Monitoring for Marine Pests

Darwin Harbour

2009-10 Report

Published by:
The Northern Territory Government
Department of Resources
ABN 84 085 734 992
January 2011

ISSN: 1836-6066 (print version)
ISSN: 1836-6198 (online version)

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INTRODUCTION

There has been increasing awareness of introduced marine pest species in the wake of various potential and actual outbreaks of invasive plant and animal species in Australian and international marine environments. This has led to urgent control measures to tackle the rapidly growing rate of introduced exotic species into our waterways.

An 'introduced species' is defined as one which is not native to a region and has been introduced inadvertently or intentionally. The term 'introduced species' is often used interchangeably with various others, including exotic, non-indigenous, non-native or alien species (Ray 2005). The introduction of such species is perceived to be a major threat to both terrestrial and marine biodiversity (Hewitt 2002; Tan and Morton 2006).

An 'invasive species' is an introduced species that has the potential to cause economic, environmental, social or health-related damage, or a combination of these (Ray 2005). Geographic boundaries, such as mountain ranges and ocean basins, acted as natural barriers in the past, preventing the spread of many species. Australia's isolated location once provided a natural quarantine against the introduction of exotic plants and animals (MacIsaac et al. 2001). However, increased traffic of commercial and recreational vessels in and out of international ports now enables pest species to establish outside of their natural range (Gunasekera et al. 2005).

Means of Introduction

There is at least one introduced marine species present in all the coastal bioregions of Australia (Hewitt 2002). Over 130 non-native species are known to have established in Australian waters (Hayes et al. 2005). Such species have been introduced to Australian waters or translocated to new areas of Australia by a number of vectors. Two major vectors are ballast water and biofouling on commercial, recreational and illegal foreign fishing vessels. Other vectors may include movement of marine equipment or infrastructure, translocation of species for aquaculture, intentional or accidental releases into waterways and movement of species across floodplains from one system to another after heavy rains (Gunasekera et al. 2005; Hewitt and Martin 2001; Russell et al. 2003; The Senate Committee Report 2004).

Shipping ports are considered a main entry point for invasive species, particularly due to the large quantities of ballast water that are picked up and discharged in such areas (The Senate Committee Report 2004). In Victoria's Port Phillip Bay alone, an estimated three or more new species are establishing each year (Hewitt et al. 2004). As highly disturbed regions are more prone to invasion from pests, ports are very susceptible to incursions from such species (Paulay et al. 2002). Marinas can also act as habitat islands to support assemblages that are distinct from neighbouring communities (Glasby 1999). If such assemblages are formed from constituents of local native populations, there is no need for major concern. However, marinas have the potential to function as an entry point for exotic species through fouling on commercial and recreational craft. From there, the marina is able to provide a network of suitable habitats for the continued spread of a species through domestic vessel activity (Ashton et al. 2006).

Impact of Invasive Species

Biological invasions threaten natural ecosystems at all scales, from a genetic level right through to entire populations. The introduction of new viruses and diseases, displacement of native species, potential homogenisation of assemblages and adverse alteration of the physical structure of an ecosystem are all potential outcomes from introduced species (Hewitt and Martin 2001; Ray 2005).

A decline in the number and abundance of native species with the steady rise of introduced plants and animals is a major concern. Many pest species possess advantageous competitive qualities, such as high fecundity, high growth rates and flexible habitat requirements, allowing them to out-compete native species for resources, such as food, light and habitat (Pimentel et al. 2000; Ray 2005; The Senate Committee Report 2004). A loss of, or reduction in, native species may also occur due to predation by introduced species. This is evident in the case of the northern Pacific sea star (*Asterias amurensis*) which was introduced to southern Tasmanian and Victorian waters in the 1980s (Deagle et al. 2003). *A. amurensis* is a voracious generalist predator in soft sediment habitats and is considered a major threat to benthic communities, particularly to commercial bivalves (Ross et al. 2002).

All of these outcomes lead to a less diverse ecological community, which in turn can threaten income derived from aquaculture, commercial and recreational fishing, and tourism. Approximately 50 000 introduced terrestrial and marine species, and introduced pathogens and diseases were estimated to cause environmental damage worth $US137 billion per year In the United States (Pimental et al. 2000). In Australia, marine pests pose a substantial threat to the aquaculture industry, which is worth more than $600 million per year (The Senate Committee Report 2004). In New Zealand, the invasive colonial ascidian *Didemnum vexillum* has become a significant fouling pest on mussel farms, threatening aquaculture enterprises in the area (Denny 2008). However, the cost associated with invasive pest species is not solely restricted to these industries alone. Tourism, shipping and port infrastructure, coastal amenities, human and environmental health, all have the potential to be adversely affected by the invasion of our coastal zones and waterways by pest species (The Senate Committee Report 2004).

Northern Territory (NT) Perspective

Although tropical regions have often been considered fairly resilient to introduced species, there is growing evidence to suggest that such communities are not immune to invasion (Hewitt 2002; Paulay et al. 2002; Russell et al. *2*003). Highly disturbed habitats, in particular, are known to be very susceptible areas for invasive species to colonise (Paulay et al. 2002). This is particularly true when such habitats are additionally subjected to either a high influx of exotic species, or vectors of such species, as in man-made marinas (Bax et al. 2002).

In July 2001, the Australian Quarantine and Inspection Service introduced the ballast water Decision Support System (DSS) as part of border control protocols. The DSS was designed to assist in managing the marine pest risk from ballast water. As a basis for the DSS, primary ports of Australia, including Darwin Harbour, were surveyed to obtain baseline information on established marine communities.

Prior to the introduction of the DSS, the Port of Darwin was surveyed in the dry season in August 1998 and in the wet season in March 1999. In the March 1999 survey, black-striped mussel (*Mytilopsis sallei*), a bivalve native to Central America, was detected in Cullen Bay Marina at densities up to 23 650 individuals/m^2 (Bax et al. 2002). A few days later, the mussel was also found in Tipperary Waters Marina and on the hull of a yacht in Frances Bay Mooring Basin. Considering it was not present during the dry season survey, just six months earlier, the mussel displayed potential for an extremely rapid growth in marina environments posing a significant environmental and economic threat.

The fortunate early detection of the black-striped mussel led to a swift response by the NT Government. Within three days of detection, emergency management teams were convened and the three marinas were quarantined to prevent further spread of the mussel. Laboratory and field trials were conducted to determine a suitable treatment, which resulted in the use of copper sulphate and sodium hypochlorite to destroy the pest in the marinas. In 28 days and at a cost of over $2.2 million, the black-striped mussel was successfully eradicated.

Due to the proximity of Darwin to Asian ports and its use as a first port of call into Australia for many visiting vessels, the risk of possible introduction of invasive marine pests is considered high. As a direct result of the black-striped mussel incident, the Aquatic Biosecurity unit was established in the Department of Resources. It regularly monitors the marine fouling communities of the NT coastline, enabling early detection of marine pest invasions.

This report describes the composition of marine fouling assemblages monitored by the unit in Darwin Harbour and its marinas in 2009-10.

MATERIALS AND METHODS

Location

Darwin Harbour is a macro-tidal tropical estuary, with a maximum tidal range of 7.8 m and strong currents of up to 2 m/second that transport sediment within the harbour (Bax et al. 2002; Burford et al. 2008). The harbour has four marinas: the Cullen Bay Marina, the Frances Bay Mooring Basin, the Tipperary Waters Marina and the Bayview Marina. All four operate with double lock gates to pass vessels into and out of the marinas. During the wet season, the marinas can become strongly stratified with an overlying layer of fresh water up to 3 m deep (Cribb 2005).

The Aquatic Biosecurity unit first began monitoring water quality and biofouling communities in Darwin Harbour and its marinas in February 2000. As well as marina sites, a number of open-water locations were selected for monitoring as they were deemed to be high-risk areas for marine pest incursions due to the large flow of international vessels. The open-water sites, where settlement collectors are located and water quality monitoring takes place, are at Cullen Bay pontoon, HMAS Coonawarra and Stokes Hill Wharf. The location of each monitoring site is shown in Figure 1.

There are three additional locations (East Arm wharf, Fort Hill Wharf and Fannie Bay) where settlement collectors are deployed and monitored monthly for marine pests but no water quality or quantitative biofouling community data is collected. Two settlement collectors are deployed alongside East Arm Wharf. In Fannie Bay, two settlement collectors are deployed directly offshore from the Darwin Sailing Club, one of which was installed in May 2009. These two collectors are removed before the wet season due to the likelihood of prevailing weather conditions damaging equipment during those months. In March 2009, two settlement collectors were deployed along Fort Hill Wharf (Figure 1). Water quality data is also collected at Fisherman's Wharf.

For the purposes of this report, only sites where quantitative data is collected (the four marinas, Cullen Bay Pontoon, HMAS Coonawarra and Stokes Hill Wharf) will be examined. However, no marine pests were detected on surfaces from any of the settlement collectors deployed at East Arm Wharf, Fort Hill Wharf or in Fannie Bay in the past 12 months of monitoring.

Figure 1. Aerial photograph of monitoring locations in Darwin Harbour - marina sites are marked in red and open water sites in yellow.

Settlement Collectors

The marine fouling communities at each location were sampled using settlement collectors. Each collector consisted of a rope backbone supporting horizontal pipe arms, to which artificial settlement surfaces were attached: PVC plates and rope mops (Figure 2). The arms of the collector were two 600-mm lengths of 20-mm poly pipe, with holes drilled where settlement plates were attached with cable ties. A 600-mm (top piece) and a 300-mm (bottom piece) length of poly pipe were attached vertically to the cross piece and a 10 mm rope was threaded through both these vertical pipes. A suitable weight was attached to the bottom of the rope. The top end of the rope was secured to a float or an appropriate structure such as a mooring buoy or pontoon. A 6-mm rope was also threaded through the horizontal arms and then secured to the 10-mm rope at the top of the settlement collector. Cable ties were attached to one side of the collector to identify each side as either 'tagged' or 'untagged'.

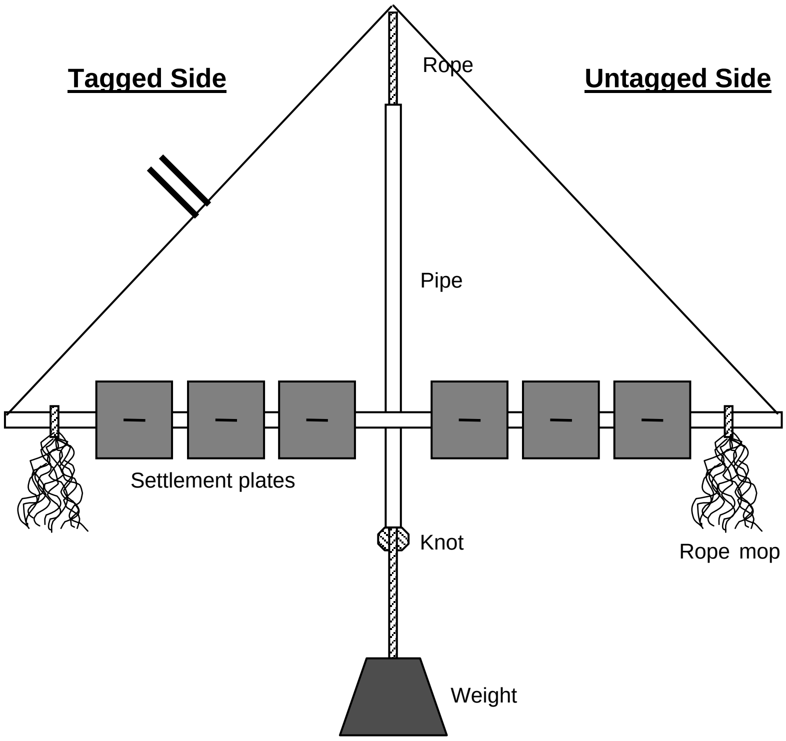


Figure 2. Diagram of a settlement collector used to sample fouling organisms and detect marine pests

Deployment and Collection Schedule

A settlement collector was secured to a floating structure at each site (e.g. marina pontoon, mooring, wharf structure) allowing the device to move vertically with the tides whilst keeping the settlement surfaces at a depth of approximately 2.5 m. For the first month, only the tagged side of the settlement collector was fitted with three settlement plates and a rope 'mop'. Inspections of the plates and rope mop were carried out on a monthly basis. Monthly inspections involved recording a brief description of fouling organisms growing on the plates and within the rope mop, and photographing the plates (front and back) and rope mop using a digital camera. It was also noted whether or not any known marine pest species were present on the settlement surfaces.

After three months, three settlement plates and a rope mop were fixed to the untagged side and similar monthly inspections took place. After four months of deployment, the settlement surfaces were collected from the tagged side only. This essentially allowed for two concurrent sampling regimes (one for each side of the collector). Settlement surfaces were left in the water for four months; however, the one-month overlap in deployment periods resulted in a quarterly collection regime (Table 1).

Upon collection, settlement surfaces were placed in individual plastic containers and immersed in 70% alcohol. Following transport to the laboratory, both sides of each plate and the rope mop were photographed. The wet weights of each settlement plate were recorded and the plates and rope mops were inspected for known marine pest species before fouling community analysis commenced.

Fouling Community Analysis

Analysis of the fouling communities on each settlement plate comprised three assessments: taxonomic frequency, species diversity and biomass.

Fouling biomass

The wet weight of each settlement plate was recorded prior to analysis. Following analysis, the plates were cleaned of fouling organisms and reweighed to determine the wet biomass of biofouling on each settlement plate.

Taxonomic frequency

The percentage frequency of occurrence of individual taxonomic groups on each side of the settlement plates was assessed by recording the presence/absence of each group (or bare space) in a series of regularly-spaced squares (frequency assessment grid) placed over the plate (Committee CH-003 2004). The frequency assessment grid comprised 25, 5 x 5 mm squares. The total number of 'presence' scores for each taxonomic group represented the frequency of occurrence of that group. Following this assessment, any taxa present that remained unrecorded were given a score of one in order to record their presence. Frequencies of occurrence were then converted to a percentage.

This method of assessment allowed for the recording of species which may have been grown over by other species. As a result, the sum of all taxon abundances may be greater than 100%.

The biofouling taxonomic groups of interest were algae, ascidians, barnacles, hydroids, molluscs, polychaetes, sponges, tube forming amphipods and others. Areas remaining not fouled (bare space) were also recorded.

Species diversity

Recognised marine pests are most often species in the ascidian (chordata), barnacle (crustacea), bivalve (mollusca), bryozoan and polychaete (annelida) taxonomic groups. Organisms observed on settlement plates from these groups were identified and recorded to a species level. Species from lower risk taxonomic groups (such as algae, hydroids, and sponges) were not identified or recorded.

Water Quality

Physicochemical water quality data [temperature (^{o}C), salinity (parts per thousand, ppt), pH, conductivity (milliSiemens, mS cm^{-1}) and dissolved oxygen (mg O_2 L^{-1})] were collected using a Hydrolab multiparameter probe. The probe was calibrated immediately prior to sampling. Water quality measurements were taken each month at all sites except for East Arm Wharf, Fort Hill Wharf and Fannie Bay.

Water quality was recorded at the surface and then at depth intervals of 0.5 m until either the substrate or a depth of 5 m was reached. To measure turbidity, a Secchi disc was used to the depth at which the difference between the white and black quarters was no longer visible.

RESULTS

Marine Pest Observations

No known marine pest species were observed on artificial settlement surfaces collected from Darwin Marina and open water sites in the past 12 months of monitoring. Representative photographs of the fouling communities that developed on settlement plates from these locations are shown in Appendices A to G.

Collection Schedule

The majority of inspections and collections of settlement surfaces went according to schedule except for those at the Stokes Hill Wharf site (Table 1). In November 2009, one arm of the Stokes Hill Wharf settlement collector was missing and hence there was no collection of settlement surfaces from that site for the January 2010 collection. Then in March 2010, the entire device went missing and was replaced. However, in April 2010 the device was again damaged, possibly due to the position it was deployed alongside the wharf. The device was therefore replaced and moved to an area of the wharf where it was thought it would receive less damage from weather conditions. This also put the collection schedule out of time so that settlement surfaces collected in July 2010 had only received a three month soak time. The settlement collector at Stokes Hill Wharf is currently deployed and in good working order. Due to other constraints, it was necessary for the June 2010 inspection to occur in late May 2010.

Table 1. Chronology of settlement surface collection in four Darwin Harbour marinas and three open-water sites between June 2009 and July 2010

	Month	Date	Tagged side	Untagged side
2009	June	4th	Surfaces attached.	Surfaces inspected and photographed.
	July	8th	Surfaces inspected and photographed.	Surfaces collected except at HMAS Coonawarra site as no plates were attached due to previous damage.
	August	7th	Surfaces inspected and photographed.	No surfaces attached.
	September	4th	Surfaces inspected and photographed.	Surfaces attached to collectors.
	October	8th	Surfaces collected.	Surfaces inspected and photographed.
	November	11th	No surfaces attached.	Surfaces inspected and photographed Untagged arm of Stokes Hill Wharf collector missing.
	December	2nd	Surfaces attached to collectors.	Surfaces inspected and photographed Stokes Hill collector repaired.
2010	January	5th	Surfaces inspected and photographed.	Surfaces collected (except Stokes Hill Wharf).
	February	5th	Surfaces inspected and photographed.	No surfaces attached.
	March	2nd	Surfaces inspected and photographed Stokes Hill Wharf collector missing and replaced	Surfaces attached to collectors.
	April	1st	Surfaces collected. Damage to Stokes Hill Wharf collector repaired.	Surfaces inspected and photographed.
	May	7th	No surfaces attached.	Surfaces inspected and photographed.
	May	27th	June inspection required to be undertaken early Surfaces attached to collector.	Surfaces inspected and photographed.
	July	9th	Surfaces inspected and photographed.	Surfaces collected. However, surfaces at Stokes Hill Wharf only received a 3 month soak due to damage to the device in April 2010.

Biomass

The greatest mean fouling biomass on settlement plates was recorded from the Bayview Marina site in October 2009 where the biomass averaged 121.7 g (Figure 3). For the three other collection periods at that site, mean fouling biomass was much less but also quite consistent ranging between 28.1 and 28.9 g.

The Cullen Bay Marina site had a very consistent fouling biomass which only ranged between 26.3 g and 35.5 g over the four collection periods.

Three of the four collections at the Frances Bay Mooring Basin had similar mean fouling biomass on settlement plates, ranging between 78.3 g and 93.8 g. The only fluctuation came from the January 2010 collection where average fouling biomass was just 13.1 g.

At the Tipperary Waters Marina site the fouling biomass differed considerably for each collection ranging between 8 g for the January 2010 collection to 66.5 g for the April 2010 collection.

Of the open-water locations, the greatest mean fouling biomass was recorded from the July 2010 collection at the Cullen Bay Pontoon site (Figure 3). At that site, biomass on settlement plates ranged between 43.2 g and 100.5 g.

Fouling was greatest at the HMAS Coonwarra site for the July 2010 collection, with an average biomass of 48.0 g. The least amount of fouling of settlement plates at that location was observed in October 2009, where plates had an average biomass of 17.3 g.

Due to recurring damage to the settlement collector at the Stokes Hill wharf site, biomass data was only available for the October 2009 collection period where the average fouling biomass recorded from settlement plates was 92.0 g.

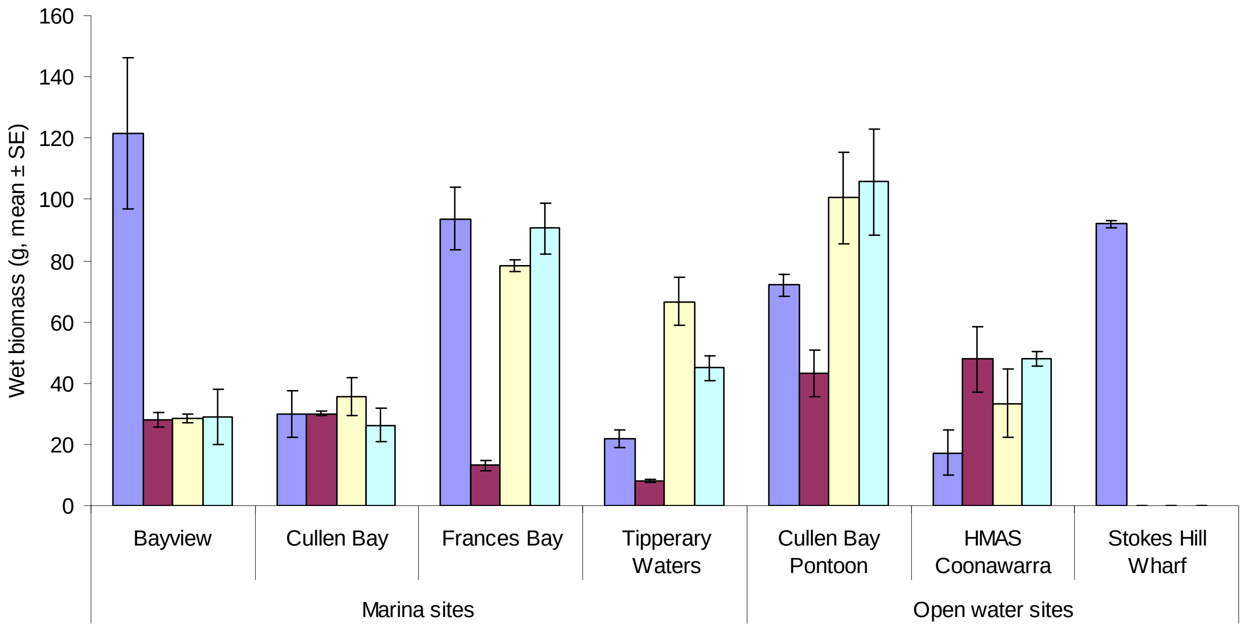


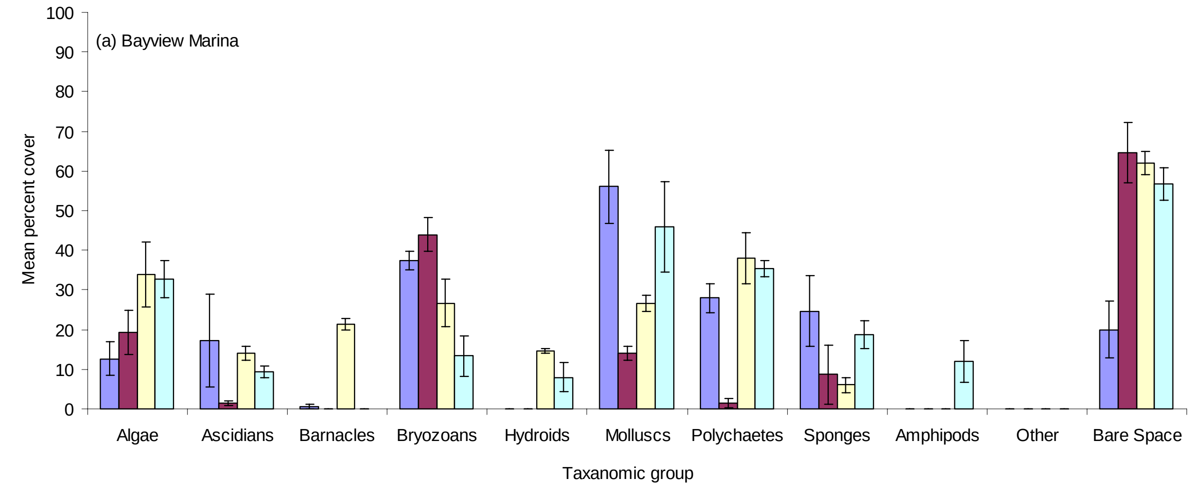
Figure 3. Wet biomass (g; mean ± standard error) of biofouling communities developing on settlement plates from sites within Darwin Harbour and its marinas over four sampling periods: October 2009 (■), January 2010 (■), April 2010 (■) and July 2010 (■)

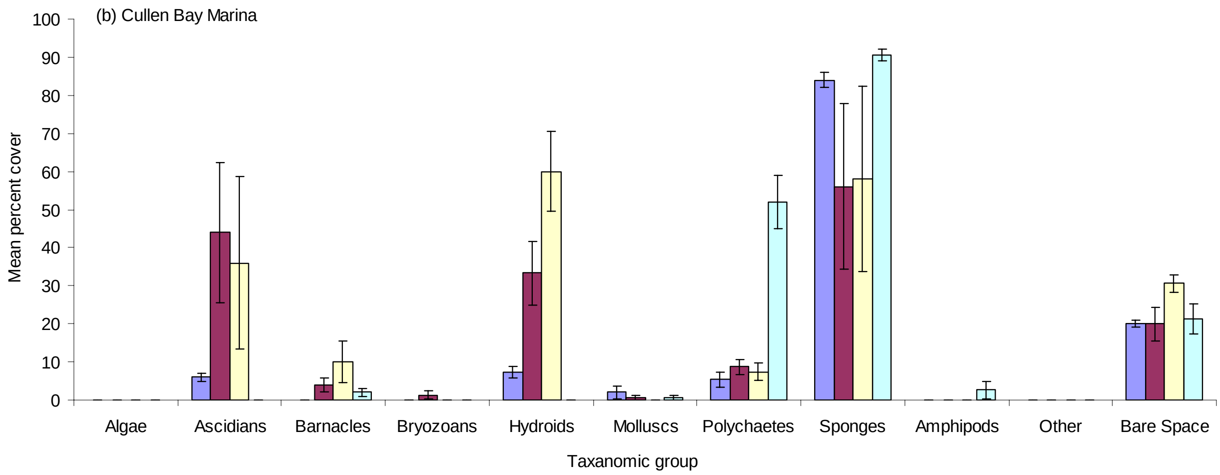
Taxonomic Frequency

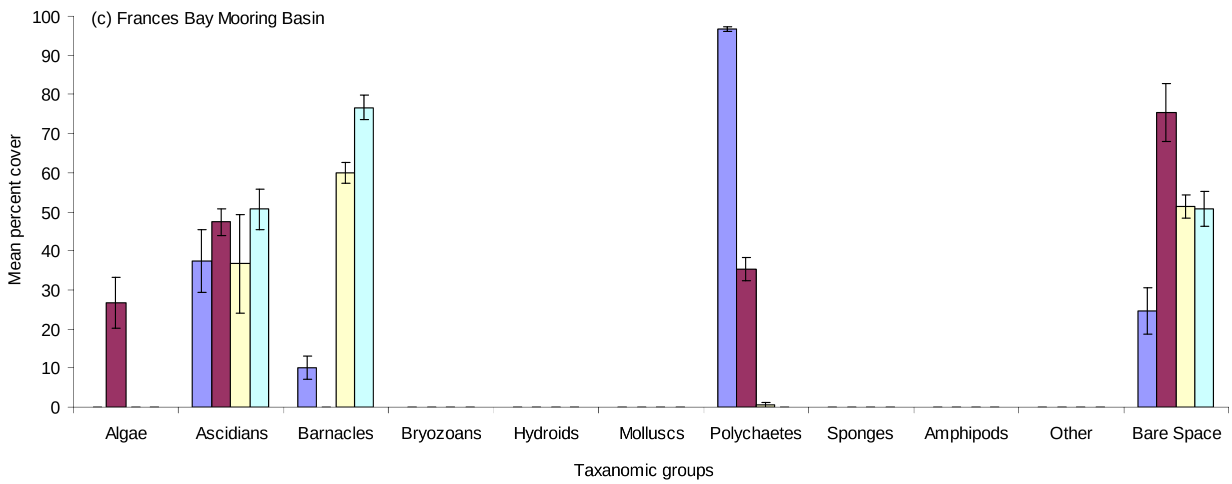
Figures 4 and 5 illustrate the frequency of occurrence of each taxonomic group fouling settlement plates in marina and open water locations over four sampling periods in 2009 and 2010.

Excluding Bayview Marina, the marina sites tended to have periodic peaks where one or two taxonomic groups would dominate the fouling assemblage on settlement plates for a particular period of time. Biofouling at the Frances Bay Mooring Basin site was dominated by polychaetes in the October 2009, and to a lesser extent, January 2010 collections but were then replaced by a majority of barnacles in the April and July 2010 collections with polychaete frequency dropping dramatically (Figure 4c). Bayview Marina tended to have a more even distribution compared to the other marinas.

The frequency of occurrence of each taxonomic group on settlement plates from the open water locations tended to have a more uniform distribution compared with marina locations. For example, at the Cullen Bay Pontoon site, each taxonomic group was generally represented by a similar coverage throughout the year (Figure 5a). However, there were still occasional peaks and disparities, such as a greater coverage of ascidians in the April and July 2010 collections, as well as a slightly increased frequency of sponge in the April 2010 collection.







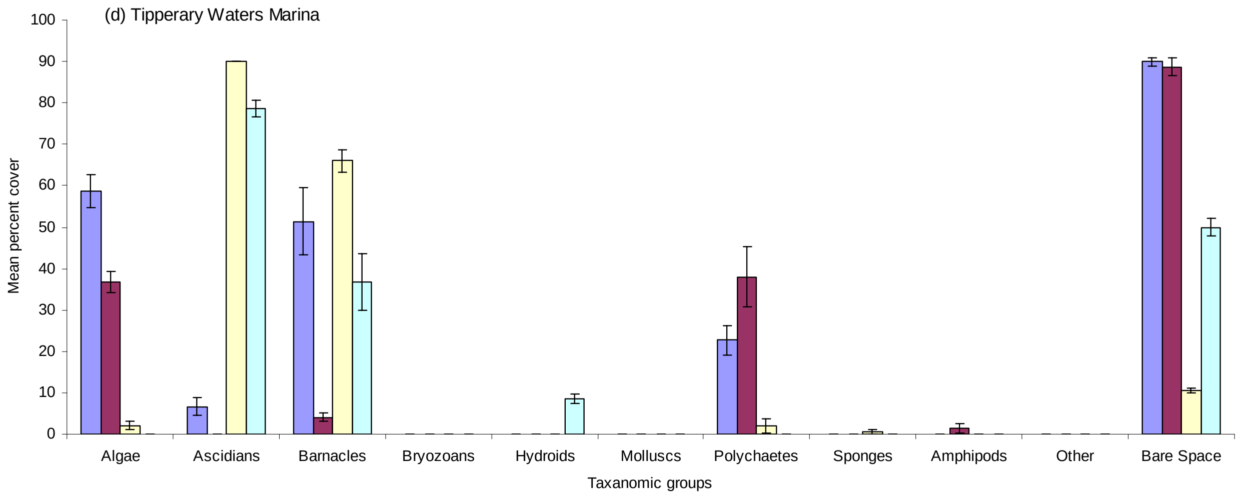


Figure 4. Percentage frequency of occurrence of each taxonomic group and of the area remaining un-fouled recorded on settlement plates in Darwin's four marinas over four sampling periods: October 2009 (■), January 2010 (■), April 2010 (■) and July 2010 (■)

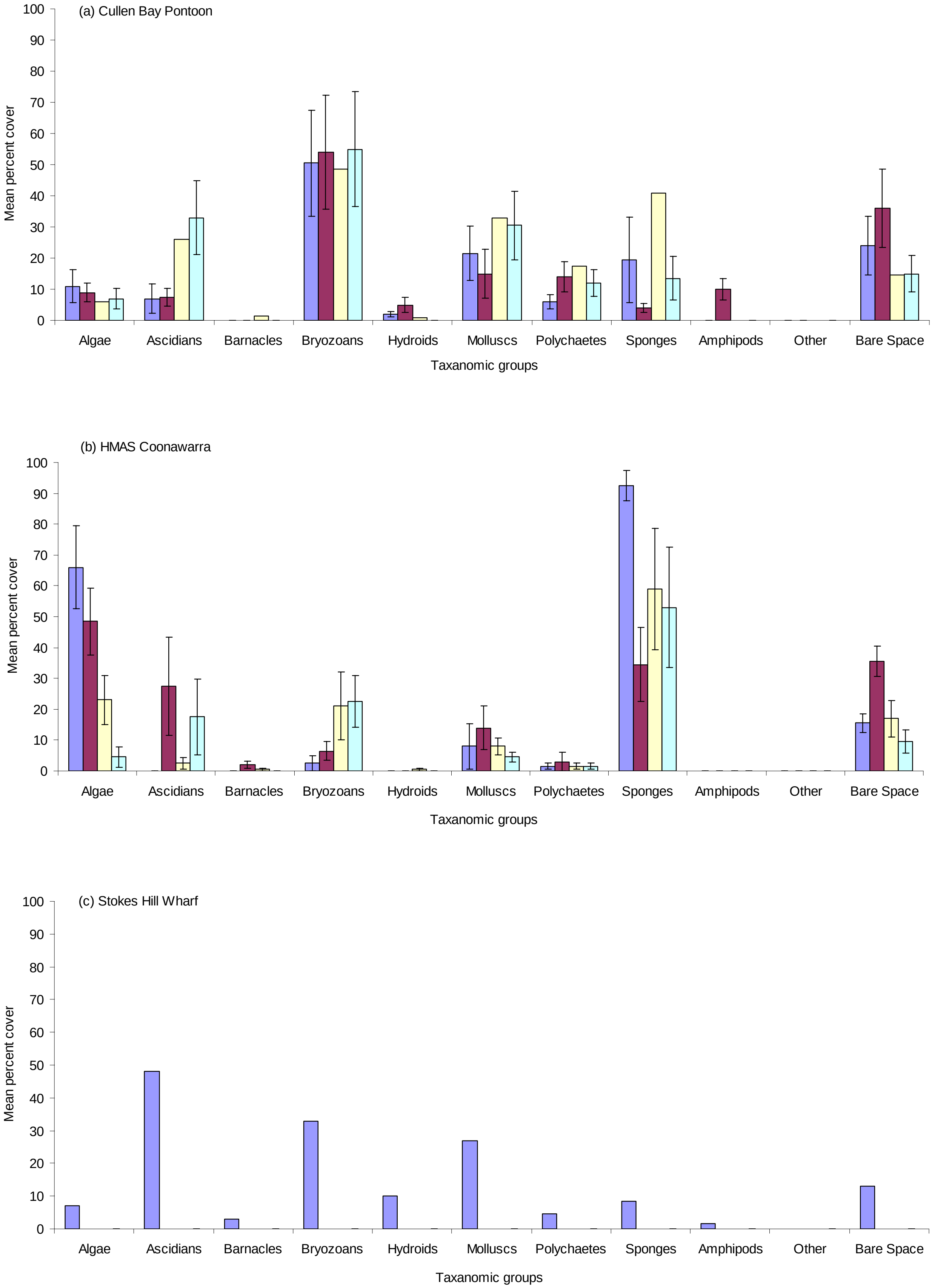


Figure 5. Percentage frequency of occurrence of each taxonomic group and of the area remaining un-fouled recorded on settlement plates in open water locations around Darwin Harbour over four sampling periods: October 2009 ( ), January 2010 ( ), April 2010 ( ) and July 2010 ( )

Species Diversity

The largest number of species (from the five selected taxonomic groups) was recorded at the Cullen Bay Pontoon site where 23 species were observed on settlement plates for the April 2010 collection (Figure 6). Species diversity tended to be greater at open water locations, with the exception of two collection periods at the HMAS Coonawarra site, during October 2009 and July 2010. At this site, the number of species being observed over the four collection periods ranged between seven and 15. It should be noted that for the July 2010 collection at the Stokes Hill Wharf location, settlement surfaces only received a three month period in the water due to previous damage to the settlement collector.

Each marina location had a fairly consistent number of species being observed over the four collection periods. Of the marina sites, the most number of species (10) were recorded at Bayview Marina for the July 2010 collection (Figure 6). At Cullen Bay Marina, species diversity ranged between five and seven, at the Frances Bay site between two and four, and at Tipperary Waters Marina the number of species ranged between three and five.

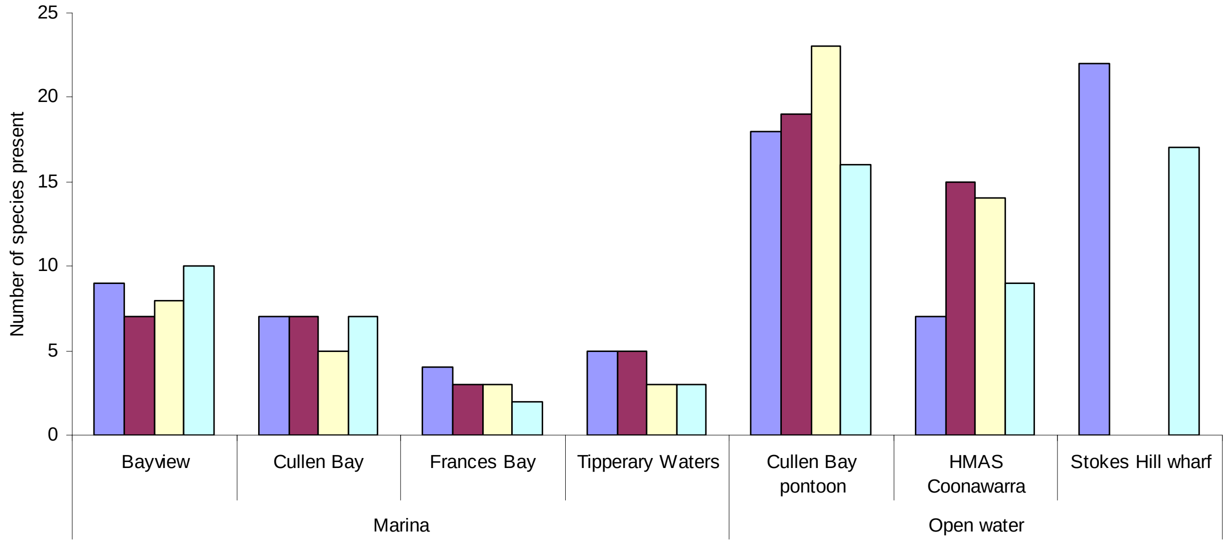


Figure 6. The number of species (within specific taxa) recorded on settlement surfaces from Darwin Harbour and Darwin marina sites over four sampling periods: October 2009 ( ), January 2010 ( ), April 2010 ( ) and July 2010 ( )

Figure 6 compares the number of species observed during individual collection periods. Tables 2 to 8 identify the individual species identified at each marina and open water site between June 2009 and July 2010.

A combined total of 51 species from the five selected taxonomic groups were observed on settlement plates from the four marina and three open water sites in Darwin Harbour (Tables 2 to 8). They consisted of 11 ascidian species, four barnacle species, five bivalve species, 21 bryozoan species, and 10 polychaete species.

Twenty one of those 51 species were observed from the four marina locations. Of the marinas, Bayview Marina had the highest total number of species (13) observed on settlement plates (Table 2). Eleven species were recorded at the Cullen Bay Marina site, four species from the Frances Bay Mooring Basin site, and eight species from settlement plates at the Tipperary Waters Marina site (Tables 3, 4 and 5, respectively).

Among the three open water locations 46 of the 51 species were observed. The highest numbers of species were recorded at the Cullen Bay Pontoon site where 32 species were identified (Table 6). There were 23 species observed at the HMAS Coonawarra site (Table 7) and 30 species at the Stokes Hill Wharf site (Table 8).

Table 2. Species (from specific taxonomic groups) observed on settlement surfaces collected from Bayview Marina between June 2009 and July 2010

Bayview Marina								2009	2010		
Kingdom	Phylum	Subphylum	Class	Family	Taxa	Species no.	Scientific name	Oct	Jan	Apr	Jul
Animalia											
	Chordata										
			Ascidiacea		**Ascidians**						
						Spp. 2			✓		✓
						Spp. 4		✓	✓	✓	✓
						Spp. 10		✓			✓
	Arthropoda										
		Crustacea									
			Cirripedia		**Barnacles**						
						Spp. 1	*Balanus amphitrite*			✓	
	Mollusca										
			Bivalvia								
					Bivalves						
						Spp. 1	*Planostrea pestigris*	✓	✓		✓
						Spp. 25	*Dendostrea* sp.	✓	✓	✓	✓
	Bryozoa										
					Bryozoans						
						Spp. 5	*? Electra bengalensis*			✓	✓
						Spp. 6	*? Celleporina sp.*	✓	✓		
						Spp. 14	*Scrupocellaria sp.*	✓			
						Spp. 15					✓
						Spp. 29			✓		
						Spp. 37		✓		✓	✓
						Spp. 38				✓	
	Annelida										
		Polychaeta			**Polychaetes**						
						Spp. 1		✓			
						Spp. 7	*Hydroides sanctaecrucis*			✓	✓
						Spp. 16	*Branchiomma boholense*	✓	✓	✓	✓
							Total species observed	9	7	8	10

Table 3. Species (from specific taxonomic groups) observed on settlement surfaces collected from Cullen Bay Marina between June 2009 and July 2010

Cullen Bay Marina								2009	2010		
Kingdom	Phylum	Subphylum	Class	Family	Taxa	Species no.	Scientific name	Oct	Jan	Apr	Jul
Animalia											
	Chordata										
			Ascidiacea		**Ascidians**						
						Spp. 1		✓			
						Spp. 2			✓	✓	✓
						Spp. 4		✓	✓	✓	✓
						Spp. 10		✓	✓		
	Arthropoda										
		Crustacea									
			Cirripedia		**Barnacles**						
						Spp. 1	*Balanus amphitrite*		✓	✓	✓
	Mollusca										
			Bivalvia								
					Bivalves						
						Spp. 1	*Planostrea pestigris*	✓			✓
						Spp. 25	*Dendostrea* sp.	✓	✓		
	Annelida										
		Polychaeta			**Polychaetes**						
						Spp. 4	*Ficopomatus uschakovi*	✓			✓
						Spp. 7	*Hydroides sanctaecrucis*				✓
						Spp. 16	*Branchiomma boholense*	✓	✓	✓	✓
						Spp. 17	*Demonax* sp.		✓	✓	
							Total species observed	7	7	5	7

Table 4. Species (from specific taxonomic groups) observed on settlement surfaces collected from Frances Bay Mooring Basin between June 2009 and July 2010

Frances Bay Mooring Basin								2009	2010		
Kingdom	Phylum	Subphylum	Class	Family	Taxa	Species no.	Scientific name	Oct	Jan	Apr	Jul
Animalia											
	Chordata										
			Ascidiacea		**Ascidians**						
						Spp. 2		✓	✓	✓	✓
	Arthropoda										
		Crustacea									
			Cirripedia		**Barnacles**						
						Spp. 1	*Balanus amphitrite*	✓		✓	✓
	Annelida										
		Polychaeta			**Polychaetes**						
						Spp. 8	*Hydroides elegans*	✓	✓	✓	
						Spp. 17	*Demonax* sp.	✓	✓		
							Total species observed	4	3	3	2

Table 5. Species (from specific taxonomic groups) observed on settlement surfaces collected from Tipperary Waters Marina between June 2009 and July 2010

Tipperary Waters Marina								2009	2010		
Kingdom	Phylum	Subphylum	Class	Family	Taxa	Species no.	Scientific name	Oct	Jan	Apr	Jul
Animalia											
	Chordata										
			Ascidiacea		**Ascidians**						
						Spp. 2				✓	✓
						Spp. 4		✓			✓
	Arthropoda										
		Crustacea									
			Cirripedia		**Barnacles**						
						Spp. 1	*Balanus amphitrite*	✓	✓	✓	✓
	Bryozoa										
					Bryozoans						
						Spp. 31	? *Bowerbankia gracilis*	✓			
	Annelida										
		Polychaeta			**Polychaetes**						
						Spp. 1		✓	✓		
						Spp. 8	*Hydroides elegans*		✓		
						Spp. 16	*Branchiomma boholense*	✓	✓		
						Spp. 17	*Demonax* sp.		✓	✓	
							Total species observed	5	5	3	3

Table 6. Species (from specific taxonomic groups) observed on settlement surfaces collected from Cullen Bay Pontoon between June 2009 and July 2010

Cullen Bay pontoon								2009	2010		
Kingdom	Phylum	Subphylum	Class	Family	Taxa	Species no.	Scientific name	Oct	Jan	Apr	Jul
Animalia											
	Chordata										
			Ascidiacea		**Ascidians**						
						Spp. 1		✓	✓	✓	✓
						Spp. 2			✓	✓	
						Spp. 4		✓	✓	✓	
						Spp. 6			✓		
						Spp. 10				✓	✓
						Spp. 12		✓		✓	
	Arthropoda										
		Crustacea									
			Cirripedia		**Barnacles**						
						Spp. 1	*Balanus amphitrite*			✓	
						Spp. 5	*Amphibalanus. reticulatus*			✓	
	Mollusca										
			Bivalvia		**Bivalves**						
						Spp. 1	*Planostrea pestigris*	✓	✓		✓
						Spp. 2	*Anomia trigonopsis*	✓	✓	✓	
						Spp. 9	*Musculus miranda*			✓	
						Spp. 21	*Pinctada maxima*				✓
						Spp. 25	*Dendostrea* sp.	✓	✓	✓	✓
	Bryozoa										
					Bryozoans						
						Spp. 1	*Zoobotyron* sp.			✓	✓
						Spp. 5		✓	✓	✓	
						Spp. 6	? *Celleporina* sp.	✓	✓	✓	✓
						Spp. 14	*Scrupocellaria* sp.	✓			✓
						Spp. 17	? *Bowerbankia gracilis*	✓	✓	✓	✓
						Spp. 19			✓	✓	✓
						Spp. 21	*Savignyella lafontii*	✓	✓	✓	✓
						Spp. 22	*Amathia distans / crispa*	✓	✓	✓	✓
						Spp. 27		✓			
						Spp. 40	*Bugula robusta*	✓			
						Spp. 50	*Aetea engiuna / truncata*				✓
	Annelida										
		Polychaeta			**Polychaetes**						
						Spp. 1		✓	✓	✓	✓
						Spp. 4	*Ficopomatus ushakovi*		✓	✓	✓
						Spp. 7	*Hydroides sanctaecrucis*			✓	
						Spp. 8	*Hydroides elegans*		✓		
						Spp. 9	*Hydroides malleolaspina*		✓		
						Spp. 10	*Hydroides rectus*	✓	✓	✓	
						Spp. 15	*Hydroides albiceps*	✓		✓	
						Spp. 16	*Branchiomma boholense*	✓	✓	✓	✓
							Total species observed	18	19	23	16

Table 7. Species (from specific taxonomic groups) observed on settlement surfaces collected from HMAS Coonawarra between June 2009 and July 2010

HMAS Coonawarra								2009	2010		
Kingdom	Phylum	Subphylum	Class	Family	Taxa	Species no.	Scientific name	Oct	Jan	Apr	Jul
Animalia											
	Chordata										
			Ascidiacea		**Ascidians**						
						Spp. 2			✓	✓	
						Spp. 4			✓	✓	
						Spp. 5			✓		
						Spp. 10			✓		
						Spp. 15			✓	✓	✓
						Spp. 16					✓
						Spp. 23					✓
						Spp. 30				✓	
						Spp. 35			✓		
	Arthropoda										
		Crustacea									
			Cirripedia		**Barnacles**						
						Spp. 1	*Balanus amphitrite*		✓		
						Spp. 2	*Amphibalanus variegatus*	✓		✓	
	Mollusca										
			Bivalvia		**Bivalves**						
						Spp. 1	*Planostrea pestigris*	✓	✓	✓	
						Spp. 9	*Musculus miranda*				✓
						Spp. 25	*Dendostrea* sp.	✓	✓	✓	✓
	Bryozoa										
					Bryozoans						
						Spp. 1	*Zoobotyron verticillatum*	✓	✓	✓	✓
						Spp. 6	? *Celleporina* sp.	✓	✓		
						Spp. 17	? *Bowerbankia gracilis*			✓	✓
						Spp. 19	*Bowerbankia* sp.		✓	✓	
						Spp. 21	*Savignyella lafontii*	✓	✓	✓	✓
						Spp. 40	*Bugula robusta*			✓	
	Annelida										
		Polychaeta			**Polychaetes**						
						Spp. 1		✓	✓		
						Spp. 10	*Hydroides rectus*			✓	✓
						Spp. 16	*Branchiomma boholense*		✓	✓	
							Total species observed	7	15	14	9

Table 8. Species (from specific taxonomic groups) observed on settlement surfaces collected from Stokes Hill Wharf between June 2009 and July 2010

Stokes Hill Wharf								2009	2010		
Kingdom	Phylum	Subphylum	Class	Family	Taxa	Species no.	Scientific name	Oct	Jan	Apr	Jul
Animalia											
	Chordata										
			Ascidiacea		**Ascidians**						
						Spp. 1		✓			
						Spp. 2		✓			✓
						Spp. 4		✓			
						Spp. 10		✓			
						Spp. 15		✓			✓
						Spp. 23					✓
	Arthropoda										
		Crustacea									
			Cirripedia		**Barnacles**						
						Spp 2.	*Amphibalanus variegatus*	✓			✓
						Spp. 5	*Amphibalanus reticulatus*				✓
						Spp. 6	*Striatobalanus amaryllis*				✓
	Mollusca										
			Bivalvia		**Bivalves**						
						Spp. 1	*Planostrea pestigris*	✓			
						Spp. 2	*Anomia* sp.	✓			✓
						Spp. 21	*Pinctada maxima*	✓			
						Spp. 25	*Dendostrea* sp.	✓			
	Bryozoa										
					Bryozoans						
						Spp. 2	? *Hippopodina / Calyptotheca*				✓
						Spp. 5	? *Electra bengalensis*				✓
						Spp. 6	? *Celleporina* sp.	✓			✓
						Spp. 14	*Scrupocellaria* sp.	✓			✓
						Spp. 15		✓			
						Spp. 17		✓			✓
						Spp. 19	*Bowerbankia* sp.				✓
						Spp. 21		✓			
						Spp. 22		✓			✓
						Spp. 24		✓			
						Spp. 26		✓			
						Spp. 27		✓			
						Spp. 35	*Mucropetraliella* sp.				✓
						Spp. 40					✓
						Spp. 41		✓			
	Annelida										
		Polychaeta			**Polychaetes**						
						Spp. 1		✓			✓
						Spp. 12		✓			
							Total species observed	22	0	0	17

Water Quality

The highest mean water temperature between June 2009 and July 2010 was recorded at Cullen Bay Marina in January 2010, where the water temperature reached 34.5^{o}C (Figure 7). In open-water locations, the highest mean water temperature of 31.6^{o}C was recorded in December 2009. The lowest water temperatures were recorded in July 2009. In open-water sites, temperatures dropped to 25.9^{o}C and at Cullen Bay Marina to 26.1^{o}C.

Salinity fluctuated much more in marina locations than at open-water sites. The highest mean salinities were recorded in November 2009. At Bayview Marina, the salinity reached 37.0 ppt and in open-water sites, concentrations reached 36.3 ppt (Figure 8). Salinity fluctuated only slightly in open water sites with the lowest concentration of 29.1 ppt being recorded in January 2010. In the same month, the lowest salinity of 4.6 ppt was recorded at the Tipperary Waters Marina site.

Both temperature and salinity stratification were observed in the marina sites (except Bayview Marina), with a 2-3 m layer of cool fresh water often evident during the wet season months. This was especially apparent in Cullen Bay and Tipperary Waters Marina. No stratification was observed at open-water sites.

There was no water quality data available in August 2009 or February 2010 due to equipment problems.

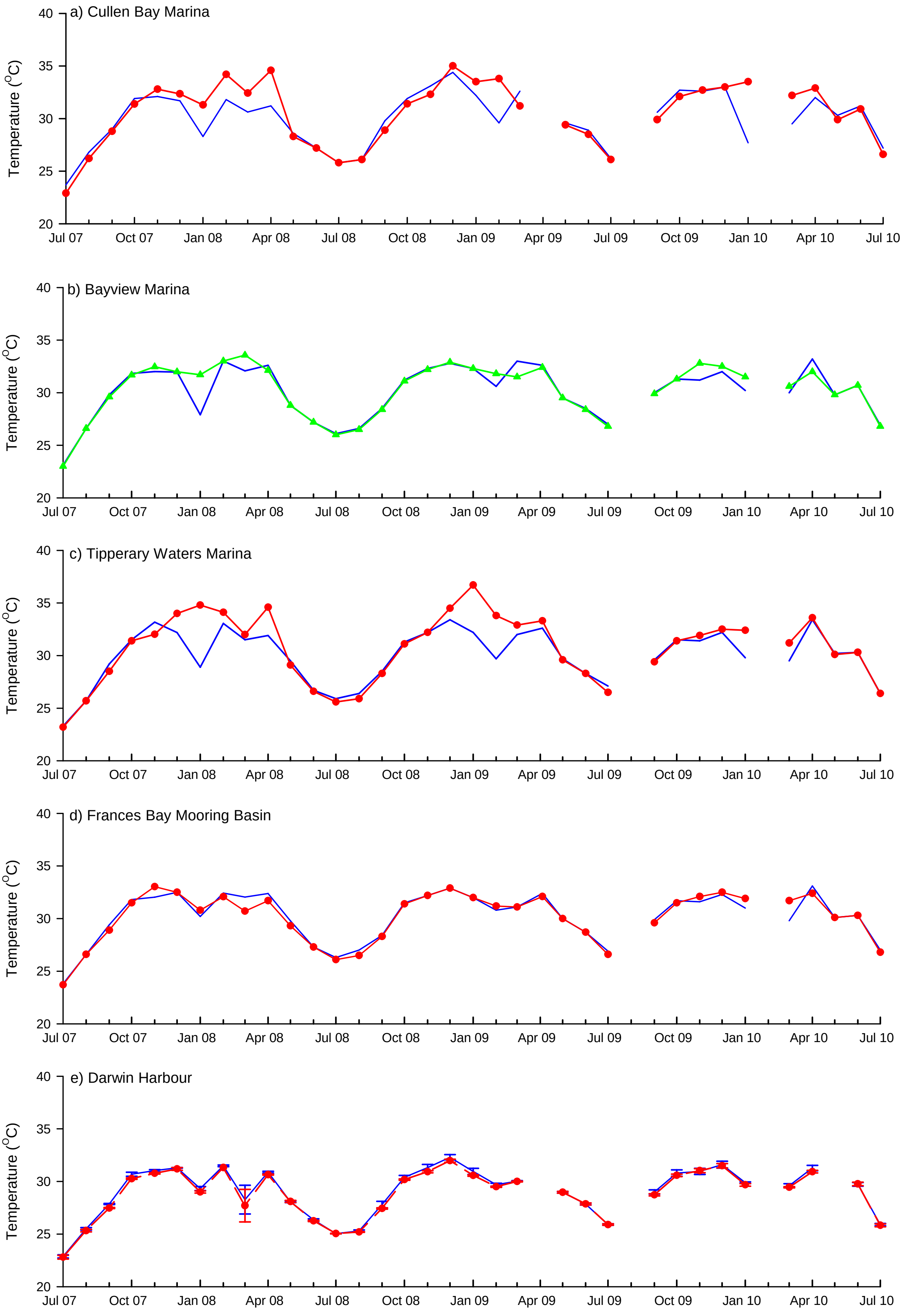


Figure 7. Temperatures (°C; mean ± standard error) recorded at marina and open water sites of Darwin Harbour at 0.5 m (——) and 3.0 m (—●—) depth between July 2007 and July 2010 [Note: 2.0 m (—▲—) at Bayview Marina]

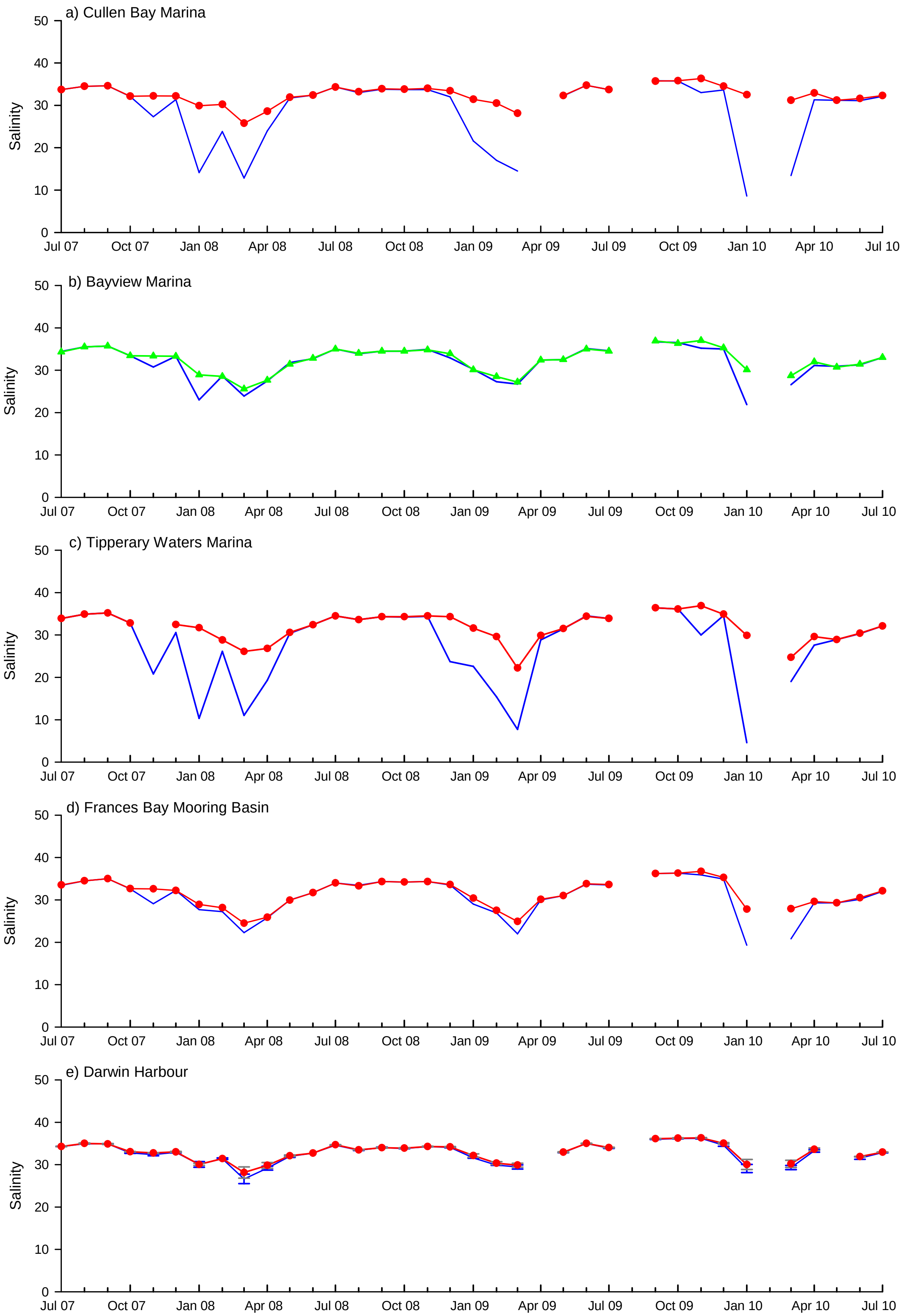


Figure 8. Salinity (ppt; mean ± standard error) recorded at marina and open water sites of Darwin Harbour at 0.5 m (—) and 3.0 m (—●—) depth between July 2007 and July 2010 [Note: 2.0 m (—▲—) at Bayview Marina]

DISCUSSION

No recognised marine pest species were observed on artificial settlement surfaces collected from Darwin Harbour or its four marinas during the past 12 months of monitoring. Due to limited taxonomic resources, it was not possible to identify all fouling organisms to a genus or species level. It is also uncertain whether all species recorded on settlement plates are native to the region in which they were observed. This is in part due to some species being classified as cryptogenic (i.e. it is unclear whether the species is native to a region or has been introduced from an unknown source and since naturalised). Secondly, the taxonomic knowledge of some tropical systems may be insufficiently advanced to aid in determining which species are introduced (Hewitt 2002). For example, little was known about the distribution of barnacles in Australian waters until the early 1990s (Jones 2003). It therefore becomes difficult to determine if a species is indeed native to a region or had been introduced before such data was collated. However, no known marine pests were found in any of the monitoring locations over the past 12 months of monitoring and no species were observed that displayed invasive characteristics.

Although the monitoring program provides some information on natural biofouling communities, it is not intended to describe seasonal patterns in abundance between sites. To achieve this, a more detailed and rigorous study would be required. Nonetheless, some such observations have been made.

At the four marina locations, biofouling on settlement plates tended to be dominated by blooms of one or two species, with the species (and quite often also the taxonomic group) that dominated, varying both between marinas and over time. At the Frances Bay Mooring Basin site in the October 2009 and to a lesser extent in January 2010, settlement plates were dominated by growth of the calcareous polychaete, *Hydroides elegans*. In the following April and July 2010 collections, these polychaetes were all but replaced by the growth of the barnacle, *Balanus amphitrite*. There was a similar occurrence at the Tipperary Waters Marina site with the same barnacle, *B. amphitrite*, being the main fouling species for three of the four collection periods but then being replaced by *H. elegans* as well as another polychaete, *Branchiomma boholense*, for the January 2010 collection. Growth of ascidians at this site also fluctuated considerably shifting from nearly no growth at all being present for the October 2009 and January 2010 collections, to ascidians covering the majority of the settlement plates in April and July 2010 collections. Bayview marina was somewhat dissimilar from the other three marina sites, as a more diverse and consistent fouling community was observed there.

Water quality is potentially a significant factor contributing to these blooms within marinas. Although seasonal patterns in water temperature and salinity were similar between marina and open-water sites, the variations experienced in marinas were generally far more extreme. During the wet season months, from approximately December to May, stratification of the water body (layering of water possessing different temperature and salinity characteristics) occurred in the marinas, particularly at Cullen Bay and Tipperary Waters marinas. This stratification was largely driven by the marina acting as a sink for freshwater run-off and resulted in a layer of cooler, less saline water forming at the surface over warmer more saline water. This cool freshwater layer was, in some cases, up to 3 m deep.

It is possible that this stratification contributed to the booms and busts of barnacles and tubeworms in the aforementioned examples. Conversely, the homogenous mixing of water that occurs within Darwin Harbour may be a factor for a more stable and diverse suite of organisms experienced on settlement plates at the open-water locations. It was atypical for a single species to dominate the biofouling assemblage to the exclusion of others at an open-water site.

It is suggested that ecosystems with high species diversity (as is often evident in tropical environments) will be more resistant to invasions by exotic species (Tan and Morton 2006). Marine pest invasions are also more likely to occur in disturbed environments. Given that man-made marinas are disturbed, artificial environments and that seasonal environmental fluctuations result in a lack of competition from established populations of native species, opportunities may be considered to exist for the establishment of invasive species in Darwin marinas. Seasonal stratification can be minimised by marina management implementing practices to promote adequate flushing and mixing of marina waters so as to support the establishment of a more diverse and resilient fouling community.

Exotic marine organisms possess the potential to endanger the biodiversity and amenity of coastal waters. Along with the current expansion of many industries in the NT, there come associated risks of the introduction of pest species via increased international and domestic maritime traffic into and out of NT ports. As such, the Aquatic Biosecurity unit will continue to monitor the coastline for the presence of introduced species so as to assist in keeping NT waters free of marine pests.

REFERENCES

Ashton, G., Boos, K., Shucksmith, R. and Cook, E. (2006). Rapid assessment of the distribution of marine non-native species in marinas in Scotland. *Aquatic Invasions* **1**(4)**:** 209-213.

Bax, N., Hayes, K., Marshall, A., Parry, D. and Thresher, R. (2002). Man-made marinas as sheltered islands for alien marine organisms: Establishment and eradication of an alien invasive marine species. *In*: Veitch, C. R. and Clout, M. N. (Eds.) (2002) Turning the Tide: the Eradication of Invasive Species. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK, pp 26-39.

Burford, M. A., Alongi, D. M., McKinnon, A. D., and Trott, L. A. (2008). Primary production and nutrients in a tropical macrotidal estuary, Darwin Harbour, Australia. *Estuarine, Coastal and Shelf Science* **79:** 440-448.

Committee CH-003, Paints and Related Materials (2004). Australian Standard. Paints and related materials – Methods test. Method 481.5: Coatings – Durability and resistance to fouling – Marine underwater paint systems. Council Standards Australia, November 2004.

Deagle, B. E., Bax, N., Hewitt, C. L. and Patil, J. G. (2003). Development and evaluation of a PCR-based test for detection of *Asterias* (Echinodermata: Asteroidea) larvae in Australian plankton samples from ballast water. *Marine and Freshwater Research* **54**: 709-719.

Denny, C. M. (2008). Development of a method to reduce the spread of the ascidian *Didemnum vexillum* with aquaculture transfers. *ICES Journal of Marine Science* **65:** 805-810.

Glasby, T. M. (1999). Difference between subtidal epibiota on pier pilings and rocky reefs at marina in Sydney, Australia. *Estuarine, Coastal and Shelf Science* **48:** 281-290.

Gunasekera, R. M., Jawahar, G. P., McEnnulty, F. R. and Bax, N. J. (2005). Specific amplification of mt-*COI* gene of the invasive gastropod *Maoricolpus roseus* in planktonic samples reveals a free-living larval life-history stage. *Marine and Freshwater Research* **56:** 901-912.

Hayes, K. R., Sliwa, C., Migus, S., McEnnulty F., and Dunstan, P. (2005). National priority pests: Part II Ranking of Australian marine pests. Report for the Department of Environment and Heritage by CSIRO Marine Research, Hobart.

Hewitt, C. L. and Martin, R. B. (2001). Revised Protocols for Baseline Port Surveys for Introduced Marine Species: Survey Design, Sampling Protocols and Specimen Handling. CRIMP Technical Report 22, CSIRO Marine Research, Hobart, Tasmania.

Hewitt, C. L. (2002). Distribution and biodiversity of Australian tropical marine bio-invasions. *Pacific Science* **56**(2)**:** 213-222.

Hewitt, C., Campbell, M., Thresher, R., Martin, R., Boyd, S., Cohen, B., Currie, D., Gomon, M., Keough, M., Lewis, J., Lockett, M., Mays, N., McArthur, M., O'Hara, T., Poore, G., Ross, D., Storey, M., Watson, J. and Wilson, R. (2004). Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology*. **144**(1)**:** 183-220.

Jones, D. S. (2003). The biogeography of Western Australian shallow-water barnacles. *In:* Wells, F. E., Walker, D. I., and Jones, D. S. (Eds.) (2003) the Marine Flora and Fauna of Dampier, Western Australia. Western Australia Museum, Perth.

MacIsaac, H. J., Grigorovich, I. A. and Ricciardi, A. (2001). Reassessment of species invasions concepts: the Great Lakes basin as a model. *Biological Invasions* **3:** 405-416.

Paulay, G., Kirkendale, L., Lambert, G. and Meyer, C. (2002). Anthropogenic biotic interchange in a coral reef ecosystem: A case study from Guam. *Pacific Science* **56**(4)**:** 403-422.

Pimentel, D., Lach, L., Zuniga, R. and Morrison, D. (2000). Environmental and economic costs of non-indigenous species in the United States. *Bioscience* **50**(1)**:** *53*-65.

Ray, G. L. (2005). Invasive Animal Species in Marine and Estuarine Environments: Biology and Ecology. Report prepared for Headquarters, U. S. Army Corps of Engineers, Washington, DC 20314-1000.

Ross, D. J., Johnson, C. R. and Hewitt, C. L. (2002). Impact of introduced sea stars *Asterias amurensis* on survivorship of juvenile commercial bivalves *Fulvia tenuicostata*. *Marine Ecology Progress Series* **241:** 99-112.

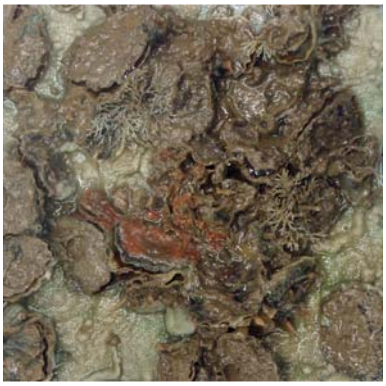
Russell, B. C., Neil, K. and Hilliard, R. (2003). Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve Marine and Terrestrial Introduced Species Prevention and Management Strategy. Report for the Department of Environment and Heritage, January, 2004.

Tan, K. S. and Morton, B. (2006). The invasive Caribbean bivalve *Mytilopsis sallei* (Dreissenidae) introduced to Singapore and Johor Bahru, Malaysia. *The Raffles Bulletin of Zoology* **54**(2)**:** 429-434.

The Senate Committee Report (2004). Turning back the tide – the invasive species challenge, The Senate Environment, Communications, Information Technology and the Arts References Committee Inquiry into the regulation, control and management of invasive species and the Environment Protection and Biodiversity Conservation Amendment (Invasive Species) Bill 2002, The Commonwealth of Australia, December 2004.

APPENDICES

APPENDIX A: Representative photographs of biofouling communities on settlement plates collected at Bayview Marina, Darwin, from June 2009 to July 2010

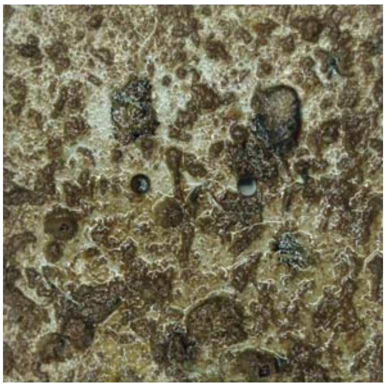


Oct 09 – Plate 1 (front)

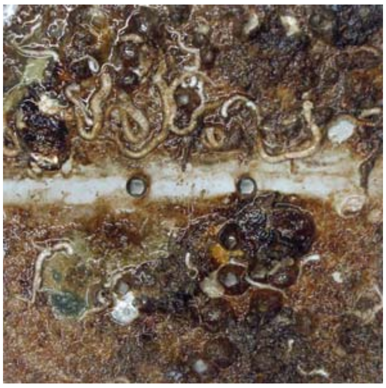
Oct 09 – Plate 2 (rear)

Jan 10 – Plate 3 (front)

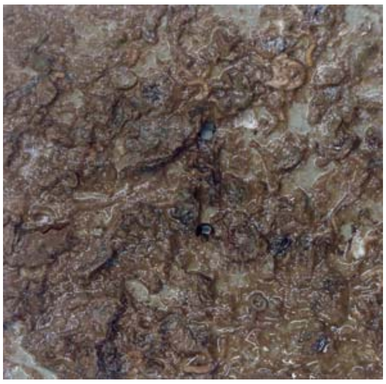
Jan 10 – Plate 3 (rear)



Apr 10 – Plate 2 (front)



Apr 10 – Plate 3 (rear)

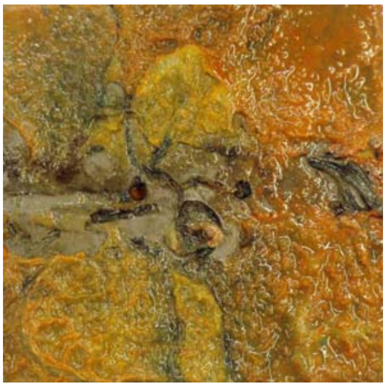


Jul 10 – Plate 2 (front)

Jul 10 – Plate 1 (rear)

APPENDIX B: Representative photographs of biofouling communities on settlement plates collected at Cullen Bay Marina, Darwin, from June 2009 to July 2010

Oct 09 – Plate 1 (front)



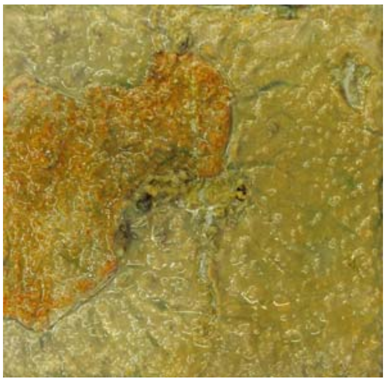
Oct 09 – Plate 2 (rear)

Jan 10 – Plate 3 (front)

Jan 10 – Plate 1 (rear)

Apr 10 – Plate 2 (front)

Apr 10 – Plate 2 (rear)



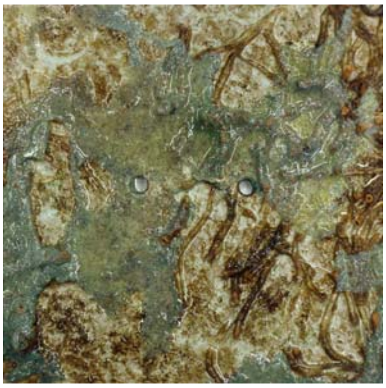
Jul 10 – Plate 1 (front)

Jul 10 – Plate 1 (rear)

APPENDIX C: Representative photographs of biofouling communities on settlement plates collected at Frances Bay Mooring Basin, Darwin, from June 2009 to July 2010

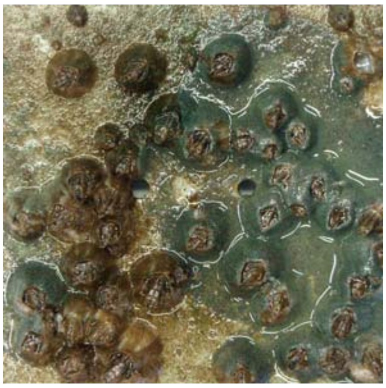
Oct 09 – Plate 1 (front)

Oct 09 – Plate 2 (rear)

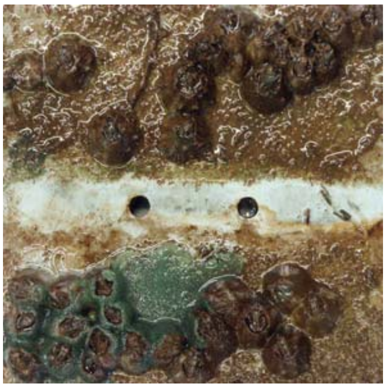


Jan 10 – Plate 2 (front)

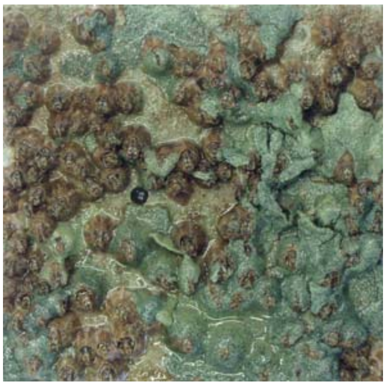
Jan 10 – Plate 3 (rear)



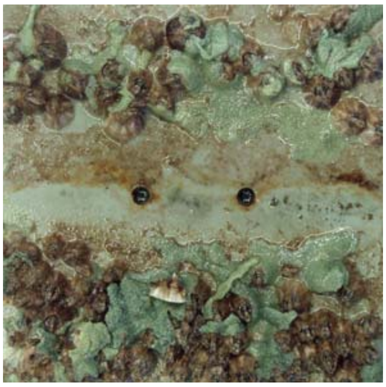
Apr 10 – Plate 2 (front)



Apr 10 – Plate 3 (rear)

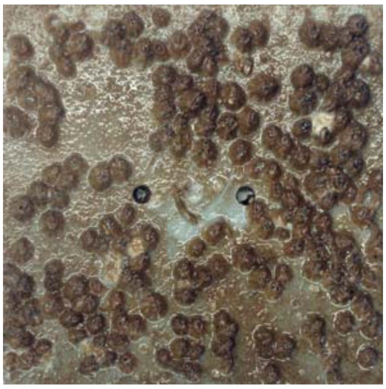


Jul 10 – Plate 2 (front)

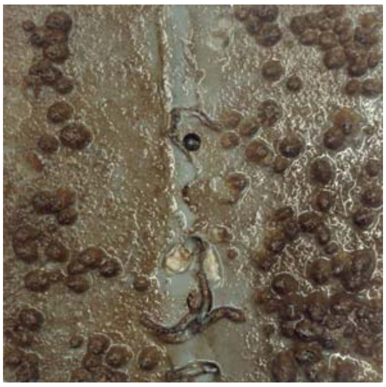


Jul 10 – Plate 3 (rear)

APPENDIX D: Representative photographs of biofouling communities on settlement plates collected at Tipperary Water Marina, Darwin, from June 2009 to July 2010



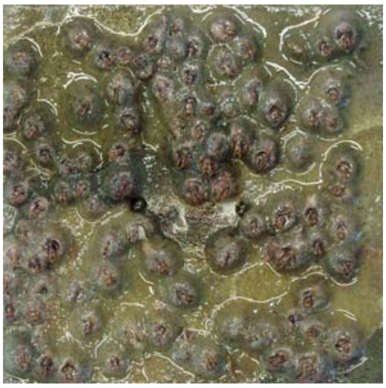
Oct 09 – Plate 3 (front)



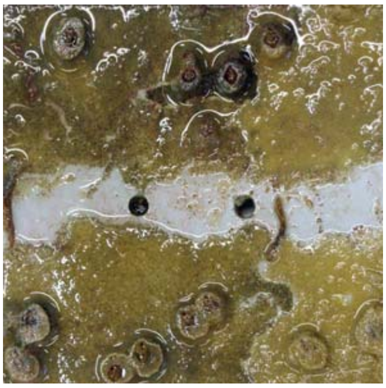
Oct 09 – Plate 3 (rear)

Jan 10 – Plate 2 (front)

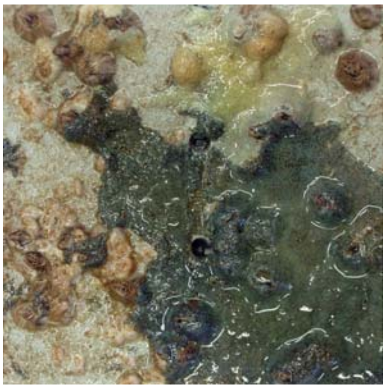
Jan 10 – Plate 2 (rear)



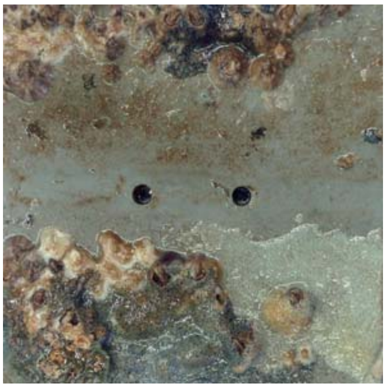
Apr 10 – Plate 1 (front)



Apr 10 – Plate 3 (rear)



Jul 10 – Plate 2 (front)



Jul 10 – Plate 3 (rear)

APPENDIX E: Representative photographs of biofouling communities on settlement plates collected at Cullen Bay Pontoon, Darwin, from June 2009 to July 2010

Oct 09 – Plate 2 (front)

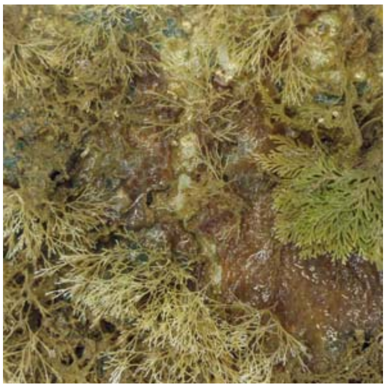
Oct 09 – Plate 3 (rear)

Jan 10 – Plate 3 (front)

Jan 10 – Plate 1 (rear)

Apr 10 – Plate 1 (front)

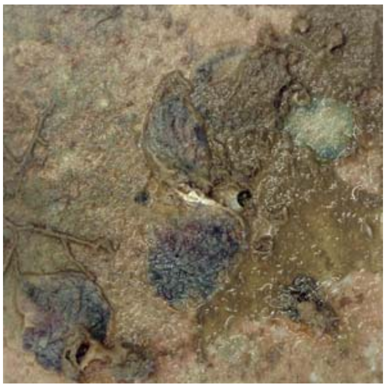
Apr 10 – Plate 1 (rear)



Jul 09 – Plate 1 (front)

Jul 10 – Plate 3 (rear)

APPENDIX F: Representative photographs of biofouling communities on settlement plates collected at HMAS Coonawarra, Darwin, from June 2009 to July 2010

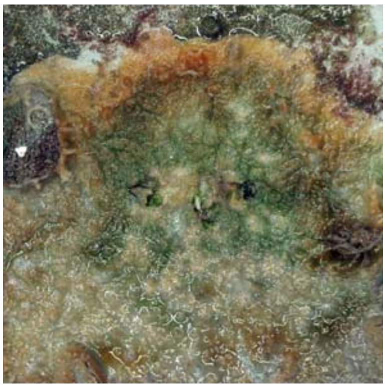


Oct 09 – Plate 2 (front)

Oct 09 – Plate 2 (rear)

Jan 10 – Plate 2 (front)

Jan 10 – Plate 2 (rear)



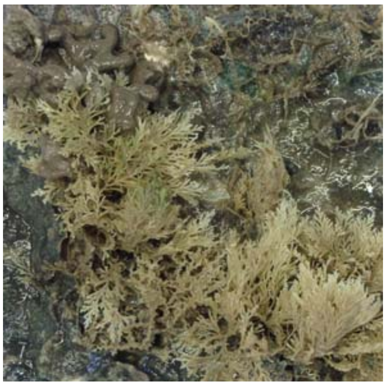
Apr 10 – Plate 3 (front)

Apr 10 – Plate 2 (rear)

Jul 09 – Plate 1 (front)

Jul 10 – Plate 1 (rear)

APPENDIX G: Representative photographs of biofouling communities on settlement plates collected at Stokes Hill Wharf, Darwin, from June 2009 to July 2010



Oct 09 – Plate 3 (front)

Oct 09 – Plate 3 (rear)

NO PHOTOGRAPHS AVAILABLE FOR JANUARY 2010

NO PHOTOGRAPHS AVAILABLE FOR APRIL 2010

Jul 10 – Plate 1 (front)

Jul 10 – Plate 2 (rear)

APPENDIX H: Average wet biomass (g) of biofouling developing on settlement surfaces from Darwin Marina and open water sites over four sampling periods during 2009-10

	Oct-09		**Jan-10**		**Apr-10**		**Jul-10**	
Location	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Marina sites								
Bayview	121.73	24.73	28.10	2.32	28.40	1.36	28.87	8.99
Cullen Bay	29.77	7.67	30.07	0.77	35.50	6.12	26.33	5.28
Frances Bay	93.77	10.05	13.13	1.63	78.33	2.13	90.53	8.27
Tipperary Waters	21.90	2.97	8.00	0.55	66.53	7.80	44.93	4.18
Open water sites								
Cullen Bay Pontoon	71.93	3.33	43.20	7.38	100.47	14.96	105.70	17.37
HMAS Coonawarra	17.30	7.33	47.73	10.57	33.30	11.11	47.97	2.28
Stokes Hill Wharf	91.97	1.10	-	-	-	-	-	-

APPENDIX I: Average frequency (%) of occurrence of each taxonomic group developing on settlement surfaces from Darwin Marina and open water sites over four sampling periods during 2009-10

Bayview marina

Taxonomic	Oct-09		Jan-10		Apr-10		Jul-10	
group	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Algae	12.67	4.16	19.33	5.51	34.00	8.19	32.67	4.73
Ascidians	17.33	11.72	1.33	0.58	14.00	1.73	9.33	1.53
Barnacles	0.67	0.58	0.00	0.00	21.33	1.53	0.00	0.00
Bryozoans	37.33	2.31	44.00	4.36	26.67	6.03	13.33	5.03
Hydroids	0.00	0.00	0.00	0.00	14.67	0.58	8.00	3.61
Molluscs	56.00	9.17	14.00	1.73	26.67	2.08	46.00	11.36
Polychaetes	28.00	3.61	1.33	1.15	38.00	6.56	35.33	2.08
Sponges	24.67	9.02	8.67	7.51	6.00	2.00	18.67	3.51
Amphipods	0.00	0.00	0.00	0.00	0.00	0.00	12.00	5.29
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare space	20.00	7.21	64.67	7.64	62.00	3.00	56.67	4.16

Cullen Bay Marina

Taxonomic	Oct-09		Jan-10		Apr-10		Jul-10	
group	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ascidians	6.00	1.00	44.00	18.36	36.00	22.72	0.00	0.00
Barnacles	0.00	0.00	4.00	1.73	10.00	5.57	2.00	1.00
Bryozoans	0.00	0.00	1.33	1.15	0.00	0.00	0.00	0.00
Hydroids	7.33	1.53	33.33	8.33	60.00	10.54	0.00	0.00
Molluscs	2.00	1.73	0.67	0.58	0.00	0.00	0.67	0.58
Polychaetes	5.33	2.08	8.67	2.08	7.33	2.31	52.00	7.00
Sponges	84.00	2.00	56.00	21.70	58.00	24.33	90.67	1.53
Amphipods	0.00	0.00	0.00	0.00	0.00	0.00	2.67	2.31
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare space	20.00	1.00	20.00	4.36	30.67	2.31	21.33	4.04

Frances Bay Mooring Basin

Taxonomic group	Oct-09		Jan-10		Apr-10		Jul-10	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Algae	0.00	0.00	26.67	6.43	0.00	0.00	0.00	0.00
Ascidians	37.33	8.02	47.33	3.51	36.67	12.58	50.67	5.13
Barnacles	10.00	3.00	0.00	0.00	60.00	2.65	76.67	3.21
Bryozoans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molluscs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polychaetes	96.67	0.58	35.33	3.06	0.67	0.58	0.00	0.00
Sponges	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphipods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare space	24.67	5.86	75.33	7.51	51.33	3.06	50.67	4.51

Tipperary Waters Marina

Taxonomic group	Oct-09		Jan-10		Apr-10		Jul-10	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Algae	58.67	4.04	36.67	2.52	2.00	1.00	0.00	0.00
Ascidians	6.67	2.08	0.00	0.00	90.00	0.00	78.67	2.08
Barnacles	51.33	8.08	4.00	1.00	66.00	2.65	36.67	6.81
Bryozoans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroids	0.00	0.00	0.00	0.00	0.00	0.00	8.67	1.15
Molluscs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polychaetes	22.67	3.51	38.00	7.21	2.00	1.73	0.00	0.00
Sponges	0.00	0.00	0.00	0.00	0.67	0.58	0.00	0.00
Amphipods	0.00	0.00	1.33	1.15	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare space	90.00	1.00	88.67	2.08	10.67	0.58	50.00	2.00

Cullen Bay Pontoon

Taxonomic group	Oct-09		Jan-10		Apr-10		Jul-10	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Algae	11.00	5.32	9.00	3.11	6.00	3.16	7.00	3.32
Ascidians	7.00	4.73	7.50	2.87	26.00	11.83	33.00	11.79
Barnacles	0.00	0.00	0.00	0.00	1.50	0.96	0.00	0.00
Bryozoans	50.50	17.02	54.00	18.24	48.50	16.46	55.00	18.48
Hydroids	2.00	0.82	5.00	2.52	1.00	1.00	0.00	0.00
Molluscs	21.50	8.73	15.00	7.72	33.00	11.39	30.50	11.00
Polychaetes	6.00	2.16	14.00	4.83	17.50	6.08	12.00	4.24
Sponges	19.50	13.67	4.00	1.41	41.00	19.19	13.50	6.99
Amphipods	0.00	0.00	10.00	3.37	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare space	24.00	9.42	36.00	12.68	14.50	4.99	15.00	5.80

HMAS Coonawarra

Taxonomic group	Oct-09		Jan-10		Apr-10		Jul-10	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Algae	66.00	13.34	48.50	10.81	23.00	7.94	4.50	3.30
Ascidians	0.00	0.00	27.50	15.84	2.50	1.89	17.50	12.26
Barnacles	0.00	0.00	2.00	1.15	0.50	0.50	0.00	0.00
Bryozoans	2.50	2.50	6.50	2.99	21.00	11.00	22.50	8.30
Hydroids	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00
Molluscs	8.00	7.35	14.00	7.16	8.00	2.83	4.50	1.71
Polychaetes	1.50	0.96	3.00	3.00	1.50	0.96	1.50	0.96
Sponges	92.50	4.92	34.50	12.04	59.00	19.71	53.00	19.47
Amphipods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare space	15.50	3.10	35.50	4.99	17.00	5.97	9.50	3.69

Stokes Hill Wharf

Taxonomic group	Oct-09		Jan-10		Apr-10		Jul-10	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Algae	7.00	2.89	-	-	-	-	-	-
Ascidians	48.00	16.02	-	-	-	-	-	-
Barnacles	3.00	1.29	-	-	-	-	-	-
Bryozoans	33.00	13.18	-	-	-	-	-	-
Hydroids	10.00	3.83	-	-	-	-	-	-
Molluscs	27.00	11.90	-	-	-	-	-	-
Polychaetes	4.50	3.20	-	-	-	-	-	-
Sponges	8.50	6.13	-	-	-	-	-	-
Amphipods	1.50	0.50	-	-	-	-	-	-
Other	0.00	0.00	-	-	-	-	-	-
Bare space	13.00	4.65	-	-	-	-	-	-

APPENDIX J: Number of species (within specific taxonomic groups) developing on settlement surfaces from Darwin Marina and open-water sites over four sampling periods during 2009-10

Location	Oct-09	Jan-10	Apr-10	Jul-10
Marina sites				
Bayview	9	7	8	10
Cullen Bay	7	7	5	7
Frances Bay	4	3	3	2
Tipperary Waters	5	5	3	3
Open water sites				
Cullen Bay Pontoon	18	19	23	16
HMAS Coonawarra	7	15	14	9
Stokes Hill Wharf	22	-	-	17