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Phytoplankton communities of East Arm in Darwin Harbour

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Executive summary

- Phytoplankton communities of East Arm of Darwin Harbour were described to provide reference data for the assessment of potential future impacts on water quality. A total of ninety six samples were collected and analysed from four sites in East Arm on 24 occasions from June 2010 to June 2012. Two hundred and thirty five phytoplankton taxa were identified from nine major taxonomic groups including Bacillariophyceae, Chlorophyceae, Chrysophyceae, Euglenophyceae, Dictyochophyceae, Prasinophyceae, Dinophyceae and Cyanobacteria.
- Diatoms (Bacillariophyceae) comprised >50% of the overall summed cell density of phytoplankton, and >70% of the total number of taxa. Abundant diatom taxa included *Chaetoceros*, *Bacteriastrum* and *Asterionellopsis*. This is typical of tropical marine waters.
- The extent and duration of freshwater inflows in the wet season had a marked effect on the abundance and composition of phytoplankton communities. Wet season flows at the upper estuarine site reduced phytoplankton abundance and shifted dominance from Bacillariophyceae.
- High phytoplankton concentrations, as indexed by the concentration of chlorophyll *a*, occurred erratically but predominantly in the early or mid-wet season. At these times samples tended to be dominated by few taxa. Examples include *Cryptomonas* (Cryptophyceae) and gymnodinioid dinoflagellates (Dinophyceae) in early March 2011.
- Community patterns were analysed at different taxonomic levels: (i) by Class, and (ii) by genera within the Class Bacillariophyceae (diatoms). Both sets of analyses identify similar seasonal patterns and similar inter-annual differences between wet season communities.
- Forty-one taxa were identified as potentially toxic or potentially harmful. Four genera containing potentially toxic species were identified: *Dinophysis*, *Prorocentrum*, *Planktothrix* and *Pseudo-nitzschia*. These taxa are either known or presumed to be producers of toxins. Potentially harmful taxa may present a physical challenge to marine fauna through irritation or clogging of respiratory surfaces. These taxa are in low concentrations and as such do not pose a human health concern, and are considered a natural part of the harbour's phytoplankton composition.
- Phytoplankton provide the basis of the pelagic (water column) food web in Darwin Harbour. The study provides a valuable reference dataset to assess changes in the harbour's phytoplankton composition in the future. Intensive monitoring of phytoplankton composition is not recommended annually, but could be conducted at estuarine sites vulnerable to water pollution, such as the upper estuaries.

Contents

1. Introduction..2

2. Methods..3

2.1 Rainfall and river flow..3

2.2 Sampling methods..4

2.3 Identification and enumeration of phytoplankton samples..8

2.4 Data analysis..8

3. Results and Discussion..9

3.1 Phytoplankton community composition..9

3.2 Community dynamics..12

3.2.1 All phytoplankton classes..12

3.2.2 Bacillariophyceae..15

3.3 Potentially toxic and harmful taxa..21

3.4 Water quality..23

4. Acknowledgements..24

5. References..24

6. Appendices..25

6.1 Figures of temporal trends in water quality parameters..25

6.2 Sampling dates, times and tidal conditions..35

6.3 Nutrient and chlorophyll data..39

6.4 Physico-chemical data..43

1. Introduction

There is limited information on the phytoplankton communities of Darwin Harbour, and thus limited basis for the assessment of potential future impacts. This report presents baseline reference data on phytoplankton community composition and structure, and water quality parameters at four sites in East Arm of Darwin Harbour. Samples were collected at approximately monthly intervals for two years from June 2010 to June 2012.

This study represents the first detailed account of phytoplankton communities in estuarine waters of Darwin Harbour. Previous studies found low harbour–wide chlorophyll concentrations, and minor differences between dry and wet seasons. McKinnon *et al*. (2006) report wet season chlorophyll concentrations of 0.77 µg/l and dry season chlorophyll concentrations of 0.89 µg/l.

In this present study average dry season chlorophyll concentrations were similarly low, but wet season chlorophyll concentrations were relatively higher and variable between sites. At the most upstream site average chlorophyll concentrations are low, reflecting the influence of freshwater inflows from Elizabeth River; higher values at other sites reflect occasional early/mid wet season high phytoplankton concentrations.

Seasonal effects due to reduced salinity from wet season freshwater inflows are evident at all levels of taxonomic resolution. During the wet season of 2010/11 and to a lesser extent the wet season of 2011/12, there was a reduction in abundance but an increase in high level phytoplankton diversity. These effects were increasingly muted at downstream sites.

There are several caveats to be borne in mind when considering the results of this study. Firstly, collection times were not strictly standardised by tidal height or stage. This is evident in the general lack of seasonal pattern in most water quality parameters. Secondly, the quantification of phytoplankton samples was standardised by counting and identification of a proportion of cells rather than a constant number of cells.

2. Methods

2.1 Rainfall and river flow

Monthly rainfall data for Darwin Airport (station 014015) were obtained from the Bureau of Meteorology. Most rainfall occurs during the wet season, in the months December to March. Average annual rainfall is 1,732 mm. Rainfall for the 2010/11 12 month period (July-June) was the highest on record (2,960 mm; record 1941/42 – 2011/12); rainfall for the 2009/10 12 month period was 2,116 mm; and for the 2011/12 12 month period was 1,927 mm. Rainfall totals for the months July 2009 to June 2012 are shown in Figure 1. The pattern of wet season flow at gauge station G8150018 on the Elizabeth River varied between years, with highest flows recorded in the 2010/11 wet season (Figure 2).

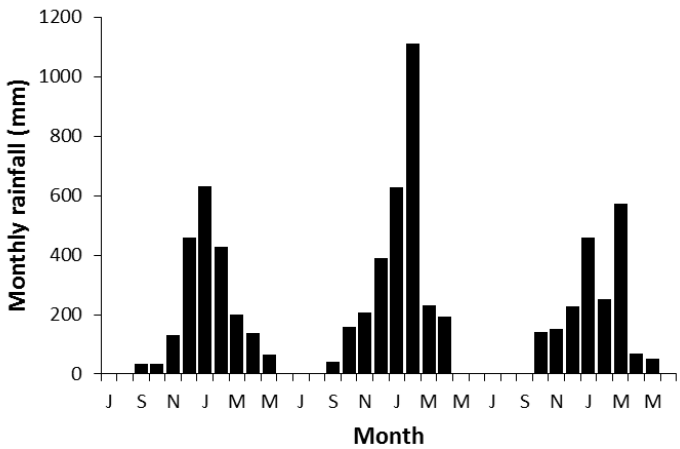

Figure 1. Monthly rainfall from January 2010 to December 2012 recorded at Darwin Airport.

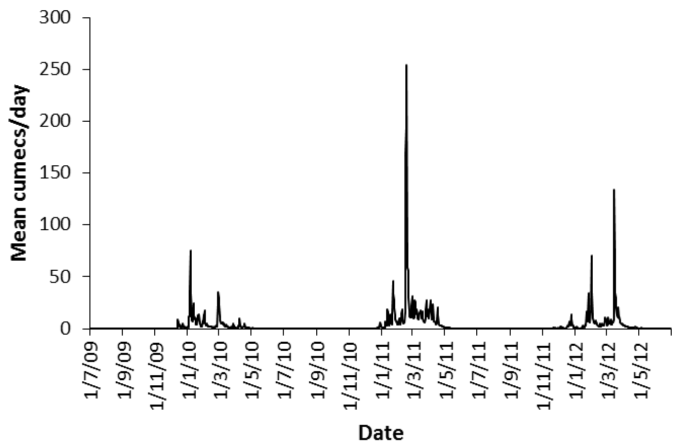

Figure 2. Mean daily flow (mean cumecs/day) in Elizabeth River from July 2009 to June 2012.

2.2 Sampling methods

Four sampling sites were located within East Arm in Darwin Harbour (Table 1, Figure 3). Sites are distributed from the upper reaches of East Arm estuary (Site 11) to the middle reaches of the harbour (Site 17). These sites are separated by approximately 18 kilometres. The water quality in the upper reaches is strongly influenced by wet season runoff from the catchment of the Elizabeth River.

Table 1. Coordinates of sites for collection of phytoplankton samples in the East Arm of Darwin Harbour.

Site	Hydstra site code	Latitude (°S)	Longitude (°E)
Eliz11	G8150161	12.5844	131.0340
Eliz13	G8150163	12.5657	131.0080
Eliz15	G8150168	12.5346	130.9665
Eliz17	G8150170	12.5019	130.9053

Sampling was conducted on 24 occasions at mostly monthly intervals from June 2010 to June 2012 (Table 2).

Table 2. Dates for collection of phytoplankton samples at four sites in East Arm of Darwin Harbour.

	Year		
Month	2010	2011	2012
January		27/1/11	
February			6/2/12 24/2/12
March		1/3/11 31/3/11	28/3/12
April			27/4/12
May		20/5/11	31/5/12
June	17/6/10	10/6/11	28/6/12
July	16/7/10	28/7/11	
August	16/8/10		
September	15/9/10	2/9/11 30/9/11	
October	27/10/10		
November	26/11/10	11/11/11 29/11/11	
December	20/12/10	16/12/11	

Figure 3. Location of sites for collection of phytoplankton samples in East Arm of Darwin Harbour.

At each site, near-surface water samples were collected for laboratory measurement of nutrients (total nitrogen, total phosphorus, nitrate, nitrite, ammonia and filterable reactive phosphorus). A field water quality meter was used to measure pH, conductivity, salinity, temperature, dissolved oxygen and % saturation dissolved oxygen. Phytoplankton samples were collected in a one litre plastic bottle and preserved using Lugol's iodine solution.

Sampling was mostly conducted within hours of the peak of spring high tides. Nearly 80% (19 of 24) of sampling occasions were during tides of at least 6 metres (Figure 4). The mean tidal height was 6.5 m. The marked exception is 28/7/11 when sampling was conducted on a tide of 5.1 m. Details of tidal conditions during sampling are presented in Appendix 6.2.

Sampling was mostly conducted within an hour of high tide (Figure 5, Table 3). Approximately half (47.9%) of all samples were collected within an hour of inferred high tide, with about 80% within 2 hours of high tide. The exceptions to this were almost entirely within wet season months. At sites 11 and 13 the proportion of samples collected during incoming and ebbing tides was approximately equal; at sites 15 and 17 samples were collected predominantly during incoming tides.

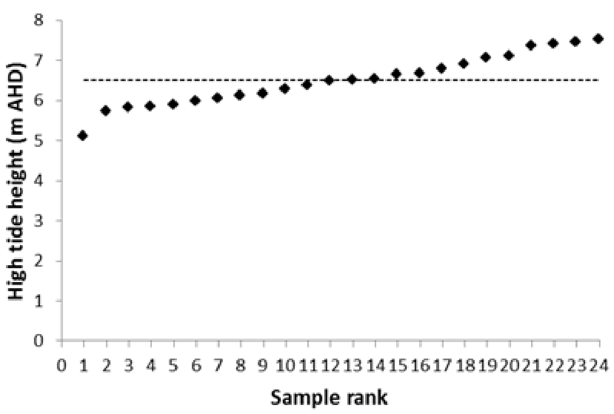

Figure 4. Ranked height of high tides during sampling. Dotted line shows mean tide height of 6.5 m.

Table 3. Frequency of sampling within one and two hour windows either side of high tide.

Site	±60 mins	±120 mins	<120 mins	>120 mins
11	15	20	11/11/2011	20/12/10, 6/2/12, 1/3/11
13	12	20	11/11/2011	20/12/10, 6/2/12, 1/3/11
15	12	19	11/11/2011	31/3/11, 6/2/12, 20/12/10, 1/3/11
17	7	17	11/11/11, 17/6/10, 24/2/12	31/3/11, 1/3/11, 6/2/12, 20/12/10

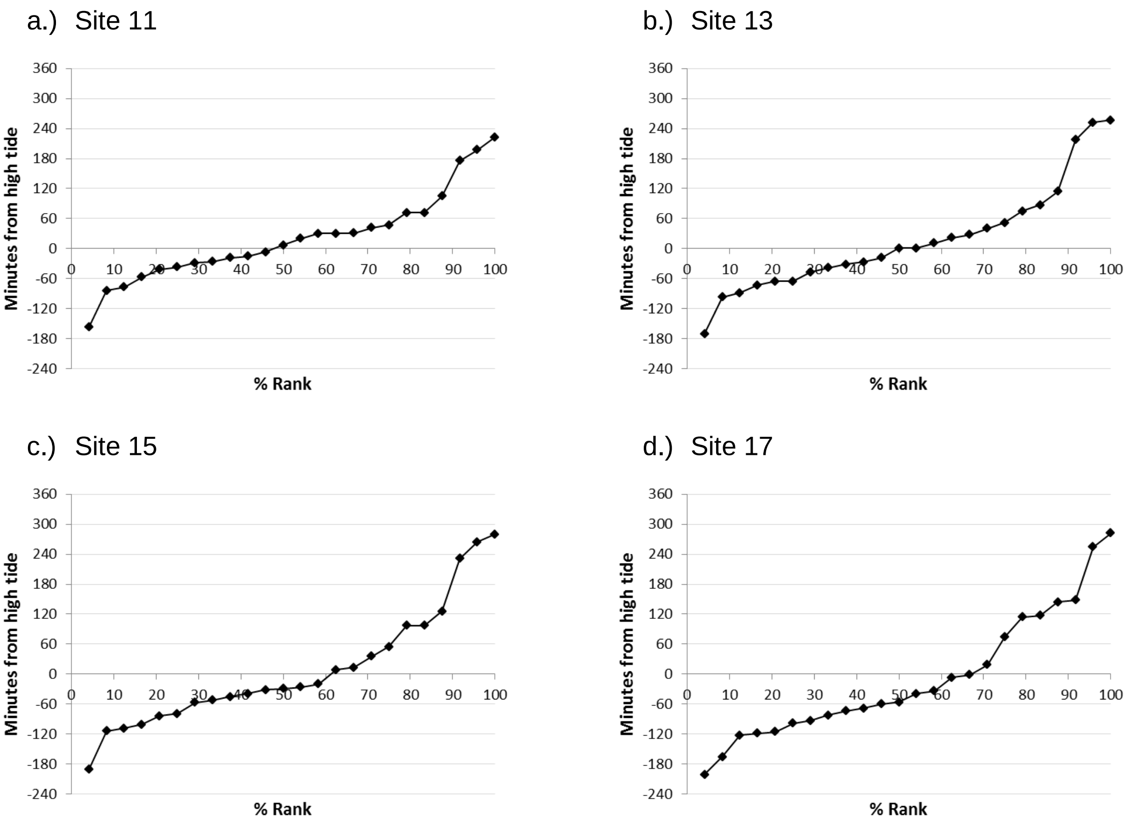

Figure 5. Difference between time of sample collection and time of high tide in Darwin Harbour.

2.3 Identification and enumeration of phytoplankton samples

Phytoplankton samples were identified and enumerated by a commercial laboratory (Dalcon Environmental Services). A Utermohl chamber was used to quantify cell abundance. All cells found in four transects of the chamber were identified and counted. Results were converted to cells per litre.

2.4 Data analysis

Multivariate analyses were conducted using the software program PRIMER version 6.1.13 (Clarke and Gorley 2006). Abundance data for each taxon were transformed using square root transformation prior to analysis. The Bray-Curtis dissimilarity measure was used to calculate the similarity of compositional structure among samples. Discrete groups in the data were identified using SIMPROF in the CLUSTER classification procedure.

Principal coordinates analysis (PCO) was used to display the structural similarity of samples and to display vectors associated with values for extrinsic water quality variables. Extrinsic variables included concentrations of nitrate, nitrite, filtered reactive phosphorus, total phosphorus, total nitrogen, salinity, temperature and pH. The BEST procedure was used to identify the best match between multivariate among-sample patterns and environmental variables associated with these samples. The procedure BVSTEP within BEST searches for high rank correlations between a similarity matrix and matrices generated from different normalised variable subsets (Clarke and Gorley 2006). Vectors for variables identified from the BEST procedure are displayed on the PCO plot.

Separate analyses were conducted for two levels of taxonomic resolution: (i) Class (i.e. Bacillariophyceae, Dinophyceae etc), and (ii) genera within the Class Bacillariophyceae. For these analyses the raw data from Dalcon Environmental Services was aggregated to the level of genus. The same set of analyses was conducted on both sets of data.

The relative abundance of taxa identified by the consultants as being potentially harmful or toxic was calculated.

3. Results and Discussion

3.1 Phytoplankton community composition

The phytoplankton community of East Arm included 235 taxa in nine major taxonomic groups (Tables 4 and 5). Bacillariophyceae, or diatoms, comprised 50.8% of the overall summed density of phytoplankton cells, and 72.8% (171 of 235) of the total number of taxa identified. Other prominent groups were Dinophyceae (28.6% of summed cell density, and 16.6% of the number of taxa) and Cryptophyceae (11.5% of summed cell density, and 1.3% of the number of taxa) (Figures 6 and 7). Within Bacillariophyceae prominent genera were *Chaetoceros*, *Bacteriastrum*, *Navicula*, *Amphora* and *Nitzschia*. The genus *Chaetoceros* comprised 18.7% of the overall summed cell density, and included 19 taxa.

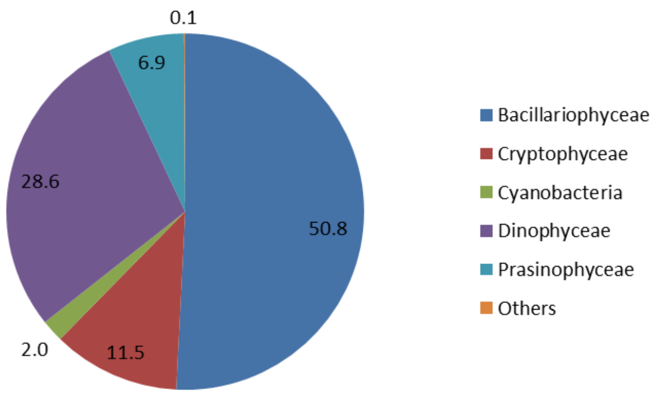

Figure 6. Pie diagram showing percentage of total estimated cell density for six major taxonomic groups of phytoplankton. Data for four groups (Chlorophyceae, Chrysophyceae, Euglenophyceae, and Dictyochophyceae) are pooled within 'Others'.

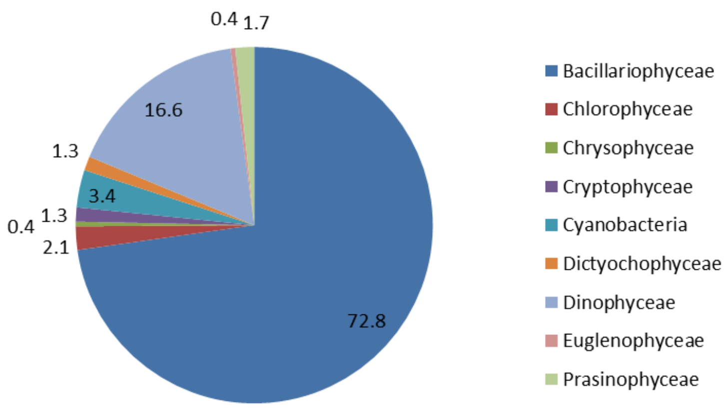

Figure 7. Pie diagram showing percentage number of taxa in each of nine major taxonomic groups of phytoplankton.

Table 4. Number of taxa, estimated total density of taxa, percentage of total density and number of taxa in raw data for Bacillariophyceae.

Class	Taxon	Sum of density	%	No. taxa
Bacillariophyceae	*Amphora*	53253	0.9	19
Bacillariophyceae	*Asterionellopsis*	273768	4.6	1
Bacillariophyceae	*Bacillaria*	23607	0.4	1
Bacillariophyceae	*Bacteriastrum*	349896	5.9	11
Bacillariophyceae	*Cerataulina*	183	<0.1	1
Bacillariophyceae	*Chaetoceros*	1118130	18.7	19
Bacillariophyceae	*Cocconeis*	1830	<0.1	4
Bacillariophyceae	*Coscinodiscus*	19398	0.3	14
Bacillariophyceae	*Cylindrotheca*	110349	1.8	1
Bacillariophyceae	*Detonula*	15738	0.3	2
Bacillariophyceae	Diatom 101	17568	0.3	1
Bacillariophyceae	Diatom 109	366	<0.1	1
Bacillariophyceae	Diatom 116	366	<0.1	1
Bacillariophyceae	Diatom 119	549	<0.1	1
Bacillariophyceae	*Diploneis*	2928	<0.1	3
Bacillariophyceae	*Ditylum*	732	<0.1	1
Bacillariophyceae	*Entomoneis*	1464	<0.1	2
Bacillariophyceae	*Eucampia*	12444	0.2	1
Bacillariophyceae	*Grammatophora*	1098	<0.1	1
Bacillariophyceae	*Guinardia*	34221	0.6	3
Bacillariophyceae	*Hemiaulus*	68076	1.1	5
Bacillariophyceae	*Leptocylindrus*	234789	3.9	2
Bacillariophyceae	*Licmophora*	2928	<0.1	2
Bacillariophyceae	*Lioloma*	3477	0.1	1
Bacillariophyceae	*Mastogloia*	549	<0.1	2
Bacillariophyceae	*Melosira*	1464	<0.1	2
Bacillariophyceae	*Navicula*	119865	2.0	19
Bacillariophyceae	*Nitzschia*	66795	1.1	12
Bacillariophyceae	*Odontella*	11346	0.2	2
Bacillariophyceae	*Paralia*	4209	0.1	1
Bacillariophyceae	*Pleurosigma*	15006	0.3	6
Bacillariophyceae	*Pseudo-nitzschia*	115473	1.9	4
Bacillariophyceae	*Rhizosolenia*	77592	1.3	15
Bacillariophyceae	*Rhopalodia*	183	<0.1	1
Bacillariophyceae	*Skeletonema*	2013	<0.1	1
Bacillariophyceae	*Surirella*	183	<0.1	1
Bacillariophyceae	*Thalassionema*	214110	3.6	2
Bacillariophyceae	*Thalassiosira*	60024	1.0	3
Bacillariophyceae	*Thalassiothrix*	732	<0.1	1
Bacillariophyceae	*Toxarium*	732	<0.1	1
Total		3037434	50.8	171
All phytoplankton total		5979342	100	235

Table 5. Number of taxa, estimated total density of taxa, percentage of total density and number of taxa in raw data for non-Bacillariophyceae phytoplankton.

Class	Taxon	Sum of density	%	No. taxa
Chlorophyceae	*Ankistrodesmus*	732	<0.1	1
Chlorophyceae	*Cosmarium*	732	<0.1	1
Chlorophyceae	*Crucigenia*	732	<0.1	1
Chlorophyceae	*Mougeotia*	732	<0.1	1
Chlorophyceae	*Scenedesmus*	2196	<0.1	1
Chrysophyceae	Chrysophyte	183	<0.1	1
Cryptophyceae	*Cryptomonas*	505446	8.5	1
Cryptophyceae	Cryptophyte	1281	<0.1	1
Cryptophyceae	*Hillea*	182268	3.0	1
Cyanobacteria	*Merismopedia*	1464	<0.1	1
Cyanobacteria	*Planktothrix*	33123	0.6	1
Cyanobacteria	*Pseudanabaena*	5124	0.1	1
Cyanobacteria	*Spirulina*	48312	0.8	2
Cyanobacteria	Cyanobacteria 011	3111	0.1	1
Cyanobacteria	Cyanobacteria 039	9699	0.2	1
Cyanobacteria	Cyanobacteria 057	20679	0.3	1
Dictyochophyceae	*Dictyocha*	732	<0.1	3
Dinophyceae	*Ceratium*	17019	0.3	4
Dinophyceae	Dinoflagellate 003	1098	<0.1	1
Dinophyceae	Dinoflagellate 036	1647	<0.1	1
Dinophyceae	Dinoflagellate 041	31476	0.5	1
Dinophyceae	*Dinophysis*	2013	<0.1	3
Dinophyceae	Gymnodinioid dinoflagellates	1422642	23.8	1
Dinophyceae	*Gymnodinium* sp. 006	549	<0.1	1
Dinophyceae	*Gyrodinium*	11163	0.2	4
Dinophyceae	*Heterocapsa*	2379	<0.1	1
Dinophyceae	*Mesoporos*	2379	<0.1	1
Dinophyceae	*Peridinium*	199836	3.3	1
Dinophyceae	*Prorocentrum*	2928	<0.1	4
Dinophyceae	*Protoperidinium*	17385	0.3	15
Dinophyceae	*Scrippsiella*	366	<0.1	1
Euglenophyceae	*Euglena*	183	<0.1	1
Prasinophyceae	Prasinophyte	346968	5.8	3
Prasinophyceae	*Tetraselmis*	65331	1.1	1
Total		2941908	49.2	64
All phytoplankton total		5979342	100	235

3.2 Community dynamics

3.2.1 All phytoplankton classes

Nine major taxonomic groups were identified in phytoplankton samples. The Class Bacillariophyceae (diatoms) is numerically dominant at most sites on most sampling occasions. Bacillariophyceae comprised >50% of the total number of cells. Conversely, four groups comprised <1% of the total number of cells (Chlorophyceae, Dictyochophyceae, Chysophyceae and Euglenophyceae) (Table 6).

The abundance and relative abundance of phytoplankton groups varied between sites and samples (Figures 8 and 9). Phytoplankton are most diverse but least abundant in the wet season of 2010/11 at sites 11, 13 and 15. Site 17 is relatively stable and predictable with communities dominated by Bacillariophyceae (diatoms) in most samples. Dinophyceae are occasionally prominent; mid-wet season samples are dominated by Cyanobacteria.

Table 6. Percent composition of phytoplankton communities at four sites, and percent composition of pooled total data.

	Site				
Taxa	**11**	**13**	**15**	**17**	**Total**
Bacillariophyceae	68.4	32.4	63.1	90.68	50.8
Dinophyceae	16.9	41.4	19.1	3.33	28.6
Cryptophyceae	1.1	21.4	1.2	0.05	11.5
Prasinophyceae	2.6	4.4	16.3		6.9
Cyanobacteria	10.2	0.4	0.4	5.80	2.0
Chlorophyceae	0.6	<0.1		0.11	0.1
Dictyochophyceae	0.1		<0.1	0.03	<0.1
Chrysophyceae	<0.1				<0.1
Euglenophyceae			<0.1		<0.1

The SIMPROF procedure identified 7 groups, of which group g comprised 79 of the 96 samples (Table 7). Most dry season samples belonged to this group; wet season samples in 2010/11 were classified into 6 groups, whereas wet season samples in 2011/12 were classified into 4 groups. Group 4 (group b) only occurred in 2011/12. Group g is characterised by high abundance of Bacillariophyceae (Table 8).

The BEST procedure identified the preferred minimum set of environmental predictors. The preferred set included only the variable salinity, with a correlation of 0.393 (Table 9). All variables identified in the BEST procedure are displayed as vectors in a plot of the principal co-ordinates analysis (Figure 10). Salinity appears to be correlated with the second PC axis. Much of the variation in the first PC axis remains unexplained.

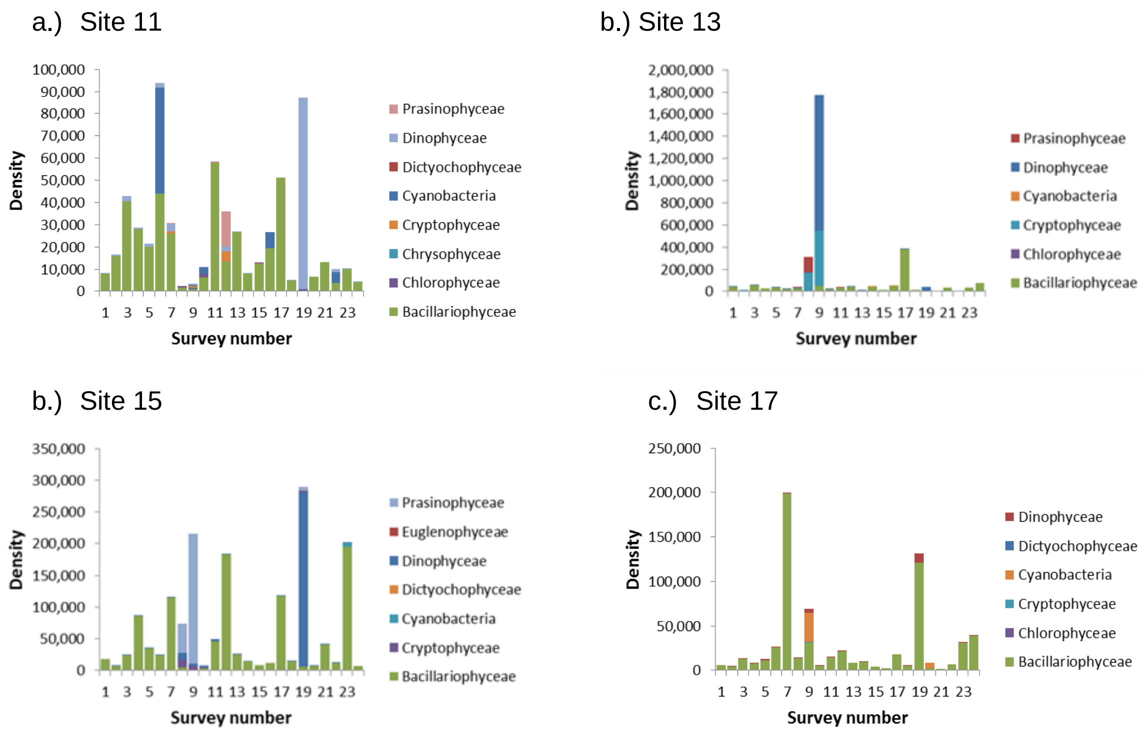

Figure 8. Temporal changes in abundance of major phytoplankton taxonomic groups (see Table 7 for sample dates).

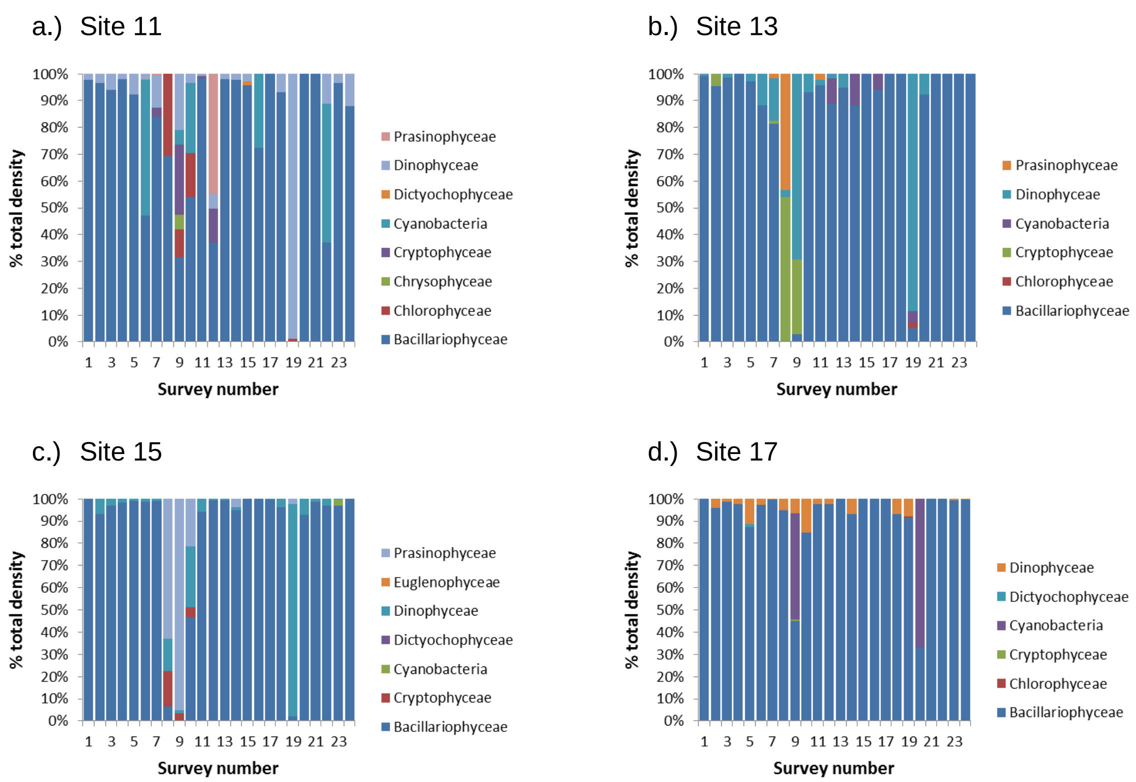

Figure 9. Temporal changes in relative abundance of major phytoplankton taxonomic groups.

Table 7. Distribution of six groups of samples based on SIMPROF procedure.

#	Season	Date	Site 11	13	15	17
1	Dry	17 Jun 10	g	g	g	g
2	Dry	16 Jul 10	g	g	g	g
3	Dry	16 Aug 10	g	g	g	g
4	Dry	15 Sep 10	g	g	g	g
5	Dry	27 Oct 10	g	g	g	g
6	Transition	26 Nov 10	g	g	g	g
7	Wet	20 Dec 10	g	g	g	g
8	Wet	27 Jan 11	e	c	c	g
9	Wet	1 Mar 11	d	a	c	g
10	Wet	31 Mar 11	f	g	c	g
11	Dry	20 May 11	g	g	g	g
12	Dry	10 Jun 11	c	g	g	g
13	Dry	28 Jul 11	g	g	g	g
14	Dry	2 Sep 11	g	g	g	g
15	Dry	30 Sep 11	g	g	g	g
16	Dry	11 Nov 11	g	g	g	e
17	Transition	29 Nov 11	g	g	g	g
18	Wet	16 Dec 11	g	g	g	g
19	Wet	6 Feb 12	b	b	b	g
20	Wet	24 Feb 12	g	e	g	f
21	Wet	28 Mar 12	g	g	g	e
22	Transition	27 Apr 12	f	g	g	g
23	Dry	31 May 12	g	g	g	g
24	Dry	28 Jun 12	g	g	g	g

Table 8. Characteristic phytoplankton taxa, in descending order of influence (1 = most influential) as identified from CLUSTER and SIMPER analyses.

Taxa	g	f	c	b	e
Bacillariophyceae	1	2	4	2	1
Cyanobacteria		1			
Prasinophyceae			1		
Dinophyceae			2	1	
Cryptophyceae			3		
No. of samples	79	3	5	3	4

Table 9. Results of BEST procedure to identify minimum set of environmental predictors of phytoplankton community structure.

No. of vars.	Correlation	Selected variables
1	0.393	Salinity
2	0.387	Nitrate, Salinity
3	0.364	Nitrate, Salinity, TSS
2	0.353	pH, Salinity
3	0.352	Nitrate, Salinity, Total N
4	0.344	Nitrate, Salinity, Total N, TSS
3	0.344	Nitrate, pH, Salinity
2	0.344	Salinity, TSS
2	0.34	Salinity, Total N
4	0.337	Nitrate, pH, Salinity, TSS

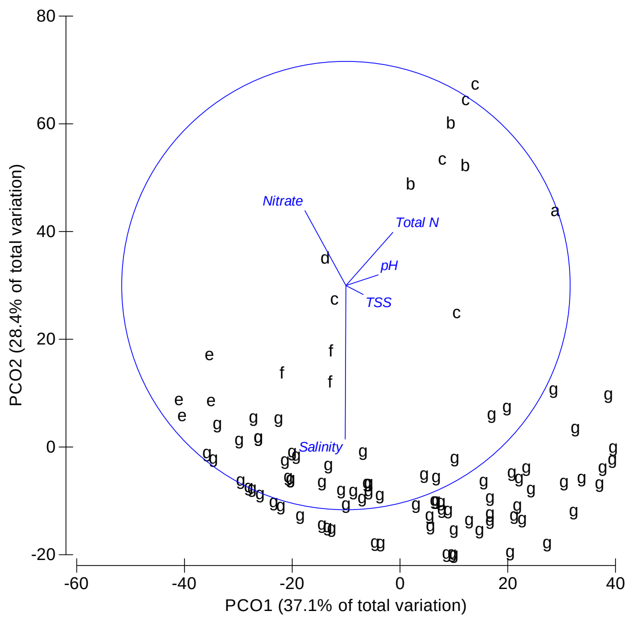

Figure 10. Principal coordinates analysis of sample data overlain by sample groups, and showing vectors identified by BEST procedure.

3.2.2 Bacillariophyceae

The diatom community was represented by 36 identified genera, and 4 taxa presumed to be distinct genera, but identified as Diatom 101, Diatom 109, Diatom 116 and Diatom 119. The genus *Chaetoceros* was prominent and comprised 36.8 % of total diatom abundance. Only 14 diatom genera comprised >1 % of the total number of cells (Table 10). Prominent taxa include *Chaetoceros*, *Bacteriastrum*, *Asterionellopsis*, *Leptocylindricus* and *Thalassionema*.

Abundance of diatom genera varied between sites and seasonally (Figures 11 and 12). Site 11 is distinguished by marked seasonal differences in abundance, with marked declines to very low levels in the wet season. Other sites are distinguished by individual samples with exceptionally high abundances of some taxa. At site 13 there were relatively high concentrations of *Chaetoceros* and *Bacteriastrum* in late November 2011. Sites 15 and 17 featured similar peaks in abundance in early wet season samples. For example site 17 spiked in numbers of *Asteronellopsis* in late December 2010 and in numbers of *Leptocylindricus* in early February 2012 (Figure 11).

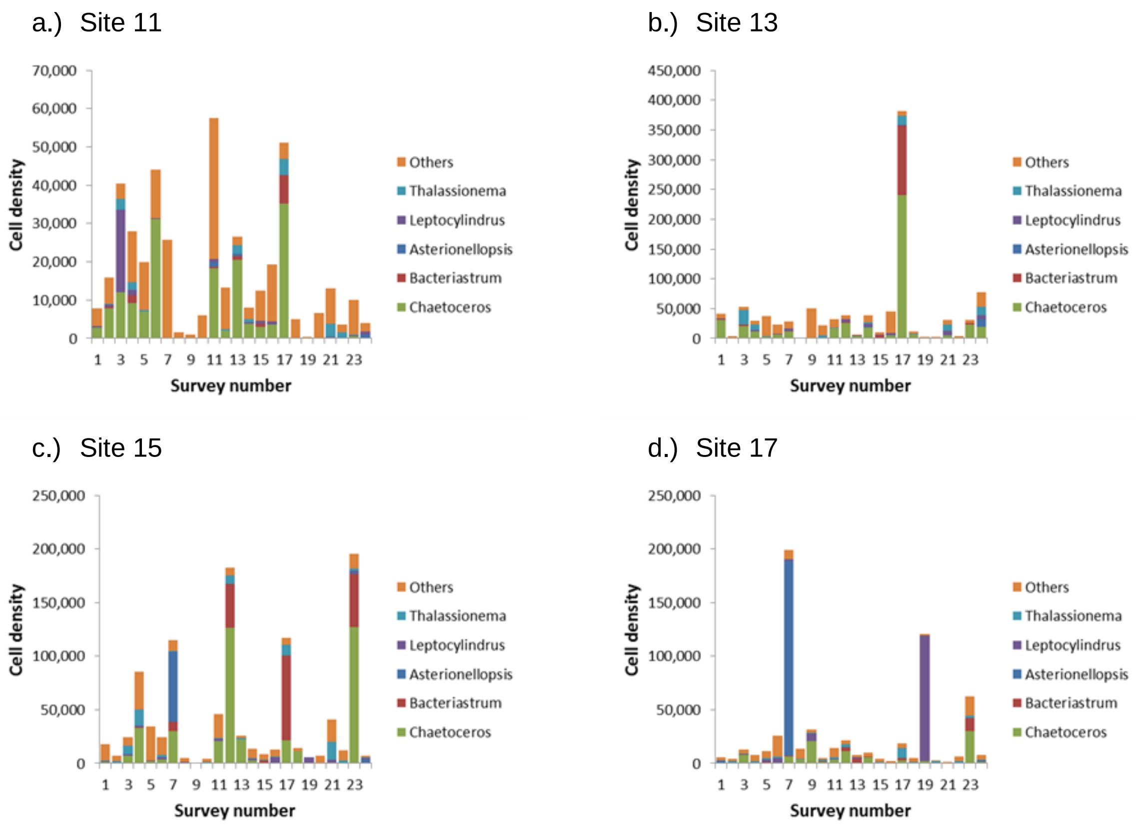

Figure 11. Abundance of five abundant diatom taxa and remaining diatom taxa at four sites in East Arm of Darwin Harbour.

The BEST procedure identified the preferred minimum set of environmental predictors. The preferred set included the variables nitrate and salinity, with a correlation of 0.420 (Table 13). All variables identified in the BEST procedure are displayed as vectors in a plot of the principal co-ordinates analysis (Figure 13).

Table 10. Percentage composition of diatom communities at four sites, and percentage composition of pooled total data.

	Site				
Taxa	**11**	**13**	**15**	**17**	**Total**
Chaetoceros	37.3	44.9	40.7	16.5	36.8
Bacteriastrum	2.9	12.8	18.3	4.1	11.5
Asterionellopsis	0.7	1.6	6.9	30.7	9.0
Leptocylindrus	6.7	4.2	2.7	22.7	7.7
Thalassionema	4.4	8.6	7.4	5.7	7.0
Navicula	6.4	4.9	2.8	2.5	3.9
Pseudo-nitzschia	5.1	3.7	4.2	2.3	3.8
Cylindrotheca	10.0	2.1	2.3	4.0	3.6
Rhizosolenia	7.1	2.0	1.8	1.7	2.6
Hemiaulus	1.3	3.1	2.9	0.4	2.2
Nitzschia	2.8	3.3	1.5	1.0	2.2
Thalassiosira	4.3	1.0	2.6	1.0	2.0
Amphora	5.2	2.4	0.5	0.3	1.8
Guinardia	0.8	0.9	1.4	1.4	1.1
Bacillaria	1.0	1.5	0.4		0.8
Coscinodiscus	0.7	0.5	0.5	1.0	0.6
Diatom 101	1.6	0.3	0.5	0.4	0.6
Detonula		1.0	0.5	0.2	0.5
Pleurosigma	0.4	0.3	0.7	0.6	0.5
Eucampia	<0.1	<0.1	0.3	1.5	0.4
Odontella		0.2	0.6	0.6	0.4
Paralia		0.1	<0.1	0.5	0.1
Lioloma	0.1	0.1	0.2	0.1	0.1
Diploneis	0.4	0.1	<0.1	<0.1	0.1
Licmophora	0.1	0.1		0.2	0.1
Skeletonema				0.3	0.1
Cocconeis	0.3	<0.1	<0.1	<0.1	0.1
Entomoneis	0.1	0.1		0.1	<0.1
Melosira	0.2	0.1			<0.1
Grammatophora	0.1	0.1		<0.1	<0.1
Ditylum		<0.1	<0.1	0.1	<0.1
Thalassiothrix			0.1		<0.1
Toxarium		<0.1	0.1		<0.1
Diatom 119		0.1			<0.1
Mastogloia		<0.1		0.1	<0.1
Diatom 109		<0.1			<0.1
Diatom 116		<0.1	<0.1		<0.1
Cerataulina			<0.1		<0.1
Rhopalodia	<0.1				<0.1
Surirella				<0.1	<0.1
Number of taxa	27	35	30	31	40

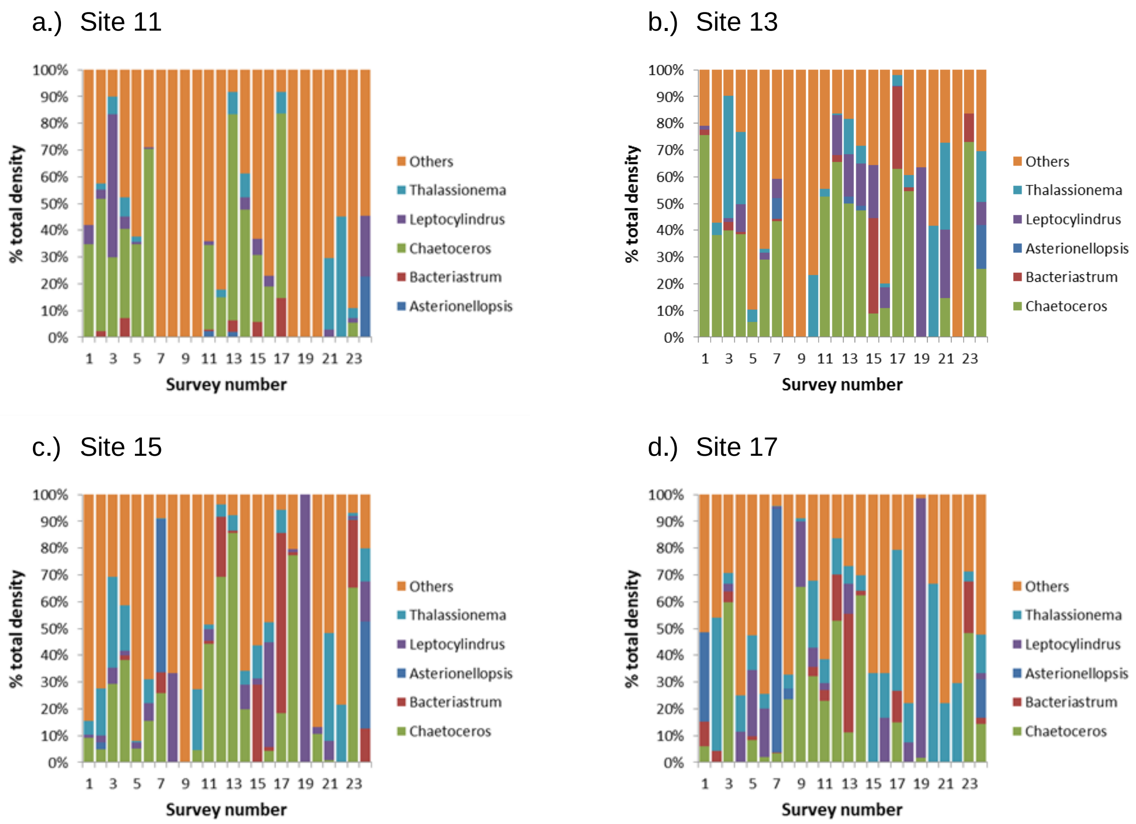

Figure 12. Relative abundance of five abundant diatom taxa in samples from four sites in East Arm in Darwin Harbour.

The diatom community was comprised of six groups dominated by group f (n=68) and group e (n=14) (Table 11). Group f dominated dry season samples in 2010 and 2011, and was characterised by genera *Chaetoceros*, *Navicula* and *Thalassionema* (Table 12). These patterns mirrored those evident for the entire community. Similarly there were marked differences in composition between dry and wet season samples and between wet season samples.

Table 11. Distribution of six groups of samples based on SIMPROF procedure.

#	Season	Date	Site 11	13	15	17
1	Dry	17 Jun 10	f	f	f	f
2	Dry	16 Jul 10	f	f	f	e
3	Dry	16 Aug 10	f	f	f	f
4	Dry	15 Sep 10	f	f	f	f
5	Dry	27 Oct 10	f	f	f	f
6	Transition	26 Nov 10	f	f	f	f
7	Wet	20 Dec 10	c	f	f	f
8	Wet	27 Jan 11	a	c	f	f
9	Wet	1 Mar 11	c	c	d	f
10	Wet	31 Mar 11	c	e	f	f
11	Dry	20 May 11	f	f	f	f
12	Dry	10 Jun 11	f	f	f	f
13	Dry	28 Jul 11	f	f	f	f
14	Dry	2 Sep 11	f	f	f	f
15	Dry	30 Sep 11	f	f	e	e
16	Dry	11 Nov 11	f	f	f	e
17	Transition	29 Nov 11	f	f	f	f
18	Wet	16 Dec 11	d	f	f	e
19	Wet	6 Feb 12	a	a	b	b
20	Wet	24 Feb 12	d	e	f	e
21	Wet	28 Mar 12	f	f	f	e
22	Transition	27 Apr 12	e	c	e	e
23	Dry	31 May 12	f	f	f	f
24	Dry	28 Jun 12	e	f	e	f

Table 12. Top five characteristic diatom taxa, in descending order of influence (1 = most influential) as identified from CLUSTER and SIMPER analyses.

Taxa	Group f	c	d	a	e	b
Chaetoceros	1					
Navicula	2	1			4	
Thalassionema	3				1	
Cylindrotheca	4	2	3			
Rhizosolenia	5					
Amphora		3		1		
Thalassiosira			1		3	
Nitzschia			2			
Diatom 101				2		
Coscinodiscus					2	
Thalassiosira						
Rhizosolenia					5	
Leptocylindrus						1
No. of samples	68	6	3	3	14	2

Table 13. Results of BEST procedure to determine minimum set of environmental variables correlated with phytoplankton resemblance matrix (using diatom data).

No. of vars.	Correlation	Selected variables
2	0.420	Nitrate, Salinity
1	0.406	Salinity
3	0.386	Nitrate, Nitrite, Salinity
3	0.384	Nitrate, Salinity, TSS
3	0.381	Nitrate, Salinity, Temp
3	0.380	Nitrate, Salinity, Total N
2	0.373	Nitrite, Salinity
3	0.368	Nitrate, pH, Salinity
3	0.366	FRP, Nitrate, Salinity
2	0.365	pH, Salinity

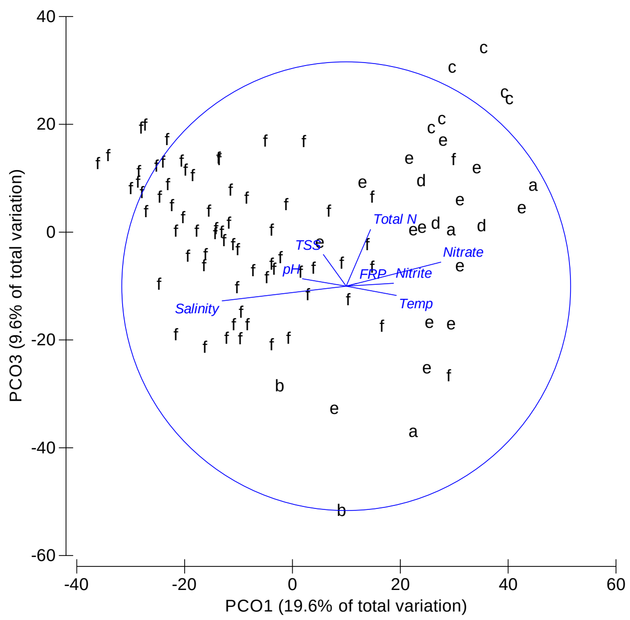

Figure 13. Principal coordinates analysis of diatom data overlain by sample groups, and showing vectors identified by BEST procedure.

3.3 Potentially toxic and harmful taxa

Forty one taxa were listed as being either potentially toxic or potentially harmful (Table 14). These taxa were designated toxic if they are known, or are presumed to be, producers of toxins. These taxa are listed on the Western Australian Shellfish Quality Assurance Program. Four genera were identified as potentially toxic: *Dinophysis*, *Prorocentrum*, *Planktothrix* and *Pseudo-nitzschia*. These taxa comprised 2.5% of the total estimated cell abundance. Potentially harmful taxa include those taxa which may be harmful to marine fauna due to the shape of the cell (i.e. needle-shaped, or bearing long spines). These taxa may cause irritation to marine fauna, or may cause clogging of respiratory surfaces.

Table 14. Percentage composition of potentially harmful and toxic taxa in each of four sites, and percentage of total cell density. Potentially toxic taxa indicated by *.

	Site				
Taxa	**11**	**13**	**15**	**17**	**% total**
Cosmarium sp. 007	0.1				<0.1
Cryptomonas spp.	0.2	16.0	0.4	0.1	8.5
Dictyocha fibula var. *rhombica*			<0.1	<0.1	<0.1
Dictyocha octonaria	<0.1				<0.1
Dictyocha sp. 001	<0.1				<0.1
*Dinophysis acuminata**	<0.1				<0.1
Nitzschia longissima	0.9	0.2	0.6	0.1	0.4
Nitzschia sp. 008		<0.1	0.1	<0.1	<0.1
Nitzschia sp. 015				<0.1	<0.1
Nitzschia sp. 016		<0.1			<0.1
Nitzschia sp. 022	0.1	0.3	0.1	0.1	0.2
Nitzschia sp. 023		0.2	0.1	0.1	0.2
Nitzschia sp. 026		<0.1			<0.1
Nitzschia sp. 030	<0.1		<0.1		<0.1
Nitzschia sp. 032	0.1				<0.1
Nitzschia sp. 035	0.7	0.1	0.1	0.1	0.2
Nitzschia sp. 046				0.1	<0.1
Nitzschia spp.	0.1	0.2		0.4	0.2
Peridinium spp.	0.1	6.4			3.3
Planktothrix sp.*				5.0	0.6
*Prorocentrum mexicanum**		<0.1	<0.1	0.1	<0.1
Pseudanabaena sp.		0.2			0.1
Pseudo-nitzschia fraudulenta (cf)*			<0.1		<0.1
Pseudo-nitzschia sp. 003*		<0.1			<0.1
Pseudo-nitzschia spp.*	3.4	1.2	2.6	1.9	1.9
*Pseudo-nitzschia turgidula**	0.1		0.1	0.2	0.1
Rhizosolenia clevei			<0.1		<0.1
Rhizosolenia imbricata var. *shrubsolei*	0.1	0.1	0.1	0.1	0.1
Rhizosolenia setigera	2.2	0.2	0.4	0.7	0.5
Rhizosolenia sp. 010				0.1	<0.1
Rhizosolenia sp. 014	<0.1				<0.1
Rhizosolenia sp. 015		<0.1			<0.1
Rhizosolenia sp. 016		<0.1			<0.1
Rhizosolenia sp. 021	0.1	0.2	0.1	0.1	0.1
Rhizosolenia sp. 024	<0.1	<0.1	0.1	0.1	<0.1
Rhizosolenia sp. 025			<0.1		<0.1
Rhizosolenia sp. 026	<0.1	<0.1	<0.1	0.2	<0.1
Rhizosolenia sp. 030			<0.1		<0.1
Rhizosolenia sp. 031	0.1	<0.1			<0.1
Rhizosolenia spp.	2.3	<0.1	0.3	0.2	0.3
Rhizosolenia striata		0.2		0.1	0.1
Total harmful/toxic	66063	792207	83631	64416	16.8
Total non-harmful/toxic	550647	2306532	1514691	601155	83.2
% harmful/toxic	10.7	25.6	5.2	9.7	
Total cells	616710	3098739	1598322	665571	100

3.4 Water quality

Correlations between water quality variables were generally low, with the exception of nitrate and nitrite (*r* = 0.54) (Table 15).

Table 15. Correlation coefficients for water quality variables at four sites in East Arm, Darwin Harbour.

	TN	NO_3	NO_2	NH_4	TP	FRP	Chl-a	pH	Sal	Temp	TSS
TN	1.00										
NO_3	0.21	1.00									
NO_2	0.18	**0.54**	1.00								
NH_4	-0.15	-0.09	-0.21	1.00							
TP	0.05	-0.18	-0.14	-0.23	1.00						
FRP	0.08	0.39	0.18	0.01	0.20	1.00					
Chl-a	0.20	-0.14	-0.02	-0.02	0.18	-0.02	1.00				
pH	0.12	-0.07	-0.15	0.01	0.12	0.08	0.02	1.00			
Sal	-0.28	-0.31	-0.19	0.20	0.04	0.05	-0.38	0.24	1.00		
Temp	0.23	0.23	-0.04	0.06	-0.11	0.04	0.31	-0.01	-0.25	1.00	
TSS	-0.20	-0.25	-0.02	-0.01	0.28	-0.05	0.13	0.03	0.04	-0.06	1.00

There were marked seasonal patterns in salinity due to freshwater inflows from catchment runoff in the wet season. Effects of freshwater inflows are most marked at the uppermost site, and are progressively diminished, and are greater in the wet season of 2010/11 than in the wet season of 2011/12. Seasonal patterns were less evident for most other water quality variables (Appendix 6.1).

4. Acknowledgements

Technical staff of the Aquatic Health Unit collected field samples.

5. References

Clarke, K.R. and Gorley, R.N. (2006). PRIMER v6: user manual / tutorial, PRIMER-E, Plymouth.

McKinnon, A.D., Smit, N., Townsend, S. and Duggan, S. (2006). Darwin Harbour: water quality and ecosystem structure in a tropical harbour in the early stages of urban development. In Wolanski, E. (Ed.), The Environment in Asia Pacific Harbours. Springer.

6. Appendices

6.1 Figures of temporal trends in water quality parameters

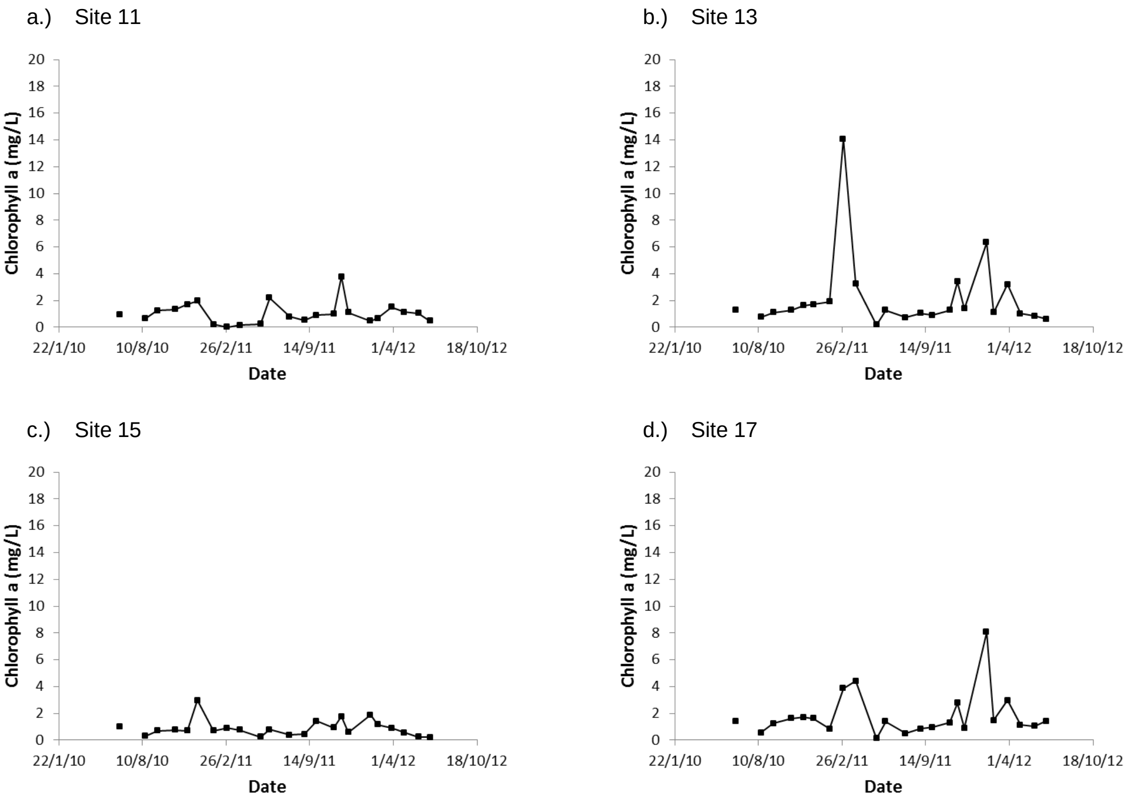

Figure A1. Temporal variation in concentration of chlorophyll *a* (mg/L) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

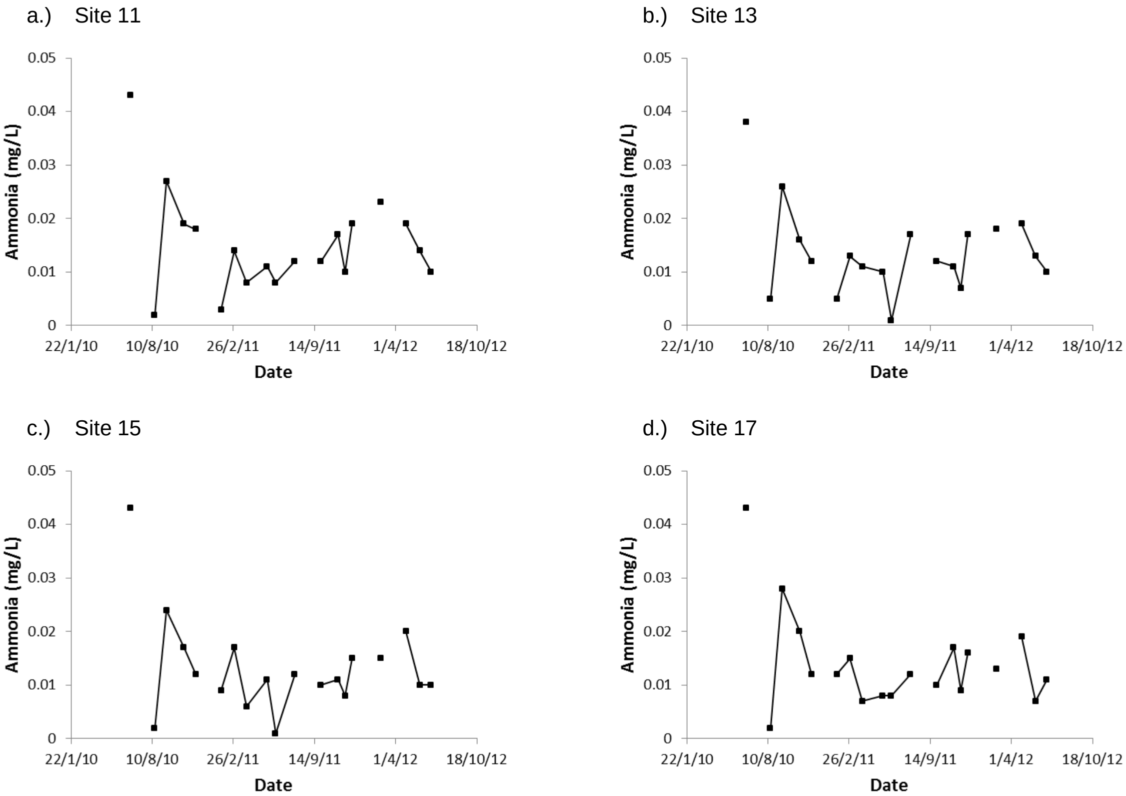

Figure A2. Temporal variation in concentration of ammonia (mg/L) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

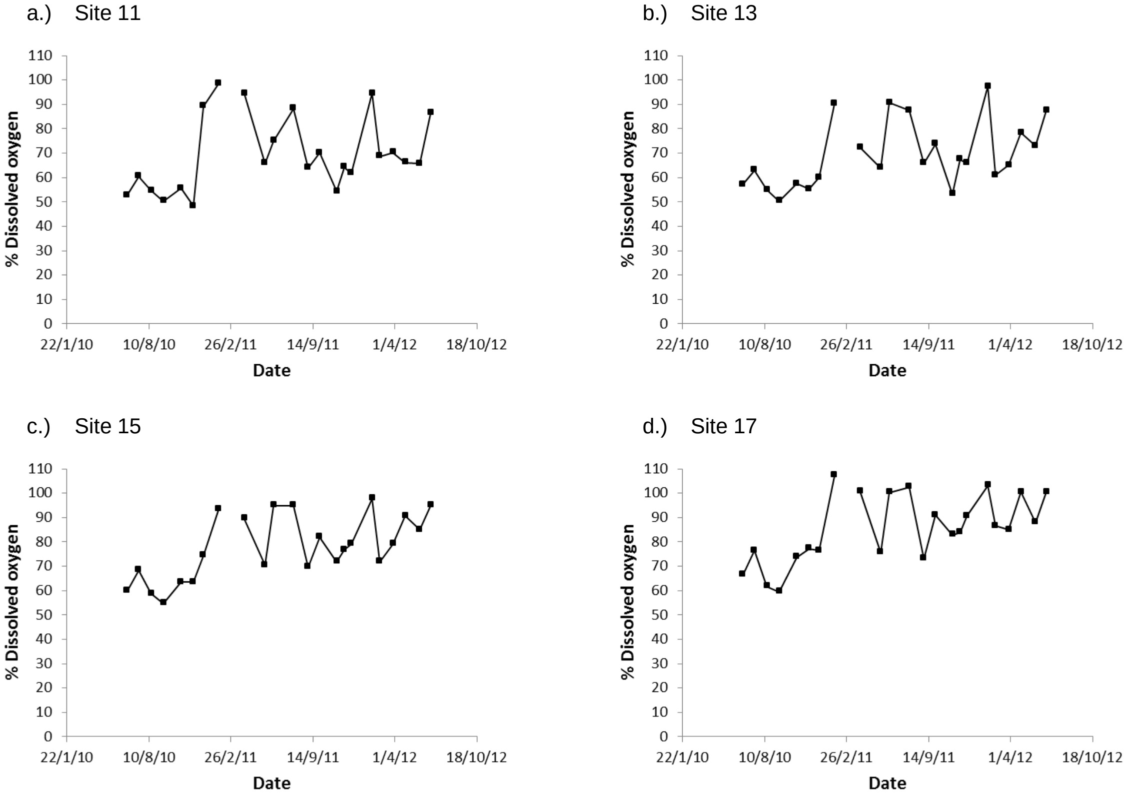

Figure A3. Temporal variation in dissolved oxygen (% saturation) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

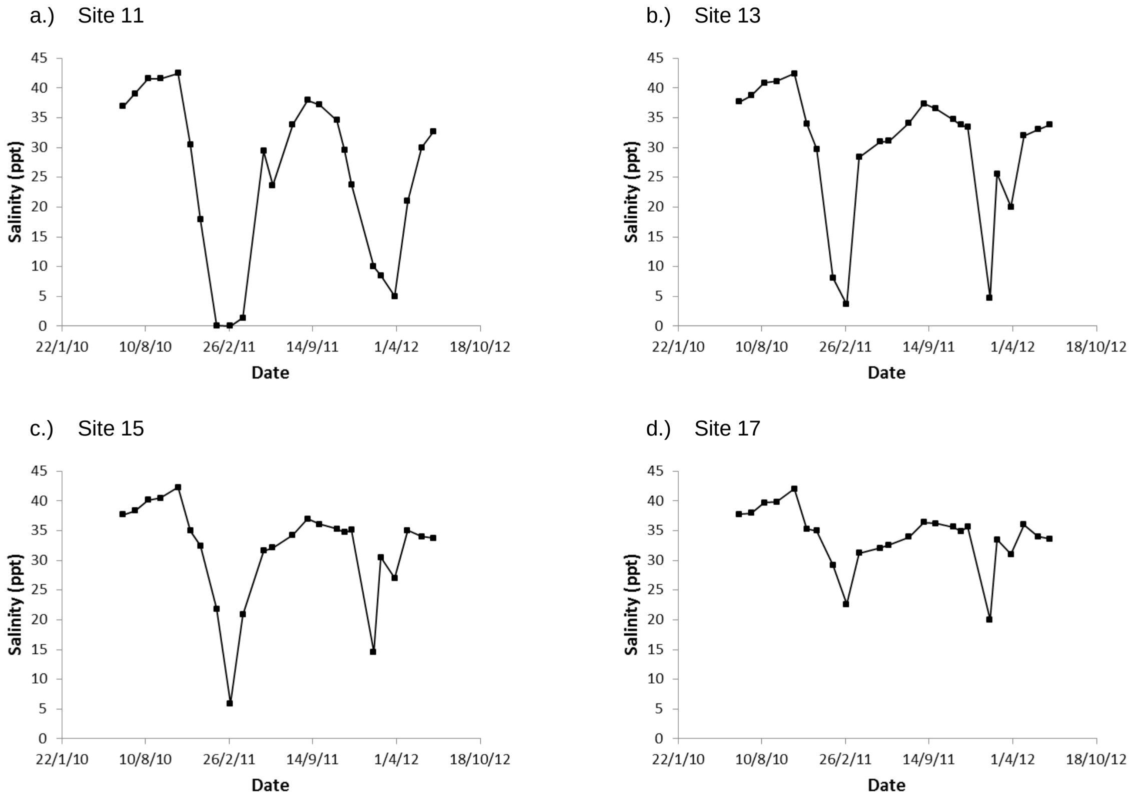

Figure A4. Temporal variation in salinity (ppt) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

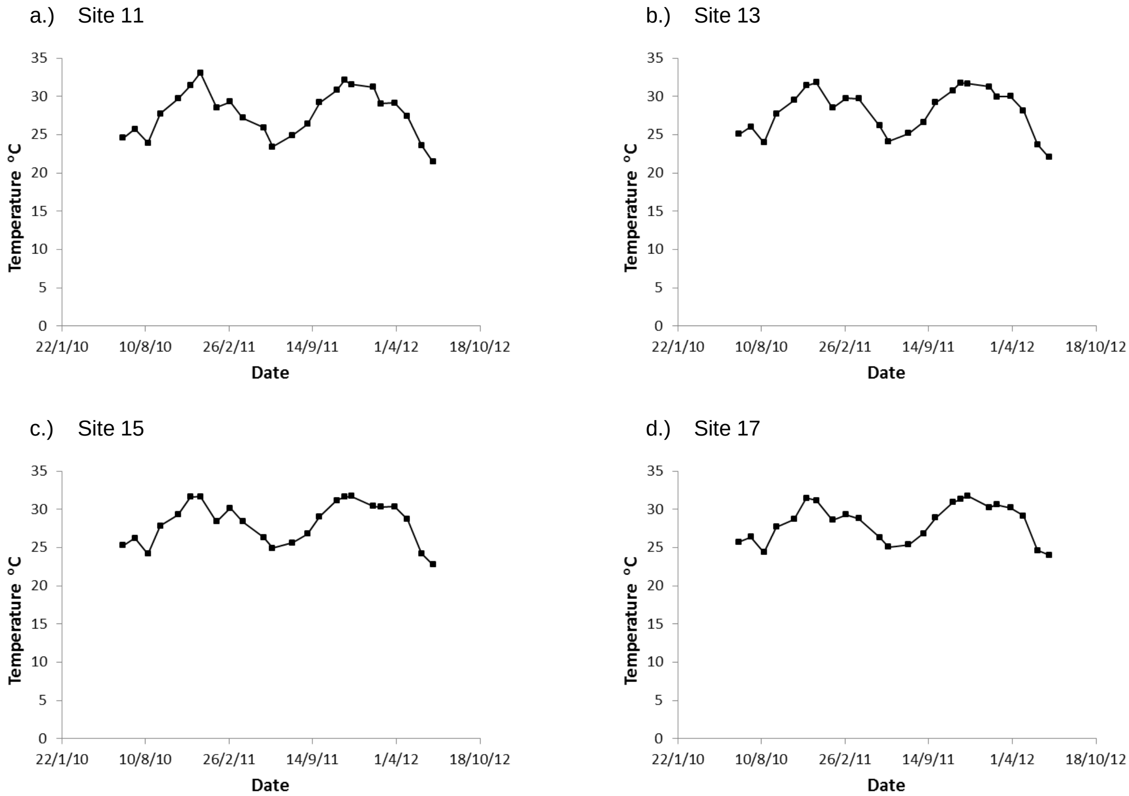

Figure A5. Temporal variation in temperature (°C) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

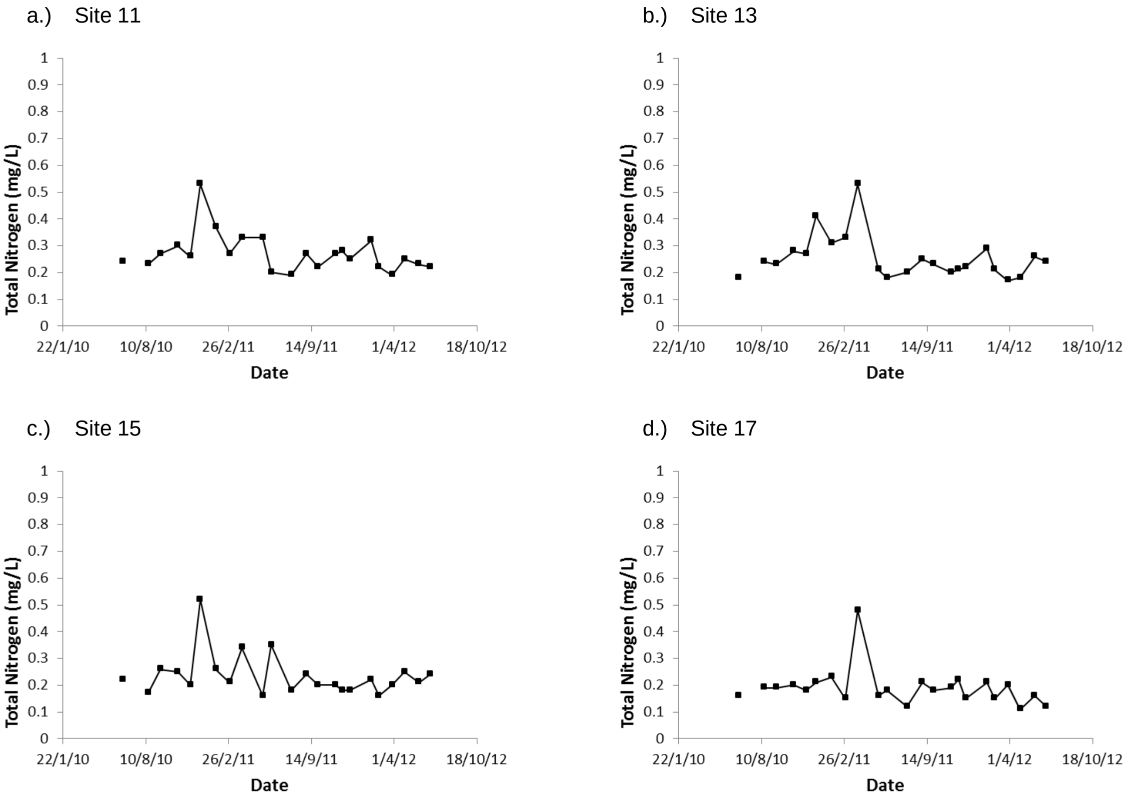

Figure A6. Temporal variation in total nitrogen (mg/L) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

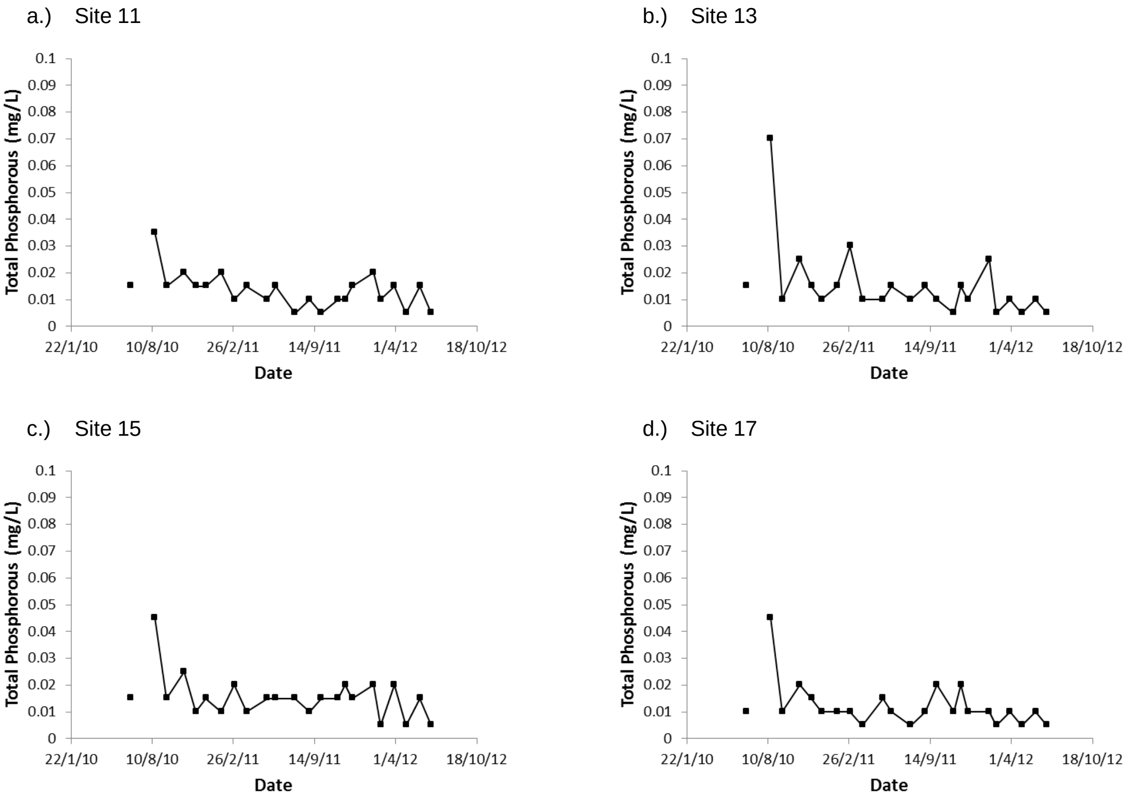

Figure A7. Temporal variation in total phosphorous (mg/L) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

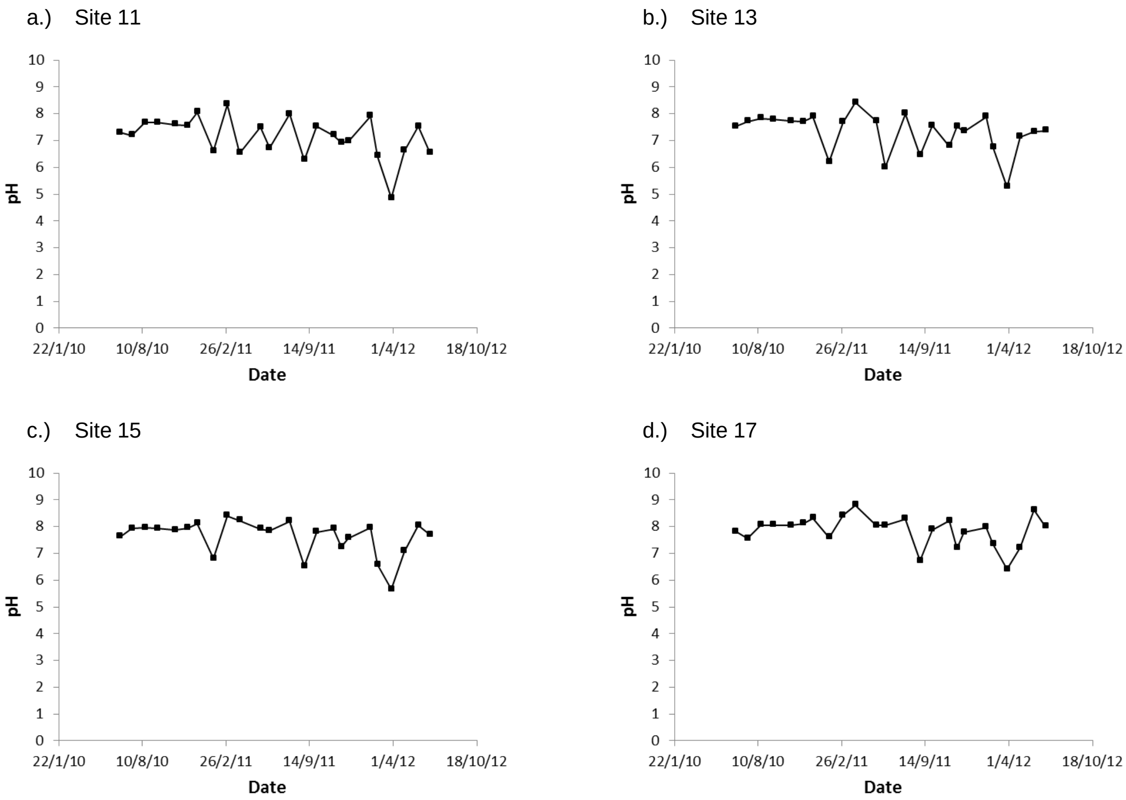

Figure A8. Temporal variation in pH at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

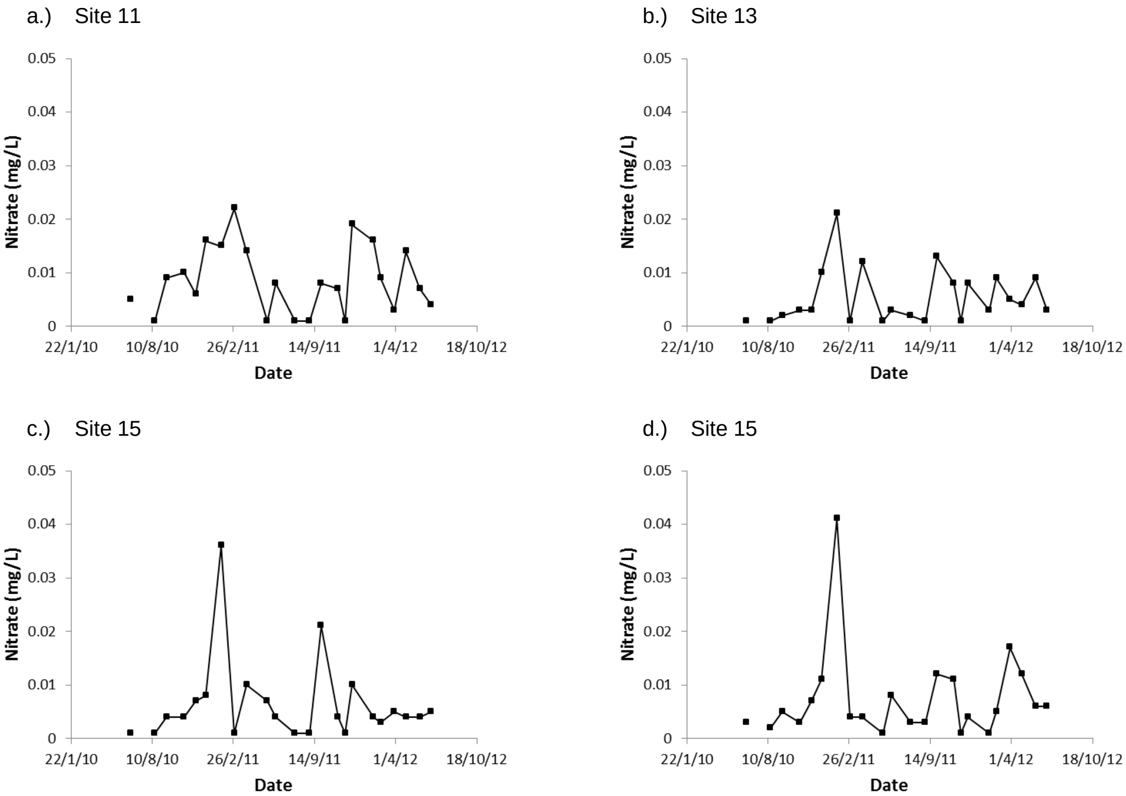

Figure A9. Temporal variation in nitrate (mg/L) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

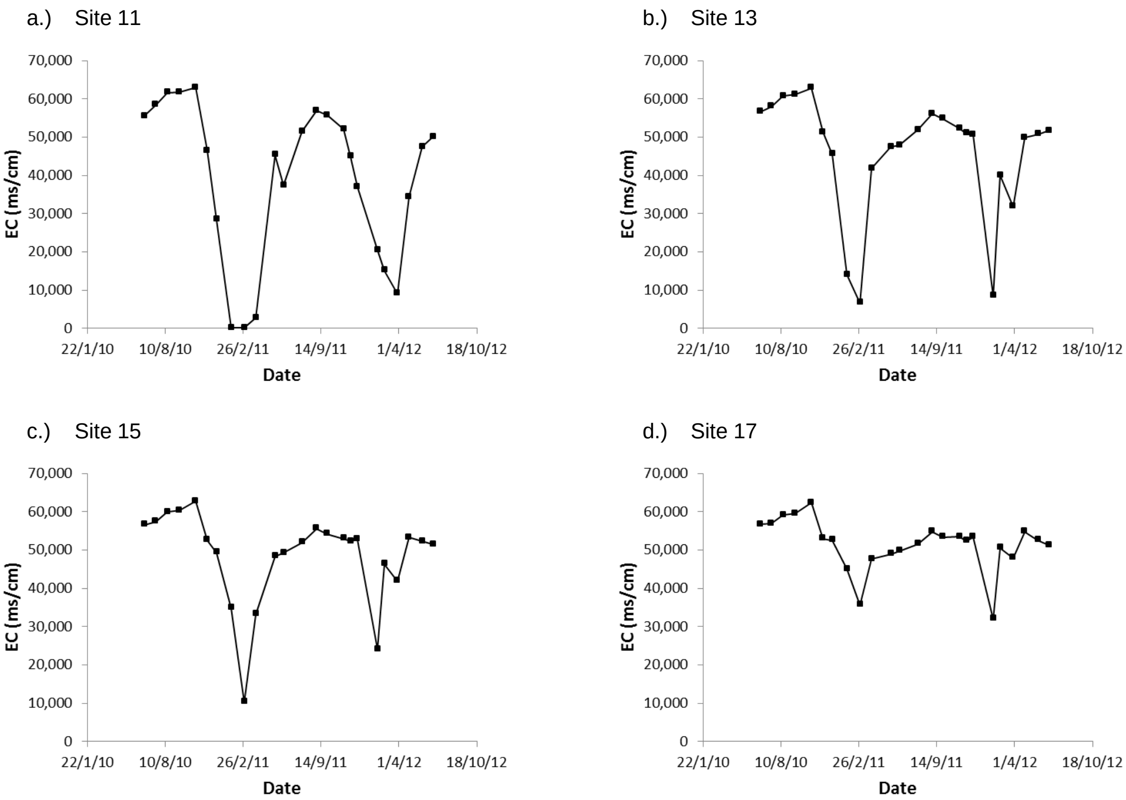

Figure A10. Temporal variation in conductivity (µS/cm) at four sites in East Arm of Darwin Harbour from June 2010 to June 2012.

Appendix 6.2 Sampling dates, times and tidal conditions

Dates, times and tidal conditions of sampling events at four sites in East Arm from June 2010 to June 2012.

Date	Time	Site	Pred tide height (m)	High tide height (m)	High tide time	Height diff (m)	Time diff (mins)
17/6/10	10:11:00	11	6.94	7.08	9:43:00	0.14	-28
16/7/10	9:14:00	11	7.29	7.37	9:21:00	0.08	7
16/8/10	9:11:00	11	6.54	6.65	9:41:00	0.11	30
15/9/10	8:43:00	11	5.66	5.83	9:30:00	0.17	47
27/10/10	7:43:00	11	6.41	6.49	7:36:00	0.08	-7
26/11/10	8:40:00	11	6.09	6.3	8:03:00	0.21	-37
20/12/10	15:18:00	11	4.76	6.91	18:14:00	2.15	176
27/1/11	10:20:00	11	5.46	5.85	11:32:00	0.39	72
1/3/11	13:27:00	11	4.04	6.13	17:10:00	2.09	223
31/3/11	15:21:00	11	5.54	6.18	17:06:00	0.64	105
20/5/11	9:15:00	11	6.98	7.47	8:18:00	0.49	-57
10/6/11	10:51:00	11	5.69	6	12:03:00	0.31	72
28/7/11	15:23:00	11	5.08	5.12	16:05:00	0.04	42
2/9/11	9:06:00	11	7.19	7.41	8:25:00	0.22	-41
30/9/11	7:46:00	11	7.37	7.53	7:20:00	0.16	-26
11/11/11	8:23:00	11	4.4	6.38	5:46:00	1.98	-157
29/11/11	9:12:00	11	5.96	6.55	7:55:00	0.59	-77
16/12/11	9:15:00	11	5.98	6.05	9:00:00	0.07	-15
6/2/12	14:50:00	11	4.32	6.79	18:07:00	2.47	197
24/2/12	9:06:00	11	6.27	7.11	7:42:00	0.84	-84
28/3/12	9:41:00	11	6.57	6.67	9:23:00	0.1	-18
27/4/12	9:19:00	11	6.41	6.51	9:39:00	0.1	20
31/5/12	13:05:00	11	5.66	5.73	13:36:00	0.07	31
28/6/12	11:07:00	11	5.84	5.91	11:37:00	0.07	30

Appendix 6.2. (cont.) Sampling dates, times and tidal conditions

Dates, times and tidal conditions of sampling events at four sites in East Arm from June 2010 to June 2012.

Date	Time	Site	Pred tide height (m)	High tide height (m)	High tide time	Height diff (m)	Time diff (mins)
17/6/10	10:48:00	13	6.54	7.08	9:43:00	0.54	-65
16/7/10	9:20:00	13	7.28	7.37	9:21:00	0.09	1
16/8/10	9:30:00	13	6.57	6.65	9:41:00	0.08	11
15/9/10	9:02:00	13	5.77	5.83	9:30:00	0.06	28
27/10/10	7:54:00	13	6.42	6.49	7:36:00	0.07	-18
26/11/10	8:50:00	13	6.04	6.3	8:03:00	0.26	-47
20/12/10	14:02:00	13	3.13	6.91	18:14:00	3.78	252
27/1/11	10:05:00	13	5.34	5.85	11:32:00	0.51	87
1/3/11	12:53:00	13	3.59	6.13	17:10:00	2.54	257
31/3/11	15:12:00	13	5.44	6.18	17:06:00	0.74	114
20/5/11	9:31:00	13	6.68	7.47	8:18:00	0.79	-73
10/6/11	11:11:00	13	5.81	6	12:03:00	0.19	52
28/7/11	14:50:00	13	4.85	5.12	16:05:00	0.27	75
2/9/11	9:30:00	13	6.82	7.41	8:25:00	0.59	-65
30/9/11	7:58:00	13	7.34	7.53	7:20:00	0.19	-38
11/11/11	8:36:00	13	4.12	6.38	5:46:00	2.26	-170
29/11/11	9:23:00	13	5.77	6.55	7:55:00	0.78	-88
16/12/11	9:27:00	13	5.92	6.05	9:00:00	0.13	-27
6/2/12	14:30:00	13	3.91	6.79	18:07:00	2.88	217
24/2/12	9:19:00	13	5.96	7.11	7:42:00	1.15	-97
28/3/12	9:54:00	13	6.55	6.67	9:23:00	0.12	-31
27/4/12	9:38:00	13	6.44	6.51	9:39:00	0.07	1
31/5/12	13:14:00	13	5.67	5.73	13:36:00	0.06	22
28/6/12	10:57:00	13	5.81	5.91	11:37:00	0.1	40

Appendix 6.2. (cont.) Sampling dates, times and tidal conditions

Dates, times and tidal conditions of sampling events at four sites in East Arm from June 2010 to June 2012.

Date	Time	Site	Pred tide height (m)	High tide height (m)	High tide time	Height diff (m)	Time diff (mins)
17/6/10	11:37:00	15	5.63	7.08	9:43:00	1.45	-114
16/7/10	9:47:00	15	7.22	7.37	9:21:00	0.15	-26
16/8/10	10:10:00	15	6.52	6.65	9:41:00	0.13	-29
15/9/10	9:17:00	15	5.77	5.83	9:30:00	0.06	13
27/10/10	8:07:00	15	6.36	6.49	7:36:00	0.13	-31
26/11/10	9:00:00	15	5.99	6.3	8:03:00	0.31	-57
20/12/10	13:50:00	15	2.88	6.91	18:14:00	4.03	264
27/1/11	9:55:00	15	5.23	5.85	11:32:00	0.62	97
1/3/11	12:30:00	15	3.32	6.13	17:10:00	2.81	280
31/3/11	15:00:00	15	5.33	6.18	17:06:00	0.85	126
20/5/11	9:42:00	15	6.5	7.47	8:18:00	0.97	-84
10/6/11	11:27:00	15	5.87	6	12:03:00	0.13	36
28/7/11	14:28:00	15	4.7	5.12	16:05:00	0.42	97
2/9/11	9:44:00	15	6.6	7.41	8:25:00	0.81	-79
30/9/11	8:12:00	15	7.13	7.53	7:20:00	0.4	-52
11/11/11	8:57:00	15	3.64	6.38	5:46:00	2.74	-191
29/11/11	9:36:00	15	5.56	6.55	7:55:00	0.99	-101
16/12/11	9:39:00	15	5.87	6.05	9:00:00	0.18	-39
6/2/12	14:16:00	15	3.62	6.79	18:07:00	3.17	231
24/2/12	9:30:00	15	5.68	7.11	7:42:00	1.43	-108
28/3/12	10:08:00	15	6.44	6.67	9:23:00	0.23	-45
27/4/12	9:59:00	15	6.47	6.51	9:39:00	0.04	-20
31/5/12	13:27:00	15	5.68	5.73	13:36:00	0.05	9
28/6/12	10:42:00	15	5.71	5.91	11:37:00	0.2	55

Appendix 6.2. (cont.) Sampling dates, times and tidal conditions

Dates, times and tidal conditions of sampling events at four sites in East Arm from June 2010 to June 2012.

Date	Time	Site	Pred tide height (m)	High tide height (m)	High tide time	Height diff (m)	Time diff (mins)
17/6/10	12:28:00	17	4.54	7.08	9:43:00	2.54	-165
16/7/10	10:35:00	17	6.58	7.37	9:21:00	0.79	-74
16/8/10	11:39:00	17	5.34	6.65	9:41:00	1.31	-118
15/9/10	10:04:00	17	5.75	5.83	9:30:00	0.08	-34
27/10/10	8:44:00	17	5.97	6.49	7:36:00	0.52	-68
26/11/10	9:25:00	17	5.62	6.3	8:03:00	0.68	-82
20/12/10	13:32:00	17	2.56	6.91	18:14:00	4.35	282
27/1/11	9:35:00	17	4.96	5.85	11:32:00	0.89	117
1/3/11	14:42:00	17	5.05	6.13	17:10:00	1.08	148
31/3/11	14:42:00	17	5.09	6.18	17:06:00	1.09	144
20/5/11	9:56:00	17	6.24	7.47	8:18:00	1.23	-98
10/6/11	11:44:00	17	5.94	6	12:03:00	0.06	19
28/7/11	14:11:00	17	4.58	5.12	16:05:00	0.54	114
2/9/11	9:58:00	17	6.4	7.41	8:25:00	1.01	-93
30/9/11	7:21:00	17	7.43	7.53	7:20:00	0.1	-1
11/11/11	9:07:00	17	3.44	6.38	5:46:00	2.94	-201
29/11/11	9:50:00	17	5.32	6.55	7:55:00	1.23	-115
16/12/11	9:56:00	17	5.79	6.05	9:00:00	0.26	-56
6/2/12	13:53:00	17	3.18	6.79	18:07:00	3.61	254
24/2/12	9:44:00	17	5.33	7.11	7:42:00	1.78	-122
28/3/12	10:23:00	17	6.23	6.67	9:23:00	0.44	-60
27/4/12	10:18:00	17	6.31	6.51	9:39:00	0.2	-39
31/5/12	13:43:00	17	5.69	5.73	13:36:00	0.04	-7
28/6/12	10:23:00	17	5.59	5.91	11:37:00	0.32	74

Appendix 6.3. Nutrient and chlorophyll data

Nutrient (mg/L) and chlorophyll (µg/L) concentrations in water samples from 4 sites in East Arm, Darwin Harbour.

Site	Date	Total N (mg/L)	TKN (mg/L)	NO_3_N (mg/L)	NO_2_N (mg/L)	NH_4_N (mg/L)	Total P (mg/L)	FRP (mg/L)	Chl-a (µg/L)
11	17/6/10	0.24	0.22	0.005	0.002	0.043	0.015	0.003	0.965
11	16/7/10								
11	16/8/10	0.23	0.1	<0.001	0.002	0.002	0.035	0.002	0.649
11	15/9/10	0.27	0.24	0.009	<0.001	0.027	0.015	0.001	1.258
11	27/10/10	0.3	0.28	0.01	<0.001	0.019	0.02	0.002	1.342
11	26/11/10	0.26	0.19	0.006	0.001	0.018	0.015	0.004	1.697
11	20/12/10	0.53	0.4	0.016	0.004		0.015	0.005	1.981
11	27/1/11	0.37	0.33	0.015	0.009	0.003	0.02	0.003	0.207
11	1/3/11	0.27	0.27	0.022	0.004	0.014	0.01	0.002	0.004
11	31/3/11	0.33		0.014	0.004	0.008	0.015	0.002	0.165
11	20/5/11	0.33		0.001	<0.001	0.011	0.01	<0.001	0.238
11	10/6/11	0.2		0.008	0.007	0.008	0.015	0.003	2.191
11	28/7/11	0.19		<0.001	<0.001	0.012	0.005	0.001	0.791
11	2/9/11	0.27	0.27	<0.001	<0.001		0.01	0.002	0.539
11	30/9/11	0.22		0.008	0.009	0.012	<0.005	0.002	0.901
11	11/11/11	0.27		0.007	<0.001	0.017	0.01	<0.001	0.98
11	29/11/11	0.28		<0.001	0.003	0.01	0.01	<0.001	3.782
11	16/12/11	0.25		0.019	0.001	0.019	0.015	0.002	1.109
11	6/2/12	0.32		0.016	0.002		0.02	0.004	0.484
11	24/2/12	0.22		0.009	0.009	0.023	0.01	0.003	0.677
11	28/3/12	0.19		0.003	0.002		0.015	0.004	1.497
11	27/4/12	0.25		0.014	<0.001	0.019	<0.005	<0.001	1.144
11	31/5/12	0.23		0.007	0.017	0.014	0.015	0.002	1.036
11	28/6/12	0.22		0.004	0.001	0.01	<0.005	0.001	0.479

Appendix 6.3. (cont.) Nutrient and chlorophyll data

Nutrient (mg/L) and chlorophyll (µg/L) concentrations in water samples from 4 sites in East Arm, Darwin Harbour.

Site	Date	Total N (mg/L)	TKN (mg/L)	NO_3_N (mg/L)	NO_2_N (mg/L)	NH_4_N (mg/L)	Total P (mg/L)	FRP (mg/L)	Chl-a (µg/L)
13	17/6/10	0.18	0.15	<0.001	0.003	0.038	0.015	0.005	1.303
13	16/7/10								
13	16/8/10	0.24	0.15	<0.001	0.001	0.005	0.07	0.004	0.749
13	15/9/10	0.23	0.22	0.002	<0.001	0.026	0.01	0.002	1.119
13	27/10/10	0.28	0.26	0.003	<0.001	0.016	0.025	0.005	1.271
13	26/11/10	0.27	0.03	0.003	<0.001	0.012	0.015	0.005	1.626
13	20/12/10	0.41	0.22	0.01	0.002		0.01	0.003	1.697
13	27/1/11	0.31	0.28	0.021	0.011	0.005	0.015	0.004	1.91
13	1/3/11	0.33	0.32	0.001	0.001	0.013	0.03	0.004	14.058
13	31/3/11	0.53		0.012	0.015	0.011	0.01	0.002	3.222
13	20/5/11	0.21		<0.001	0.001	0.01	0.01	<0.001	0.173
13	10/6/11	0.18		0.003	<0.001	<0.001	0.015	0.004	1.277
13	28/7/11	0.2		0.002	<0.001	0.017	0.01	<0.001	0.741
13	2/9/11	0.25	0.24	<0.001	<0.001		0.015	0.002	1.042
13	30/9/11	0.23		0.013	0.016	0.012	0.01	0.004	0.901
13	11/11/11	0.2		0.008	<0.001	0.011	0.005	<0.001	1.27
13	29/11/11	0.21		<0.001	0.003	0.007	0.015	<0.001	3.396
13	16/12/11	0.22		0.008	<0.001	0.017	0.01	<0.001	1.397
13	6/2/12	0.29		0.003	<0.001		0.025	0.004	6.345
13	24/2/12	0.21		0.009	0.006	0.018	<0.005	0.003	1.109
13	28/3/12	0.17		0.005	0.007		0.01	0.003	3.203
13	27/4/12	0.18		0.004	<0.001	0.019	<0.005	<0.001	1.027
13	31/5/12	0.26		0.009	0.011	0.013	0.01	0.001	0.851
13	28/6/12	0.24		0.003	0.001	0.01	0.005	0.001	0.619

Appendix 6.3. (cont.) Nutrient and chlorophyll data

Nutrient (mg/L) and chlorophyll (µg/L) concentrations in water samples from 4 sites in East Arm, Darwin Harbour.

Site	Date	Total N (mg/L)	TKN (mg/L)	NO_3_N (mg/L)	NO_2_N (mg/L)	NH_4_N (mg/L)	Total P (mg/L)	FRP (mg/L)	Chl-a (µg/L)
15	17/6/10	0.22	0.2	0.001	0.002	0.043	0.015	0.006	1.4
15	16/7/10								
15	16/8/10	0.17	0.15	<0.001	0.001	0.002	0.045	0.005	0.55
15	15/9/10	0.26	0.26	0.004	0.001	0.024	0.015	0.005	1.258
15	27/10/10	0.25	0.22	0.004	<0.001	0.017	0.025	0.008	1.626
15	26/11/10	0.2	0.02	0.007	<0.001	0.012	0.01	0.008	1.697
15	20/12/10	0.52	0.36	0.008	0.001		0.015	0.003	1.626
15	27/1/11	0.26	0.18	0.036	0.014	0.009	0.01	0.011	0.846
15	1/3/11	0.21	0.16	0.001	0.001	0.017	0.02	0.001	3.866
15	31/3/11	0.34		0.01	0.01	0.006	0.01	0.002	4.402
15	20/5/11	0.16		0.007	0.001	0.011	0.015	0.001	0.141
15	10/6/11	0.35		0.004	0.001	<0.001	0.015	0.01	1.384
15	28/7/11	0.18		<0.001	<0.001	0.012	0.015	0.002	0.492
15	2/9/11	0.24	0.24	0.001	0.003		0.01	0.004	0.841
15	30/9/11	0.2		0.021	0.005	0.01	0.015	0.004	0.952
15	11/11/11	0.2		0.004	<0.001	0.011	0.015	<0.001	1.318
15	29/11/11	0.18		0.001	0.004	0.008	0.02	<0.001	2.768
15	16/12/11	0.18		0.01	<0.001	0.015	0.015	0.002	0.917
15	6/2/12	0.22		0.004	<0.001		0.02	0.001	8.074
15	24/2/12	0.16		0.003	0.006	0.015	<0.005	0.002	1.493
15	28/3/12	0.2		0.005	0.009		0.02	0.002	2.967
15	27/4/12	0.25		0.004	<0.001	0.02	<0.005	<0.001	1.144
15	31/5/12	0.21		0.004	0.01	0.01	0.015	<0.001	1.036
15	28/6/12	0.24		0.005	0.005	0.01	0.005	0.001	1.408

Appendix 6.3. (cont.) Nutrient and chlorophyll data

Nutrient (mg/L) and chlorophyll (µg/L) concentrations in water samples from 4 sites in East Arm, Darwin Harbour.

Site	Date	Total N (mg/L)	TKN (mg/L)	NO_3_N (mg/L)	NO_2_N (mg/L)	NH_4_N (mg/L)	Total P (mg/L)	FRP (mg/L)	Chl-a (µg/L)
17	17/6/10	0.16	0.13	0.003	0.001	0.043	0.01	0.005	1.014
17	16/7/10								
17	16/8/10	0.19	0.15	0.002	0.001	0.002	0.045	0.004	0.302
17	15/9/10	0.19	0.14	0.005	0.001	0.028	0.01	0.004	0.702
17	27/10/10	0.2	0.17	0.003	<0.001	0.02	0.02	0.007	0.775
17	26/11/10	0.18	0.14	0.007	<0.001	0.012	0.015	0.008	0.704
17	20/12/10	0.21	0.04	0.011	0.002		0.01	0.005	2.974
17	27/1/11	0.23	0.14	0.041	0.017	0.012	0.01	0.011	0.704
17	1/3/11	0.15	0.12	0.004	0.001	0.015	0.01	0.002	0.916
17	31/3/11	0.48		0.004	0.007	0.007	0.005	0.003	0.755
17	20/5/11	0.16		<0.001	<0.001	0.008	0.015	0.004	0.254
17	10/6/11	0.18		0.008	0.002	0.008	0.01	0.009	0.793
17	28/7/11	0.12		0.003	<0.001	0.012	0.005	0.002	0.392
17	2/9/11	0.21	0.18	0.003	0.005		0.01	0.002	0.438
17	30/9/11	0.18		0.012	0.01	0.01	0.02	0.005	1.416
17	11/11/11	0.19		0.011	<0.001	0.017	0.01	0.002	0.932
17	29/11/11	0.22		<0.001	0.005	0.009	0.02	0.001	1.753
17	16/12/11	0.15		0.004	0.002	0.016	0.01	0.003	0.58
17	6/2/12	0.21		0.001	<0.001		0.01	<0.001	1.877
17	24/2/12	0.15		0.005	0.002	0.013	<0.005	0.001	1.157
17	28/3/12	0.2		0.017	0.01		0.01	0.006	0.909
17	27/4/12	0.11		0.012	<0.001	0.019	<0.005	<0.001	0.556
17	31/5/12	0.16		0.006	0.01	0.007	0.01	0.002	0.247
17	28/6/12	0.12		0.006	<0.001	0.011	<0.005	<0.001	0.201

Appendix 6.4. Physico-chemical data

Physico-chemical data for water samples at four sites in East Arm, Darwin Harbour.

Site	Date	Depth (m)	DO (mg/L)	DO%	EC (µS/cm)	pH	Salinity	Temp (°C)	TSS (mg/L)	VSS (mg/L)	Turb (NTU)
11	17/6/10		4.74	52.8	55485	7.3	36.88	24.57	16	4	
11	16/7/10	4.8	5.21	60.4	58400	7.19	39.02	25.73	24	6	3.82
11	16/8/10	2.4	4.87	54.7	61670	7.67	41.55	23.91	21	7	2.5
11	15/9/10	1.7	4.2	50.3	61766	7.67	41.56	27.75	1.9	<1	2.77
11	27/10/10	2.3	4.45	55.6	62906	7.59	42.43	29.71	5	<1	3.35
11	26/11/10	2.6	2.96	48.3	46400	7.55	30.4	31.4	9.8	1.5	4.6
11	20/12/10	0.9	5.75	89.3	28400	8.06	17.85	33.09	13	2.5	6.92
11	27/1/11	2.2	7.5	98.6	125	6.6	0.07	28.57	8.5	3	11.1
11	1/3/11	2.9			106	8.35	0.05	29.29	5.5	3	9.4
11	31/3/11	2.1	7.37	94.4	2760	6.53	1.4	27.19	4.7	3.3	9.34
11	20/5/11	2.9	6.01	65.8	45289	7.49	29.37	25.92	6	2.5	5.7
11	10/6/11	1.5	5.63	75	37400	6.72	23.63	23.4	3	1	3.15
11	28/7/11	2.9	5.91	88.3	51500	7.99	33.83	24.95	4	2	2.37
11	2/9/11	4	4.15	63.9	56900	6.27	37.93	26.36	6.5	<5	3.66
11	30/9/11	4	4.29	70.1	55700	7.52	37.19	29.19	7.5	<5	
11	11/11/11	2.4	3.32	54.3	52100	7.2	34.57	30.81	<5	<5	2.17
11	29/11/11	3	3.9	64.2	44900	6.92	29.52	32.12	16.5	<5	
11	16/12/11	2.1	4.21	61.8	37000	6.97	23.74	31.56	7	7	
11	6/2/12	2	6.86	94.4	20500	7.91	10	31.19	<5	<5	6.3
11	24/2/12	4.4	4.93	68.7	15100	6.42	8.5	29.06			
11	28/3/12	4.7	5.14	70.3	9060	4.85	5	29.13	5	<5	
11	27/4/12	4.2	4.53	66.2	34400	6.62	21	27.4	12	<5	
11	31/5/12	1.3	4.57	65.7	47400	7.52	30	23.62	18	5.5	
11	28/6/12	3.5	6.24	86.4	50100	6.55	32.62	21.46	5	<5	

Appendix 6.4. (cont.) Physico-chemical data

Physico-chemical data for water samples at four sites in East Arm, Darwin Harbour.

Site	Date	Depth (m)	DO (mg/L)	DO%	EC (µS/cm)	pH	Salinity	Temp (°C)	TSS (mg/L)	VSS (mg/L)	Turb (NTU)
13	17/6/10		5.07	57.2	56556	7.52	37.68	25.09	18	4	
13	16/7/10	6.7	5.3	63	58000	7.71	38.74	26.01	28	7	5.19
13	16/8/10	5.8	4.9	54.9	60722	7.82	40.82	23.95	23	7	3.3
13	15/9/10	4.8	4.22	50.3	61120	7.78	41.09	27.75	9.6	1.6	2.2
13	27/10/10	5.6	4.63	57.5	62867	7.72	42.41	29.52	2.8	<1	3.62
13	26/11/10	5.3	3.3	55.2	51300	7.7	34	31.4	14	2.8	5.6
13	20/12/10	2.8	3.67	60	45500	7.88	29.73	31.84	7.4	1.7	4.78
13	27/1/11	4.5	6.8	90.4	14000	6.2	8.14	28.5	9	1.5	6.9
13	1/3/11	3.5			6720	7.68	3.65	29.77	17	7	9.78
13	31/3/11	4.5	4.54	72.3	41800	8.41	28.34	29.7	6	2	4.17
13	20/5/11	6.2	5.67	63.9	47439	7.72	30.92	26.19	22	6.5	7.27
13	10/6/11	4.8	6.82	90.6	47800	6	31.07	24.11	7.5	2.5	2.62
13	28/7/11	4.6	5.77	87.5	51900	8	34.13	25.17	9	3	
13	2/9/11	6.7	4.28	65.8	56100	6.44	37.34	26.62	14	8.5	3.07
13	30/9/11	7.2	4.48	73.8	54800	7.55	36.51	29.19	7.5	<5	
13	11/11/11	4.3	3.39	53.2	52300	6.79	34.72	30.78	<5	<5	3.17
13	29/11/11	5.8	4.04	67.4	51000	7.53	33.79	31.75	26	<5	
13	16/12/11	5.9	3.91	65.8	50600	7.34	33.42	31.66	11.5	5.5	
13	6/2/12	3.8	6.86	97.3	8530	7.88	4.78	31.26	26	20	9.9
13	24/2/12	6.1	3.9	60.9	40000	6.73	25.61	29.94			
13	28/3/12	5.5	4.26	65.1	31800	5.27	20	30.03	16	5	
13	27/4/12	6.5	5.42	78.3	49900	7.14	32	28.14	23.5	6.5	
13	31/5/12	5	4.97	72.9	50800	7.33	33	23.74	18	6.5	
13	28/6/12	5.5	6.26	87.5	51700	7.36	33.82	22.05	<5	<5	

Appendix 6.4. (cont.) Physico-chemical data

Physico-chemical data for water samples at four sites in East Arm, Darwin Harbour.

Site	Date	Depth (m)	DO (mg/L)	DO%	EC (µS/cm)	pH	Salinity	Temp (°C)	TSS (mg/L)	VSS (mg/L)	Turb (NTU)
15	17/6/10		5.28	59.8	56589	7.62	37.7	25.28	20	3	
15	16/7/10	8.2	5.87	68.3	57400	7.92	38.3	26.23	21	6	9.77
15	16/8/10	7.5	5.24	58.7	59908	7.95	40.16	24.18	16	4	3.1
15	15/9/10	6.7	4.61	54.8	60279	7.92	40.46	27.83	6	<1	2.42
15	27/10/10	7.1	5.13	63.4	62686	7.87	42.26	29.29	3.2	1	3.41
15	26/11/10	6.5	3.7	63.5	52600	7.94	34.98	31.6	11	2.5	5.7
15	20/12/10	3.5	4.37	74.4	49300	8.11	32.45	31.65	11	3.1	10.7
15	27/1/11	6	6.5	93.5	34900	6.8	21.8	28.4	10	2	4.9
15	1/3/11	4.7			10280	8.4	5.94	30.16	18	5.5	8.7
15	31/3/11	5.9	6.04	89.5	33300	8.23	20.85	28.4	4.5	2.5	5.35
15	20/5/11	7.3	6.22	70.5	48354	7.91	31.62	26.33	21	4.5	9.78
15	10/6/11	6.6	6.46	95	49200	7.84	32.13	24.91	11	2.5	3.09
15	28/7/11	6.7	6.23	95	52000	8.2	34.23	25.62	3	2.5	
15	2/9/11	8.3	4.48	69.6	55600	6.52	36.98	26.78	17	5	2.98
15	30/9/11	9.6	5.08	81.9	54200	7.8	36.05	29.07	7	<5	
15	11/11/11		4.29	71.8	53000	7.91	35.26	31.15	6	<5	2.31
15	29/11/11	7	4.66	76.8	52300	7.24	34.68	31.6	27	5	
15	16/12/11	7	4.71	79.2	52800	7.57	35.06	31.74	11	<5	
15	6/2/12	7.2	6.69	97.8	24100	7.96	14.56	30.4	<5	<5	6.5
15	24/2/12	7.7	4.49	71.8	46300	6.58	30.47	30.31			
15	28/3/12	8	4.91	79.1	41900	5.65	27	30.37	15.5	<5	
15	27/4/12	8	5.65	90.6	53300	7.08	35	28.68	25	5.5	
15	31/5/12	6.4	5.74	85	52300	8.04	34	24.24	19	5.5	
15	28/6/12	8.3	6.67	94.9	51500	7.7	33.71	22.74	<5	<5	

Appendix 6.4. (cont.) Physico-chemical data

Physico-chemical data for water samples at four sites in East Arm, Darwin Harbour.

Site	Date	Depth (m)	DO (mg/L)	DO%	EC (µS/cm)	pH	Salinity	Temp (°C)	TSS (mg/L)	VSS (mg/L)	Turb (NTU)
17	17/6/10		5.84	66.5	56677	7.81	37.77	25.71	12	3	
17	16/7/10	12.8	6.47	76.4	56900	7.55	37.93	26.38	10	6	6.73
17	16/8/10	11.1	5.54	61.8	59141	8.06	39.65	24.37	19	2	3.3
17	15/9/10	10.3	5.04	59.6	59462	8.05	39.81	27.71	3.8	<1	3.67
17	27/10/10	11.2	6.02	73.8	62360	8.04	42.04	28.7	4	<1	3.68
17	26/11/10	11.8	4.65	77.2	53000	8.12	35.27	31.45	8	2	5.09
17	20/12/10	7.4	4.59	76.4	52600	8.31	34.96	31.16	7.7	1.3	4.35
17	27/1/11	8	7.1	107.3	45000	7.6	29.2	28.6	9	2.5	8.2
17	1/3/11	10.8			35700	8.42	22.62	29.29	41	7	1.69
17	31/3/11	10.3	6.37	100.8	47600	8.81	31.22	28.81	2.5	1.5	4.7
17	20/5/11	10.1	6.66	75.7	48979	8.04	32.07	26.33	29	8.5	13.9
17	10/6/11	10.5	6.82	100.3	49800	8.04	32.58	25.09	14	<1	3
17	28/7/11	10.3	6.81	102.5	51600	8.29	33.92	25.37	8	3	1.2
17	2/9/11	12.9	4.67	73.1	54800	6.72	36.38	26.84	11	5.5	2.98
17	30/9/11	13.2	5.67	91	53400	7.89	36.21	28.89	25.5	<5	
17	11/11/11	8.4	4.96	82.9	53500	8.22	35.62	30.9	8	<5	3.02
17	29/11/11	10	5.1	83.9	52400	7.2	34.89	31.33	15	<5	
17	16/12/11	12	5.38	90.6	53400	7.79	35.59	31.75	5.5	5	
17	6/2/12	9.5	6.77	103.2	32000	7.97	19.99	30.28	<5	<5	1.6
17	24/2/12	11.4	5.26	86.6	50600	7.34	33.44	30.63			
17	28/3/12	14	5.23	85	47900	6.41	31	30.23	6.5	<5	
17	27/4/12	10.4	6.31	100.5	54800	7.21	36	29.17	9	<5	
17	31/5/12	10.1	5.84	88	52600	8.62	34	24.61	7	<5	
17	28/6/12	12.9	6.96	100.4	51300	8	33.58	24.04	<5	<5	