Ex-HMAS Adelaide Artificial Reef

Review of Ecological Monitoring Five Years Post-Scuttling

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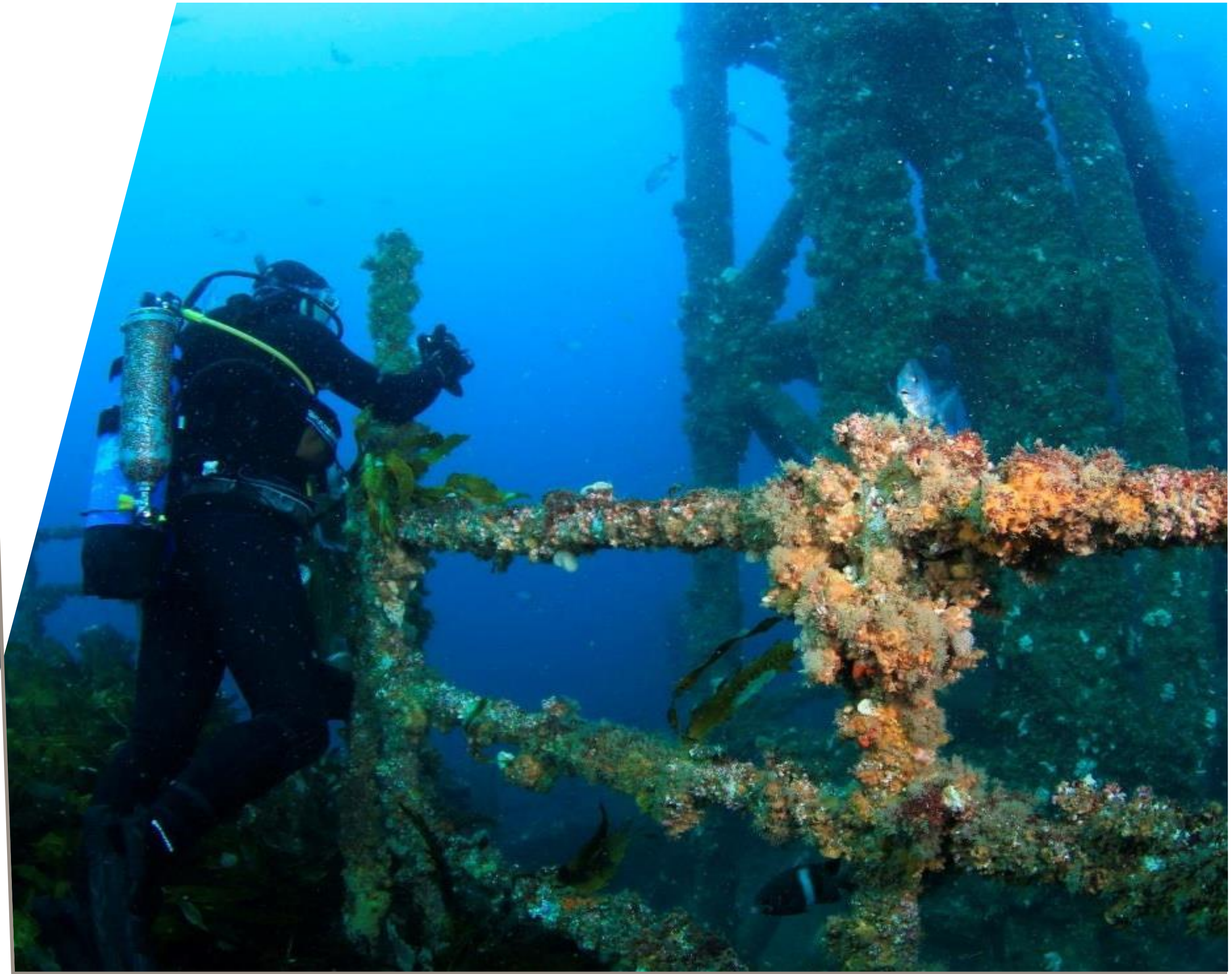

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Executive Summary

Overview

The Ex-HMAS Adelaide is a former Australian naval frigate that was purpose prepared and scuttled to create an artificial dive reef off the Central Coast of New South Wales (NSW), Australia. The vessel and dive reef, located approximately 1.8 km offshore of Avoca Beach, has now been in operation since April 2011. As part of the environmental assessment process, approval was required under the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) and 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 Sea Dumping Permit was that NSW Department of Primary Industries - Lands (NSW DPI – Lands), who are the custodians of the ship, must implement a Long Term Monitoring and Management Plan (LTMMP).

The LTMMP outlined the ecological and structural monitoring requirements for the first five years post-scuttling and forms the basis for ongoing monitoring and maintenance over the operational life of the vessel as a dive site (estimated to be 40 years). The ecological monitoring aspects of the LTMMP included three main components:

> Reef communities;

> Sediment quality; and

> Bioaccumulation studies.

Structural monitoring is also addressed through the LTMMP but has been carried out as a separate scope of works. A requirement of the LTMMP was that the environmental monitoring requirements were reviewed following the first two years post-scuttling, after which a summary report was prepared by Cardno. At this stage, recommendations were made to reduce the number of reef community surveys from quarterly to biannual and to consider alternative methods of investigating the potential for contamination. Following the review, an additional five reef community surveys and one additional sediment quality survey were undertaken over the remaining three years of the five year monitoring period. Cardno (NSW/ACT) Pty Ltd was commissioned by NSW DPI – Lands to undertake this five year review. The specific aims of the review are to:

> Summarise and disseminate the results of the five year monitoring program;

> Determine whether the aims of the LTMMP have been met; and

> Provide a basis on which to inform the direction of future management requirements.

Reef Communities

The aims of the reef community monitoring as outlined in the LTMMP were to gain an understanding of:

> Types of flora and fauna assemblages present;

> Rate of development of fouling assemblages and how they change over time;

> Variation in the rates at which assemblages develop on different surfaces of the vessel; and

> Presence of introduced or pest species.

A range of methods were used to address the aims of the reef community component of the LTMMP. These included analyses of photoquadrats taken of the ship's surface, fixed point photographs and review of video footage. Surface scrapings were also collected and analysed to gain a better understanding of the types of encrusting biota present and fish observations were recorded during dive surveys. These latter components of the study were not, however, a requirement of the LTMMP. A total of 13 reef community surveys were carried out over the five year monitoring period, in addition to the baseline survey undertaken in April/May 2011 by Worley Parsons.

Colonisation of the Ex HMAS Adelaide was rapid over the first six months of scuttling, with an early increase in taxonomic diversity, which was similar to the findings for other artificial structures and ex-naval vessels on the east coast of Australia and abroad. Five years and two months post-scuttling, the assemblage is diverse and supports a variety of encrusting invertebrates (including barnacles, bryozoans, sponges, ascidians, soft coral and hydroids), algae and fish. Following an initially rapid colonisation, taxon richness increased at a relatively gradual rate, although taxonomic composition continued to change through time. Some species, for example were recorded only in early surveys but were overgrown by barnacles, hydroids and turfing algae and therefore not recorded in later surveys. Conversely, several species did not colonise until several years post-scuttling, such as jewel anemones (*C. Australis*), large sponges, soft corals and sea urchins (*C. rodgersii*). A large proportion of the ship has also been covered by a matrix of serpulid worms, barnacles and encrusting algae throughout the sampling program, which provides habitat for errant polychaete worms, amphipod and decapod crustaceans, gastropod and bivalve molluscs. The continual occurrence of new taxa on the ship over time is indicative that successional changes are continuing to occur and it is likely that it will take many years (or even decades) before a state of equilibrium is reached.

There has been a strong and recurrent pattern of differences in the composition of assemblages between horizontally orientated (deck) surfaces and the vertically orientated (hull) surfaces, which is consistent with the findings of several other studies of temperate reefs. Species associated with horizontally orientated surfaces of the Ex-HMAS Adelaide included serpulid polychaetes with barnacles and encrusting algae, red encrusting algae and red filamentous algae. Kelp (*Ecklonia radiata*), was also only recorded on horizontal deck surfaces and not in any vertically orientated transects throughout the study. Light is therefore likely to be an important factor for these algae. Solitary ascidians, anemones and large barnacles were consistently present only on vertically orientated (hull) surfaces for all surveys during which they were recorded. Bryozoans and sponges, were also associated more with vertically orientated surfaces. It is possible that these groups proliferate on more shaded portions of the ship or that the currents are such that feeding efficiency is optimal. Video footage and fixed photos also showed that large filter feeding barnacles and ascidians tend to occur around portholes, doorframes and ladders, which may also be related to small-scale currents and eddies which improve feeding efficiency.

Depth was also a factor in structuring the encrusting reef assemblage, with shallow assemblages characterised by red and brown algae and deeper assemblages characterised by a greater percent cover of serpulid, barnacle and algal matrix). The effect of depth observed in this study was therefore considered to be related to light (due to the proliferation of algae at shallow depths), although other factors such as predation and grazing by fish and mobile invertebrates may also have been influential.

The diversity of fish species observed in association with the Ex-HMAS Adelaide increased from three to 17 species within the first six months of scuttling. Thereafter, the number of species fluctuated, but had increased to a total of 31 by the final survey (five years and two months post-scuttling). Over the course of the monitoring program a total of 62 species of fish from 31 families were recorded. Families represented by the most number of species included Monacanthidae (leatherjackets), Labridae (wrasses), Carangidae (trevallies, jacks, mackerels and scad) and Pomacentridae (damselfishes). Several of the species recorded were of recreational and/or commercial importance. No species listed as threatened or protected were recorded during the monitoring period, although anecdotal evidence suggests grey nurse sharks (*Carcharias taurus*) may occur at the site on occasion.

No pest species were observed during the study, however, one potentially introduced species of barnacle was identified.

Sediment Quality

The aim of the sediment quality monitoring survey, as outlined in the LTMMP, was to gain an understanding of how metal corrosion and degradation of paint layers may be influencing/impacting on the marine environment and whether benthic organisms are likely to be affected by metal enrichment.

The LTMMP stipulated that sediments be tested for aluminium, iron, chromium, copper, lead, nickel; and zinc as these metals are associated with the ships materials, particularly the hull which is made of steel and the superstructure which is composed of an aluminium alloy.

Sediment sampling was carried out adjacent to the ship and at reference sites once before and one, six, 21 and 62 months post-scuttling. In general, metal concentrations recorded 62 months post-scuttling (June 2016) were similar to those recorded after only one month post-scuttling (May 2011) and therefore, did not indicate any significant effects as a result of the ship. There was, however, an overall increase in concentrations of aluminium at impact sites 62 months post-scuttling in comparison with that recorded one month post-scuttling. This increase appeared to be greater at the impact location compared to the control location (in June 2016) which may be indicative of metal corrosion associated with the ship, although this difference was not statistically significant, due to the large variation among control samples. For metals where guidelines are available (chromium, copper, nickel, lead and zinc), concentrations were all well below the Interim Sediment Quality Guideline (ISQG) lower trigger values and were not therefore considered to represent a contamination risk to the marine environment.

Sediments were also collected from within the ship's hull due to concerns regarding the breakdown of lead based paints in this part of the ship. Lead concentrations found in these samples were less than 5 mg/kg which was well below the lower ISQG trigger value of 50 mg/kg.

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 was considered unlikely.

Bioaccumulation

Biomonitoring was carried out to determine whether resident biota were likely to be affected by zinc chromate paint, which may have been used on the aluminium alloy of the Ex-HMAS Adelaide while in service.

Bioaccumulation surveys were undertaken one, seven and 15 months post-scuttling. Sentinel species (mussels and oysters) were deployed in bags attached to the ship and at control sites. Results showed that mean concentrations of chromium and zinc in sentinal organisms attached to the vessel were similar to concentrations recorded in those sourced from the aquaculture facility (baseline controls) and attached to mooring buoys (background controls). In some instances, however, control samples were lost and meaningful comparisons could not be made. In general, results indicated that zinc and chromium potentially leached from the Ex-HMAS Adelaide would not affect the levels of these metals in filter feeders living in association with the vessel. Furthermore, the levels of zinc and chromium recorded in the tissues of sentinel species were generally similar to background levels recorded at their source and would not be of toxicological significance.

Conclusions and Recommendations

The focus of the LTMMP was to inform management actions and contingency measures to minimise potential risks to the users of the reef and the environment. A summary of conclusions and recommendations in relation to the specific aims and objectives of the LTMMP are presented in **Table ES1**. While specific recommendations have been outlined, an overarching recommendation is that a risk assessment approach be used, on the basis of current information and research, to guide ongoing management objectives and associated monitoring requirements (if any).

Table ES1. Summary of conclusions and recommendations

LTMMP Environmental Monitoring Component	Aims and Objectives	Aims Met	Recommendations
Reef Communities	> Document the types of flora and fauna assemblages present.	✓✓	Any ongoing monitoring would be useful in terms of ecological research or educational purposes, but is not considered necessary in terms of managing environmental risk or safety.
	> Gain an understanding of the rate of development of fouling assemblages and how they change over time.	✓✓	Any ongoing monitoring would be useful in terms of ecological research or educational purposes, but is not considered necessary in terms of managing environmental risk or safety.
	> Gain an understanding of the variation in the rates at which assemblages develop on different surfaces of the vessel.	✓✓	Any ongoing monitoring would be useful in terms of ecological research or educational purposes, but is not considered necessary in terms of managing environmental risk or safety.
	> Gain an understanding of the presence of introduced or pest species.	✓	Aims met, however there is a continued risk that marine pests may occur on the Ex-HMAS Adelaide in future. Objectives for the monitoring of marine pests on the EX-HMAS Adelaide should therefore be revised and appropriate methods, timing and frequency of surveillance monitoring be developed and implemented.
Sediment Quality	> Gain an understanding of how metal corrosion and degradation of paint layers may be influencing/impacting on the marine environment and whether benthic organisms are likely to be affected by metal enrichment.	✓	Aims met, however, over time, there will be continued potential for metals to enter the surrounding marine sediments through continued corrosion. As such, monitoring would be recommended to continue every three to five years. This should include additional control sites to better understand background levels of metals.
Bioaccumulation	> To determine whether resident biota (i.e. biota in direct contact with the superstructure), were likely to be affected by zinc chromate paint.	✓	In order to fully meet the requirements of the LTMMP, it is recommended that a single survey using *in-situ* biota be implemented.

✓✓ = Aims fully met

✓ = Aims met - scope for longer-term monitoring

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INTRODUCTION

1 Introduction

1.1 Background

The Ex-HMAS Adelaide was gifted from the Australian 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. Prior to the projects approval, 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 2011). The LTMMP outlines environmental and structural monitoring requirements for the first five years post-scuttling and forms the basis for ongoing monitoring and maintenance over the operational life of the vessel as a dive site, estimated to be 40 years. The focus of the monitoring was to inform management actions and contingency measures to minimise potential risks to users of the artificial reef and the marine environment.

The environmental monitoring part of the LTMMP included three main components:

> Reef communities;

> Sediment quality; and

> Bioaccumulation studies.

Structural monitoring was carried out as a separate scope of works.

A requirement of the LTMMP was also that the environmental monitoring requirements were reviewed the first two years post-scuttling, after which a summary report was prepared (Cardno 2014). At this stage, recommendations were made to reduce the number of reef community surveys from quarterly to biannual (as per the LTMMP) and to consider alternative methods of investigating the potential for contamination. Following the two year post-scuttling monitoring review, an additional five reef community surveys and one additional sediment quality survey were undertaken. Cardno (NSW/ACT) Pty Ltd was commissioned by NSW DPI – Lands to undertake the five year review which incorporates the results of these additional surveys. The specific aims of this five year review are to:

> Summarise and disseminate the results of the five year monitoring program;

> Determine whether the aims of the LTMMP have been met; and

> Provide a basis on which to inform the direction of future management requirements.

Scuttling of the EX-HMAS Adelaide on 13 April 2011. Source: C. Roberts (Cardno)

1.2 Study Site and Vessel

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 1 m – 2 m into the flat, sandy, seabed.

The vessel is orientated with the bow facing into the prevailing ESE swell direction and is managed within Crown Reserve (R.1014968) (**Figure 1**). Approximate depths to various levels on the ship from Lowest Astronomical Tide (LAT) are shown in **Figure 2**.

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 from the keel 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 also to allow light to penetrate. Further holes were also made to allow air to escape during the scuttling process (NSW Government 2011). Loose or flaking paint was also removed.

The Ex-HMAS Adelaide was prepared in order to meet standards specified by the Department of the Environment prior to scuttling. This included a series of inspections to confirm that these detailed requirements were achieved.

	EASTING	NORTHING
A	356428.713	6296117.693
B	356538.438	6296341.142
C	356850.615	6296188.618
D	356742.410	6295963.310

Figure 1 Location of Ex-HMAS Adelaide Artificial Reef and Dive Site. The approximate location and orientation of the ship is indicated by the yellow line. Points A-D represent the boundaries of the Crown Reserve

1.3 Overview of Environmental Monitoring

In accordance with the requirements of the LTMMP investigations were carried out prior to scuttling and/or immediately post-scuttling to provide a baseline against which later studies were compared. Dates and timing of all environmental monitoring surveys completed to date are listed in **Table 1**.

Table 1 Summary of environmental monitoring surveys

Reef Communities

Survey	Sampling Dates	Time Post-Scuttling
Baseline	18 April and 30 May 2011	1 week
1	11 and 13 October 2011	6 months
2	14 and 16 February 2012	10 months
3	03 and 04 May 2012	12 months
4	27 July 2012	15 months
5	31 October and 01 November 2012	18 months
6	16 and 17 January 2013	21 months
7	29 and 30 April 2013	24 months
8	16 and 17 July 2013	27 months
9	16 and 21 October 2013	2 years 6 months
10	03 and 04 March 2014	2 years 11 months
11	22, 23 and 29 September 2014	3 years 5 months
12	26 and 27 March 2015	3 years 11 months
13	01 and 02 June 2016	5 years and 2 months

Bioaccumulation

Survey	Sampling Dates	Time Post-Scuttling
Baseline*	19 April 2011	1 week
1	24 November 2011	7 months
2	21 September 2012	15 months

Sediment Quality

Survey	Sampling Dates	Time Post-Scuttling
Baseline*	Not Provided	Prior to scuttling
1*	17 May 2011	1 month
2	20 October 2011	6 months
3	11 January 2013	21 months
4	10 June 2016	62 months

(*) Baseline surveys were carried out by Worley Parsons. Further details are provided under the relevant sections.

Review of Ecological Monitoring
Five Years Post-Scuttling

02

REEF COMMUNITIES

Cardno
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2 Reef Communities

2.1 Aims and Objectives

The aims of the reef community monitoring survey, as outlined in the LTMMP, were to gain an understanding of:

> Types of flora and fauna assemblages present;

> Rate of development of fouling assemblages and how they change over time;

> Variation in the rates at which assemblages develop on different surfaces of the vessel; and

> Presence of introduced or pest species.

A range of methods were used to address the aims and objectives of the LTMMP. A brief outline of these methods is provided in **Section 2.3**. For detailed information relating to field and statistical methods refer to Reef Community Monitoring Report 13 (Cardno 2016).

2.2 Existing Information

Ex-naval vessels have been scuttled for the purpose of creating artificial recreational dive reefs in the waters of several Australian states. Examples include the Ex-HMAS Swan (Dunsborough, WA) the Ex-HMAS Hobart (Yankalilla Bay, South Australia), the Ex-HMAS Perth (King George Sound, Albany, WA), the Ex-HMAS Brisbane (Sunshine Coast, Queensland) and the Ex-HMAS Canberra (Victoria).

Colonisation of these structures by sessile invertebrates has proven to be relatively rapid. Within three months of deployment, surfaces of the Ex-HMAS Brisbane became colonised by red, brown and blue/green algae, limpets and goose barnacles (Queensland EPA 2007). Mobile invertebrates such as crabs, shrimps, crayfish and octopus were recorded within nine months. A diverse assemblage of mobile marine invertebrates including nudibranchs, opisthobranchs, cuttlefish, octopus and starfish have been observed around the wreck of the Ex-HMAS Hobart (South Australia) following its deployment in November 2002. Sessile sponges, ascidians, polychaete worms and soft corals are now well established. Biological monitoring of the Ex-HMAS Swan over a two year period showed that the structure was initially colonised by hydroids, covering approximately 70% – 90% of the area surveyed (Morrison 2001). Algal growth also dominated the encrusting marine life during the summer months, particularly on the upper surfaces. Other sessile groups such as sponges, ascidians, anemones and soft corals were shown to proliferate on shaded portions of the vessel.

Ecological processes affecting the recruitment, colonisation and development of benthic assemblages occurring on hard surfaces of reefs (natural or artificial) are strongly influenced by a wide range of environmental variables including water depth, light, temperature, salinity (Rule and Smith 2007, Moura et al. 2007), orientation in relation to prevailing currents (Baynes and Szmant 1989), orientation of surfaces (Glasby and Connell 2001, Knott et al. 2004), complexity of surfaces and structure (Edwards and Smith 2005, Moura et al. 2007) and rates of sedimentation (Baynes and Szmant 1989).

Comparisons of benthic assemblages on natural and artificial reefs indicate that although they may share many similar taxa, there may be differences with respect to the overall assemblages. Some taxa may be more abundant and diversity may be greater on natural compared to artificial reefs and vice-versa (Edwards and Smith 2005). Diversity of species on new reefs (such as artificial reefs) generally increases through time to a point of relative stability (Ardizzone et al. 1989 in Edwards and Smith 2005), although this may take many years and may never become similar to natural reefs.

2.3 Overview of Study Methods

2.3.1 Encrusting Assemblages

2.3.1.1 Photoquadrats

Line transects were demarcated along vertical and horizontal planes of the ship on the hull, superstructure and deck. Along each line transect, replicate photoquadrats (50 x 50 cm) were taken to sample reef assemblages on different parts of the ship. In total, 82 photoquadrats and 16 line transects were sampled during each survey (**Figure 2**). Photoquadrats were analysed for percentage cover of encrusting biota (algae, bryozoans, sponges, sessile invertebrates, etc.) using Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006). A ‘virtual’ photoquadrat scaled to 50 x 50 cm was digitally overlaid on each frame. Within each photoquadrat, 100 points configured as a 10 x 10 point grid were overlayed on the image and the taxon, matrix or substratum under each point identified visually. These data were then used to estimate percentage cover. This technique has the advantage of providing a quantitative, relatively rapid and detailed assessment that can be done back at the laboratory. Limitations of this method, are however noted as follows:

- Photographic quality and hence the ability to accurately identify taxa was dependent on the conditions at the time of sampling. Good quality photoquadrats may therefore result in the identification of a greater number of taxa than would be the case for photoquadrats where visibility was poor.
- Certain taxa were harder to distinguish and identify than others, potentially resulting in a bias towards more conspicuous species. Sponges, bryozoans and colonial ascidians were often difficult to distinguish.
- Only organisms visible on the surface of the encrusting layer were recorded in photoquadrats. Organisms living embedded within or beneath the encrusting layer may therefore be under represented.

Variability in reef assemblages in space and time was analysed with multivariate statistical techniques using Primer v6. This included the following analyses:

1. All Times: Mean percent cover for all transects (nested within survey) was compared among the 13 surveys. Note that results of the baseline survey were not included in any analyses as the majority of transects were bare surface with an algal film only.
2. Orientation: horizontally orientated (deck) transects were compared with vertically orientated (hull) transects located at similar depths and through time.
3. Depth: Shallow transects on the horizontally orientated deck superstructure (between 13 m and 20 m depth) at the mid-ships were compared with deep transects (between 20 m and 30 m depth) on the deck bow and stern through time.

In order to help discriminate between groups of interest, multivariate data were represented graphically using nMDS (non-Metric Multidimensional Scaling). Similarity Percentage Analysis (SIMPER) was used to identify those taxa, or groups of taxa, contributing most to dissimilarities between assemblages where appropriate. Data were square root transformed prior to analysis to down weight the influence of highly abundant taxa.

2.3.1.2 Surface Scrapings

Three 20 cm x 20 cm surface scrapings were collected on a one-off basis from two locations on the deck and one location on the vertical superstructure to provide a qualitative indication of species present within the encrusting assemblage, which could not otherwise be identified from photoquadrats. Samples were sieved on a 1 mm mesh sieve, fixed in formalin and preserved in ethanol prior to identification at Cardno’s Sydney laboratory. Taxa recorded were listed in the overall species inventory.

2.3.1.3 Fixed Photos

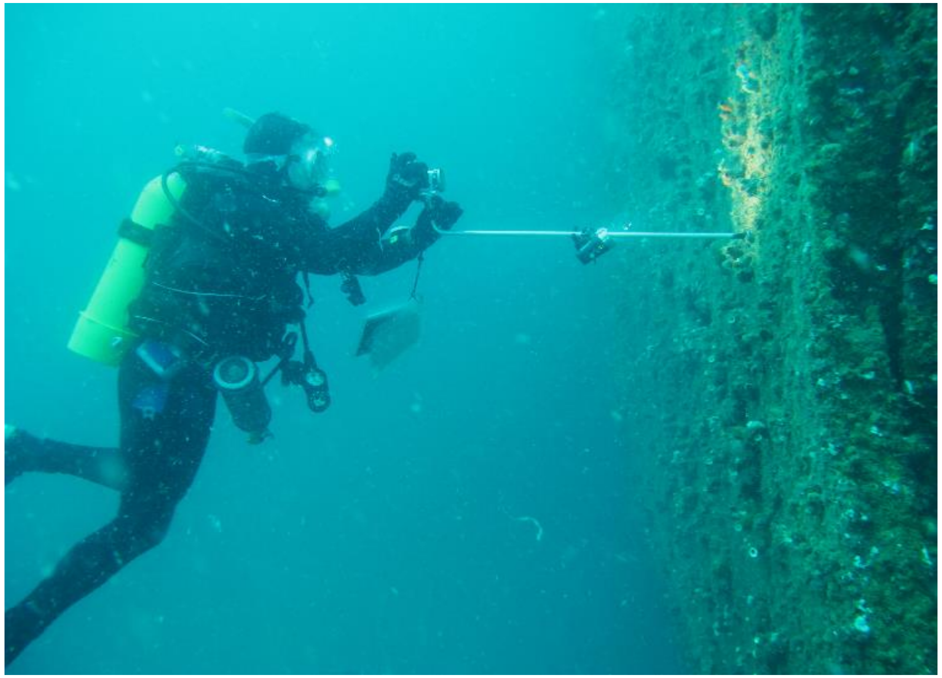
Photographs were taken at 10 fixed point locations throughout the ship to provide a qualitative record of changes through time. These included more complex surfaces such as ladders, doorframes and railings, which were not captured in the photoquadrat survey. The location of the fixed point photographs are indicated in **Figure 3**.

2.3.2 Fish Assemblages

Species of fish observed in association with the vessel were recorded by divers during reef community photoquadrat surveys providing an indication of taxonomic richness through time. Additional species were also identified from review of the video footage taken along each of the 16 line transects, fixed photos and photoquadrats. These data were limited to presence/absence only as abundances were not recorded. These data should therefore be treated as indicative only.

2.3.3 Pest Species

Taxa identified in photoquadrats, surface scrapings, video footage and/or fixed photos were checked for species listed by NSW DPI as marine pests known to occur in NSW.



Cardno diver taking photoquadrat of the hull of the Ex-HMAS Adelaide

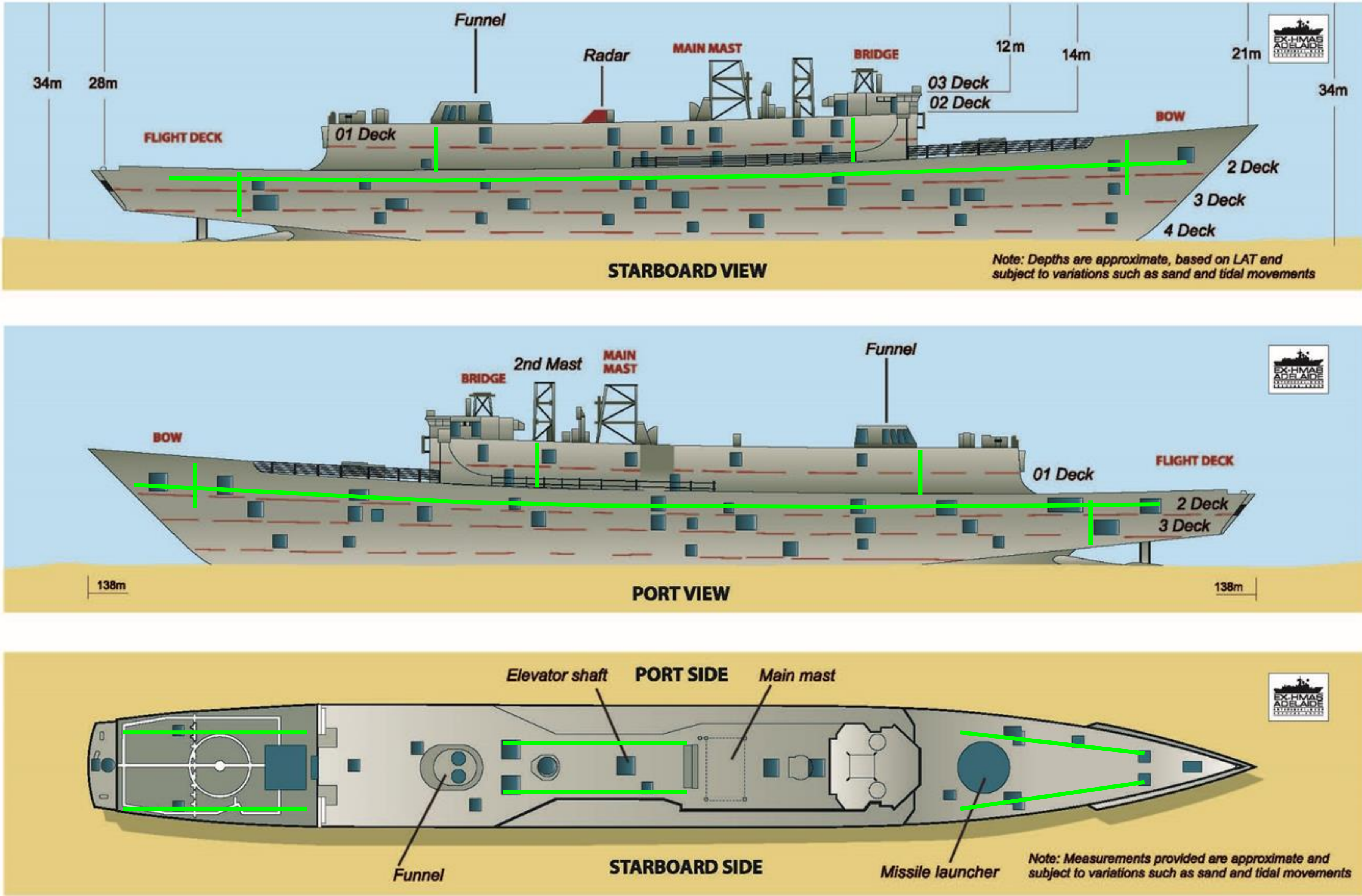


Figure 2 Location of line transects sampled on the Ex-HMAS Adelaide during surveys 1 -13

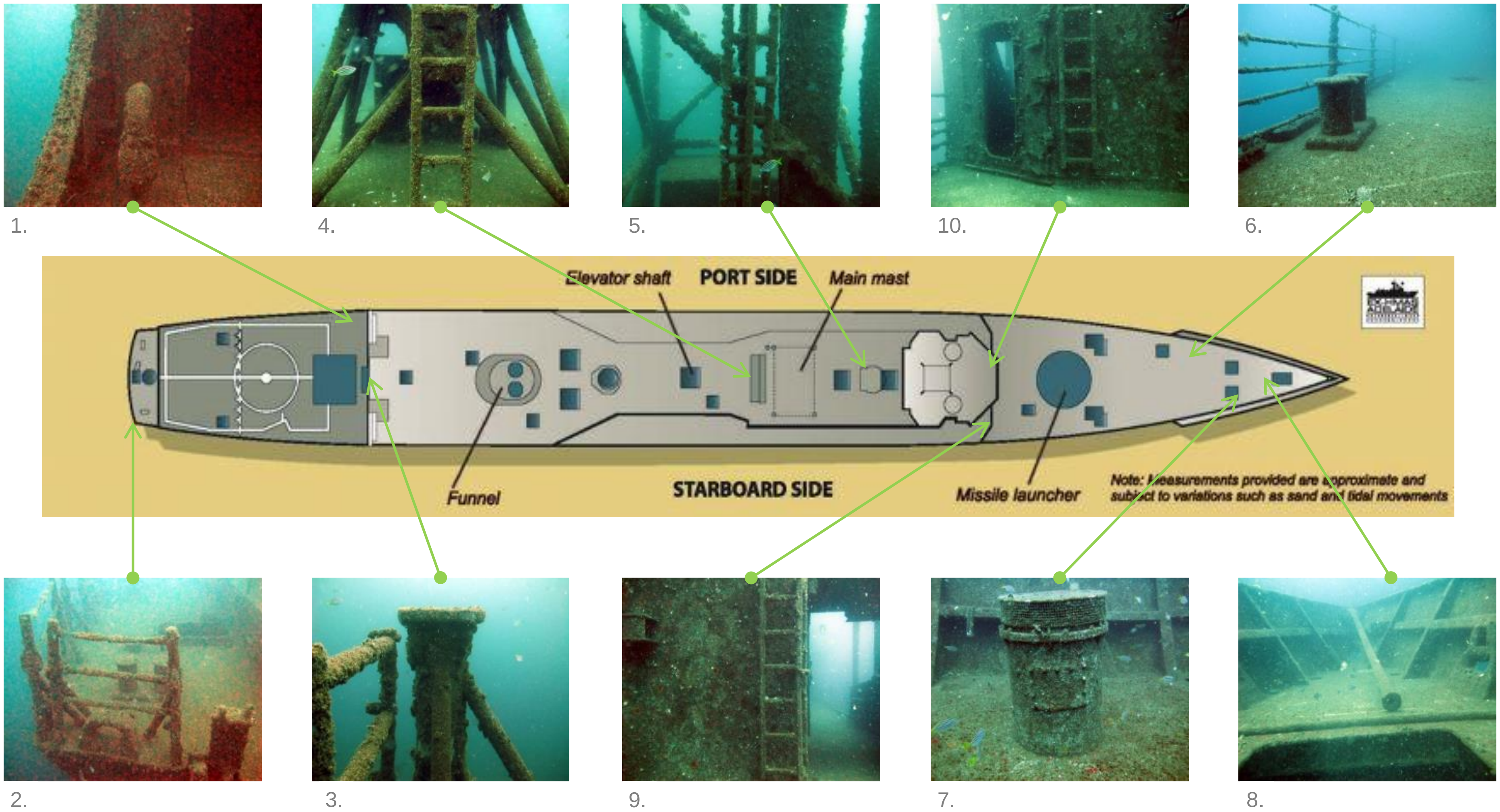


Figure 3 **Fixed photo sampling locations**

2.4 Results Summary

2.4.1 Encrusting Assemblages

2.4.1.1 General Findings

The phyla or subphyla represented by the most number of families were Crustacea and Polychaeta (16% of total families recorded), followed by Mollusca (15%), Porifera (12%), Chordata (8%), Bryozoa (10%) and Cnidaria (7%). Algae (Chlorophyta, Rhodophyta and Phaeophceae), sipunculids, echiurans, echinoderms and arthropods (namely pycnogonids (sea spiders)) were represented by 5% or less of the total number of families recorded (**Figure 4**). Approximately 82 taxa from 67 families and 13 phyla were recorded from photoquadrats, surface scrapings and diver photographs taken during the 13 reef community surveys. Of the 82 taxa recorded, 39 were identified from surface scrapings, 38 from photoquadrats and 36 from diver photographs/video (**Table 2**). Examples of invertebrate and algal families recorded from each phyla or subphyla are presented in **Figure 6** and **Figure 7**.

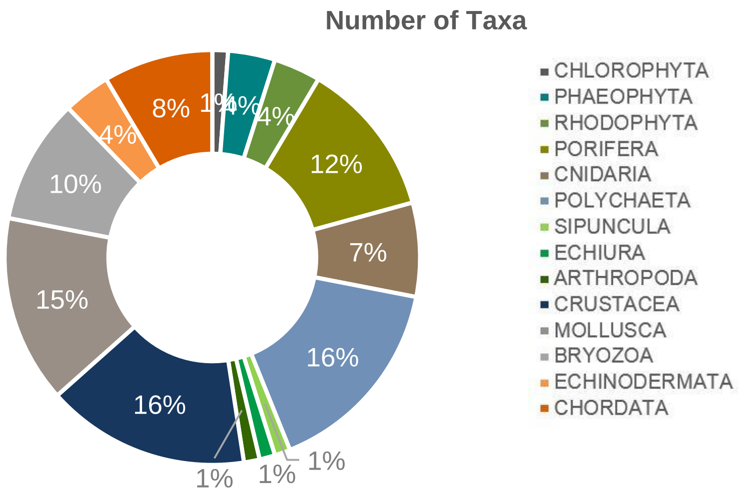


Figure 4 Percent contribution of Phyla/Subphyla by families recorded on the Ex-HMAS Adelaide during surveys 1- 13

The taxonomic composition of the different categories of taxa recorded from Surveys 1 – 13 (in photoquadrats only) is presented in **Figure 5**.

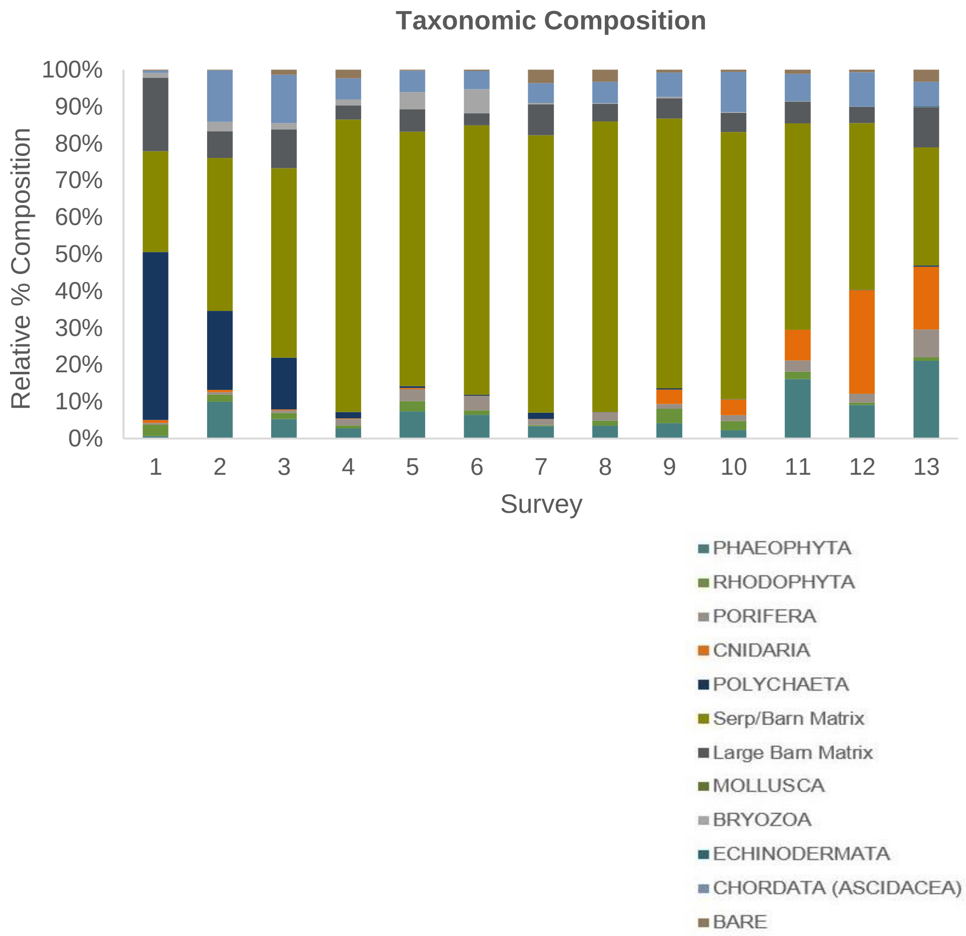
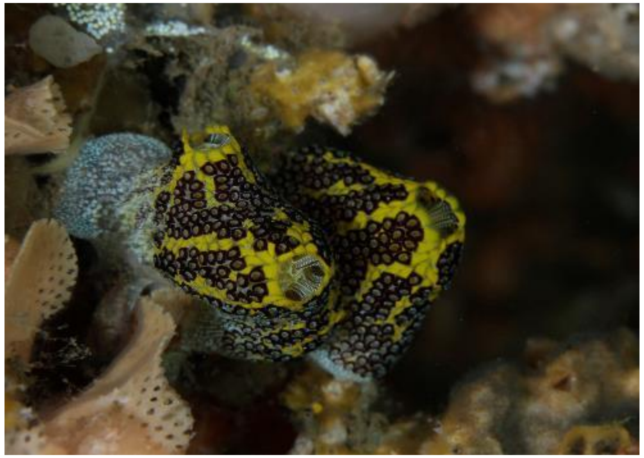


Figure 5 Taxonomic composition of photoquadrats recorded on the Ex-HMAS Adelaide during surveys 1 – 13

Table 2 Inventory of taxa identified from reef community surveys 1 - 13 using different methods

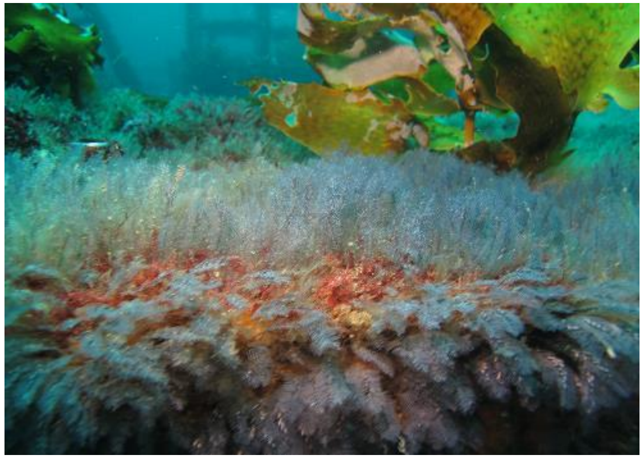
Taxonomic Group			Sampling Method		
Phylum	**(Class) Family**	**Taxon/Species Name**	**Photoquadrat**	**Diver Photo/Video**	**Scraping**
CHLOROPHYTA	Cladophoraceae	Green filamentous	•		
PHAEOPHYTA	Aliariaceae	*Ecklonia radiata*	•	•	
	Dictyotaceae	*Lobophora* sp.	•	•	
	Ectocarpaceae	Brown filamentous	•	•	
RHODOPHYTA	Bonnemaisoniaceace	*Delisea pulchra*	•	•	
		Encrusting red algae	•	•	
	Corallinaceae	Encrusting coralline	•		
PORIFERA	Clionidae	*Cliona* sp.	•		
		White encrusting	•		
		White globular	•	•	
		White papillate	•	•	
		Orange encrusting	•	•	
		Yellow encrusting	•	•	
	Microcionidae	*Holopsamma laminaefavosa*		•	
		Purple encrusting	•	•	
	Darwinellidae	Pink spikey sponge	•	•	
		Red tubular solitary sponge	•	•	
CNIDARIA	Sagartiidae	*Anthothoe albocincta*	•	•	
		Unidentified hydroid 1	•		
	Neptheidae	Unidentified tree coral		•	
	Corallimorphidae	*Corynactis australis*	•		
	Clavulariidae	*Carijoa sp.*		•	
	Aglaopheniidae	*Gymnangium* sp.		•	
POLYCHAETA	Cirratulidae				•
	Eunicidae				•
	Glyceridae				•
	Hesionidae				•
	Polynoidae				•
	Sabellidae				•
	Serpulidae	*Hydroides brachyacantha*			•
	Serpulidae	*Filograna implexa*	•	•	
	Serpulidae	*Spirobranchus* sp.			•
	Serpulidae	*Salmacina australis*			•
	Spirorbidae		•	•	
	Syllidae				•
	Terebellidae				•
SIPUNCULA		Unidentified sipunculid			•
ECHIURA		Unidentified echiuran			•
ARTHROPODA		Unidentified pycnogonid			•

Taxonomic Group			Sampling Method		
Phylum	**(Class) Family**	**Taxon/Species Name**	**Photoquadrat**	**Diver Photo/Video**	**Scraping**
CRUSTACEA	Mysidae				•
Order: Amphipoda	Aoridae/Isaeidae/Photidae				•
	Iciliidae				•
	Liljeborgiidae				•
	Lysianassidae				•
Order: Decapoda	Penaeidae				•
lOrder Caridea	Alpheidae				•
lOrder Brachyura	Goneplacidae				•
	Grapsidae				•
	Hymenosomatidae				•
	Xanthidae				•
Class: Cirripedia	Tetraclitidae		•	•	•
	Balanidae	*Megabalanus coccpoma* ?		•	•
MOLLUSCA	Unidentified chiton		•		
Class: Gastropoda	Columbellidae				•
	Eulimidae				•
	Muricidae	*Dicathais orbita*		•	•
	Muricidae				
	Rissoidae				•
		Unidentified gastropoda			•
Class: Bivalvia	Arcidae				•
	Galeommatidae				•
	Hiatellidae				•
	Mytilidae				•
	Ostreidae				•
BRYOZOA	Membraniporidae	*Biflustra perfragilis*	•	•	
		Encrusting orange	•	•	
		Encrusting yellow	•	•	
	Bugulidae	Encrusting white	•		
		Bugula dentata		•	
	Horneridae	*Hornera* sp.	•	•	
	Phydoloporidae	*Tryphyllozoan* sp.	•	•	
ECHINODERMATA	(Class) Holothuroidea				•
	(Class) Ophiuroidea		•		•
	(Class) Echinoidea	*Centrostephanus rodgersii*		•	
CHORDATA	Pyuridae	*Herdmania momus*	•	•	
Class: Ascidiacea	Styelidae	*Botryloides magnicoecum*	•	•	
	Styelidae	*Botryloides* sp.	•	•	
	Ascidiidae	Unidentified red ascidian	•	•	
	Polyclinidae	Orange colonial ascidian 1	•	•	
	Clavelinidae	*Pycnoclavella* sp.	•	•	
	Didemnidae		•	•	



a)

b)



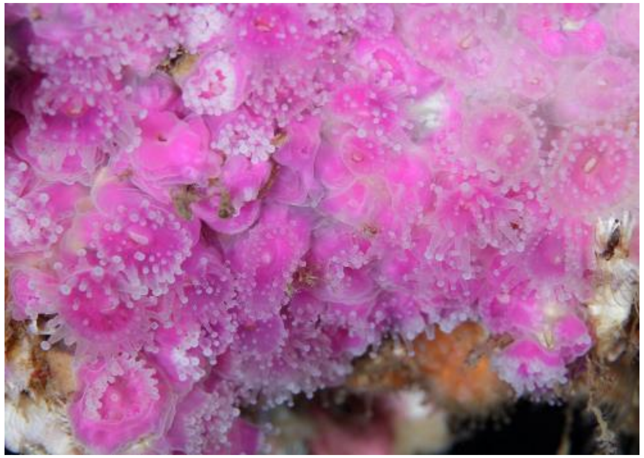
c)

d)

e)

f)

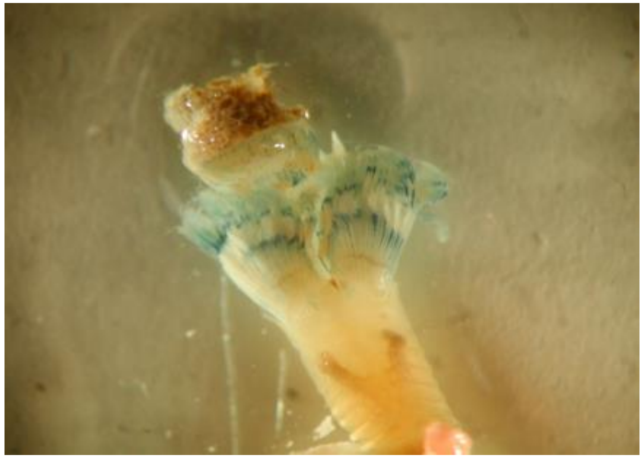
Figure 6 **Examples of representative taxa recorded on the Ex – HMAS Adelaide during surveys 1 – 13: a) colonial ascidian (*Botryloides magnicoecum*) b) anemone (*Anthothoe albocincta*) c) hydroid (*Gymnangium* sp.) and kelp (*Ecklonia radiata*) in background d) White papillated sponge e) sponge (*Holopsamma laminaefavosa*) f) barnacles (*Megabalanus coccopoma*).**



a)

b)

c)



d)

e)

f)

Figure 7 **Examples of representative taxa recorded on the Ex – HMAS Adelaide during surveys 1 – 13: a) anemones (*Corynactis australis*) b) Bryozoan (*Bugula dentata*) c) soft coral (family; Nephtheidae) d) polychaete (family: Serpulidae) e) Echinoderm (Class: Ophiuroidea) f) Amphipod Crustacean (family: Lysianassidae).**

2.4.1.2 Photoquadrats

Temporal and Spatial Variation

1. All Times

A total of 42 taxa/taxon groups were identified from the 13 surveys. In terms of total percentage cover, the ten most numerically abundant taxa/taxonomic groups identified included: serpulid, barnacle and encrusting algae (57.8 %); large barnacles and brown filamentous algae (7.2 %), solitary ascidians (6.7 %), serpulid polychaetes (6.5 %) jewel anemones (*Corynactis australis*) (4.4 %), brown filamentous algae (4.3 %), Kelp (*Ecklonia radiata*) (2.3 %), early colonising matrix (2.2 %), bare surface (1.3 %) and red encrusting algae (1.3 %). All other taxonomic categories contributed to less than 1 % of the total mean percent cover.

Multivariate analysis indicated that 'Survey' was a significant factor in structuring the overall assemblage composition on the ship (regardless of transect positions). Cluster analysis indicated that at the 70 % similarity level, Survey 1 was distinct from all others and that Surveys 2 and 3, Surveys 4 to 11 and Surveys 12 and 13 were similar to one another (**Figure 8**). Pairwise tests also showed that all Surveys were significantly different from one another apart from surveys 2 and 3, 4 and 7, 7 and 8, 9 and 10, 12 and 13 and 11 and 12. Further analyses showed that survey 1 was characterised by relatively monospecific matrices of serpulid worms and/or serpulid worms with barnacles and encrusting algae. Surveys 2 and 3 were similar to Survey 1 in that serpulid worms, barnacles and encrusting algae contributed to a large proportion of the percent cover, although solitary ascidians were a distinguishing taxon. Surveys 4 to 9 were generally characterised by a high percentage cover of serpulids, barnacles and encrusting algae whereas Surveys 11 to 13 were represented by a more taxonomically diverse assemblage including jewel anemones (*C. australis*), solitary ascidians, yellow sponge and brown filamentous algae.

The nMDS plot with trajectory overlay (**Figure 9**) illustrates how the encrusting assemblage has changed through time, with the assemblage at Survey 13 being the most different to that at Survey 1.

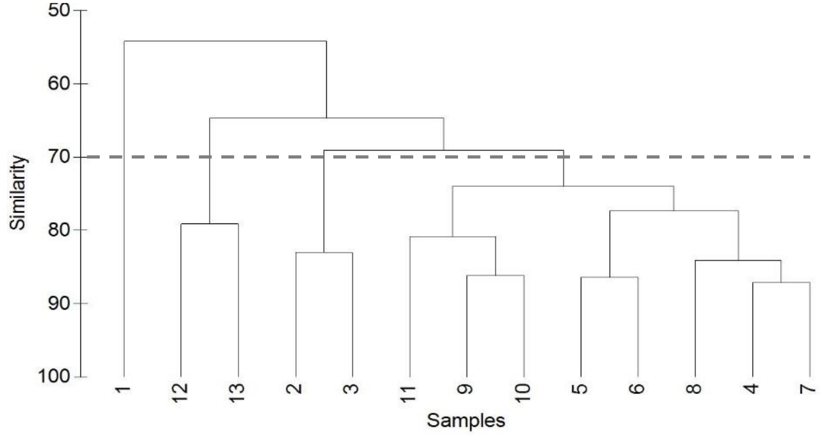


Figure 8 Dendrogram for hierarchical clustering (using group average linking) of encrusting assemblages for factor Time (Survey)'

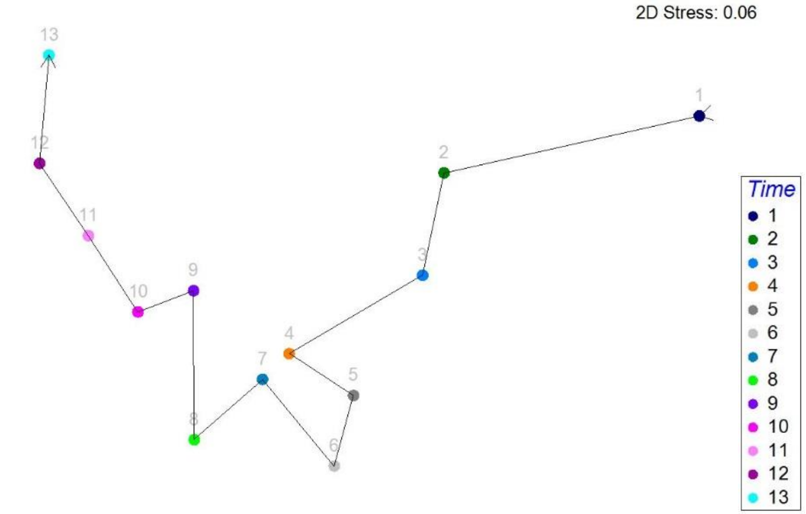


Figure 9 non-metric Multi-Dimensional Scaling (nMDS) ordination of percent cover of encrusting assemblages for factor 'Time' (Survey) with trajectory overlayed

2. Orientation

Orientation was a significant factor in structuring the encrusting epibenthic assemblage associated with the Ex-HMAS Adelaide over the five year monitoring period, with the assemblages associated with horizontal (deck) surfaces consistently different from that of the vertically orientated (hull) surfaces during all surveys. This is illustrated in the nMDS plot (**Figure 10**).

As determined by further SIMPER analyses, the taxa or taxon groups contributing to greater than five percent dissimilarity between deck and hull assemblages included serpulid, barnacle and encrusting algae matrix, large barnacles, solitary ascidians, anemones (*C. australis*), red encrusting algae, brown filamentous algae, yellow and orange encrusting bryozoans and red filamentous algae among others. Bare surface was also influential in determining differences in orientation in some surveys.

Taxa or taxon groups found predominantly in association with horizontally orientated (deck) surfaces included: serpulids with barnacles and encrusting algae, red encrusting algae and red filamentous algae. Kelp (*Ecklonia radiata*), was also only recorded on deck surfaces (mainly midships) and not in any vertically orientated transects throughout the study. Solitary ascidians, *C. australis* and large barnacles were consistently present only on vertically orientated (hull) surfaces for all surveys during which they were recorded. Bryozoans and sponges, were generally only recorded on vertically orientated surfaces, but were only recorded in some of the 13 surveys.

Differences between surveys were also evident within treatments but did not show any consistent or obvious patterns.

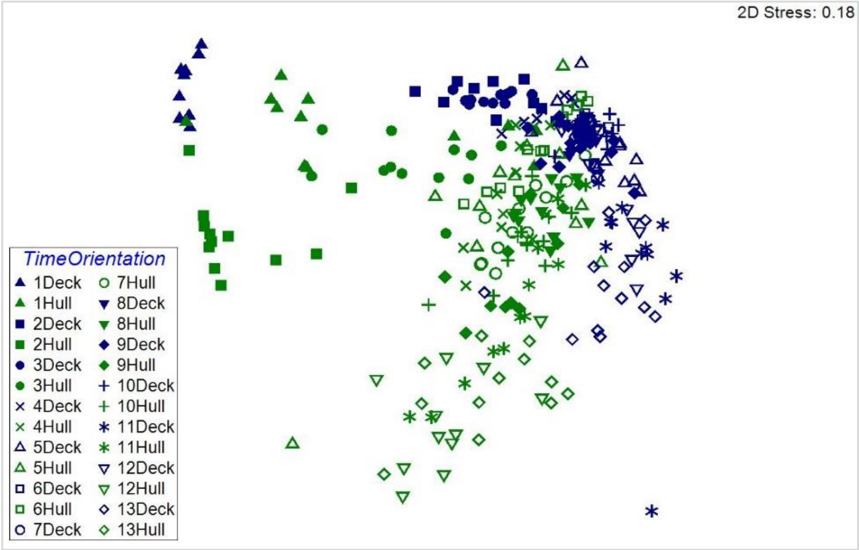


Figure 10 non-metric Multi-Dimensional Scaling (nMDS) ordination of percent cover of encrusting assemblages for factor 'Time' (Survey) and 'Orientation'

3. Depth

Depth was a significant factor in structuring the epibenthic assemblage associated with the Ex-HMAS Adelaide over the five year monitoring period. Results indicated that assemblages associated with deep surfaces (between 20 m and 30 m depth) were significantly different from those associated with the shallower (13 m to 20 m depth) surfaces and that this was consistent across all surveys. These differences are evident in the nMDS plot presented in **Figure 11** which also indicates that the variability among samples within the 'shallow' group appear to be more variable than that among samples within the deep group, as evident by the clustering of 'deep' sample points.

Further analyses indicated that overall, the shallow transects were characterised by the presence of kelp (*E. radiata*), brown algae (*Lobophora* sp.), and red encrusting algae, which were either not present at all in deep photoquadrats or the percentage cover was comparatively lower. The percent cover of serpulid, barnacle and encrusting algae matrix occurred on both deep and shallow transects but was consistently more prevalent on the deeper transects.

Differences between surveys were also evident within treatments but did not show any consistent or obvious patterns.

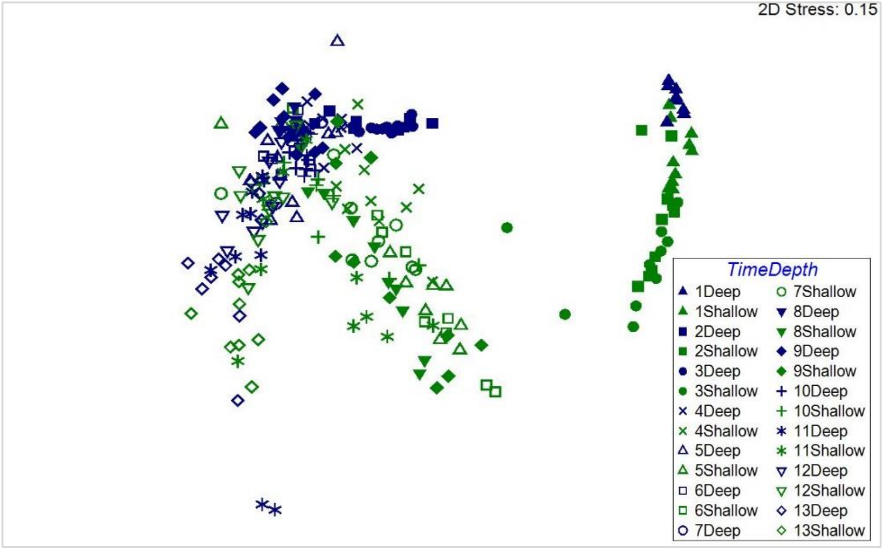


Figure 11 **non-metric Multi-Dimensional Scaling (nMDS) ordination of percent cover of encrusting assemblages for factor 'Time' (Survey) and 'Depth'**

2.4.1.3 Fixed Photos

Inspection of fixed photos showed that after the first six months of scuttling (during Survey1) the majority of the bare ships surface was rapidly colonised with an encrusting layer of serpulid polychaete worms, small and large barnacles, filamentous and encrusting algae, bryozoans and hydroids.

One year post-scuttling (Survey 3), some areas which were previously completely covered in encrusting biota showed exposed bare patches (e.g. fixed photo 1) indicating that the encrusting layer had broken away (e.g. from storms) or potentially been eaten by predatory fishes. The more complex structures such as ladders, railings and mast structures appeared to be more quickly colonised by large barnacles, solitary ascidians, as well as a matrix of filamentous algae, hydroids, sponges and bryozoans (e.g. fixed photo 10). Other mobile and sedentary invertebrates such as small gastropod molluscs, polychaetes and crabs were likely to be present at this stage. Kelp (*E. radiata*) was noted to have developed at this stage but only on the railing structure at the stern (fixed point location 3. Rope bollards, vents and the deck bow (fixed photo 8) did not appear to have developed as quickly as the more complex ladder and railing surfaces.

During Survey 6 (1 year 9 months post-scuttling) there had been a notable increase in the occurrence of a white papillate sponge, particularly at fixed point locations 1, 6, 9 and 10, but was not as conspicuous in later surveys. Soft tree corals (neptheidae) and small tubular sponges could also been seen starting to grow on the deck from around Survey 6. During Survey 8 (2 years and 3 months post-scuttling) large bare patches were noted on the port-side bridge (fixed photo 10), which later has become recolonised.

Overall, following a relatively fast initial colonisation, the encrusting layer appears to have very gradually developed over the 5 year period with subtle differences in thickness and complexity of the biotic assemblage across most structures photographed. Examples are show in **Figure 12**. All fixed photos through time are provided in the Survey 13 Reef Community Monitoring Report (Cardno 2016).

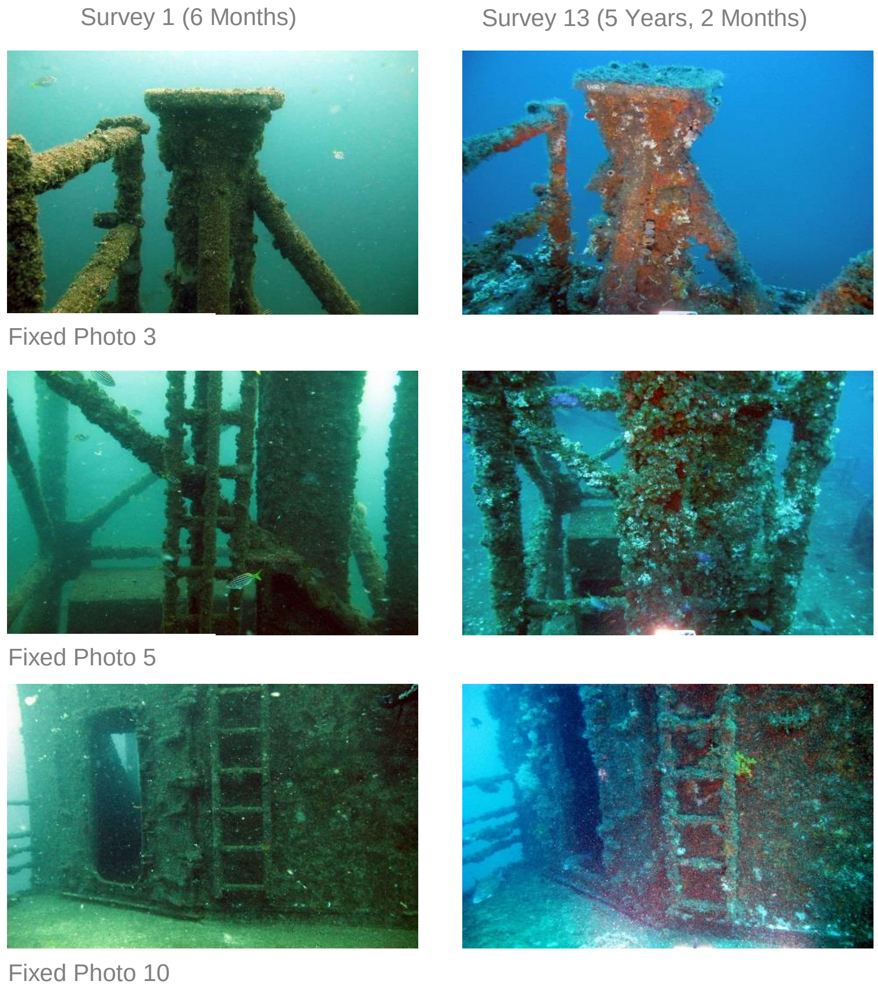


Figure 12 Examples of fixed photos taken during Survey 1 (6 months post-scuttling) and Survey 13 (5 years, 2 months post-scuttling)

2.4.2 Fish Assemblages

A total of 62 species of fish from 31 families were recorded in association with the Ex-HMAS Adelaide during Surveys 1 - 13 (**Table 3**). The family Monacanthidae (leatherjackets) was represented by the most number of species (seven in total) followed by Labridae (wrasses) represented by six species, Carangidae (trevallies, jacks, mackerels and scad) represented by five species and Pomacentridae (damselfishes) represented by four species. Serranidae (bass and grouper), Sparidae (breams and snappers) and Cheilodactylidae (morwongs) were represented by three species. All other families were represented by one or two species only.

Red morwong (*Cheilodactylus fuscus*) was the most frequently observed species, recorded in all 13 monitoring surveys (but not in the baseline survey). Tarwhine (*Rhabdosargus sarba*) and eastern blue groper (*Archeorodus viridis*) were recorded in 12 out of the 13 surveys. Yellowtail kingfish (*Seriola lalandi*), silver sweep (*Scorpis lineolatus*) and white ear (*Parma microlepis*) were recorded in 11 out of 13 surveys. Sergeant baker (*Aulopus purpurrissatus*), eastern red scorpioncod (*Scorpaena cardinalis*) and silver trevally (*Pseudocaranx dentex*) were also relatively abundant, being recorded in 10 out of the 13 surveys. Other commonly recorded species included eastern hulafish (*Trachinops taeniatus*), juvenile snapper (*Pagrus auratus*), blackspot goatfish (*Parupeneus spilurus*), girdled scalyfin (*Parma unifasciata*) and blue morwong (*Nemadactylus douglasii*).

A large proportion of the total species were recorded only once throughout the monitoring program. Several of the species recorded were of recreational and/or commercial importance, while no threatened or protected species were recorded during the monitoring period. Anecdotal evidence,however, suggests grey nurse sharks (*Carcharias taurus*) may occur at the site on occasion.

Overall, there has been a clear increase in the number of species observed in association with the ship. Following an initial rapid increase from only three species at the baseline survey (one week post-scuttling) to 17 species during Survey 1 (six months post-scuttling) there was then a gradual increase from Surveys 1 to Survey 7. Species numbers then remained relatively steady until Survey 13 (five years and two months post-scuttling) (**Figure 13**). It is noted that the majority of rarer species were not recorded until over a year post-scuttling.

Examples of representative or common species of fish recorded on the Ex-HMAS Adelaide are presented in **Figure 14** and **Figure 15**.

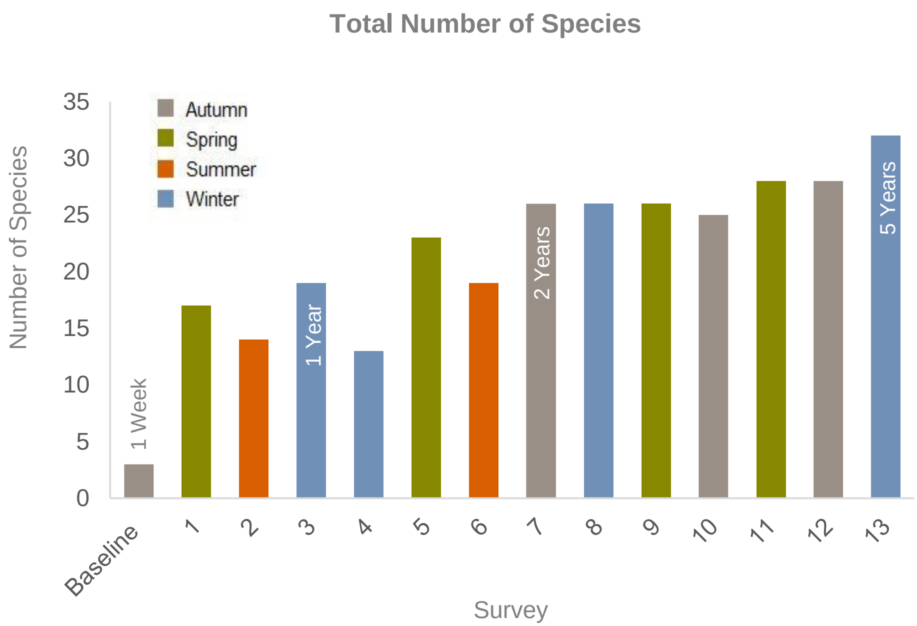


Figure 13 Total number of species recorded in association with the Ex-HMAS Adelaide by diver observations and video footage during surveys 1 – 13

Family	Species Name	Common Name	Baseline Survey (April/May 2011)	Survey 1 (October 2011)	Survey 2 (February 2012)	Survey 3 (May 2012)	Survey 4 (August 2012)	Survey 5 (October 2012)	Survey 6 (January 2013)	Survey 7 (April 2013)	Survey 8 (July 2013)	Survey 9 (October 2013)	Survey 10 (March 2014)	Survey 11 (September 2014)	Survey 12 (March 2015)	Survey 13 (June 2016)	
Cheilodactylidae	*Cheilodactylus fuscus*	Red morwong*		●	●	●	●	●	●	●	●	●	●	●	●	●	13
Sparidae	*Rhabdosargus sarba*	Tarwhine*			●	●	●	●	●	●	●	●	●	●	●	●	12
Labridae	*Achoerodus viridis*	Eastern blue groper		●	●	●	●	●	●	●		●	●	●	●	●	12
Carangidae	*Seriola lalandi*	Yellowtail kingfish*			●	●		●	●	●	●	●	●	●	●	●	11
Scorpididae	*Scorpis lineolatus*	Silver sweep*		●	●	●			●	●	●	●	●	●	●	●	11
Pomacentridae	*Parma microlepis*	White ear		●			●	●	●	●	●	●	●	●	●	●	11
Aulopodidae	*Aulopus purpurrissatus*	Sergeant baker		●	●	●		●	●		●	●		●	●	●	10
Scorpaenidae	*Scorpaena cardinalis*	Eastern red scorpioncod		●	●			●		●	●	●	●	●	●	●	10
Carangidae	*Pseudocaranx dentex*	Silver trevally				●	●	●		●	●	●	●	●	●	●	10
Plesiopidae	*Trachinops taeniatus*	Eastern hulafish						●	●	●	●	●	●	●	●	●	9
Sparidae	*Pagrus auratus*	Snapper (juv)*+		●	●	●		●	●	●				●	●	●	9
Mullidae	*Parupeneus spilurus*	Blackspot goatfish	●					●	●	●	●	●		●	●	●	9
Pomacentridae	*Parma unifasciata*	Girdled scalyfin			●			●	●	●	●	●	●	●	●		9
Cheilodactylidae	*Nemadactylus douglasii*	Blue morwong*		●	●				●	●		●	●	●	●	●	9
Enoplosidae	*Enoplosus armatus*	Old wife				●	●			●		●	●	●	●	●	8
Aplodactylidae	*Crinodus lophodon*	Rock cale						●		●	●	●	●	●	●	●	8
Latrididae	*Latridopsis forsteri*	Bastard trumpeter		●				●	●	●	●	●		●		●	8
Labridae	*Notolabrus gymnogenis*	Crimson banded wrasse				●		●	●			●	●	●	●	●	8
Monacanthidae	*Meuschenia freycineti*	Six-spined leatherjacket*						●		●	●	●	●	●	●	●	8
Monacanthidae	*Meuschenia trachylepis*	Yellow-finned leatherjacket*				●		●	●	●	●	●	●	●			8
Serranidae	*Hypoplectrodes maccullochi*	Half-banded sea perch				●	●			●	●			●	●	●	7
Cirritidae	*Cirritichthys aprinus*	Blotched hawkfish						●	●	●	●	●	●		●		7
Scorpididae	*Atypicthys strigatus*	Mado		●	●	●	●			●						●	6
Scorpididae	*Microcanthus strigatus*	Stripey		●	●	●							●		●	●	6
Tetraodonitdae	*Dicotlichthys punctulatus*	Three-bar porcupinefish		●				●	●				●	●	●		6
Scorpaenidae	*Centropogon australis*	Eastern fortesque		●	●	●										●	4
Dinolestidae	*Dinolestes leweni*	Longfinned pike		●			●					●				●	4
Chaetodontidae	*Heniochus diphreutes*	Schooling bannerfish	●	●				●			●						4
Cheilodactylidae	*Cheilodactylus vestitus*	Magpie morwong								●		●		●		●	4
Monacanthidae	*Nelusetta ayraudi*	Chinaman leather jacket*+		●	●	●									●		4
Monacanthidae	*Eubalichthys bucephalus*	Black reef leatherjacket											●	●	●	●	4
Monacanthidae	*Meuschenia spp.*	Unidentified leatherjackets				●	●	●								●	4
Carangidae	*Trachurus novaezelandiae*	Yellowtail scad+		●			●				●						3
Kyphosidae	*Kyphosus sydneyanus*	Silver drummer*				●						●	●				3
Ephippidae	*Platax* sp.	Batfish					●					●	●				3
Pomacentridae	*Parma polylepis*	Banded parma												●	●	●	3
Labridae	*Notolabrus parilus*	Brown spotted wrasse				●							●	●			3
Labridae	*Psuedolabrus luculentus*	Luculentus wrasse								●	●		●				3
Serranidae	*Acanthistius ocellatus*	Eastern wirrah									●					●	2
Serranidae	*Hypoplectrodes nigroruber*	Black-banded sea perch								●		●					2
Pomacentridae	*Chromis hypsilepis*	One-spot puller									●					●	2
Chironemidae	*Chironemus marmoratus*	Eastern kelpfish						●						●			2
Blenniidae	*Petroscirtes lupus*	Brown sabretooth blenny	●						●								2
Heterodontidae	*Heterodontus portusjacksoni*	Port Jackson shark									●						1
Orectolobidae	*Orectolobus* sp.	Wobbegong shark											●			●	1
Scorpaenidae	*Scorpaenodes scaber*	Pygmy scorpionfish												●			1
Platycephalidae	*Platycephalus fuscus*	Dusky flathead*+					●										1
Glaucosomidae	*Glaucosoma scapulare*	Pearl perch*+													●		1
Carangidae	*Seriola hippos*	Samson Fish*									●						1
Carangidae	*Elagatis bipinnulata*	Rainbow runner									●						1
Sparidae	*Acanthopagrus australis*	Yellowfin bream													●		1
Lutjanidae	*Paracaesio xanthurus*	Southern fusilier								●							1
Lutjanidae	*Lutjanus russelli*	Moses perch*													●		1
Chaetodontidae	*Chaetodon guentheri*	Gunther's butterflyfish								●							1
Labridae	*Coris picta*	Comb wrasse						●									1
Labridae	*Thalassoma lunare*	Moon wrasse									●						1
Blenniidae	*Parablennius intermedius*	Horned blenny							●								1
Monacanthidae	*Monacanthus chinensis*	Fan belly leatherjacket*						●									1
Monacanthidae	*Eubalichthys mosaicus*	Mosiac leatherjacket*							●								1
Sepiidae	*Sepia* sp.	Cuttlefish										●					1
Moridae	*Lotella rhacina*	Beardie														●	1
Belonidae	*Strongylura leiura*	Slender longtom														●	1
Total Number of Taxa			**3**	**17**	**14**	**19**	**13**	**23**	**19**	**26**	**26**	**26**	**25**	**28**	**28**	**32**	

Table 3 List of fish species recorded from diver observations, fixed photo and video during surveys 1-13. (*) = recreationally important species, (+) = commercially important (#) = species of conservation significance

a)

b)

c)

d)

e)

f)

Figure 14 **Examples of common fish observed in association with the Ex-HMAS Adelaide during surveys 1 -13 a) Red morwong (*Cheilodactylus fuscus*) b) Tarwhine (*Rhabsosargus sarba*) c) Eastern blue groper (*Archoerodus viridis*) d) Yellowtail kingfish (*Seriola lalandi*) e) Silver sweep (*Scorpis lineolatus*) f) Eastern red scorpioncod (*Scorpaeana cardinalis*)**

a)

b)

c)

d)

e)

f)

Figure 15 Examples of representative fish observed in association with the Ex-HMAS Adelaide during surveys 1 -13 a) Six-spined leatherjacket (*Meuschenia freycineti*) b) Old wife (*Enoplosus armatus*) c) Girdled scalyfin (*Parma unifasciata*), d) Crimson banded wrasse (*Notolabrus gymnogenus* e) Luculentus wrasse (*Pseudolabrus luculentus*) f) Black banded sea perch (*Hypoplectrodes nigroruber*)

2.4.3 Marine Pests

Marine pests listed by NSW DPI that are known to occur in NSW include:

> Caulerpa (*Caulerpa taxifolia*);

> European fan worm (*Sabella spallanzanii*);

> European green crab (*Carcinus maenas*);

> Japanese goby (*Tridentiger trigonocephalus*);

> New Zealand screwshell (*Maoricolpus roseus*);

> Pacific oyster (*Crassostrea gigas*);

> Yellowfin goby (*Acanthogbius flavimanus*); and

> Mozambique tilapia (*Oreochromis mossambicus*).

None of the species listed above were identified from photoquadrats, fixed photos, video footage or surface scrapings. Furthermore, 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 more associated with sheltered waters. Several other marine pests are known to occur in other parts of Australia, but have not yet been recorded in NSW. These include:

Marine pests listed by NSW DPI as known to occur within Australia include the following:

> Asian date mussel or bag mussel (*Musculista senhousia*);

> Asian green mussel (*Perna viridis*);

> Asian paddle crab (*Charybdis japonica*);

> Black-striped mussel (*Mytilopsis sallei*);

> Japanese seaweed / Wakame (*Undaria pinnatifida*); and

> Northern Pacific seastar (*Asterias amurensis*)

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.

Numerous 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. One species of potentially introduced barnacle, the Panamanian large barnacle (*Megabalanus coccopoma*) for example (**Figure 6**), 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.

For detailed results refer to Reef Community Survey 13 (Cardno 2016).

2.5 Discussion

2.5.1 Encrusting Assemblages

2.5.1.1 General

Initial colonisation of the Ex-HMAS Adelaide was rapid, with an increase in total number of taxa recorded in photoquadrats from three (during the baseline survey) to 19 within the first six months. By Survey 5 (1 year and 6 months post-scuttling), the taxonomic abundance reached 29 taxa before declining to 23 taxa during Survey 8, then increasing again overall to 30 taxa by Survey 13 (5 years and 2 months post-scuttling). Serpulid polychaete worms and barnacles comprised the large majority of the early colonising taxa with red algae also present but to a much lesser extent. 'Pioneer' species such as these, as well as hydroids and bryozoans, have been found to occupy a large proportion of available space on newly created artificial reefs (Ardizzone et al. 1989, Boaventura et al. 2006) although the sequence of macrobenthic colonisation appears to vary depending on seasons and locations. Colonisation of sunken vessels elsewhere in Australia by sessile invertebrates has also proven to be relatively rapid. For example, a total of 28 taxa or groups of taxa were recorded on the Ex-HMAS Canberra (Victoria) after six months of scuttling, although red and brown algae and sponges were the most abundant groups recorded. An algae-invertebrate matrix was also abundant, but this did not contain serpulid polychaetes or barnacles as found on the Ex-HMAS Adelaide. Several other taxa including other types of tube building polychaetes (e.g. *Filograna implexa*), ascidians (*Botryloides magniceocum* and *Herdmania* sp.), red encrusting and filamentous algae, sponges and hydroids, were common to both ships. The Ex-HMAS Brisbane (Queensland) became colonised within three months of deployment by red, brown and blue/green algae, limpets and goose barnacles (Queensland EPA 2007). Mobile invertebrates such as crabs, shrimps, crayfish and octopus, were recorded within nine months. The HMAS Swan (Dunsborough, Western Australia) was initially colonised by hydroids, which covered approximately 70 % – 90 % of the area surveyed (Morrison 2001). Algal growth also dominated the encrusting marine life during the summer months, particularly on the upper surfaces. It is likely that several factors will influence the types of pioneer species which initially colonise and artificial structure. These may include the material of the structure (e.g. Ushiama et al. 2015), seasonal recruitment and broad-scale currents and the conditions at the settlement site (e.g. light availability and local currents).

Following the rapid colonisation, taxon richness increased at a relatively gradual rate. The composition of the encrusting assemblage, did, however, continue to change through time. Some species, for example were recorded only in early surveys (such as serpulid polychaetes), but were overgrown by barnacles, hydroids and turfing algae and therefore not recorded in later surveys. Conversely, several species did not colonise until several years post-scuttling, such as the jewel anemones (*C. Australis*), large sponges, soft corals and sea urchins (*C. rodgersii*). The continual occurrence of new taxa on the ship over time is indicative that successional changes are continuing to occur. This may be a result of several biotic, density dependant interactions (such as predation by fish and predatory invertebrates and competition) and/or changes to physical conditions (e.g. from storms or seasonal fluctuations in sea temperature and current patterns). As new species create secondary habitat and increased habitat complexity, this could also create conditions suitable for other benthic invertebrates to occupy. New patches of bare surface appeared throughout the monitoring program, particularly in heavily encrusted locations on vertical surfaces. This is likely to be a result of reef detaching due to storms disturbance or from paint layers beneath the encrusting later flaking off under the weight of the encrusting biota. These patches would then create an attachment surface for pioneer species which have been outcompeted or overgrown on other parts of the ship.

Continuing changes indicate that the assemblage is still developing through time and has not yet reached a status of equilibrium. In many cases this has been shown to take several decades rather than years (Perkol-finkel et al. 2005).

2.5.1.2 Orientation

Orientation was a significant factor in structuring the encrusting epibenthic assemblage associated with the Ex-HMAS Adelaide. This is consistent with the findings of several other studies (Glasby 2000, Irving and Connell 2002, Knott et al.2004, Glasby and Connell 2001, Harris and Irons 1982, Todd and Turner 1986, Hurlbut 1991). In particular, Knott et al (2004) sampled both natural and artificial structures in the greater Sydney region. Large differences between assemblages on vertical and horizontal surfaces on both natural and artificial structures were evident. Similar to this study, the solitary ascidian *Herdmania momus*, was characteristic of the assemblages found on the vertically orientated surfaces. Algae, however, did not show any consistent differences in their covers on vertical or on horizontal surfaces which is contrary to this study.

The reasons for differences in orientation are not clear, but are considered to involve factors such as light (Kennelly 1989, Baynes 1999, Glasby 1999), predation/grazing (Keough and Downes 1982, Osman et al. 1992), larval behaviour (Raimondi and Keough 1990, Hurlbut 1991) and water flow at micro- or meso-scales (Breitburg et al. 1995, Guichard and Bourget 1998).

Species associated with horizontally orientated surfaces of the Ex-HMAS Adelaide included serpulids with barnacles and encrusting algae (although these were also found on vertically orientated surfaces, but in lower abundances), red encrusting algae and red filamentous algae. Kelp (*Ecklonia radiata*), was also only recorded on deck surfaces (mainly midships) and not in any vertically orientated transects throughout the study. Light was therefore likely to be an important factor for these algae, although settling of propagules onto vertical surfaces may also be an issue. Solitary ascidians, anemones (*C. australis*) and large barnacles were consistently present only on vertically orientated (hull) surfaces for all surveys during which they were recorded. A greater percent cover of bryozoans and sponges was also generally associated with vertically orientated surfaces. It is possible that these groups proliferate on more shaded portions of the ship or that the currents are such that feeding efficiency is optimal. Video footage and fixed photos also showed that large filter feeding barnacles and ascidians tend to occur around portholes, doorframes and ladders, which may be related to increased current velocities and eddies created in association with these more complex structures. *C. australis* in particular is known to occur in shaded conditions, often forming large colonies at entrances to sea caves (Edgar 2003). Similar results were found on the Ex-HMAS Swan and Ex-HMAS Canberra where sponges, ascidians, anemones and soft corals, were shown to proliferate on shaded portions of the vessel.

A greater amount of sedimentation was generally observed on the deck surfaces in some of the earlier surveys which may have been a factor contributing to differences in assemblages between vertical and horizontal surfaces. This was shown to be a factor in a study by Glasby (2000).

2.5.1.3 Depth

Depth was also a significant factor in structuring the reef assemblage with shallow transects characterised by brown algae (*E. radiata* and *Lobophora* sp.) and red encrusting algae. The serpulid, barnacle and algal matrix category was found on both deep and shallow surfaces but percent cover was generally greater on the deeper surfaces.

Given that one of the main effects of increasing depth is a reduction in the quality and intensity of light (Marinho-soriano 2012), it is likely that this was a factor in the differences in cover of brown and red algae. *E. radiata* can generally tolerate low light conditions and is one of the deepest growing large algae common to NSW, found at depths between 0 – 44 m (Edgar 2003), however, shallower depths may have provided more suitable conditions for growth. Taxa not recorded in the analyses of photoquadrats, but that were observed upon review of the video footage, included green filamentous algae and small clumps of white branching hard corals (Nephtheidae). Both these taxa require sufficient light to grow and hence were found only on the upper deck surfaces. Other factors such as predation and grazing by fish and mobile invertebrates may potentially be influential. The urchin *C. rodgersii*, for example, which was also observed to occur on the ship is known to predate upon propagules of kelp and other macroalgae. The partial burial of the ship within the seabed and slight tilt may also influence shading at different depths. The greater coverage of the filter feeding serpulids and barnacles (comprising the serpulid, barnacle and encrusting algae matrix), within the deeper depth range is less clear, but may be explained by small-scale differences in current, food availability and/or competitive interactions. Tarwhine, for example, which feed on a range of molluscs, crustaceans and worms were observed feeding on deck surfaces in several surveys. Currents and chance settlement patterns of propagules at the time of scuttling could also be factors.

Similar to the results of this study, investigations of the Ex-HMAS Canberra (Chidgey and Crocket 2010) found higher abundances of algae (including red encrusting coralline, red filamentous and green (*Ulva* sp.) at shallower depths (where light availability was greater). Many invertebrates exhibited the inverse pattern to the algae, with sponges, hydroids, molluscs and ascidians were more common on shady parts of the ship.

2.5.1.4 Fixed Photos

Similar to this study, the distribution of some categories on the Ex-HMAS Canberra appeared to have strong relationships with water movement. For example, it was noticed in the initial stages of colonisation that the heaviest growth was concentrated on edges (railings etc.) and hull openings. Such patterns have also been noted on the Troy-D in Tasmania, where the kelp *E. radiata* was generally confined to the deck edges and railings (Chidgey and Crocket 2010).

2.5.2 Fish Assemblages

The initial colonisation of artificial reefs by fish is due to the behavioural response of fish to objects, in which certain species move towards structure rather than bare, featureless habitat (Brickhill et al. 2005). It is therefore not suprising that six months post-scuttling, fish abundance and diversity observed around the Ex-HMAS Adelaide had increased substantially from three species; (blackspot goatfish, (*Parupeneus spilurus*; bannerfish, *Hemiochus* sp. and sabretooth blenny, *Petroscirtes lupus*) to 17 species. The continual but gradual increase in taxon richness over time was likely a function of the time available for species to recruit to the ship, but also related to an increased and/or diversified amount of food and habitat becoming available as a consequence of the successional development of the encrusting reef assemblage. In general, fish were observed around the superstructure at shallower depths, where more complex habitat structure was present providing refuge from predators and shade.

The extent of the colonisation of the Ex-HMAS Adelaide by fish was consistent with the findings of surveys of other scuttled vessels and artificial reefs in Australia and elsewhere. Monitoring of the Ex- HMAS Swan (WA) over a two year period, for example, showed an increase in average species richness from two to 32 species. The fish community showed a gradual increase in abundance over the monitoring period with a rapid increase in mean diversity within the first two months of deployment. The assemblage on the wreck also showed a rapid shift from omnivorous weed/sand fishes to one dominated by planktivorous and carnivorous reef fishes.

The fish observed in association with the Ex-HMAS Adelaide are commonly found on natural rocky reefs in the greater Sydney region and were also recorded in baseline fish surveys of natural reefs located to the north and south of the proposed Ex-HMAS Adelaide artificial reef and dive site (Cardno Ecology Lab 2009). The species observed in the present study were a mixture of both reef-associated residents, such as bannerfish (*Hemiochus* sp.), mado (*Atypicthys strigatus*), stripey (*Microcanthus strigatus*), eastern hula fish (*Trachinops taeniatus*) and white ear (*Parma microlepis*) and transient species such as yellowtail kingfish (*Seriola lalandi*), longfin pike (*Dinolestes leweni*), silver sweep (*Scorpis lineolatus*) and yellowtail scad (*Trachurus novaezelandiae*). Several of these species may also move among different reefs from time to time, using the artificial reef as a temporary refuge, but not feeding there continually. Several species commonly found in association with the Ex-HMAS Adelaide have also been recorded on the Ex-HMAS Canberra (Victoria).

Other studies have shown that over time, fish assemblages colonising artificial reefs may become similar in species composition to neighbouring natural reefs (Clynick et al. 2008, Santos and Monteiro 2007, Relini et al. 2002), although this may be dependent on the similarity of structural properties of the artificial reefs (Perkol-Finkel et al. 2005, Edwards and Smith 2005).

The season of deployment may be a factor in determining the type and abundance of species that colonise an artificial reef. For example, Markevich (2005) found that artificial reefs deployed in spring or early summer were more rapidly colonised than those deployed in autumn due to patterns of plankton settlement.

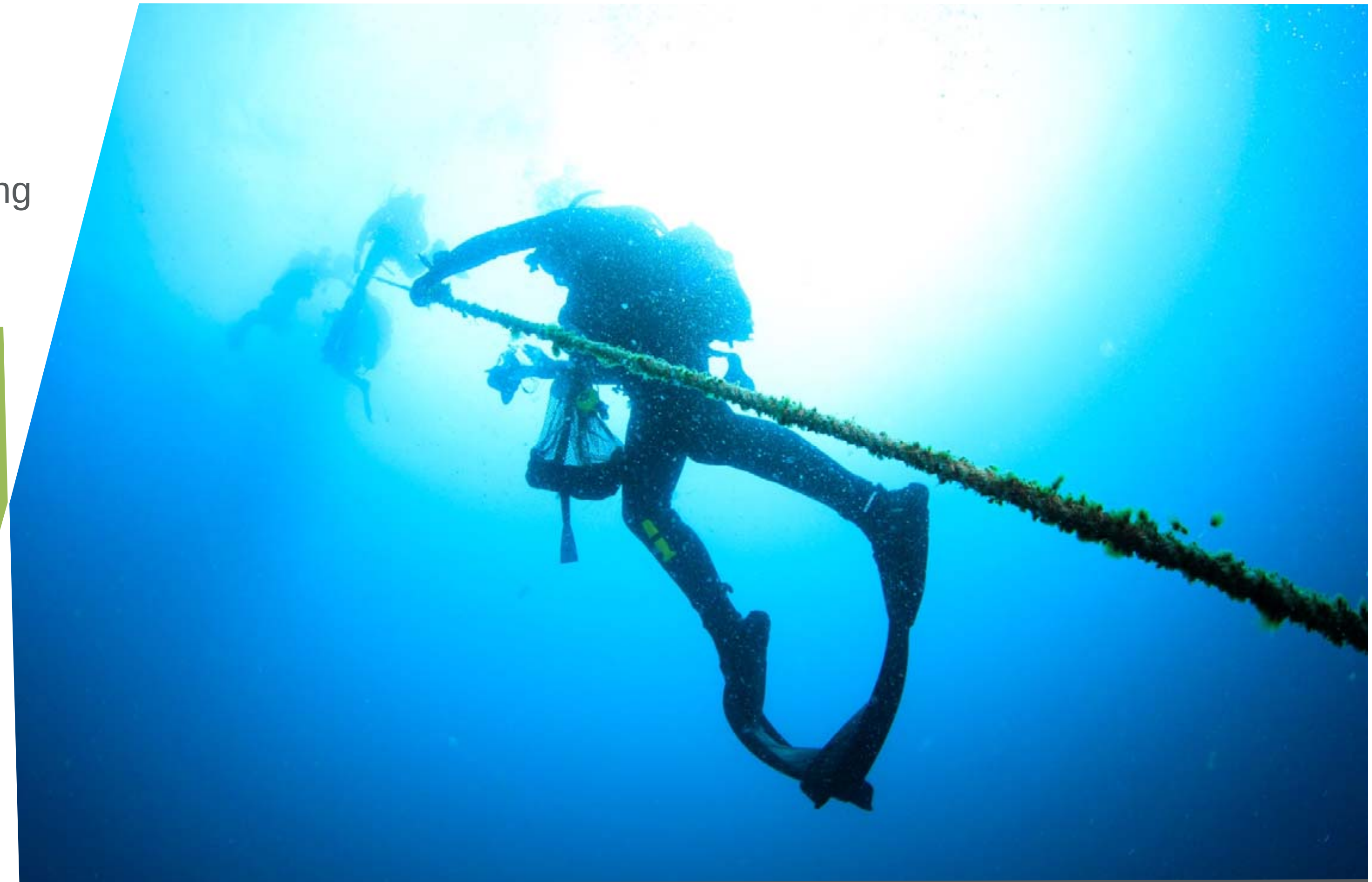
2.5.3 Marine Pests

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.

Review of Ecological Monitoring
Five Years Post-Scuttling

03

SEDIMENT QUALITY



Cardno
Shaping the Future

3 Sediment Quality

3.1 Aims and Objectives

The aim of the sediment quality monitoring survey, as outlined in the LTMMP, was to gain an understanding of how metal corrosion and degradation of paint layers may be influencing/impacting on the marine environment and whether benthic organisms are likely to be affected by metal enrichment. The LTMMP stipulated that sediment testing was carried out for the following metals: aluminium (Al), iron (Fe), chromium (Cr), copper (Cu); lead (Pb), nickel (Ni); and zinc (Zn). Baseline sediment sampling was undertaken in 2009 by Worley Parsons and 1 month post-scuttling in May 2011 (Worley Parsons 2011). In accordance with the LTMMP subsequent surveys were undertaken by Cardno, six, 21 and 62 months post-scuttling. Sampling dates are provided in **Table 1**.

3.2 Existing Information

A total of 110 paint samples, tested from representative locations across the ship, confirmed 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 not prone to leaching due to insolubility. The lead is also in a form that has low bioavailability, little potential for bioaccumulation, and does not biomagnify. Risks from 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 leaching rate declines after the first six months of application. 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 ago, thus reducing the amount of copper remaining that could be released into the marine environment.

3.3 Overview of Study Methods

Prior to scuttling, samples were collected at three locations within the approximate footprint of the proposed scuttling location. Thereafter, samples were collected from three control locations (S2, S3 and S6) and six impact locations (I1, I2, I3, I4, I5 and I6) for all survey times. One of the control locations, however, (S2) was considered too close to the vessel to be a valid control. As such, data from this site was analysed as an impact location.

Sediment samples were collected by deploying a Ponar benthic grab from a boat and tested for trace metals against NODG (National Ocean Disposal Guideline for Dredged Material and ANZECC/ARMCANZ (2000) Interim Sediment Quality Guidelines. Particle grain size was also analysed.

A monitoring condition set by the Administrative Appeals Tribunal also required that sediment from two sites within the hull were sampled and analysed for lead to measure any changes in sediment lead concentrations over time. The location of the monitoring sites were in the bottom centre of the Laundry (compartment number 4-140-0-Q); and Auxiliary Machinery Room Number 3 (compartment number 5-292-0-L). These samples were collected by commercially qualified (ADAS Part 3) divers from McLennan Diving Services and analysed for lead concentration during sediment monitoring survey 1 (May 2011), 1 month post-scuttling) only. This component of the study could not be carried in subsequent surveys due to changes in diving legislation and occupational diving health and safety requirements, which would have deemed it impractical to collect these samples.

3.4 Results Summary

Concentrations of metal contaminants in sediment samples are provided in **Table 4** and **Figure 16**. The main findings are summarised as follows:

> In general, metal concentrations recorded 62 months post-scuttling (June 2016) were similar to those recorded after only one month post-scuttling (May 2011) and therefore, did not indicate any significant long-term effects as a result of the ship.

> The exception to this was for aluminium, which showed an overall increase in concentrations at impact sites 62 months post-scuttling in comparison with that recorded one month post-scuttling. This increase appeared to be greater at the impact location compared to the control location (in June 2016) which may be indicative of metal corrosion associated with the ship, although this difference was not statistically significant, due to the large variation among control samples.

> Particle size distribution was relatively uniform across the sites and as such, this was not considered to be a factor in the differences in aluminium concentrations between control and impact sites.

> Metal concentrations recorded six months post-scuttling (Oct 2011) and 21 months post-scuttling (Jan 2013) were notably lower than the levels recorded one and 62 months post-scuttling.

> For metals where guidelines are available (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.

For detailed results refer to the Sediment Monitoring Report (Cardno 2016a).

Sediment sampling being carried out by Cardno during the final (62 month post-scuttling) monitoring survey

Table 4 Heavy metal concentrations recorded in sediment samples collected from monitoring and control locations one, six, twenty one and sixty two months post-scuttling. Where the metal concentration was below the LOR (Level of Reporting), it was treated as a zero value

		Aluminium (mg/kg)				Chromium (mg/kg)				Copper (mg/kg)				Iron (mg/kg)				Nickel (mg/kg)				Lead (mg/kg)				Zinc (mg/kg)			
ISQG low - high trigger values		n/a				80 - 370				65 - 270				n/a				21 - 52				50 - 220				200 - 410			
		Months Post-Scuttling				Months Post-Scuttling				Months Post-Scuttling				Months Post-Scuttling				Months Post-Scuttling				Months Post-Scuttling				Months Post-Scuttling			
	Sample ID	1	6	21	62	1	6	21	62	1	6	21	62	1	6	21	62	1	6	21	62	1	6	21	62	1	6	21	62
		May 2011	Oct 2011	Jan 2013	June 2016	May 2011	Oct 2011	Jan 2013	June 2016	May 2011	Oct 2011	Jan 2013	June 2016	May 2011	Oct 2011	Jan 2013	June 2016	May 2011	Oct 2011	Jan 2013	June 2016	May 2011	Oct 2011	Jan 2013	June 2016	May 2011	Oct 2011	Jan 2013	June 2016
Control	S3	1100.0	160.0	200.0	2470.0	6.9	1.3	1.6	8.2	1.7	0.0	0.0	1.9	10000.0	1080.0	1280.0	10900.0	2.5	0.0	0.0	3.1	3.1	2.2	2.9	3.8	10.0	2.3	3.4	12.0
	S6	740.0	110.0	100.0	740.0	6.0	1.0	1.0	6.4	0.8	0.0	0.0	0.0	7300.0	960.0	770.0	7200.0	1.5	0.0	0.0	2.0	3.1	2.3	2.2	3.3	6.5	1.9	2.3	7.9
	Mean	**920.0**	**135.0**	**150.0**	**1605.0**	**6.5**	**1.2**	**1.3**	**7.3**	**1.3**	**0.0**	**0.0**	**1.0**	**8650.0**	**1020.0**	**1025.0**	**9050.0**	**2.0**	**0.0**	**0.0**	**2.6**	**3.1**	**2.3**	**2.6**	**3.6**	**8.3**	**2.1**	**2.9**	**10.0**
	S.E.	**180.0**	**25.0**	**50.0**	**865.0**	**0.5**	**0.2**	**0.3**	**0.9**	**0.5**	**0.0**	**0.0**	**1.0**	**1350.0**	**60.0**	**255.0**	**1850.0**	**0.5**	**0.0**	**0.0**	**0.6**	**0.0**	**0.0**	**0.4**	**0.3**	**1.8**	**0.2**	**0.6**	**2.1**
Impact	I1	1300.0	180.0	270.0	2440.0	8.2	1.5	1.8	5.9	3.4	1.8	1.8	2.4	10000.0	1000.0	1270.0	6440.0	2.9	0.0	0.0	2.7	3.3	1.4	1.4	2.5	12.0	2.3	5.0	10.9
	I2	1300.0	240.0	250.0	2610.0	7.5	1.8	1.8	6.4	2.6	2.4	1.1	2.3	10000.0	1470.0	1380.0	7510.0	2.7	0.0	0.0	2.8	3.2	2.0	1.8	2.9	11.0	3.1	4.0	11.8
	I3	1100.0	160.0	170.0	2310.0	6.8	1.4	1.6	6.7	1.4	0.0	0.0	1.1	8900.0	1160.0	1070.0	7090.0	2.3	0.0	0.0	2.2	3.8	2.0	2.2	3.0	9.7	2.7	3.6	9.0
	I4	1100.0	150.0	170.0	2330.0	6.9	1.3	1.6	6.4	1.3	0.0	0.0	1.2	9400.0	1120.0	1070.0	7190.0	2.2	0.0	0.0	2.1	3.2	2.2	2.3	3.0	9.7	2.6	4.2	9.4
	I5	1200.0	190.0	180.0	2800.0	6.5	1.6	1.5	7.2	1.5	0.0	0.0	2.4	9900.0	1300.0	1250.0	8710.0	2.3	0.0	0.0	3.1	3.1	2.2	2.2	4.0	9.5	2.8	3.4	12.6
	I6	1100.0	160.0	210.0	2940.0	6.5	1.4	1.7	7.4	1.5	0.0	0.0	3.4	9200.0	1180.0	1320.0	9060.0	2.2	0.0	0.0	3.5	3.1	2.0	2.5	4.1	9.7	2.6	4.2	16.1
	S2*	1200.0	180.0	230.0	2460.0	7.4	1.5	1.9	5.8	1.8	2.3	0.0	2.0	10000.0	1290.0	1350.0	6600.0	2.6	0.0	0.0	2.4	3.3	2.3	2.2	2.7	11.0	3.2	4.4	9.8
	Mean	**1185.7**	**180.0**	**211.4**	**2555.7**	**7.1**	**1.5**	**1.7**	**6.5**	**1.9**	**0.9**	**0.4**	**2.1**	**9628.6**	**1217.1**	**1244.3**	**7514.3**	**2.5**	**0.0**	**0.0**	**2.7**	**3.3**	**2.0**	**2.1**	**3.2**	**10.4**	**2.8**	**4.1**	**11.4**
	S.E.	**34.0**	**11.3**	**15.2**	**90.5**	**0.2**	**0.1**	**0.1**	**0.2**	**0.3**	**0.4**	**0.3**	**0.3**	**172.8**	**57.2**	**48.0**	**380.9**	**0.1**	**0.0**	**0.0**	**0.2**	**0.1**	**0.1**	**0.1**	**0.2**	**0.4**	**0.1**	**0.2**	**0.9**

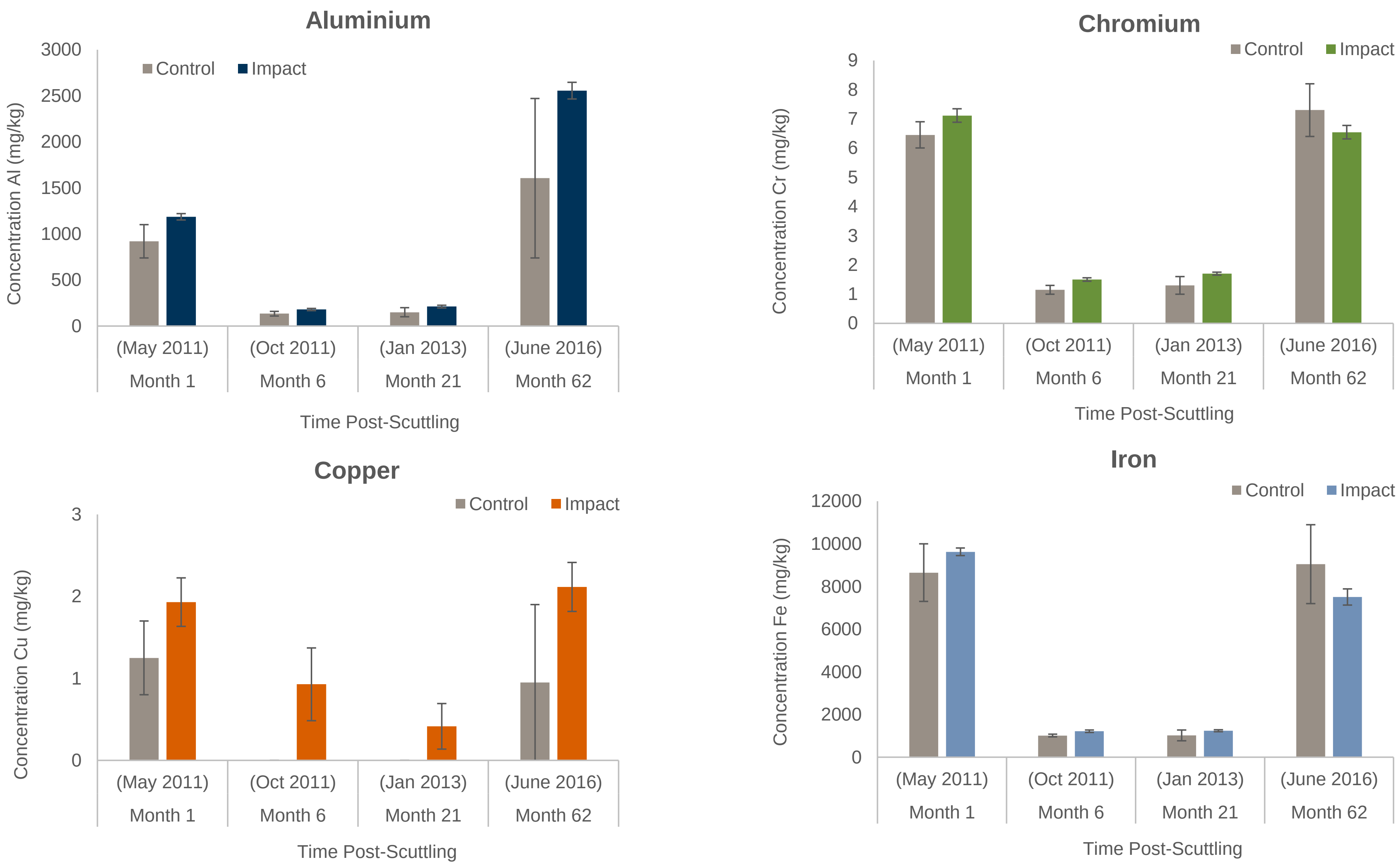


Figure 16 Mean heavy metal concentrations recorded in sediment samples collected from monitoring and control locations one, six, twenty one and sixty two months post-scuttling

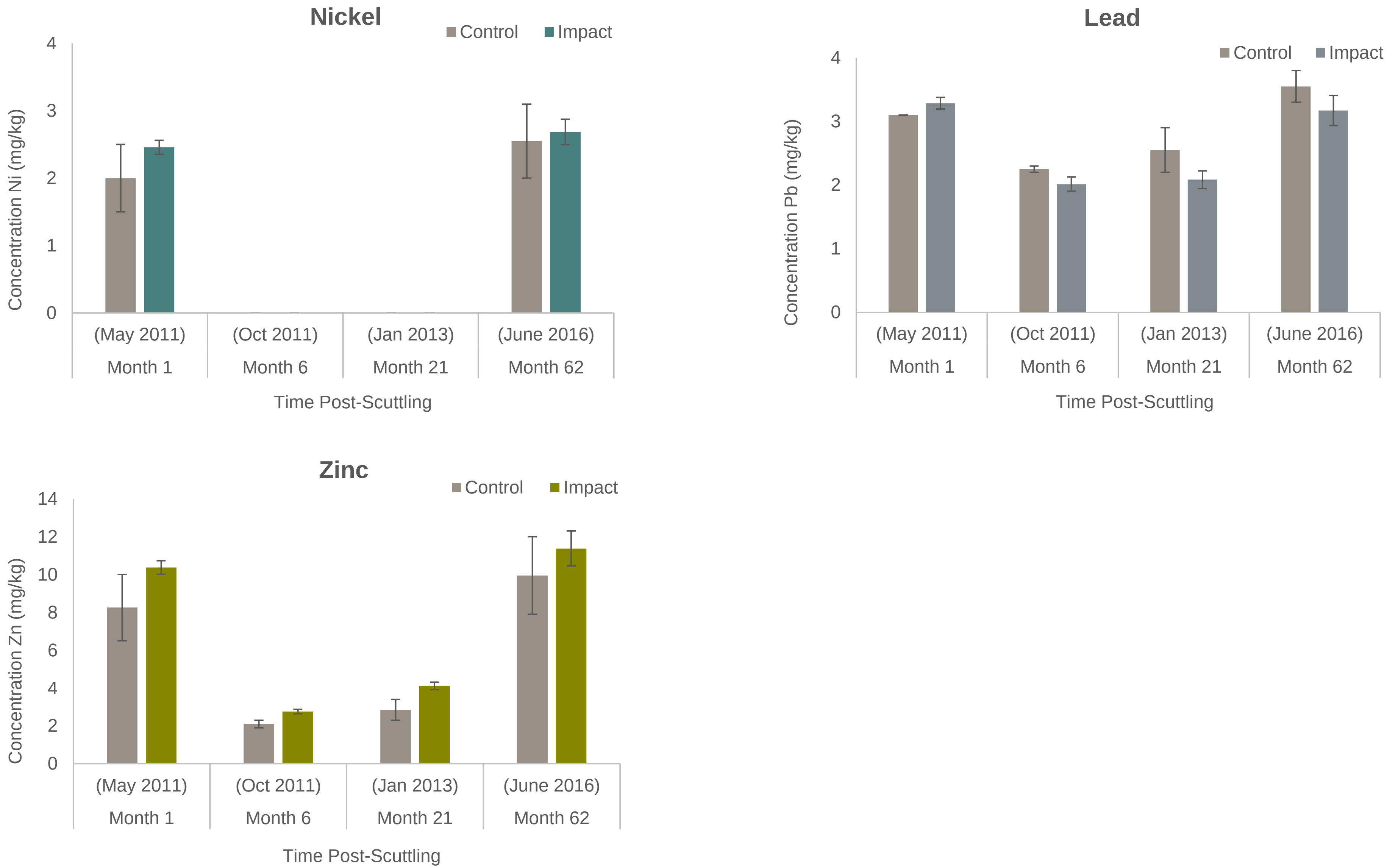


Figure 16. Continued

3.5 Discussion

It is possible that the increase in concentrations of aluminium observed may be associated with the ship, as aluminium is a component of the superstructure which is likely to corrode over time. Aluminium is also naturally present in the marine environment, often as a result of airborne inputs (Clark 1997). There is, however, very little information in the literature to provide an indication of what broader 'background' levels might be in marine sediments of the east coast of Australia and any seasonal fluctuations in natural levels. In the absence of Sediment Quality Guideline Values (SQGVs), for aluminium, it is also difficult to understand at what concentration of Al, impacts to marine biota could potentially be expected. Where SQGVs do not exist, a multiple lines of evidence approach may therefore be adopted, for example through the use of other ecological indicators, such as benthic assemblage composition or further bioaccumulation testing. This may help ascertain whether there are biological differences associated with higher concentrations of Al. As guideline trigger values are available for aluminium concentrations in water, this may also be used as a surrogate by testing of sediment pore water.

It is unclear as to what may be driving the general pattern in metal concentrations through time. As heavy metals occur naturally in marine sediments and are associated with local and regional geology, it is possible that the changes detected during this study can partly be explained by large-scale oceanographic processes (such as prevailing current, storms etc.) that could be expected to influence metal content of sediments over timeframes of months to years. It is also possible that higher concentrations are related to terrigenous inputs during rainfall events, such as that which occurred in the first week of June 2016. Between the 4th and 6th June 2016, 246 mL of rainfall was recorded at Wyong Rainfall Station 061381, approximately 7 km from Terrigal. This was just prior to the sediment sampling event on 10 June 2016. Avoca Lake receives stormwater run-off and sewage inputs from the surrounding urban areas, and it is possible that metal contaminants from stormwater run-off or other diffuse inputs had built up in lake water and / or sediments and were released into the bay.

Collection and analysis of sediment farther away from the ship (e.g. several kilometres) and over a longer time period would help determine whether the apparent changes in the concentrations of metals are associated with the ship or natural long-term processes. In any case, it should be noted that the levels of contaminants detected in this study (for which guideline values are available), were well below the lower ISQG values and are not therefore considered a risk to the marine environment.

Review of Ecological Monitoring
Five Years Post-Scuttling

04

BIOACCUMULATION

4 Bioaccumulation

4.1 Aims and Objectives

The aim of bioaccumulation monitoring, as outlined in the LTMMP, was to determine whether resident biota (i.e. biota in direct contact with the superstructure), were likely to be affected by zinc chromate paint, which may have in the past been used on the aluminium alloy of the Ex-HMAS Adelaide while in service.

The LTMMP recommended that until a substantial amount of marine growth had developed on the ship, active biomonitoring involving the deployment and collection of sentinel organisms from a non-impacted / comparatively clean location (e.g. an aquaculture facility) be undertaken. These indicators were to be deployed to the Ex-HMAS Adelaide for a period of six to eight weeks, sampled and then analysed to determine concentrations of zinc and chromium. Sampling dates are provided in **Table 1**.

4.2 Existing Information

Zinc chromate was routinely used as an anticorrosive application on the topside of naval vessels, although it is understood that the more recent coating formulations did not contain chromium salts. The original clean-up process for the Ex-HMAS Adelaide involved the removal of loose or flaking paint in accordance with DSEWPaC's requirements. Following scuttling, zinc chromate paint (if present), would be subject to corrosion and microbial attack and would likely deteriorate over time. Most available toxicological information regarding zinc chromate is based on OH&S-type exposure, in that it is a suspected carcinogen due to the presence of hexavalent chromium; the primary route of exposure being through inhalation of dust. The fate of zinc chromate in the marine environment is not well understood. It is usually described as insoluble, or very slightly soluble in Material Safety Data Sheets (Worley Parsons 2011). If present, it was assumed that zinc and chromium would be liberated into the marine environment through processes involving dissolution and flaking. The zinc and chromium could potentially affect marine organisms that live in direct association with the vessel via accumulation within their tissues (i.e. 'bioaccumulation'). Chromium occurs naturally in the trivalent chromium (III) and hexavalent chromium (VI) forms (Hart 1982), while zinc is an essential trace element required by most organisms for their growth and development. Both are found in most natural waters at low concentrations (ANZECC/ARMCANZ 2000). Neither chromium nor zinc are listed as a toxicant 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. Further information relating to toxicity of zinc and chromium to marine organisms is provided in the Ex-HMAS Adelaide Bioaccumulation Monitoring Survey 2 Report (Cardno Ecology Lab 2012).

4.3 Overview of Study Methods

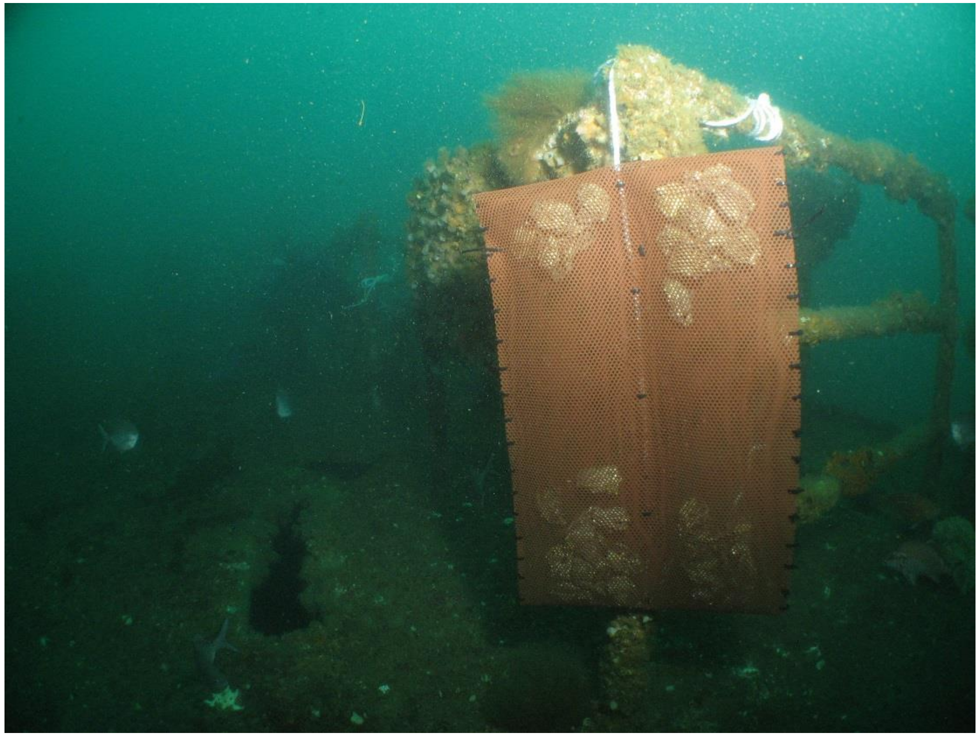
Bivalves such as mussels or oysters are commonly used as sentinel species for the purpose of bioaccumulation assessment. Three bioaccumulation surveys were undertaken over the course of the LTMMP, including a baseline and two monitoring surveys. Sampling dates are provided in **Table 1**.

The sampling design outlined in the LTMMP included multiple monitoring and control sites. This included three vessel monitoring sites (at the bow, midship and stern of the vessel) and two background control sites attached to mooring buoys approximately 35 m to the bow and stern of the vessel. Three bags of oysters (each containing 30 individuals) were attached to each site yielding a total of 15 samples and 450 oysters in total.

In addition, three samples (each of 30 oysters) were used as 'baseline controls' to provide a measure of concentrations of zinc and chromium in oysters prior to deployment. These were tested directly from the aquaculture facility.

Due to their local availability, Sydney rock oysters (*Saccostrea glomerata*) were selected for the bioaccumulation monitoring surveys. Oysters were sourced from a local supplier and delivered to Cardno's Sydney laboratory where they were prepared for deployment. Oysters used were of a similar age and size (bottle grade) to minimise the effects of growth dilution. Groups of 30 oysters were placed inside purpose built bags. Once secured by divers, the bags were left in place for a period of approximately 6 - 8 weeks to allow sufficient time for any bioavailable chromium or zinc to be assimilated into the oyster tissue. Following this period bags were collected by divers and the oyster tissue removed for analysis.

It is noted that blue mussels were used as test organisms in the baseline survey (carried by Worley Parsons approximately 1 week post-scuttling), however, these were not considered suitable in subsequent surveys due to long transport times and of risk mortality during transit. Consequently, results from the baseline study could not be directly compared with the results of Bioaccumulation Surveys 1 and 2 due to the difference in species used. Background controls attached to mooring buoys were also lost during Survey 1, so any changes in metal concentrations to could not be directly attributed to the presence of the vessel. Some sample bags were also lost from the bow and stern during Survey 1 and from the bow and background control in Survey 2.



Oyster bag deployed to the EX-HMAS Adelaide for bioaccumulation investigations

4.4 Results Summary

Results of the baseline survey showed significant differences in metal concentrations in mussel tissue between the baseline controls sampled prior to deployment and vessel monitoring sites, with concentrations higher in the latter. Post-hoc testing identified significant differences for chromium, but no differences for zinc. This result could not, however, be directly attributed to the presence of the vessel without consideration of concentrations measured from samples concurrently taken from mussels located away from, but in the vicinity of the ship. 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 could not be made. Results of monitoring Surveys 1 and 2 showed that chromium concentrations had increased slightly over time at the stern of the ship, but this was also the case for the baseline controls (**Figure 17**). Notably, concentrations at the midship appeared to have decreased substantially. None of the samples showed concentrations at levels of toxicological significance. Zinc concentrations had also increased marginally over time at the stern of the ship and baseline control, while concentrations at the midship decreased. Univariate analyses showed that, overall, concentrations of chromium and zinc did not differ significantly between monitoring Surveys 1 and 2 or between control and impact treatments. For detailed results refer to Bioaccumulation Survey 2 (Cardno 2012).

4.5 Discussion

Mean concentrations of chromium and zinc in oysters attached to the vessel were similar to concentrations recorded in oysters from the aquaculture facility (baseline controls) and attached to mooring buoys (background controls). This indicates that zinc and chromium potentially leached from the Ex-HMAS Adelaide is unlikely to have affected the levels of these metals in filter feeders living in association with the vessel. 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 oysters in the present study were similar to background levels recorded at their source and would not be of toxicological significance. The levels of zinc recorded in oyster tissues were also similar to or below that recorded in tissues of the same species in a bioaccumulation study of Port Hacking and Botany Bay (Hedge et al. 2009).

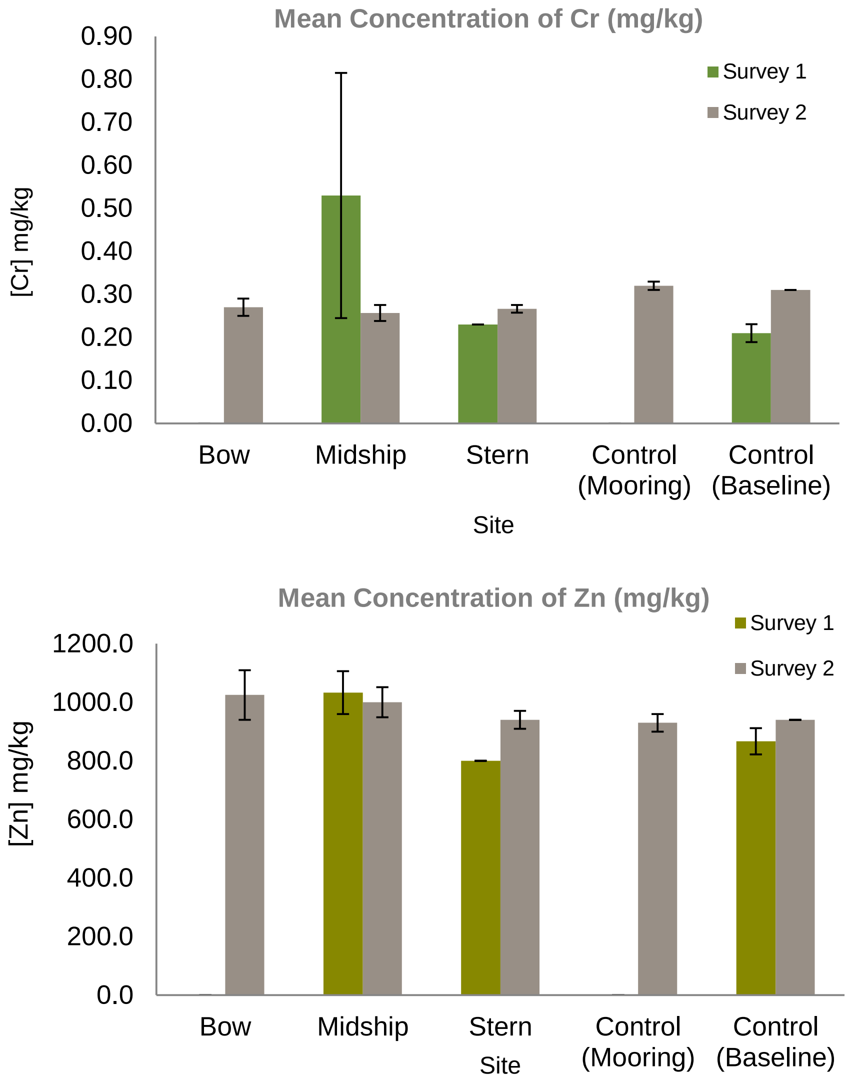


Figure 17 Mean concentrations of chromium (Cr) and zinc (Zn) recorded in oyster tissue from control and monitoring sites during bioaccumulation surveys 1 and 2

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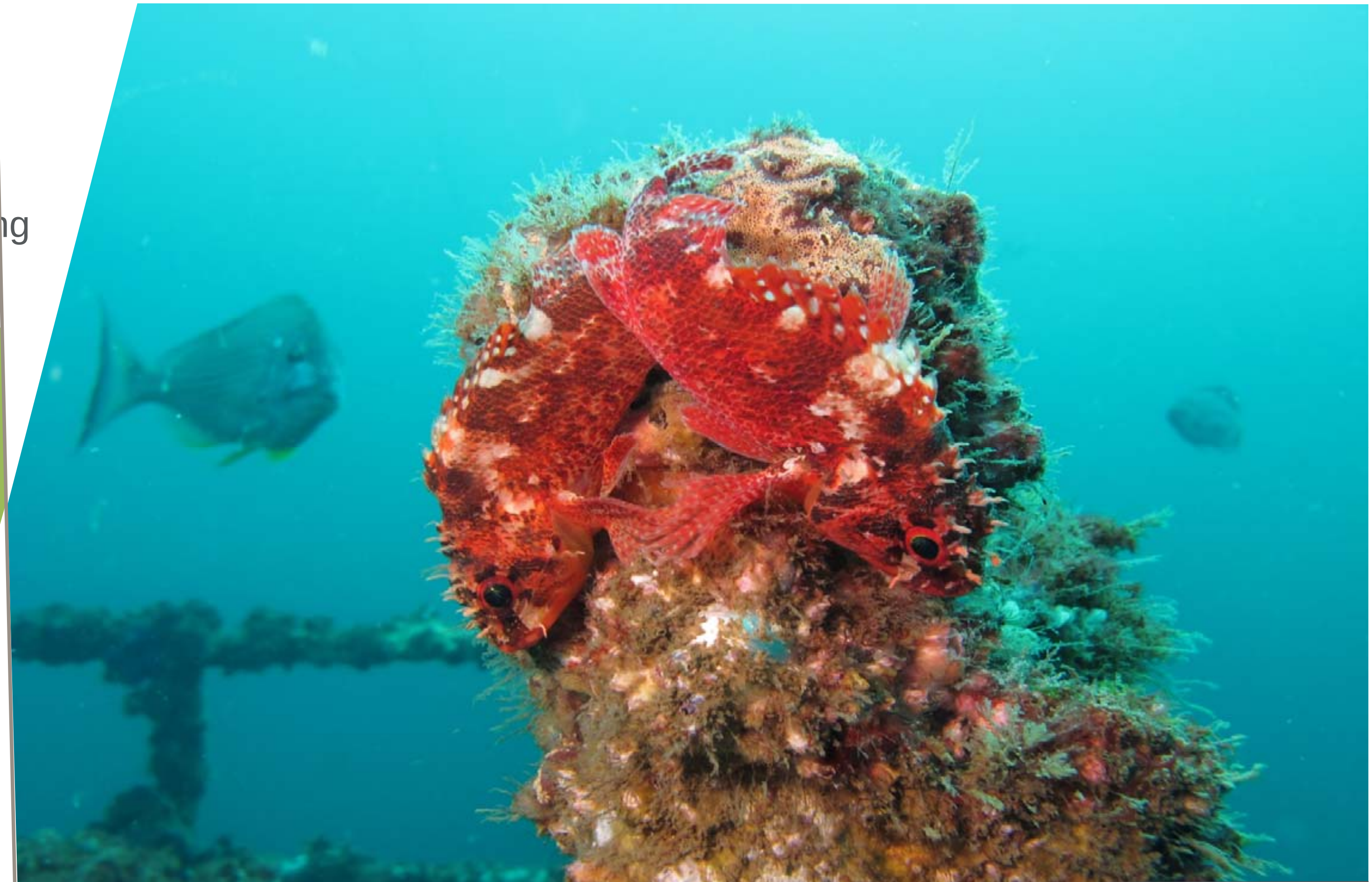
CONCLUSIONS AND RECOMMENDATIONS



5 Conclusions and Recommendations

5.1 Reef Community Monitoring

The reef community monitoring program has been successful in meeting the aims of the LTMMP over the five year monitoring program in that it has:

> Documented the types of flora and fauna assemblages present;

> Described the rate of development of fouling assemblages and how they change over time; and

> Described the variation in the rates at which assemblages develop on different surfaces of the vessel.

Quarterly monitoring over the first two years enabled the rapid colonisation of the assemblages on different parts of the ship to be captured. Following this, ongoing surveys carried out on a bi-annual basis showed that the reef is continuing to develop with some clear spatial and temporal patterns emerging. While ongoing changes are expected to continue for many years (and potentially decades), these are likely to be more subtle than the initial rapid colonisation stages. Long-term changes could therefore be captured at a significantly reduced monitoring frequency. The need to undertake any further quantitative monitoring of the assemblage composition would, however, be from an ecological research perspective only, rather than the need to manage environmental risk or safety.

The final objective of the reef monitoring survey was to 'identify the presence of introduced or pest species'. No marine pests as listed by NSW DPI as known to occur within NSW or Australia have been observed over the course of the five year monitoring program, although a potentially introduced species was identified. The methods outlined within the LTMMP are, however, no longer considered appropriate to properly survey the ship for the occurrence of marine pests due to the thickness and complexity of the encrusting community that has developed. While marine pests would have been easily detected by visual methods alone (e.g. diver, observation, video footage and/or photoquadrats) in the early surveys, more cryptic or well camouflaged species would be difficult to detect and other methods such as quadrat scraping and subsequent taxonomic analysis (in addition to observational methods) are considered more appropriate for the types of pest species with potential to occur on the ship.

It is therefore recommended that the long-term aims and objectives for the monitoring of marine pests on the EX-HMAS Adelaide are revised according to the Australian Marine Pest Monitoring Guidelines and Manual (DAFF 2010). This would require, for example, determination of clear objectives, identification of habitat suitability, target species and appropriate survey methods for those species. On that basis, appropriate timing and frequency of surveys and a process for reporting, review and evaluation should be identified.

Other aspects of long-term monitoring which were not directly addressed as part of the LTMMP but should be considered include the potential for the occurrence of threatened or protected species. This could be implemented through a volunteer sighting program and a process developed to review and evaluate information to inform management responses as and when required.

5.2 Sediment Quality

Sediment samples collected from within the hull of the ship during sediment quality Survey 2 did not indicate contamination of marine sediments. Diving restrictions introduced after the implementation of the LTMMP mean that collection of these sediments in future would have significant associated costs (due to the need for a diving support vessel and decompression chamber). In the unlikely event that elevated levels of lead were detected within hull sediments, any effects would be localised. Further monitoring of sediments from within the hull is therefore not recommended.

Results to date did not indicate any significant long-term effects on metal concentrations in sediments as a result of the ship, however, large fluctuations in concentrations of most metals were evident through time and some slightly elevated levels of aluminium were apparent although differences between control and impact sites were not statistically significant. As the ship corrodes over time, there will be continued potential for metals to enter surrounding marine sediments, although this is likely to be a long-term process.

As a precaution, a follow-up sediment sampling survey would therefore be recommended in three to five years' time. Sampling would also be recommended to occur on an ad-hoc basis should results of any structural monitoring warrant it. Any future monitoring should include the collection and analysis of additional sediment samples farther away from the ship (e.g. several kilometres) to help determine the validity of the existing control sites.

5.3 Bioaccumulation

Results of biomonitoring has largely met the objectives of the LTMMP in that it has helped ‘determine whether resident biota (i.e. biota in direct contact with the superstructure), were likely to be affected by zinc chromate paint’.

Results suggests that contamination of marine organisms via zinc chromate paint did not occur over the 27 month monitoring period post-deployment, however, some issues with the loss of samples limited the interpretation of these results. The LTMMP also recommended that when there is sufficient growth on the ship (i.e. one to two years post-scuttling) direct testing of fouling biota e.g. gastropods be carried out.

On that basis, it is recommended that a single survey be carried out using tissue collected from organisms attached to the ships surface (i.e. *in-situ*) such as large solitary ascidians or gastropods. Tissue should also be collected from target species inhabiting nearby subtidal reefs to provide a reference of ambient levels of these metals in the marine environment. Rates of corrosion (as identified in the structural monitoring components for the ship) should be reviewed to better inform the need for any ongoing monitoring requirements following this *in-situ* investigation.

5.4 Future Management

The focus of the LTMMP was to inform management actions and contingency measures to minimise potential risks to the users of the reef and the environment. A summary of conclusions and recommendations in relation to the specific aims and objectives of the LTMMP are presented in **Table 5**. While specific recommendations have been outlined, an overarching recommendation is that a risk assessment approach be used (on the basis of current information and research) to guide ongoing management objectives and associated monitoring requirements (if any).

Table 5 Summary of conclusions and recommendations

LTMMP Environmental Monitoring Component	Aims and Objectives	Aims Met	Recommendations
Reef Communities	> Document the types of flora and fauna assemblages present.	✓✓	Any ongoing monitoring would be useful in terms of ecological research or educational purposes, but is not considered necessary in terms of managing environmental risk or safety.
	> Gain an understanding of the rate of development of fouling assemblages and how they change over time.	✓✓	Any ongoing monitoring would be useful in terms of ecological research or educational purposes, but is not considered necessary in terms of managing environmental risk or safety.
	> Gain an understanding of the variation in the rates at which assemblages develop on different surfaces of the vessel.	✓✓	Any ongoing monitoring would be useful in terms of ecological research or educational purposes, but is not considered necessary in terms of managing environmental risk or safety.
	> Gain an understanding of the presence of introduced or pest species.	✓	Aims met, however there is a continued risk that marine pests may occur on the Ex-HMAS Adelaide in future. If colonised, boats travelling to and from the vessel may act as vectors for the spread of pests. Objectives for the monitoring of marine pests on the EX-HMAS Adelaide should therefore be revised and appropriate methods, timing and frequency of surveillance monitoring be developed and implemented.
Sediment Quality	> Gain an understanding of how metal corrosion and degradation of paint layers may be influencing/impacting on the marine environment and whether benthic organisms are likely to be affected by metal enrichment.	✓	Aims met, however, over time, there will be continued potential for metals to enter the surrounding marine sediments through continued corrosion. As such, monitoring would be recommended to continue every three to five years. This should include additional control sites to better understand background levels of metals.
Bioaccumulation	> To determine whether resident biota (i.e. biota in direct contact with the superstructure), were likely to be affected by zinc chromate paint.	✓	In order to fully meet the requirements of the LTMMP, it is recommended that a single survey using *in-situ* biota be implemented.

✓✓ = Aims fully met

✓ = Aims met - scope for longer-term monitoring

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Cardno is a professional infrastructure and environmental services company, with expertise in the development and improvement of physical and social infrastructure for communities around the world. Cardno's team includes leading professionals who plan, design, manage and deliver sustainable projects and community programs. Cardno is an international company listed on the Australian Securities Exchange [ASX:CDD].

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