMAS Adelaide artificial reef and dive site is located within Bulbararing Bay, approximately 1.87 km offshore from Avoca Beach. The ship lies at a depth of approximately 32 m to 34 m of water at Lowest Astronomical Tide (LAT) and is embedded approximately 1 – 2 m into the flat, sandy, seabed. There is a minimum of 6 m of sand overlying bedrock. The vessel is orientated with the bow facing into the prevailing ESE swell direction (Figure 1-1).

The ship is 138.1 m in length, with a beam of 14.3 m and an original displacement of 4,200 tonnes. The hull is made of steel and the superstructure of aluminium alloy. Heights are approximately 12 m to the main deck, 18 m to the bridge, 24 m to the top of the foremast (the mast closest to the bow), and 39 m to the top of the mainmast (NSW Government 2011). Preparation for scuttling involved the removal of the main mast structures for safety and navigation reasons and stripping of machinery, hatches and any items that could pose a risk to divers or the environment. Potential contaminants such as fuels, oils, heavy metals, batteries and electrical items containing polychlorinated biphenols (PCBs) were removed. Diver access holes were cut into the sides of the hull, floors, and ceilings to allow extra vertical access between decks and to allow light penetration. Further holes were also made to allow air to escape during the scuttling process (NSW Government 2011).

The Ex-HMAS Adelaide was prepared to meet DSEWPaC standards which were specified during the months of preparation prior to scuttling. DSEWPaC had conducted a series of inspections to confirm that its detailed requirements were achieved.

1.3 AIMS AND OBJECTIVES

The overall aim of this study is to meet the requirements of the current Plan in ensuring there is no environmental risks around biosecurity (introduced marine pests) and contamination from corrosion of metals or paints. The study has therefore been broken into three components, the aims of which are outlined below:

- **Pest species and biosecurity** – to undertake a pest species survey to understand if the ship has provided a settlement surface for any introduced marine pests (IMPs).
- **Bioaccumulation** – to collect tissue samples from suitable biota to determine whether there has been any uptake of zinc chromate paint into tissues of resident biota.
- **Sediments** – to collect sediment samples to understand if metal corrosion and degradation of protective paint layers may be influencing/impacting the surrounding marine environment and whether benthic organisms could be affected by potential metal enrichment of sediments around the vessel.

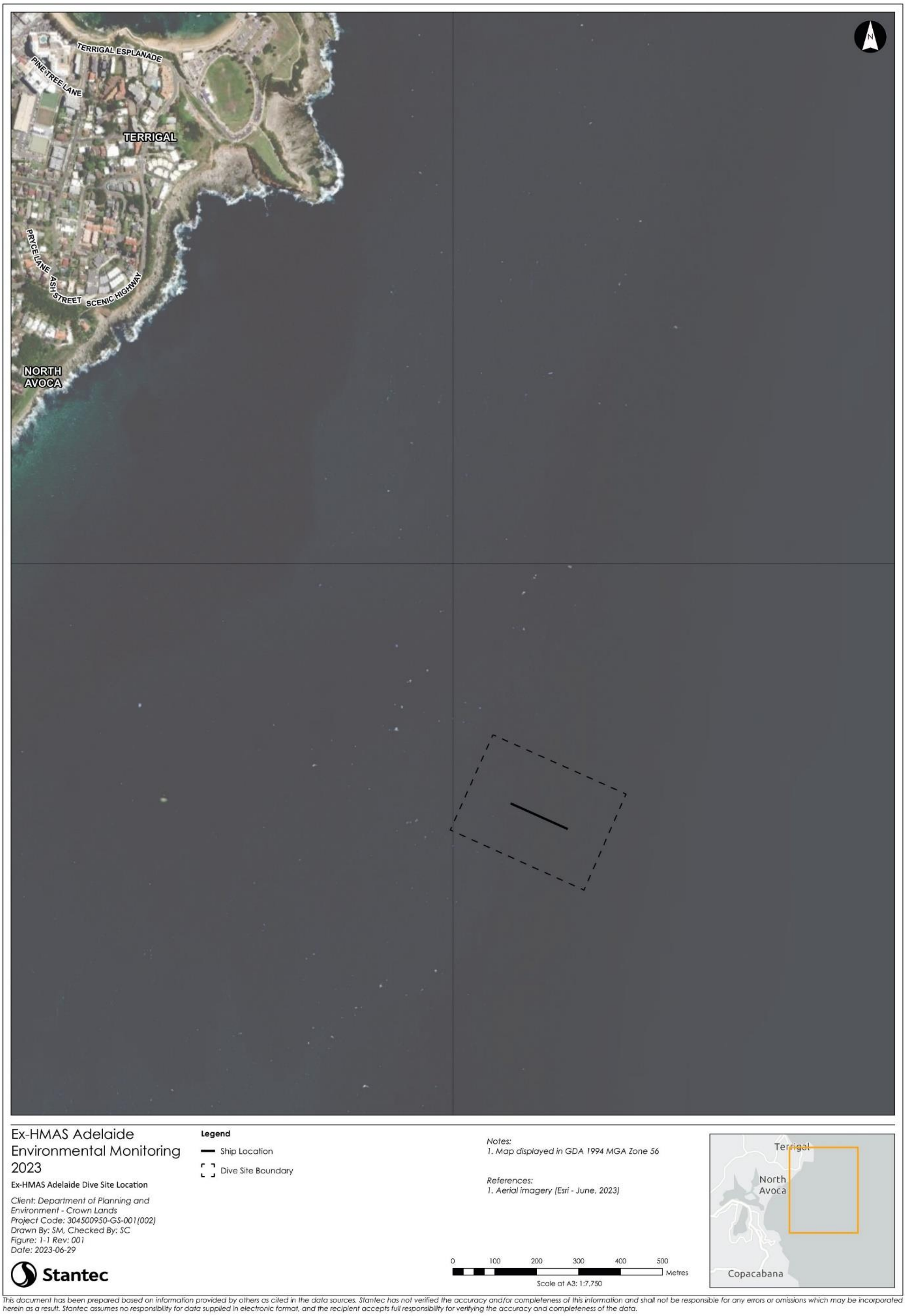


Figure 1-1 Location of Ex-HMAS Adelaide Dive Site.

2 EXISTING INFORMATION

2.1 INTRODUCED MARINE PESTS

Marine pests are non-native marine plants or animals that harm, or have the potential to harm Australia's marine environment, social amenity or industries that use the marine environment if they were to be introduced, established, or spread (NSW DPI 2023). They are usually introduced via maritime activities (e.g., biofouling or ballast water of large vessels, and wash-down points for recreational vessels) and are commonly first detected in and around ports and smaller maritime access points.

2.1.1 IMP Species Listings – NSW

Introduced marine pests (IMPs) listed by NSW DPI (2023) as known to occur or have previously been detected in NSW marine and/or estuarine waters are:

- Caulerpa (*Caulerpa taxifolia*) – Many NSW estuaries
- Pacific oyster (*Crassostrea gigas*) – Many NSW estuaries and shallow coastal waters
- New Zealand screwshell (*Maoricolpus roseus*) – Twofold Bay and nearby shelf waters
- European green crab (*Carcinus maenas*) – South Coast bays and estuaries
- Japanese goby (*Tridentiger trigonocephalus*) – Sydney Harbour and Port Kembla
- Yellowfin goby (*Acanthogbius flavimanus*) – estuaries between Sydney and Newcastle
- Mozambique tilapia (*Oreochromis mossambicus*) – Cudgen Lake (far North coast)
- European fan worm (*Sabella spallanzanii*) – Twofold Bay

Several other marine pests listed by NSW DPI are either: 1) known to occur or have been recorded in other parts of Australia but have not yet been recorded in NSW waters; or 2) not recorded in Australian waters but still considered a realistic threat (NSW DPI 2023). These species are:

- Asian clam (*Potamocorbula amurensis*) – not recorded in Australian waters
- Asian date mussel or bag mussel (*Musculista senhousia*) – found in Vic, SA, Tas and WA
- Asian green mussel (*Perna viridis*) – no populations established in Australian waters
- Black-striped mussel (*Mytilopsis sallei*) – detected and eradicated in Darwin, NT
- Soft-shelled clam (*Mya japonica*) – found in eastern Tasmania
- Rapa or Veined whelk (*Rapana venosa*) – not recorded in Australian waters
- Slipper limpet (*Crepidula fornicata*) – not recorded in Australian waters

- Asian paddle crab (*Charybdis japonica*) – single specimen found in SA

2.1.2 Previous IMP Sampling

IMPs have not been recorded in any of the monitoring surveys of the Ex-HMAS Adelaide done to date. However, one species of potentially introduced barnacle, the Panamanian large barnacle (*Megabalanus coccopoma*) has been observed to occur on the Ex-HMAS Adelaide. Collection of samples for dissection would be required to verify this identification. In any case, such non-native barnacle species are not considered harmful pests with invasive characteristics.

2.2 BIOACCUMULATION

2.2.1 Bioaccumulation Studies

Bioaccumulation is a dynamic indicator of water quality and ecosystem integrity and has gained universal acceptance as a measure of the bioavailable fraction of contaminants in the aquatic environment (Phillips 1980).

While direct measurements of metals in the sediments within and adjacent to the Ex HMAS Adelaide (and at reference locations) were carried out as part of the original LTMMP, observed concentrations of metals vary according to different chemical, hydrographical and geological processes. Direct measurements of metal concentrations in the sediment and surrounding waters do not represent the metal loads available to biota (Bryan and Langston 1992, Hatje et al. 2003).

Bivalve molluscs and other encrusting sessile invertebrates such as ascidians are filter feeding organisms that actively filter dissolved and suspended matter from the water by pumping water through specialised filtration structures. They are, therefore, suitable organisms to test for water contamination and the accumulation of contaminants or toxins (Huber 2010). Mussels and oysters tolerate a wide range of temperatures, salinity, concentrations of suspended sediments and dissolved oxygen (Anderson 2001). These animals can accumulate certain contaminants in tissue to high concentrations without lethal effects. As these organisms are sedentary and easy to sample, they provide an attractive biomonitoring tool (Phillips 1980). The Sydney rock oyster (*Saccostrea glomerata*, formerly known as *Saccostrea commercialis*), is commonly used in New South Wales (NSW) as a biomonitoring species because it is ubiquitous on the east coast, survives transplantation and exposure to contaminants, accumulates contaminants to concentrations proportional to ambient waters, and is readily available from commercial growers (Brown and McPherson 1992; Scanes 1996; Scanes and Roach 1999; Spooner et al. 2003, Hedge et al. 2009). The accumulation of metals by *S. glomerata* can occur via the gills in dissolution (Förstner et al. 1989; Simpson et al. 1998) or as particulates via digestion (Wang and Fisher 1999). There are several studies that document the use of Sydney rock oysters for toxicity studies on the east coast of Australia (e.g., Hedge et al. 2009, Scanes 1996, Scanes and Roach 1999). These studies may provide an indication of the concentration of metals which may be expected to occur in moderately urbanised coastal areas. Less information is available regarding the levels of metal toxicants in blue mussels.

Previous HMAS Adelaide bioaccumulation sampling events involved the deployment of 'sentinel' organisms (Sydney rock oysters) onto the ship to determine levels of uptake of zinc chromate contaminants (refer to Section 2.2.4), which is a relatively simple way of inferring metal bioavailability and assessing metal concentrations over both long and short periods of time (Rainbow 2006). This approach was deemed necessary due to the prohibitively under-established encrusting assemblage of naturally occurring sessile invertebrates.

Over a decade later, however, such natural assemblages are well established, with suitable bivalve molluscs and other encrusting sessile invertebrates abundant and available to be sampled for the current study.

2.2.2 Toxicity of Chromium in The Marine Environment

Chromium occurs naturally in the trivalent chromium (III) and hexavalent, chromium (VI) forms (Hart 1982). The form of chromium present affects toxicity to aquatic organisms and the behaviour of chromium in the aquatic environment. Precipitation of chromium hydroxide is thought to be the dominant removal mechanism for chromium (III) in natural water (ANZECC/ARMCANZ 2000). Chromium (VI) may bioaccumulate to some degree and chromium (III) may be bioavailable from suspended material (ANZECC/ARMCANZ 2000). Pawlisz et al. (1997) reported marine toxicity data for chromium. Cr (III) was shown to affect the filtering rate of the mussel *Perna perna* at EC50 (median effective concentration) of 2 µg/L. The lowest acute EC50 reported for Cr (III) was 1,600 µg/L for nauplii of the marine copepod *Tisbe battagliai* over 96 h. The 7-d LOEC (lowest observed effect concentration) for reproduction of this species was 320 µg/L. For Cr (VI), Pawlisz et al. (1997) reported marine acute toxicities to Australian blue swimmer crab *Portunus pelagicus* of 1,300 µg/L and to the Australian amphipod *Allorchestes compressa* of 5,560 µg/L. Several other species had similar toxicities. The most sensitive fish was the flatfish *Citharichthys stigmaeus*, with a 21-d LC50 of 5,000 µg/L. Short-term (2−4 d) acute toxicities to marine fish were all above 16,000 µg/L.

Chromium (VI) is considered more toxic to marine organisms than Cr (III). For example, the diatom *Nitzschia closterium*, isolated from estuarine waters near Sydney at 33 ‰ salinity, had a 72-h EC50 of 2.4 mg/L for Cr (VI), compared to a 72-h EC50 of >5.0 mg/L for Cr (III) (Florence & Stauber1991). Fertilisation of the macroalga (*Hormosira banksia*), isolated from Port Phillip Bay, was insensitive to Cr (VI), with an EC50 of 360 mg/L. In studies with *P. pelagicus*, deleterious sub-lethal effects were found at Cr (VI) concentrations of 300 µg/L (Mortimer and Miller 1994) while the 96-h LC50 for the Tasmanian blenny, a tidepool fish, was reported as 2.6 mg/L (Stauber et al. 1994a).

The ANZECC/ARMCANZ water quality default guideline value (DGV) for Cr (VI) (at the 95 % protection level) in marine waters is 4.4 µg L^{-1}. In marine and estuarine conditions, high sulfate concentrations make chromium toxicity unlikely, except at very polluted sites (ANZECC/ARMCANZ 2000). A recommendation of 5 µg L^{-1} (dissolved annual average) is broadly accepted for the protection of saltwater life, although where there is concern that the health of communities in sites of nature conservation importance may be compromised as a result of the presence of particularly sensitive species, a lower value may be used as a guideline.

2.2.3 Toxicity of Zinc in The Marine Environment

Zinc is an essential trace element required by most organisms for their growth and development. It is found in most natural waters at low concentrations (ANZECC/ARMCANZ 2000).

Mance and Yates (1984) reviewed data on the toxicity of Zinc to marine organisms. Similar to chromium, invertebrates were generally more sensitive than the fish species investigated, while effects on marine macro and microalgae were noted at concentrations slightly lower than those reported for invertebrates. The apparent development of increased tolerance was noted as a complicating factor. Mance and Yates also reported the toxicity and bioaccumulation of Zn to be greater at lower salinities. Hunt and Hedgecott (1992) proposed a guideline value of 10 µg L^{-1} as appropriate for the protection of saltwater life. This value (also expressed as a dissolved annual average) was based on the lowest, most reliable NOECs (No Observed Effects Concentrations) reported for a range of organisms. In Australia, the current ANZECC/ARMCANZ water quality DGV for Zn (at the 95 % protection level) in marine waters is 8 µg L^{-1}, reduced from the 15 µg L^{-1} level that was current at the time of the most recent previous bioaccumulation report (Cardno Ecology Lab 2012).

Neither chromium nor zinc are listed as toxicants for which possible bioaccumulation and secondary poisoning effects require special consideration in terms of the ANZECC/ARMCANZ water quality guidelines. For some chemicals (e.g., mercury and PCBs), this is the main issue of concern rather than direct effects of toxicants. Metals such as chromium, zinc and copper can accumulate in shellfish without causing harm to the animals.

Acute toxicity testing of chromium and zinc has been carried out for several different groups of marine species and are published in the ANZECC Guidelines. These guidelines, however, are not directly relevant to the current study as water quality testing was not carried out in conjunction with the bioaccumulation study.

2.2.4 Previous Bioaccumulation Sampling Events

2.2.4.1 Baseline Investigation (April 2011)

As per the requirements of the original LTMMP, the first bioaccumulation study (Worley Parsons 2011b) took place one week after scuttling of the Ex-HMAS Adelaide (April 2011). Blue mussels, sourced from Eden Sea Farms aquaculture facility (southern NSW) were used as the test organism. Mussels were deployed at three monitoring sites attached to the vessel (“vessel sites”) and two control sites on mooring lines approximately 35 m from the vessel to provide an indication of background concentrations of metals. Mussel samples collected directly from the aquaculture facility were also tested to determine baseline levels of contaminants. Mussels were retrieved from the monitoring sites after a six-week deployment period. Some mussel bags from the control sites were lost as they were attached to moorings that became displaced.

The mean concentration of Cr in mussel tissue taken from baseline controls was 0.67 mg/kg^{-1} dry weight (S.D. = 0.1 mg/kg^{-1} dw). All concentrations quoted here and for subsequent surveys outlined below are in dry weight. Mean Zn concentration in tissue taken from baseline controls was 152 mg/kg with a standard deviation of 29.5 mg/kg^{-1}.

A comparison of mean concentrations of metals in tissue among the three impact sites found that concentrations from the bow, stern and midship sections were generally similar. Overall, there were no statistically significant differences in metal concentrations in tissues among the three vessel sites after a six-week deployment period. When data were combined, the vessel samples had a mean chromium concentration of 1.4 mg/kg^{-1} (S.D. = 0.47 mg/kg^{-1}). Zinc had a mean value of 178 mg/kg^{-1} (S.D. = 44.4 mg/kg^{-1}).

Significant differences in metal concentrations in mussel tissue between the baseline controls and vessel sites were evident. Post-hoc testing identified significant differences for concentrations of chromium, but no differences for zinc. Although metal concentrations in mussel tissue samples from the vessel sites were found to be higher than those for the baseline controls, the significant increase noted for chromium could not be directly attributed to the presence of the vessel without consideration of environmental control concentrations, as the references would have provided a measure of background concentrations. Given the limited amount of data available regarding metal concentrations in blue mussels in the study region, broader comparisons of the data with expected ambient levels were not made.

2.2.4.2 Monitoring Survey 1 (November 2011)

Sentinel oysters (Sydney rock oysters) were deployed at vessel sites and control sites on 24 November 2011 and retrieved on 20 January 2012 (a period of approximately 10 weeks). The background control oysters attached to the special marker buoys, were, however, lost due to adverse weather, hence comparisons could only be made between the vessel oysters and baseline control oysters.

The mean concentration of Cr in the baseline control samples was 0.21 mg/kg^{-1} (S.E. = <0.1). The mean concentration of Cr in monitoring samples collected from the midship was 0.53 mg/kg^{-1} (± 0.29), while the concentration of Cr from the stern sample was 0.23 mg/kg^{-1}. Note that means and standard errors for the stern were not calculated due to lack of replicate samples.

The mean concentration of Zn in the baseline control samples was 866.67 mg/kg^{-1} (± 44.7). The mean concentration of Zn in monitoring samples collected from the midship was 1,033.33 mg/kg^{-1} (± 73.11), while the concentration of Zn from the stern sample was 800 mg/kg^{-1}. Moisture content measured across all samples was similar.

For both Cr and Zn the mean concentration appeared to be marginally higher at the monitoring sites on the vessel than for the baseline control samples. Univariate statistical analysis did not, however, indicate that these differences were statistically significant ($P = 0.543$ for Cr, $P = 0.373$ for Zn).

2.2.4.3 Monitoring Survey 2 (September 2012)

Sentinel oysters (Sydney rock oysters) were deployed at vessel sites and control sites on 21 September 2012 and retrieved on 31 October and 01 November 2012 (a period of approximately 6 weeks).

The mean concentration of Cr in oyster tissue was similar at the bow, midship and stern of the vessel, with values of 0.27 mg/kg^{-1} (S.E. ± 0.02), 0.26 mg/kg^{-1} (± 0.02) and 0.27 mg/kg^{-1} (± 0.01) recorded respectively. The mean concentration of Cr in oyster tissue from the mooring buoy control location was 0.32 mg/kg^{-1} (± 0.01), while in baseline oyster tissue the concentration was 0.31 mg/kg^{-1}. Means and standard errors were not calculated for baseline controls due to lack of replicate samples. The mean concentration of Zn in oyster tissue ranged from 940 mg/kg^{-1} (S.E. ± 31) at the stern to 1,025 mg/kg^{-1} (± 85.0) at the bow. The mean concentration of Cr in oyster tissue from the mooring buoy control location was 930 mg/kg^{-1} (± 30), while in baseline oyster tissue the concentration was 940 mg/kg^{-1}. Moisture content measured across all samples appeared to be consistent among all samples. Univariate statistical analysis showed that the concentrations of chromium or zinc recorded from the three vessel locations were not significantly different from those recorded at control locations.

Univariate analysis results from Survey 2 also showed that the concentrations of Cr and Zn did not differ significantly between Survey 1 (November 2011) and Survey 2 (October/November 2012). While not statistically significant, Cr concentrations appeared to have increased slightly over time at the stern of the ship but also at the baseline control, while concentrations at the midship appeared to have decreased substantially. Zn concentrations also appeared to have increased slightly over time at the stern of the ship and baseline control, while concentrations at the midship decreased.

2.3 SEDIMENTS

2.3.1 Nature Of Contaminants

The original clean-up process included removing loose or flaking paint from the vessel in accordance with DSEWPaC's requirements. A total of 110 paint locations were tested from representative locations across the ship, confirming the presence of lead primer at some locations on the steel lower decks of the ship. The paint at other locations tested had yellow primer, red oxide, white topcoat and grey topcoat, which did not contain lead. The use of lead-based primer is only relevant to the internal steel hull and lower decks of the ship where it was used for corrosion protection, as the superstructure is constructed of aluminium.

Environmental risk experts concluded that the risks to the environment and human health from the presence of lead-based primer are negligible because the lead primer used is in the form of lead tetroxide, which is very insoluble so there would be minimal leaching. The lead is also in a form that has low bioavailability, little potential for bioaccumulation, and does not biomagnify.

Risks due to copper in the anti-fouling paint are not a significant concern because the coating is designed to leach as part of its protective process and the rate of leaching declines after the first six months. Because of this declining rate, the Navy's standard practice is to apply a new coating every five years and the last coating was applied to the Adelaide seven years prior to scuttling, so it is therefore near the end of its useful life, thus reducing the amount of copper remaining that could be released into the marine environment.

2.3.2 Previous Sediment Sampling Events

2.3.2.1 Baseline Survey (2009)

During the baseline survey (Worley Parsons 2009) marine sediments were collected from three sites in the approximate location in which the Ex-HMAS Adelaide would be scuttled. Concentrations of all metals were found to be less than their respective ANZECC / ARMCANZ (2000) interim sediment quality guidelines (ISQG) low values (where these had been established). As these were taken from locations different from those taken in subsequent surveys (as specified in the LTMMP), these were not considered appropriate 'baseline' samples for comparison with later surveys but are nonetheless useful in providing context of the broader conditions within the study area as required.

2.3.2.2 One Month Post-scuttling Survey (May 2011)

One month post-scuttling, the concentrations of metals in sediment at all control and monitoring (impact) sites (as specified in the LTMMP) were below the ISQG-Low values and similar to the concentrations found at the three sites sampled during the baseline survey, indicating that there was a low risk that any adverse biological effects would occur to marine organisms living within the sediments surrounding the Ex-HMAS Adelaide (Worley Parsons 2011c).

2.3.2.3 Six Months Post-scuttling Survey (October 2011)

A further investigation was carried out 6 months post-scuttling (Cardno Ecology Lab 2011). Results of that investigation indicated that six months post-scuttling, there were no appreciable increases in the concentrations of the metals tested in marine sediments adjacent to the ship, and that for many of the metals analysed (aluminium, chromium, iron, nickel and zinc), concentrations were lower than those recorded for previous surveys. Sediments tested from within the hull of the ship did not indicate any significant lead contamination.

2.3.2.4 Twenty-one Months Post-scuttling Survey (January 2013)

The results of the sediment quality survey undertaken 21 months post-scuttling did not show any notable increase in the concentrations of the metals tested (aluminium, chromium, copper, iron, nickel, lead and zinc) in marine sediments adjacent to the ship (Cardno Ecology Lab 2013). For many of the metals analysed (aluminium, chromium, iron, lead and zinc), mean concentrations were marginally higher than in previous surveys, while mean concentrations of copper had decreased and concentrations of nickel remained the same. Based on these findings, impact to the marine environment and associated benthic biota as a result of metal corrosion and/or degradation of paint layers from the Ex-HMAS Adelaide was considered unlikely.

2.3.2.5 Sixty-two Months Post-scuttling Survey (June 2016)

The most recent previous sediment quality survey was undertaken in 2016, 62 months post-scuttling and approximately three-and-a-half years after the preceding, 2013 survey. Results showed that in general, metal concentrations recorded 62 months post-scuttling were similar to those recorded only one month post-scuttling (May 2011), indicating that at that time there were no significant long-term effects attributable to the ship. The exception to this was for aluminium, which showed an overall increase in concentrations at vessel monitoring sites 62 months post-scuttling in comparison to those recorded one month post-scuttling. This increase in aluminium concentration to 2016 appeared to be greater for the vessel location compared to the control location, although this difference was not statistically significant. It was concluded that for metals where ANZECC/ARMCANZ (2000) ISQG were available (i.e., chromium, copper, nickel, lead and zinc), concentrations were all well below the ISQG lower trigger values and were not therefore considered to represent a contamination risk to the marine environment.

3 METHODOLOGY

3.1 INTRODUCED MARINE PEST SURVEY

3.1.1 Approach

Stantec (previously Cardno) recently prepared the NSW Marine Pest Surveillance Plan (Cardno 2022) on behalf of NSW DPI (Fisheries). This plan outlines the approaches to marine pest surveillance, advantages and limitations of different sample collection methods and response and control methods. The methods and approaches outlined in this plan are considered to supersede the 2010 Marine Pest Monitoring Guidelines and the Australian Marine Pest Monitoring Manual (DAFF 2010). This manual was reviewed in 2015 and it was concluded that the marine pest surveillance programs in the manual had not been adopted across Australia due to an overly prescriptive sampling methodology and high cost of implementation. Moving forward it has been recognised that while there are many different surveillance methods to target different life stages and ecological niches, it is not feasible to employ all of these within the scope of most jurisdictional government surveillance budgets and resource pools.

Our sampling approach aimed to use methods targeted towards suitable species most likely to occur on the Ex-HMAS Adelaide due to their known depth, temperature and habitat preferences aligning with the conditions associated with the Ex-HMAS Adelaide. These will also be targeted as species listed under the NSW Schedule 2 of the NSW Biosecurity Act 2015 as ‘prohibited matter’ and under Schedule 1, Part 2 of the NSW Biosecurity Regulation 2017 as ‘notifiable matter’, as well as those on the Australian Priority Marine Pest List (APMPL).

3.1.2 Diver Visual Assessment

3.1.2.1 Sampling Design

Diver visual assessments are suitable for identifying a broad range of invasive taxa at adult stage, including encrusting bryozoans, sponges, cnidarians, crustaceans, sedentary ascidians, polychaetes, bivalve molluscs, mobile crustaceans, gastropod molluscs, and polychaetes. Invasive macroalgae such as *Caulerpa taxifolia* can also be easily identified.

A team of two divers slowly swam along a total of 16 line transects and recorded video using an underwater camera or go pro. The line transects replicated those used in previous reef community surveys and are indicated in Figure 3-1 below.

In addition, photos and visual inspections were made at the 12 fixed-photo locations on the ship photographed in earlier surveys (Figure 3-2). Photos and /or video were taken of any other incidental sightings of potential marine pests, threatened or protected species (such as the Cauliflower Coral known to occur on the ship). An inventory of all fish species observed during the dive was recorded. Samples of any potential IMPs observed during the dive were collected.

3.1.2.2 Analysis

All video footage and fixed photos were reviewed by an experienced taxonomist. The suspected species and specific location of any potential IMPs were recorded and flagged for the following dive, with specimens collected and preserved as needed.

Any specimens or photographs / video stills of suspected IMPs were sent either to NSW Fisheries or the Australian Museum Marine Invertebrates Section for species validation. Any indications of incursions were immediately reported to the Department and the NSW Fisheries Biosecurity Unit as required.

3.1.3 Surface Scrapings

3.1.3.1 Sampling Design

Surface scrapings are suitable for identifying more cryptic and encrusting species such as adults and some juvenile stages of benthic fauna, including sedentary and mobile benthic polychaetes, crustaceans, bivalves, gastropod molluscs, echinoderms and ascidians.

A team of two divers collected a total of seven 20 cm x 20 cm surface scrapings from different representative parts of the ship. Scrapings comprised:

- Bow Deck x1
- Stern Deck x1
- Main Deck x1
- Starboard hull bow x1
- Starboard hull stern x1
- Port hull bow x1
- Port hull stern x1

3.1.3.2 Analysis

Samples were scraped, put into a labelled bag (with position and time of collection) and brought to the survey vessel. Samples were fixed in formalin and transported back to our in-house laboratory for processing. Once in the laboratory samples were rinsed of formalin over a 1-mm sieve and preserved in ethanol for long-term storage. Each sample was sorted into major taxonomic groups and then checked for any species listed as prohibited or notifiable matter in NSW and for any species listed on the Australian Priority Marine Pest List (APMPL). Sieved samples were retained for future analysis should it be of interest to do any further processing at a later stage should that be deemed necessary.

Any suspected marine pests were identified and counted, and a specimen sent either to NSW Fisheries or the Australian Museum Marine Invertebrates Section for species validation. Any indications of incursions were immediately reported to the Department and the NSW Fisheries Biosecurity Unit as required.

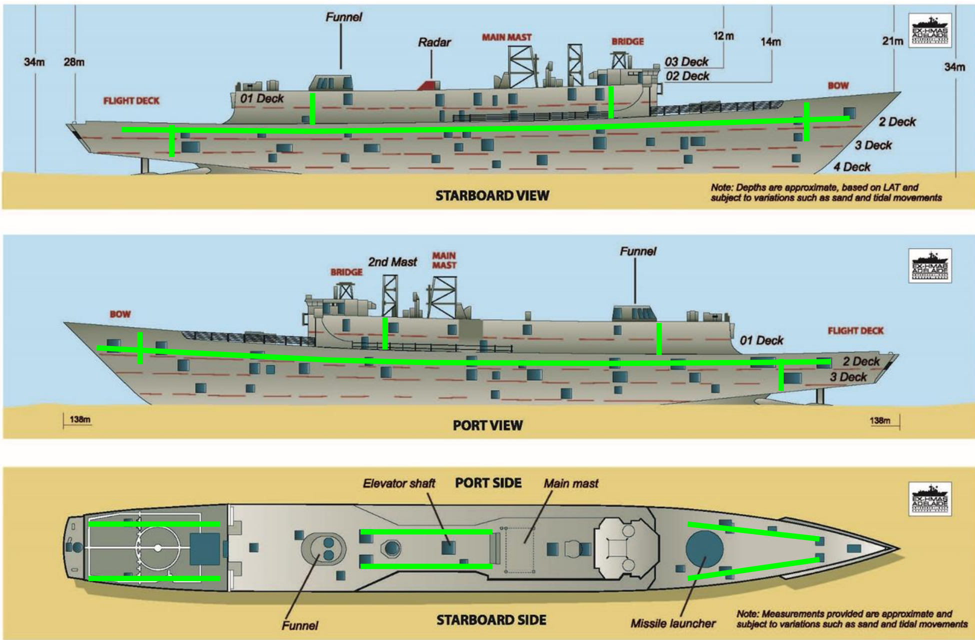


Figure 3-1 Location of line transects sampled on the Ex-HMAS Adelaide during surveys.

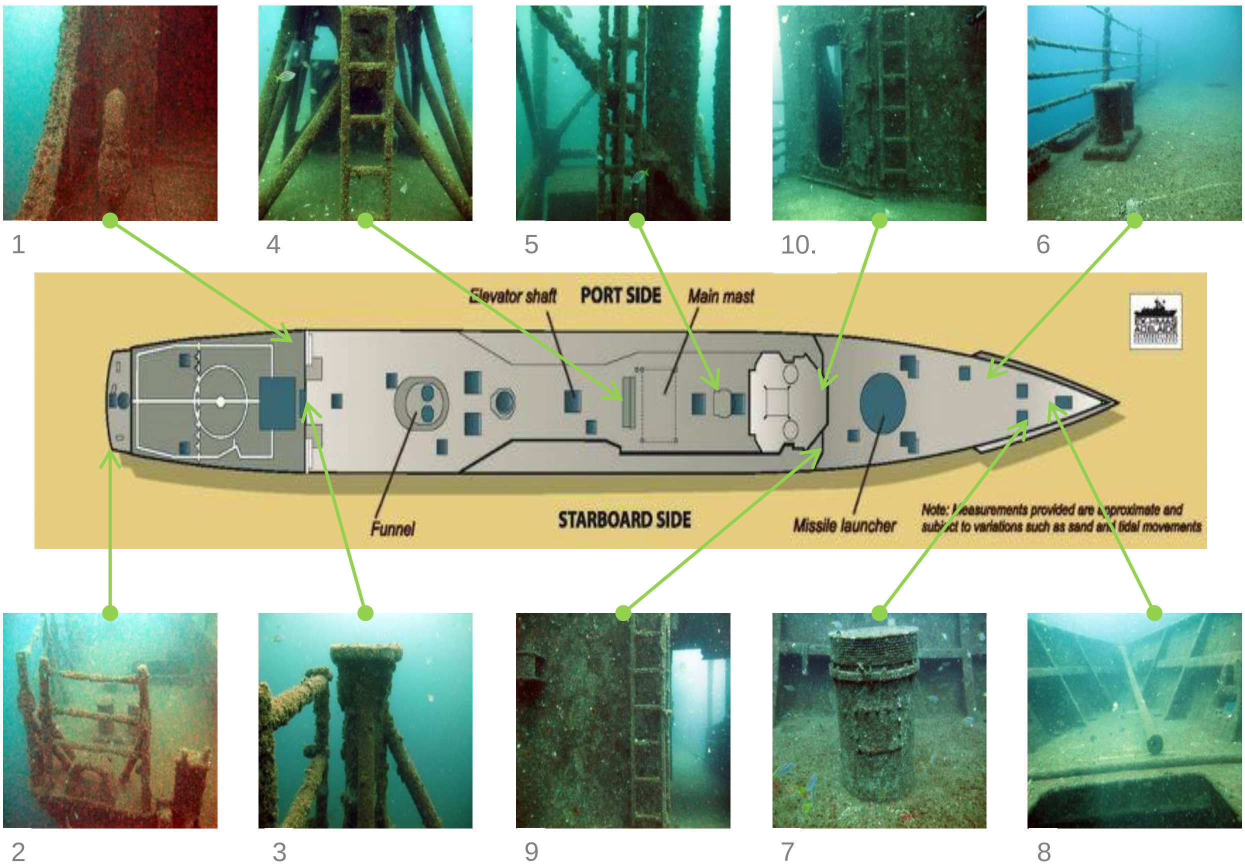


Figure 3-2 Location of fixed photos.

3.2 BIOACCUMULATION SURVEY

3.2.1 Approach

Previous bioaccumulation surveys have involved the deployment of 'sentinel' organisms (Sydney rock oysters) onto the ship to determine levels of uptake of zinc chromate contaminants. These were attached to the ship in plastic sleeves and left for 6-8 weeks before being collected and analysed. As there is now a well-established natural assemblage of encrusting sessile invertebrates present on the vessel, other naturally occurring sessile invertebrates were collected and analysed instead, as per the recommendation of the current Plan.

Notably, the inherent disparity between the previous sentinel organism approach and the established encrusting assemblage approach being taken for the current survey prevents any reliable quantitative comparison of results between the current and previous surveys. Given this, the current survey alternatively aimed to provide an indication of background contaminant levels as a 'reference' by collecting the same species from well-established encrusting assemblages on nearby subtidal reef habitat, as well as from the monitoring locations on the ship itself. This helps in understanding whether any contaminants associated with biota on the vessel are different from those associated with natural reef or not by providing inferential evidence according to a large-scale spatial sampling framework.

Our approach was to undertake the IMP surveys first (Section 3.1) and use those dives to determine the best species for bioaccumulation tissue analysis. The ascidian *Herdmania momus* was found to be suitably distributed and abundant across the vessel monitoring and reference locations described below, so was selected as the subject indicator species for the current survey.

3.2.2 Sampling Design

The sampling design was similar to previous studies, except additional natural reef 'reference' sites were included such that there was a total of three sites within each of two reference locations – one to the north and one to the south of Ex-HMAS Adelaide. For reference sites to be comparable to sites on the Ex-HMAS Adelaide we identified natural reef sites at a similar depth and with similar conditions that contained similar species of a similar size. The two locations containing the proposed reference sites are indicated on Figure 3-3.

To provide enough tissue for analysis approximately 30 individuals (around 100g of tissue) were collected from each of the following sites:

- x 3 monitoring locations (bow, stern and mid ship); and
- x 2 reference locations (reference 1 (north) and reference 2 (south).

At each location, approximately 30 individuals were to be collected from each of three sites within that location. Ideally, this sampling effort would have yielded a total of 450 individuals.

3.2.3 Laboratory Work

Once collected, the ascidians were put on ice in the field and transported immediately to Stantec's in-house laboratory for dissection and preparation. If immediate preparation was not possible the invertebrates were frozen whole in plastic containers until processing was possible. The tissue from 15–20 of the invertebrates from each site were combined to form a composite sample of adequate size for chemical tissue analysis (~100 g). All dissection and handling techniques conformed to standard procedures for the preparation of biological tissues for metal contamination testing.

Once prepared, samples were placed in appropriate containers and dispatched to National Measurement Institute (NMI) – a NATA accredited laboratory – for analyses of trace metals, chromium and zinc. Tissue from each sample was freeze-dried and homogenised into one composite sample to reduce the effect of intraspecific variability among individuals. Samples were analysed for chromium and zinc using digestion by concentrated nitric acid (or a mixture of nitric and hydrochloric acids) involving heating on top of a boiling water bath. Elements were determined using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) and/or Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) as per Cardno Ecology Lab (2012).

3.2.4 Analysis of Data

Mean and standard errors were calculated for concentrations of chromium and zinc at each of the sites from which samples were successfully collected. Univariate Permutational Analysis of Variance (PERMANOVA) was used to determine any spatial differences in concentrations of metal (chromium and zinc) in invertebrate tissues between the potentially impacted ship-based locations and the reference locations, using the PERMANOVA+ for Primer v7 statistical software package (Anderson et al. 2008). In the case of each metal, a simple nested, two-factor PERMANOVA design involved two factors – 'Location' nested within 'Vessel vs. Reference' (VvsR) – was used to analyse the Euclidean distances matrix derived from the raw data.

Where appropriate, pairwise comparisons were performed to further investigate statistically significant results identified in the PERMANOVA for factors/terms of interest. For particular terms where the number of unique permutations was less than 100, Monte Carlo probability values (P(MC)) were substituted in to assess the significance of the test as outlined by Anderson et al. (2008). The significance level was set at $P < 0.05$ for all statistical tests.

3.2.5 Assumptions and Limitations

As noted above, scouting of species present in well-established encrusting assemblages associated with the monitoring locations on the ship itself and on nearby subtidal reef habitat during the IMP surveys identified the ascidian *H. momus* as suitable for the current bioaccumulation study. While collection of *H. momus* at three spatially distinct sites was successful in the cases of the three monitoring locations on the ship, *H. momus* could be found only at two distinct sites within the northern reference location and only one site within the southern location. Given this, tissue samples from a total of twelve sites were sent to NMI laboratory for analysis, reflecting this sampling limitation. In addition, as previous sampling involved the collection of different indicator species at different locations, no direct comparison can be made between this and previous bioaccumulation surveys.

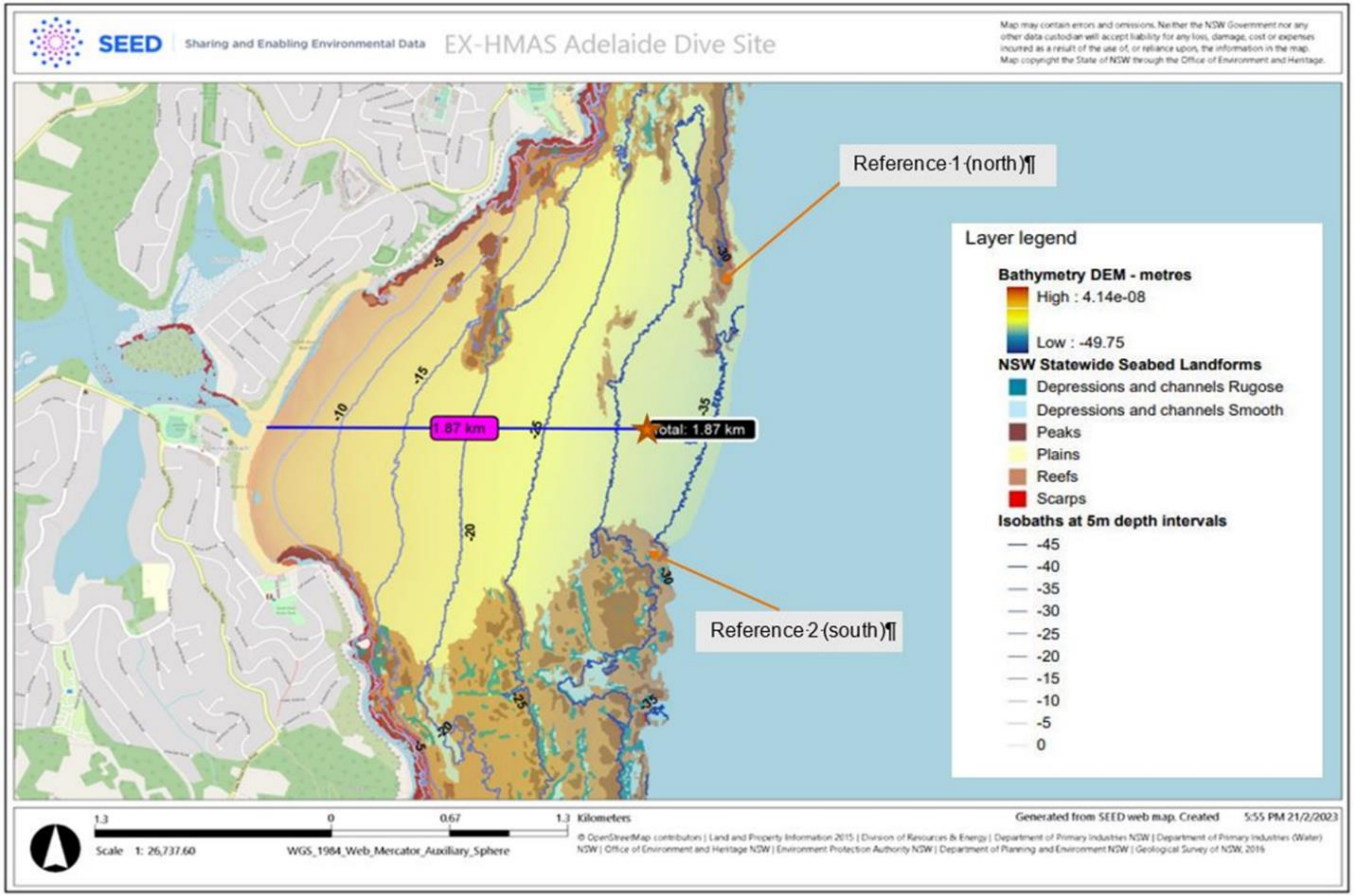


Figure 3-3 Bioaccumulation natural reef reference locations (orange star indicates approximate locations of the Ex-HMAS Adelaide artificial reef and dive site.

3.3 SEDIMENT QUALITY SURVEY

As stipulated by the current Plan, sediment testing was carried out for the following heavy metals potentially corroded from paints and coatings on the ships surface:

- Aluminium;
- Iron;
- Chromium;
- Copper;
- Lead;
- Nickel; and
- Zinc.

3.3.1 Field Methods

Sediment samples from monitoring sites in the vicinity of the Ex-HMAS Adelaide and at reference sites were collected in July 2023. Sediment samples were collected by deploying a Van Veen benthic grab from a boat. At each site, approximately 500 g of sediment was extracted from each grab, transferred into a labelled glass sample jar and chilled in an esky. Following each sample extraction, the grab was inverted and rinsed with water to avoid cross-contamination of samples. All samples were collected according to NAGD (National Assessment Guidelines for Dredging), refrigerated at 4°C and sent by courier to ALS laboratories (an NATA accredited laboratory), Sydney for processing.

3.3.2 Sampling Design

Samples were collected from the same sites as those pre-determined by Worley Parsons in earlier (one month post-scuttling survey) and subsequent monitoring surveys by Cardno now Stantec. An additional three reference sites were included in the current survey to provide further indication of natural variability and to be far enough away that there is no likely influence of the ship (Figure 3-4, Table 3-1). The sampling sites were therefore as follows:

- x 7 monitoring sites (I1, I2, I3, I4, I5, I6 and S2).
- x 2 reference sites (S3 and S6)
- x 3 new reference sites (S7, S8 and S9)

This yielded a total of 12 samples for analyses with additional QA/QC samples.

3.3.3 Laboratory Work

Sediment samples were tested for trace metals aluminium (Al), iron (Fe), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) against NODG (National Ocean Disposal Guideline for dredged material) (DEH 2002) and ANZECC/ARMCANZ (2000) ISQG.

Sediment samples were prepared by ‘Hot Block Digest’ for metals in soils, sediments and sludges and tumbler extraction of solids/sample clean up. Moisture content was calculated by a gravimetric procedure based on weight loss over a 12-hour drying period at 103 – 105°C. Total metals in sediments were calculated by the ICPMS (Inductively Coupled Plasma Mass Spectrometry) technique, which used argon plasma to ionise selected elements. Ions were then passed into a high vacuum mass spectrometer, which separated the analytes based on their distinct mass to charge ratios prior to their measurement by a discrete dynode ion detector. One gram of sample was leached at room temperature for one hour in 10% hydrochloric acid. The resultant extract was filtered and bulked for analysis of extracted metals.

In addition to the metal analysis the laboratory analysed the sediment samples for total organic content (TOC) and percent moisture. This was a procedural requirement to standardise the results of the metal analysis based on the content of organic matter in the samples.

An additional quality assurance sample and trip blank were also collected and tested for QA/QC purposes.

3.3.4 Analysis of Data

Sediment concentrations were reported as means with standard errors. Concentrations of heavy metals found within sediment samples at all sites were compared to Australian and New Zealand Fresh and Marine Water Quality Guidelines (ANZECC/ARMCANZ 2000). The recommended guideline values are tabulated as ISQG where low and high ISQG values correspond to low and medium effects ranges (ANZECC and ARMCANZ 2000).

Metal concentrations at monitoring sites (S2 and I1 – I6) were compared with concentrations at reference locations (S3 and S6 – 9) and also compared among survey times: baseline, one month post-scuttling, 6 months post-scuttling, 21 months post-scuttling, 62 months post-scuttling and the current survey (147 months post-scuttling).

3.3.5 Assumptions and Limitations

Site S2 was not considered to be appropriate as a reference location due to its close proximity to the ship and other monitoring locations. This was therefore treated as a monitoring site in considering the overall results, as was done following sampling completed in 2016.

This document has been prepared based on information provided by others as cited in the data sources. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

Figure 3-4 Sediment quality sampling sites.

Table 3-1 GPS positions of marine sediment quality sampling sites (Coordinates are in MGA 94).

Sample Site	Latitude	Longitude
Monitoring Site - I1	33°27'50.58"S	151°27'25.68"E
Monitoring Site- I2	33°27'50.94"S	151°27'28.74"E
Monitoring Site - I3	33°27'51.84"S	151°27'31.32"E
Monitoring Site - I4	33°27'56.52"S	151°27'26.94"E
Monitoring Site - I5	33°27'55.26"S	151°27'24.96"E
Monitoring Site - I6	33°27'53.82"S	151°27'22.86"E
Monitoring Site - S2*	33°27'49.74"S	151°27'24.96"E
Reference Site - S3	33°27'52.80"S	151°27'9.42"E
Reference Site - S6	33°28'5.94"S	151°27'20.82"E
Reference Site - S7	33°27'22.16"S	151°27'23.83"E
Reference Site - S8	33°27'13.49"S	151°27'36.14"E
Reference Site - S9	33°27'25.02"S	151°27'37.07"E

*Due to the proximity to the ship, this site was analysed as a monitoring site in 2016 and 2023, not a reference site.

4 RESULTS

4.1 INTRODUCED MARINE PEST SURVEY

None of the species listed by NSW DPI (2023) as marine pests known to occur in NSW were identified during diver surveys or from surface scrapings undertaken as part of 2023 IMP surveying.

4.2 BIOACCUMULATION SURVEY

Collection of individuals from sites on the Ex-HMAS Adelaide and at reference locations took place on 15 May 2023. Sea conditions at the time of sample collection were calm with approximately a 1m swell and a moderate wind from the SSW. Visibility was approximately 3 m. At the time of commencement of sampling, the tide was receding from a high of 1.69 m at 04:30 to a low of 0.44 m at 11:01.

4.2.1 General Findings

Results of the tissues analysis are presented in Table 4-1. The main findings are summarised as follows:

The mean concentration of chromium in *H. momus* tissue was generally similar at the bow, midship and stern of the ship, with values of 0.19 mg/kg^{-1} (S.E. ± 0.06), 0.22 mg/kg^{-1} (± 0.05) and 0.28 mg/kg^{-1} (± 0.08) recorded respectively (n = 3 lab samples for each) (Table 4-1, Figure 4-1). These were also generally similar to mean concentrations of chromium recorded in *H. momus* tissue from individuals collected at the reference locations to the north and south, which were 0.29 mg/kg^{-1} (± 0.05, n = 2) and 0.28 mg/kg^{-1} (n = 1) respectively. A standard error statistic was not calculated for the reference south location due to lack of replicates samples.

The mean concentration of zinc in *H. momus* tissue ranged from 4.30 mg/kg^{-1} (± 30.5) around midships to 12.97 mg/kg^{-1} (± 3.03) at the bow (n = 3 lab samples for each) (Table 4-1, Figure 4-1). The mean concentrations of zinc recorded in *H. momus* tissue from individuals collected at the reference locations to the north and south were 4.35 mg/kg^{-1} (± 0.75, n = 2) and 12.00 mg/kg^{-1} (n = 1) respectively – both within the range recorded for the ship locations. A standard error statistic was not calculated for the reference south location due to lack of replicates samples.

4.2.2 Statistical Comparisons – 2023 Data

The two-factor univariate PERMANOVA for chromium did not detect a significant difference between the vessel locations and the reference locations (P(MC) = 0.8142), nor did its nested term detect significant differences among vessel locations or between reference locations (P(perm) = 0.7944) (Table 4-2). Given this, it is concluded that there is no indication of an elevated level of chromium in *H. momus* tissue from samples collected at vessel locations compared to samples collected at reference locations.

While the equivalently designed PERMANOVA for zinc similarly did not detect a significant difference between the vessel locations and the reference locations (P(MC) = 0.9214), its nested term did detect a significant difference among vessel locations or between reference locations, or both (P(perm) =

0.0242) (Table 4-2). Subsequent pairwise tests confirmed that the significant difference was related to the vessel locations, with a significantly higher concentration of zinc in *H. momus* tissue from samples collected at the bow location than in tissue from samples collected at the midship location (*P*(MC) = 0.0476) (Table 4-2, Figure 4-1). Notably, however, no significant difference between locations was detected for the bow vs stern and the midship vs stern paired comparisons (*P*(MC) > 0.05), introducing ambiguity in logic when attempting to interpret the results of that trio of paired comparisons. The pairwise test for the two reference locations did not detect a significant difference between them (*P*(MC) = 0.1055).

4.2.3 Temporal Patterns

While temporal patterns in concentrations of metals in tissue involving data derived from this 2023 sampling event and data collected in past years (2011 and 2012) cannot be considered via statistical analysis due to the confounding factors of species (ascidians vs. oysters vs. mussels) and methodology (*in situ* organisms vs. sentinels), general observations concerning spatial patterns in concentrations among the three vessel locations can be made for each sampling event and discussed in the temporal context.

Sentinel oyster tissue sampled in 2012 contained very similar mean concentrations of chromium across the three vessel locations (~0.27 mg/kg^{-1}) (Cardno Ecology Lab 2012). A generally similar pattern of no significant difference among vessel locations was evident for the *H. momus* tissue sampled in 2023 (0.19–0.28 mg/kg^{-1}). Notably, the mean concentrations were quite comparable given the difference in indicator species.

As was the case for Chromium, mean concentrations of zinc in sentinel oyster tissue sampled in 2012 were similar across the three vessel locations (940–1025 mg/kg^{-1}) (Cardno Ecology Lab 2012). In contrast, there is limited statistical evidence that *H. momus* tissue sampled in 2023 from the bow of the vessel contained relatively elevated levels of zinc compared to levels in tissue taken from midship and stern samples (Figure 4-1; Table 4-2). Notably, however, this apparent elevation is primarily being driven by relatively high concentrations (16 mg/kg^{-1}) for only two of the three bow replicates, with the third bow replicate recording a zinc concentration (6.9 mg/kg^{-1}) within the range detected for replicate samples taken at the midship and stern locations (i.e., 3.6–7.3 mg/kg^{-1}) (Table 4-1).

It should be noted that no comparisons – observational or analytical – are possible between the 2023 reference locations and 2011/2012 non-vessel (control) locations due to the completely disparate indicator species and methodology, and the differences in spatial positions of the sampling locations.

Table 4-1 Concentrations of chromium and zinc (dry weight) in tissue samples from ascidians (*Herdmania momus*) collected from the three Monitoring Locations on the Ex-HMAS Adelaide, and two Reference Locations to the north and south of the dive site.

Location	Chromium mg/kg	Zinc mg/kg
Bow		
Rep 1	0.07	16.00
Rep 2	0.22	16.00
Rep 3	0.29	6.90
Mean (S.E.)	0.19 (0.06)	12.97 (3.03)
Midship		
Rep 1	0.33	4.60
Rep 2	0.15	3.60
Rep 3	0.19	4.70
Mean (S.E.)	0.22 (0.05)	4.30 (0.35)
Stern		
Rep 1	0.41	7.30
Rep 2	0.30	5.50
Rep 3	0.13	4.40
Mean (S.E.)	0.28 (0.08)	5.73 (0.85)
Reference North		
Rep 1	0.19	5.10
Rep 2	0.38	3.60
Rep 3	no data	no data
Mean (S.E.)	0.29 (0.09)	4.35 (0.75)
Reference South		
Rep 1	0.21	12.00
Rep 2	no data	no data
Rep 3	no data	no data
Mean (S.E.)	0.21 (n.a.)	12.00 (n.a.)

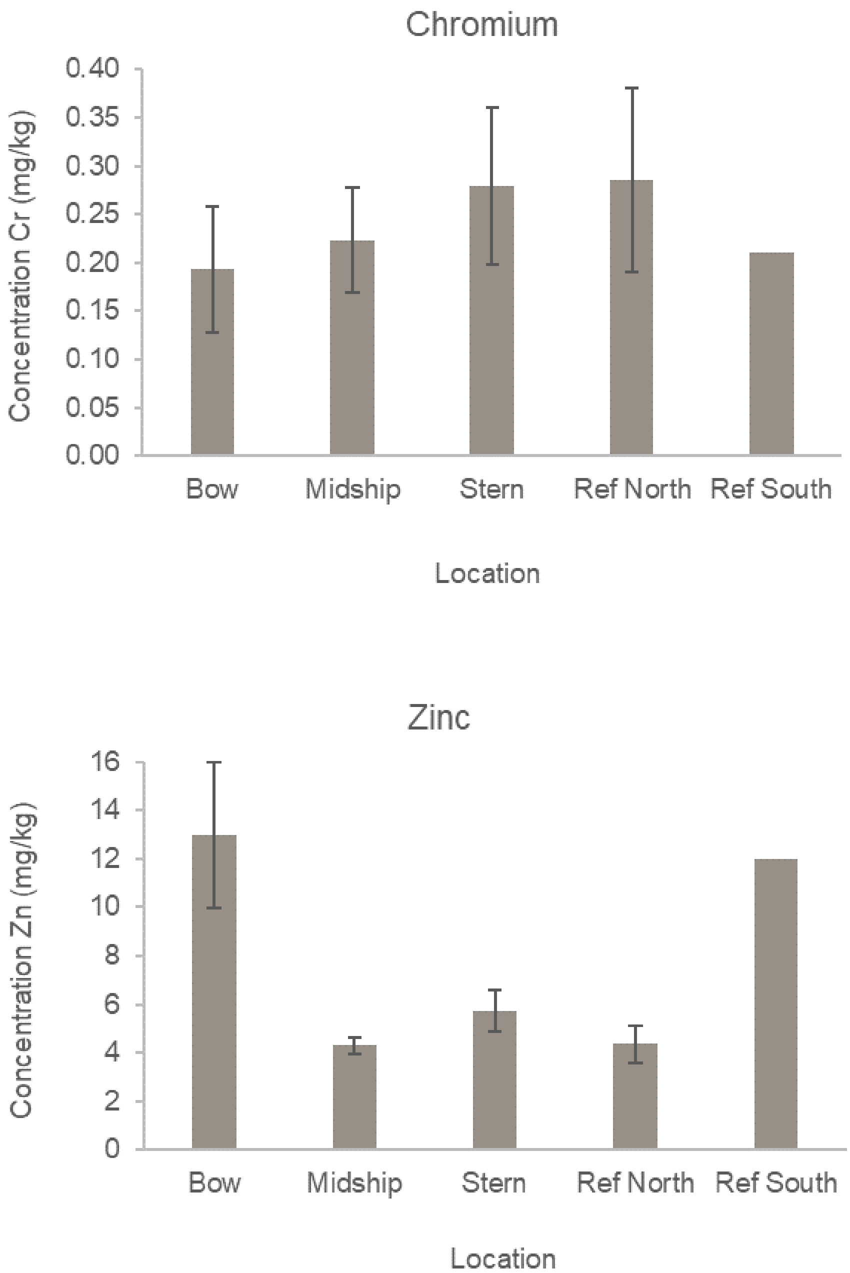


Figure 4-1 Mean concentrations of chromium and zinc (dry weight) in tissue samples from ascidians (*Herdmania momus*) collected from the three monitoring locations on the Ex-HMAS Adelaide, and two reference locations to the north and south of the dive site.

Table 4-2 PERMANOVAs and pairwise tests. The relevant P-values are in bold. *Statistically significant at P = 0.05.

A) Chromium

Source of Variation	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Vessel vs. Reference - VvsR	1	0.00047	0.00047	0.05943	0.7964	10	**0.8142**
Location(VvsR)	3	0.01522	0.00507	0.35334	**0.7944**	9087	
Residual	7	0.10049	0.01436				
Total	11	0.11742					

B) Zinc

Source of Variation	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Vessel vs. Reference - VvsR	1	0.53204	0.53157	0.01266	0.9005	10	**0.9214**
Location(VvsR)	3	168.52	56.172	6.3979	**0.0242 ***	9691	
Residual	7	61.459	8.7798				
Total	11	231.30					

Pairwise Tests - Zinc	t	P(perm)	Unique perms	P(MC)
Location(Vessel)				
Bow vs. Midship	2.8371	0.1022	7	**0.0476 ***
Midship vs. Stern	1.5583	0.3079	10	**0.1992**
Bow vs. Stern	2.2960	0.1957	10	**0.0838**
Location(Reference)				
North vs. South	5.8426	0.3369	3	**0.1055**

4.3 SEDIMENT QUALITY SURVEY

Concentrations of metal contaminants in sediment samples are provided in Table 4-3 and Figure 4-2. The main findings are summarised as follows:

Aluminium

Mean concentrations of Al detected 147 months post-scuttling (July 2023) were lower than levels detected during the previous sampling (June 2016), but greater than all other samples collected from both control and impact sites. Concentrations of Al were similar for impact and control locations and no ANZECC/ARMCANZ (2000) guidelines apply to Al in marine sediments.

Chromium

Mean concentrations of Cr detected 147 months post-scuttling (July 2023) were generally similar for the impact and control locations and similar to those recorded one month (May 2011) and 62 months (June 2016) post-scuttling, despite an apparent overall decrease in levels from the May 2011 survey detected during surveys carried out six (Oct 2011) and 21 months (Jan 2013) post-scuttling. Concentrations of Cr were well below the ANZECC/ARMCANZ (2000) ISQG lower trigger value of 80 mg/kg in all samples.

Copper

Mean concentrations of Cu detected 147 months post-scuttling (July 2023) were generally similar to those recorded one month (May 2011) and 62 months (June 2016) post-scuttling for control and impact locations, despite the apparent overall decrease detected during surveys carried out six (Oct 2011) and 21 months (Jan 2013) post-scuttling. Concentrations of Cu were higher in impact locations than in control locations but were well below the ANZECC/ARMCANZ (2000) ISQG lower trigger value of 60 mg/kg in all samples.

Iron

Mean concentrations of Fe detected 147 months post-scuttling (July 2023) were generally similar for the impact and control locations and similar to those recorded one month (May 2011) and 62 months (June 2016) post-scuttling, despite the apparent overall decrease detected during surveys carried out six (Oct 2011) and 21 months (Jan 2013) post-scuttling. No ANZECC/ARMCANZ (2000) guidelines apply to Fe in marine sediments.

Nickel

Mean concentrations of Ni detected 147 months post-scuttling (July 2023) were generally similar for the impact and control locations and similar to those recorded one month (May 2011) and 62 months (June 2016) post-scuttling, despite the zero concentrations detected during surveys carried out six (Oct 2011) and 21 months (Jan 2013) post-scuttling. Concentrations of Ni were well below the ANZECC/ARMCANZ (2000) ISQG lower trigger value of 21 mg/kg in all samples.

Lead

Mean concentrations of Pb detected 147 months post-scuttling (July 2023) were generally similar for the impact and control locations and similar to those recorded one month (May 2011) and 62 months

(June 2016) post-scuttling, despite the overall decrease detected during surveys carried out six (Oct 2011) and 21 months (Jan 2013) post-scuttling. Concentrations of Pb were well below the ANZECC/ARMCANZ (2000) ISQG lower trigger value of 50 mg/kg in all samples.

Zinc

Mean concentrations of Zn detected 147 months post-scuttling (July 2023) were generally similar for the impact and control locations and similar to those recorded one month (May 2011) and 62 months (June 2016) post-scuttling, despite the overall decrease detected during surveys carried out 6 (Oct 2011) and 21 months (Jan 2013) post-scuttling. Concentrations of Zn were well below the ANZECC/ARMCANZ (2000) ISQG lower trigger value of 200 mg/kg in all samples.

Table 4-3 Heavy metal concentrations recorded in sediment samples collected from impact and control locations during May 2011 (one month post-scuttling), October 2011 (six months post-scuttling), January 2013 (21 months post-scuttling), June 2016 (62 months post scuttling) and July 2023 (147 months post scuttling). Where the metal concentration was below the LOR (limit of reporting), it was treated as a zero value. Values exceeding ANZECC/ARMCANZ (2000) ISQG guideline levels are highlighted where applicable.

		Aluminium (mg/kg)					Chromium (mg/kg)					Copper (mg/kg)					Iron (mg/kg)				
	ISQG Low - High Trigger Values	n/a					80 - 370					65 - 270					n/a				
	Months Post-Scuttling	1	6	21	62	147	1	6	21	62	147	1	6	21	62	147	1	6	21	62	147
Impact	I1	1300.0	180.0	270.0	2440.0	440.0	8.2	1.5	1.8	5.9	2.2	3.4	1.8	1.8	2.4	2.1	10000.0	1000.0	1270.0	6440.0	3150.0
	I2	1300.0	240.0	250.0	2610.0	1120.0	7.5	1.8	1.8	6.4	5.2	2.6	2.4	1.1	2.3	1.6	10000.0	1470.0	1380.0	7510.0	6010.0
	I3	1100.0	160.0	170.0	2310.0	1210.0	6.8	1.4	1.6	6.7	6.4	1.4	0.0	0.0	1.1	1.5	8900.0	1160.0	1070.0	7090.0	6580.0
	I4	1100.0	150.0	170.0	2330.0	1540.0	6.9	1.3	1.6	6.4	9.1	1.3	0.0	0.0	1.2	2.3	9400.0	1120.0	1070.0	7190.0	13000.0
	I5	1200.0	190.0	180.0	2800.0	1600.0	6.5	1.6	1.5	7.2	6.0	1.5	0.0	0.0	2.4	2.0	9900.0	1300.0	1250.0	8710.0	8690.0
	I6	1100.0	160.0	210.0	2940.0	1500.0	6.5	1.4	1.7	7.4	8.1	1.5	0.0	0.0	3.4	2.1	9200.0	1180.0	1320.0	9060.0	11900.0
	S2*	1200.0	180.0	230.0	2460.0	1240.0	7.4	1.5	1.9	5.8	5.2	1.8	2.3	0.0	2.0	1.9	10000.0	1290.0	1350.0	6600.0	7420.0
	Mean	**1185.7**	**180.0**	**211.4**	**2555.7**	**1235.7**	**7.1**	**1.5**	**1.7**	**6.5**	**6.0**	**1.9**	**0.9**	**0.4**	**2.1**	**1.9**	**9628.6**	**1217.1**	**1244.3**	**7514.3**	**8107.1**
	S.E.	**34.0**	**11.3**	**15.2**	**90.5**	**177.2**	**0.2**	**0.1**	**0.1**	**0.2**	**1.0**	**0.3**	**0.4**	**0.3**	**0.3**	**0.1**	**172.8**	**57.2**	**48.0**	**380.9**	**1532.3**
Control	S3	1100.0	160.0	200.0	2470.0	1200.0	6.9	1.3	1.6	8.2	6.2	1.7	0.0	0.0	1.9	1.6	10000.0	1080.0	1280.0	10900.0	9370.0
	S6	740.0	110.0	100.0	740.0	930.0	6.0	1.0	1.0	6.4	6.0	0.8	0.0	0.0	0.0	1.1	7300.0	960.0	770.0	7200.0	7430.0
	S7	-	-	-	-	1380.0	-	-	-	-	7.0	-	-	-	-	1.6	-	-	-	-	10000.0
	S8	-	-	-	-	1530.0	-	-	-	-	7.5	-	-	-	-	1.4	-	-	-	-	9440.0
	S9	-	-	-	-	1220.0	-	-	-	-	7.4	-	-	-	-	1.3	-	-	-	-	9000.0
	Mean	**920.0**	**135.0**	**150.0**	**1605.0**	**1252.0**	**6.5**	**1.2**	**1.3**	**7.3**	**6.8**	**1.3**	**0.0**	**0.0**	**1.0**	**1.4**	**8650.0**	**1020.0**	**1025.0**	**9050.0**	**9048.0**
	S.E.	**180.0**	**25.0**	**50.0**	**865.0**	**100.3**	**0.5**	**0.2**	**0.3**	**0.9**	**0.3**	**0.5**	**0.0**	**0.0**	**1.0**	**0.1**	**1350.0**	**60.0**	**255.0**	**1850.0**	**435.0**

Table 4-3 Cont. Heavy metal concentrations recorded in sediment samples collected from impact and control locations during May 2011 (one month post-scuttling), October 2011 (six months post-scuttling), January 2013 (21 months post-scuttling), June 2016 (62 months post scuttling) and July 2023 (147 months post scuttling). Where the metal concentration was below the LOR (limit of reporting), it was treated as a zero value. Values exceeding ANZECC/ARMCANZ (2000) ISQG guideline levels are highlighted where applicable.

		Nickel (mg/kg)					Lead (mg/kg)					Zinc (mg/kg)				
	ISQG Low - High Trigger Values	21 - 52					50 - 220					200 - 410				
	Months Post-Scuttling	1	6	21	62	147	1	6	21	62	147	1	6	21	62	147
Impact	I1	2.9	0.0	0.0	2.7	<1.0	3.3	1.4	1.4	2.5	2.1	12.0	2.3	5.0	10.9	5.5
	I2	2.7	0.0	0.0	2.8	1.9	3.2	2.0	1.8	2.9	2.4	11.0	3.1	4.0	11.8	9.5
	I3	2.3	0.0	0.0	2.2	1.9	3.8	2.0	2.2	3.0	3.1	9.7	2.7	3.6	9.0	9.7
	I4	2.2	0.0	0.0	2.1	2.8	3.2	2.2	2.3	3.0	4.5	9.7	2.6	4.2	9.4	13.9
	I5	2.3	0.0	0.0	3.1	2.8	3.1	2.2	2.2	4.0	3.8	9.5	2.8	3.4	12.6	12.3
	I6	2.2	0.0	0.0	3.5	2.7	3.1	2.0	2.5	4.1	4.0	9.7	2.6	4.2	16.1	12.4
	S2*	2.6	0.0	0.0	2.4	2.4	3.3	2.3	2.2	2.7	2.6	11.0	3.2	4.4	9.8	11.2
	Mean	**2.5**	**0.0**	**0.0**	**2.7**	**2.4**	**3.3**	**2.0**	**2.1**	**3.2**	**3.2**	**10.4**	**2.8**	**4.1**	**11.4**	**10.6**
	S.E.	**0.1**	**0.0**	**0.0**	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**	**0.2**	**0.4**	**0.4**	**0.1**	**0.2**	**0.9**	**1.2**
Control	S3	2.5	0.0	0.0	3.1	2.6	3.1	2.2	2.9	3.8	3.0	10.0	2.3	3.4	12.0	10.8
	S6	1.5	0.0	0.0	2.0	1.7	3.1	2.3	2.2	3.3	3.2	6.5	1.9	2.3	7.9	8.0
	S7	-	-	-	-	2.8	-	-	-	-	3.5	-	-	-	-	12.8
	S8	-	-	-	-	2.6	-	-	-	-	4.2	-	-	-	-	12.6
	S9	-	-	-	-	2.3	-	-	-	-	3.0	-	-	-	-	11.0
	Mean	**2.0**	**0.0**	**0.0**	**2.6**	**2.4**	**3.1**	**2.3**	**2.6**	**3.6**	**3.4**	**8.3**	**2.1**	**2.9**	**10.0**	**11.0**
	S.E.	**0.5**	**0.0**	**0.0**	**0.6**	**0.2**	**0.0**	**0.0**	**0.4**	**0.3**	**0.2**	**1.8**	**0.2**	**0.6**	**2.1**	**0.9**

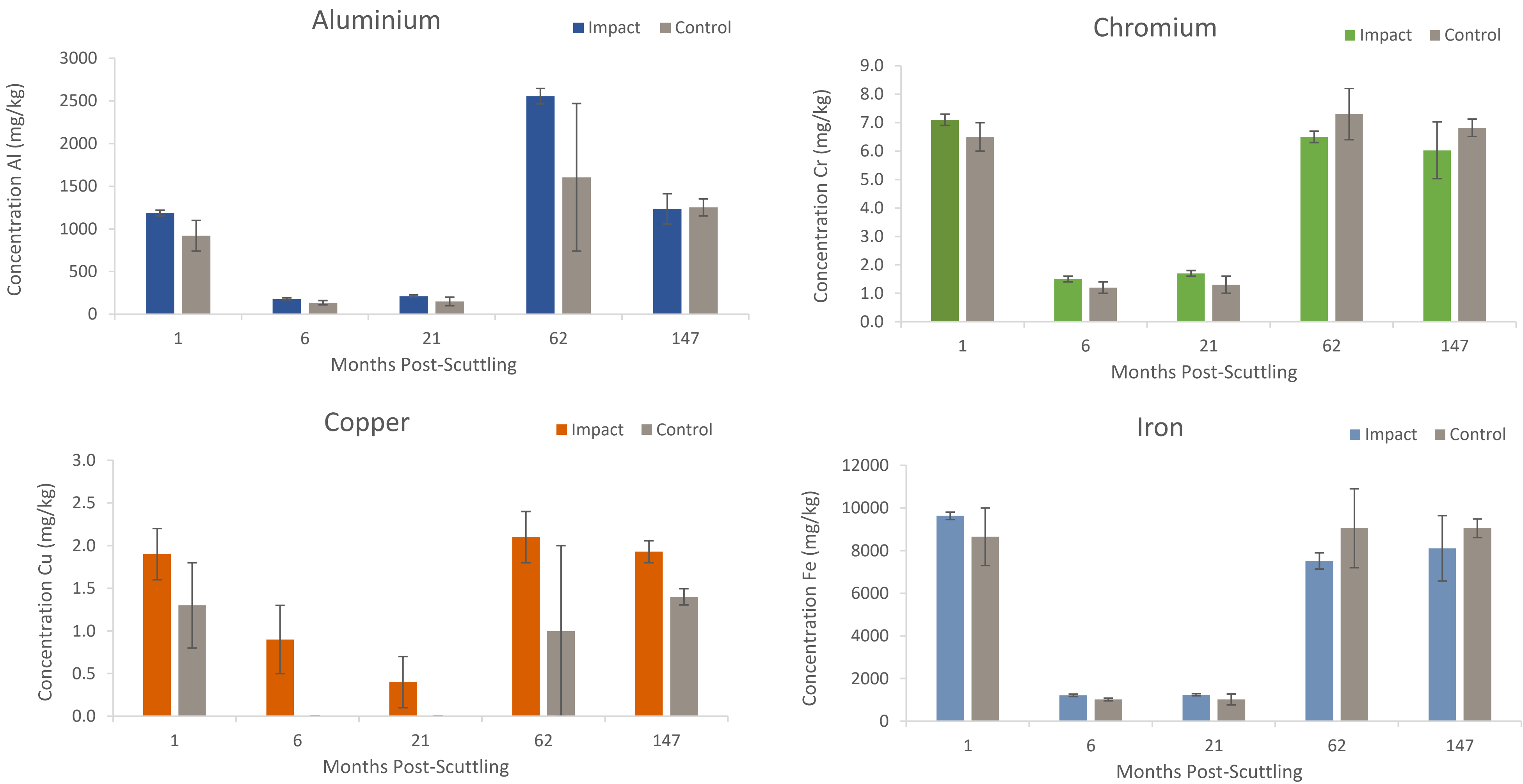
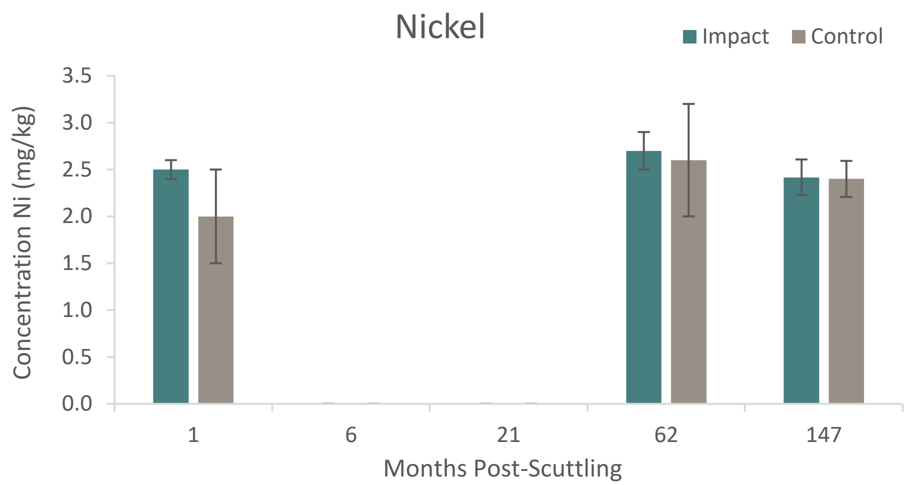
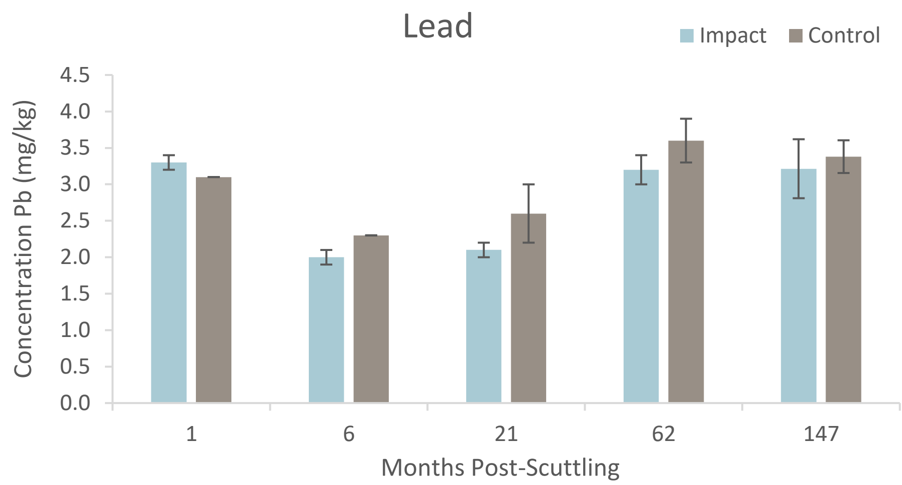


Figure 4-2 Mean heavy metal concentrations recorded in sediment samples collected from monitoring and control locations during May 2011 (one month post-scuttling), October 2011 (six months post-scuttling), January 2013 (21 months post-scuttling), June 2016 (62 months post scuttling) and July 2023 (147 months post scuttling).





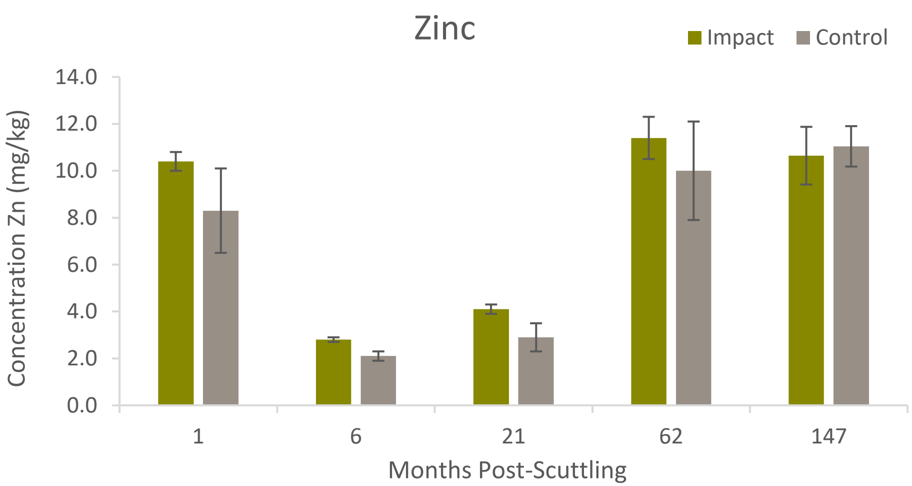


Figure 4-2 Cont. Mean heavy metal concentrations recorded in sediment samples collected from monitoring and control locations during May 2011 (one month post-scuttling), October 2011 (six months post-scuttling), January 2013 (21 months post-scuttling), June 2016 (62 months post scuttling) and July 2023 (147 months post scuttling)

DISCUSSION AND CONCLUSIONS

4.4 INTRODUCED MARINE PEST SURVEY

Although species listed as marine pests were not recorded in any of the surveys to date, methods for identification were limited to diver observations, photoquadrats and video footage. Small and cryptic pest species such as crabs, mussels and fan worms would be difficult to identify from these methods alone as they can be well camouflaged or found in crevices and overhangs. This highlights the importance of using a variety of sampling techniques to gain a better understanding of the overall species diversity rather than reliance upon a single method.

Of the species listed by NSW DPI (2023) as marine pests known to occur in NSW, the Japanese and yellowfin gobies and New Zealand screw shell are generally associated with soft or unconsolidated sediments in bays and estuaries and would be unlikely to occur in association with the Ex-HMAS Adelaide. The Pacific oyster is associated with shallow subtidal and intertidal habitats and not deep subtidal reef. Species potentially occurring on the Ex-HMAS Adelaide include *Caulerpa taxifolia* and the European shore crab. The European fan worm could potentially occur on the ship but is known to be more associated with sheltered waters.

Of the species listed by NSW DPI (2023) as potential marine pest threats but not recorded in NSW waters, Asian paddle crab, black striped mussel and Japanese seaweed have little potential to colonise the ship as they are associated with more sheltered, shallow waters. Although not recorded in NSW, Asian date and Asian green mussels would have some potential to occur.

Many other species, although not listed as marine pests, have been introduced to Australia from other countries but do not necessarily exhibit invasive or harmful characteristics. For example, one species of potentially introduced barnacle, the Panamanian large barnacle (*Megabalanus coccopoma*) has been observed to occur on the Ex-HMAS Adelaide. Collection of samples for dissection would, however, be required to verify this identification. This and other similar species, such as *M. tinntinabulum,* have been introduced to Australian waters and are only problematic as a fouling organism, rather than being a threat to native species or ecosystems. As such, it is not considered likely that the ship has provided a settlement surface for any IMPs.

4.5 BIOACCUMULATION SURVEY

Zinc and chromium are essential elements for many marine organisms and as such, readily bioaccumulate. The levels of zinc and chromium recorded in the tissues of ascidians sampled from locations on the vessel in the present study were within the range in levels recorded for those sampled from the two reference locations. This indicates that there is no evidence to suggest that zinc and chromium that may have potentially leached from zinc chromate paint of the Ex-HMAS Adelaide has affected the levels of these metals in tissues of resident ascidians living in association with the vessel. Given this, it is also reasonable to conclude that, more broadly, it is unlikely that there has been any accumulation of these metals in tissues of most if not all biota residing on the vessel to any toxicologically significant degree.

4.6 SEDIMENT QUALITY SURVEY

Heavy metal concentrations in samples collected 147 months post-scuttling (July 2023) were generally similar to those collected one month (May 2011) and 62 months (June 2016) post-scuttling, with the exception of substantially lower levels of aluminium in 2023 compared with 2016. There is very little information in the literature to provide an indication of what broader ‘background’ levels of heavy metals might be in marine sediments of the east coast of Australia and any seasonal fluctuations in those natural levels. As such, it is unclear as to what may explain the apparently lower levels of heavy metal concentrations in samples collected six months (October 2011) and 21 months (January 2013) post-scuttling. It is possible those apparent fluctuations detected during this monitoring program may partly be explained by large-scale oceanographic processes (such as prevailing current, storms etc.) or major rainfall events that would be expected to influence the heavy metal content of sediments over timeframes of months to years (Cardno Ecology Lab 2016).

Further, heavy metal concentrations in samples collected 147 months (July 2023) post-scuttling at ‘impact’ locations were generally similar to or lower than at control locations, indicating that any heavy metals detected in sediments sampled at the former are not likely associated with the ship. The exception to this is higher levels of copper found at impact locations in 2023. The levels of copper and other heavy metals detected in this monitoring program, however, were well below the lower ISQG values, where available, and are therefore not considered a risk to the marine environment.

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