DARWIN HARBOUR REGION 2015 REPORT CARD
WATER QUALITY SUPPLEMENT

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NORTHERN TERRITORY GOVERNMENT

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Cover: Insert 1: Sediment core collection (Julia Fortune), Insert 2: Seabird instrument retrieval (Ruth Patterson), Insert 3: Light trap deployment (Peter Dostine) and Insert 4: Water quality sampling (Ruth Patterson, Larrakia Rangers - Steven Dawson and Alena Talbot).

Acknowledgments

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We thank the many people who contributed photographs. Data in this report were obtained from projects funded by the Northern Territory Government and Power and Water Corporation. Also thanks to the Larrakia Nation Sea Ranger group who assisted with monitoring effort throughout the reporting year.

Symbols are courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Centre for Environmental Science, USA. Several conceptual symbols were adapted from base diagrams from the Integration and Application Network.

Reporting Zones

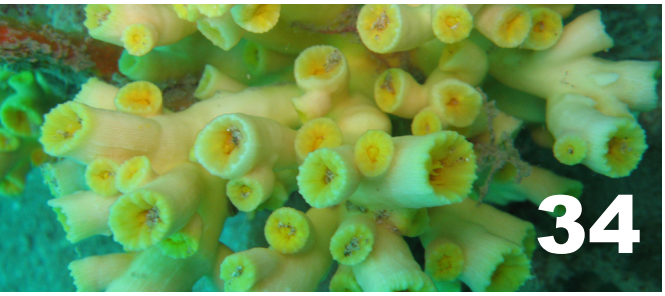
Middle Darwin Harbour

East Arm

Elizabeth River & Myrmidon Creek

Blackmore River

Shoal Bay & Buffalo Creek



Outer Harbour

West Arm

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1. Introduction

Water quality monitoring has been undertaken in Darwin Harbour by the Department of Land Resource Management (and its predecessor organisations) since 1987 (Wrigley et al. 1990). The water quality of the harbour has been summarised annually in the form of a Report Card since 2010. The 2015 grades are shown in Figure 1, and presented with the grades for previous years in Table 1.

This report supplements the 2015 Darwin Harbour Region Report Card by presenting supporting data and other information used to calculate the grades, as well as providing a more detailed analysis of Darwin Harbour water quality.

The 2015 grades indicate that water quality was good to excellent. Deviations from excellent water quality, indicative of Water Quality Objective (WQO) non-compliance, are likely to be natural and an artefact of the grading methodology and WQOs. An exception though is Buffalo Creek which has consistently poor water quality due mainly to the combined effects of effluent discharged from the Leanyer-Sanderson wastewater treatment plant, and poor flushing of the creek.

The Outer Harbour, Shoal Bay, Myrmidon Creek and Buffalo Creek had large variations in dissolved oxygen which were at times either higher or lower than the water quality objectives. These oxygen levels however were not harmful and were not persistent. Although median values did not exceed the WQO their exceedence indicates the typically applied benchmark may need to be revised to better take into account natural water quality variability.

The indicator of turbidity for the measure of water clarity was highly variable in the 2015 reporting year. Dry season winds were particularly notable and stimulated turbid eddies in the outer to middle harbour zones. These conditions influenced water clarity for a number of sites and are a reflection of natural variability rather than anthropogenic impact.

2. Darwin Harbour region

The Darwin Harbour region is located in the wet-dry tropics of northern Australia and extends from Gunn Point in the east, to Charles Point in the west. The climate consists of two seasons: the wet and the dry. The wet season occurs between November and April and is characterised by warm air temperatures, convective storms, monsoonal weather which brings heavy rain and strong north-westerly winds, and in some years cyclonic weather. The dry season occurs from May to October and is characterised by cooler air temperatures, south east winds and little or no rain.

The region has a population of over 130,000 people and covers over 3200 km² (65% terrestrial and 35% coastal and marine at high tide). Darwin Harbour is a large, macro-tidal estuary with semi-diurnal tides (two high tides and two low tides) and is characterised by strong tidal currents which result in extensive turbid plumes on outgoing tides.

Aquatic Health Unit staff and Larrakia Sea Rangers sampling on Darwin Harbour

Figure 1 – Reporting zone grades for Darwin Harbour region 2015.

Below is a table that shows water quality indicators for each region of the harbour, with a ✔indicating those that met the desired level (known formally as a Water Quality Objective) and a ✖ indicating those that were unsatisfactory.

Table 1 - Water quality evaluation for 2015 and historical grades.

	Harbour region								
Indicator	Outer Harbour			Inner Harbour				Tidal creeks	
	Outer Darwin Harbour	Shoal Bay	Middle Darwin Harbour	Blackmore	East Arm	Elizabeth	West Arm	Buffalo Creek	Myrmidon Creek
Water clarity	✖	✔	✔	✖	✖	✔	✖	✖	✖
Dissolved oxygen	✔	✔	✔	✔	✔	✔	✔	✖	✔
Algae	✔	✔	✔	✔	✔	✔	✔	✖	✔
Nutrients	✔	✔	✖	✔	✔	✖	✔	✖	✔
	Report Card grades								
2015	B	A	B	B	B	B	B	E	B
2014	B	B	A	A	B	A	A	D	C
2013	B	B	B	A	B	A	A	E	C
2012	B	B	A	A	A	A	A	E	C
2011	A	C	A	C	A	A	A	E	-
2010	A	C	B	B	A	A	A	E	C

Note: Natural variability influences the water quality of Darwin Harbour. The effect of strong seasonality and large tides can cause large natural variability. This is particularly notable for water clarity where wind driven turbulence during the dry season appeared to influence turbidity in some parts of the harbour.

3. Biological Indicators for freshwater systems.

Organisms living in streams and rivers can tell us about the condition or "health" of waterways. Diverse communities of macroinvertebrates (or water-bugs) indicate a stream in good condition, while simple communities of few water-bug types indicate a damaged or degraded stream. Annual monitoring of stream health is currently undertaken in Rapid Creek and uses an assessment system known as AUSRIVAS. This stands for Australian River Assessment System, and works by comparing water-bugs present in a stream with those expected to be present in reference streams of a similar type. AUSRIVAS produces a score based on the number of types found in a sample relative to the number of types expected. To simplify interpretation of these scores a banding system has been developed (Table 2). Band A means streams are equivalent to high quality reference steams; bands B, C, or D indicate that the stream is below reference condition and is degraded to varying degrees.

Table 2 - How to interpret bands from AUSRIVAS.

Band	Description	What it represents
X	More biologically diverse than reference	More types found than expected. Potential biodiversity "hot-spot" or mild organic enrichment.
A	Similar to reference	O/E scores range found at 80% of the reference sites, or equivalent to reference condition.
B	Significantly impaired	Potential impact either on water and/or habitat quality resulting in a loss of types.
C	Severely impaired	Many fewer types than expected. Loss of water and/or habitat quality.
D	Extremely impaired	Few of the expected types and only the hardy, pollution tolerant families remain.

3.1 Rapid Creek 2015

Two macroinvertebrate sites were sampled in 2015. These sites are in the upper reaches of the Rapid Creek system which is a small seasonally flowing coastal stream in the Darwin urban area. Results of the AUSRIVAS scores are described below in Table 3. These results are similar to previous years. The creek has an impoverished macroinvertebrate fauna which is to be expected for a stream with an urbanised catchment.

Table 3 - Rapid Creek AUSRIVAS Scores for 2015.

Site number	2013	2014	2015
RC182	B	C	B
RC142	B	B	B

Rapid Creek weir downstream of freshwater reach

4. Darwin Harbour water quality sites and sampling method

Darwin Harbour water quality data were collected from water samples and analysed in the laboratory, and by field measurements for the period of November 1st 2014 to 30th October 2015. Broad scale, ambient water quality monitoring was undertaken by the Aquatic Health Unit of the Department of Land Resource Management, whilst more spatially targeted monitoring was undertaken by the Power and Water Corporation as part of its wastewater discharge license. Data collection is biased towards the dry season, due to the often unsafe and difficult sea conditions present during the wet season. Tidal stage for each sampling event and reporting zone is presented in the Appendix.

At each site, surface water (approximately 0.25 m depth) was measured for pH, dissolved oxygen (%saturation), salinity and temperature using a multi-parameter probe. Turbidity was measured with a turbidity meter. Total Suspended Solids (TSS) was not used as an indicator of water clarity this reporting year with turbidity adopted as the key water clarity indicator. More detail on the current approach for turbidity as a measure of water clarity is explained in section 4.1 and 4.2.

Water samples were collected from the surface in plastic bottles then stored on ice in the field for the laboratory analysis of nutrients (nitrogen oxides (nitrate and nitrite), ammonia, total nitrogen, total phosphorus and filterable reactive phosphorus) and chlorophyll-a.

The number of sampled sites and number of samples is summarised in Table 4, and site location shown in Figure 2.

Table 4 - Sites and sample number for each reporting zone.

Indicators	Elizabeth River	Myrmidon Creek	Blackmore River	West Arm	East Arm	Middle Harbour	Outer Harbour	Shoal Bay	Buffalo Creek
Number of sites	18	5	30	18	10	10	9	12	4
Number of samples	88	54	143	58	92	36	18	33	44

Over 100 sites were monitored to inform the Report Card and over 500 samples taken throughout the reporting year of 2015. These monitoring locations represent major estuarine categories such as outer marine, mid estuary and upper estuary sections which include the many mangrove lined tidal creeks.

Figure 2 - Monitoring locations in Darwin Harbour.

4.1. Water quality parameters

The following water quality parameters were monitored to assess water quality in the Darwin Harbour region.

4.1.2. Parameters used in the Report Card

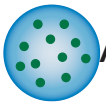
Dissolved oxygen.

Water contains small amounts of oxygen which is needed by animals. Storm water and industrial waste can lower the amount of the oxygen in the water to levels that could be harmful to aquatic animals. Chemical reactions and microbial activity that determine the amount and type of nutrients in the harbour are affected by low oxygen (hypoxia). Dissolved oxygen (DO) is measured as a concentration (mg/L). Oxygen saturation is the amount of oxygen compared to the amount water naturally holds when in equilibrium with the air (assuming no biological processes), expressed as percentage and varying with temperature and salinity. The amount of oxygen at 100% saturation decreases with temperature. The lower holding capacity of warm waters, as well as the higher microbial activity of warm temperatures that use oxygen, makes Darwin Harbour's waters vulnerable to low dissolved oxygen.

Water clarity.

Clear water allows sunlight to reach plants to grow, such as seagrass and algae (macroscopic and microscopic) that live on the seabed. Water clarity is affected by the tides, being clearest during neap tides and during the turn of the tides. Water clarity can also be affected by storm water, dredging activity and large amounts of algae.

To assess the water clarity, total suspended solids (TSS) has been previously used. Also known as total suspended sediment, this is a measure of the amount of particulates in the water column. TSS concentrations were estimated from turbidity using a TSS-turbidity relationship previously, however this year the report card has adopted turbidity as the prime indicator for water clarity.



Algae.

Algae are aquatic plants. Microscopic algae can gather together in colonies to be visible to the naked eye in either the water or on the sediments and other seabed substrates. Algae are a natural part of the ecosystem and provide food for large (e.g. mangrove snails) and small animals (zooplankton). However, when waters become polluted with nutrients, the amount of algae can be excessive and can adversely affect the marine ecosystem. The types of algae will also be affected by pollution. Sometimes though, large amounts of algae can occur naturally, such as the *Trichodesmium* blooms that occur during the "build-up" months.

To assess the quantity of algae, we measure chlorophyll-a (Chl a), a green pigment of aquatic plants, used in the process of photosynthesis.

Nutrients.

Nitrogen and phosphorus are plant nutrients. Pollution by nutrients can produce too much algae, and affect the ecosystem. The nutrients measured were nitrogen oxides (NO_x; nitrate and nitrite), ammonia, total nitrogen (TN), total phosphorus (TP) and filterable reactive phosphorus (FRP).

4.1.3. Complementary parameters

pH
This is a measure of the concentration of hydrogen ions and is an indicator of water alkalinity or acidity. Changes in pH affect metal solubility and toxicity, and an organism's ability to absorb minerals and nutrients, and respiratory efficiency of fish and aquatic invertebrates. Marine waters are normally alkaline.

Temperature
The water temperature is a significant measure as it affects other parameters such as the amount of oxygen dissolved in the water, the rate of photosynthesis of plants, and growth of aquatic organisms.

Salinity
Salinity is a measure of the total concentration of ions (mainly inorganic salts) in the water. Salinity affects aquatic organisms depending on their adaptability to a narrow or wide range of salinities. River inflows dilute marine waters to be less saline with concentration gradients consistent with a river-estuarine-marine continuum.

4.2 Water Quality Objectives and grade method

The Water Quality Objectives for Darwin Harbour recommend the water quality that supports the maintenance of the ecosystem, and are designated under Part 7 of the N.T. Water Act as a local guideline level in accordance with the National Water Quality Management Strategy and ANZECC guidelines (Fortune, 2010).

Water quality data for each Harbour reporting zone were compared with WQOs as benchmarks to evaluate water quality condition.

The Report Card grades were assessed with respect to the WQOs for Darwin Harbour. The median (50th percentile) was calculated for each Report Card water quality parameter, and compared against the WQOs shown in Table 5. If the median was less than the WQO, then the data complied with the WQO, and was assigned a green tick in the Report Card. However, if the median exceeded the WQO, then this was considered to be a departure, and may warrant investigation as to the cause of the exceedence. An exceedence can be caused by the natural variability of water quality and be unrelated to pollution. The Report Card marks this as a fail, symbolised by a red cross.

For the parameter of dissolved oxygen significant natural variation persists in Darwin Harbour in conjunction with both tidal and diurnal variation. To better accommodate this variation a lower (20th percentile) and upper (80th percentile) limit for the derivation of grades was used. Where data were observed not to meet at least one of the upper or lower limit this was deemed a failure.

The indicator of turbidity was used to assess water clarity rather than TSS. Turbidity is a responsive measure of water clarity efficiently measured in the field. A general threshold of 4 NTU was adopted for the report cards in 2015. This value was derived from the Darwin Harbour turbidity dataset whereby the frequency of turbidity values were examined in conjunction with the previous TSS-Turbidity relationship.

Only the filterable fraction of nutrients (NOx, Ammonia (NH3-N) and FRP) were assessed against the relevant guideline values for the harbour grades because total nutrient concentrations are affected by suspended solids. For a site to pass the nutrient parameter, all indicators must agree with the guideline value.

Table 5 – Darwin Harbour Water Quality Objectives.

Indicators		Upper Estuary	Mid Estuary	Outer Estuary
Dissolved Oxygen	Dissolved oxygen (% saturation)	80-100	80-100	80-100
Water clarity	Suspended solids (mg/L) or Turbidity (NTU)	<10 <4	<10 <4	<10 <4
Algae	Chlorophyll-a (µg/L)	<4	<2	<1
Nutrients	NOx_N (µg/L)	<20	<20	<10
	Ammonia as N (µg/L)	<20	<20	<20
	Filterable Reactive Phosphorus (µg/L)	<10	<5	<10

4.3 Water quality grades

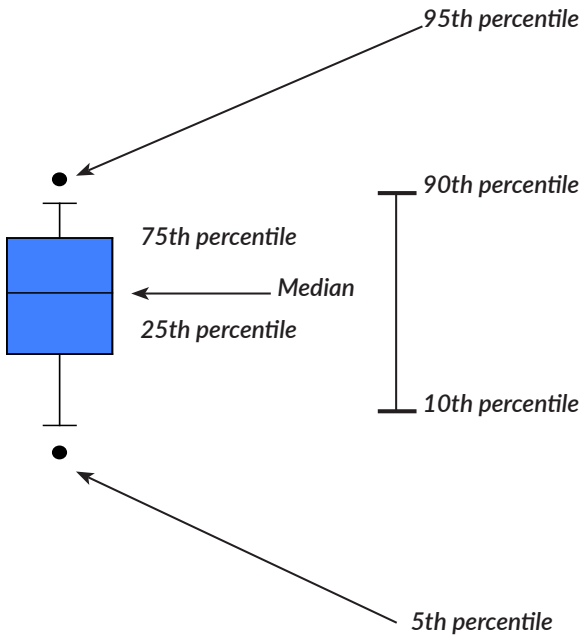
The water quality grades, from A to E, have been assigned for each area depending on compliance with local WQOs (see Table 5).

WATER QUALITY GRADES

- **A** Excellent water quality. All four water quality indicators meet desired levels.
- **B** Very good water quality. Three water quality indicators meet desired levels.
- **C** Good water quality. Two water quality indicators meet desired levels.
- **D** Poor water quality. Only one water quality indicator meets desired levels.
- **E** Very poor water quality. No water quality indicators meet desired levels.

Box and Whisker Plots

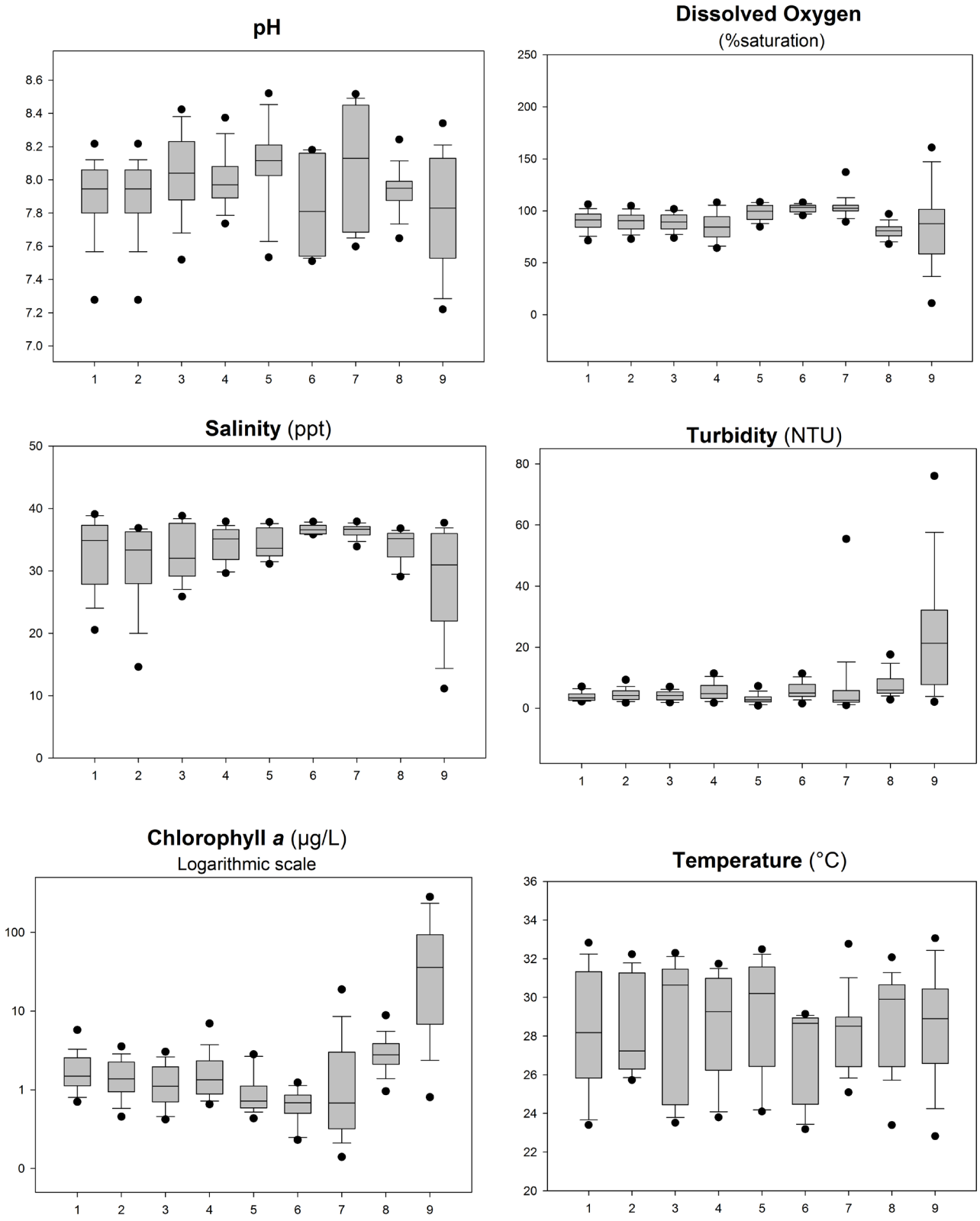
The primary purpose of box and whisker plots in this report is to provide a comparison of results between reporting zones and indicator values. Measures such as medians and percentiles provide details on the variability of data and the presence of unusually high or low values.



5. Results

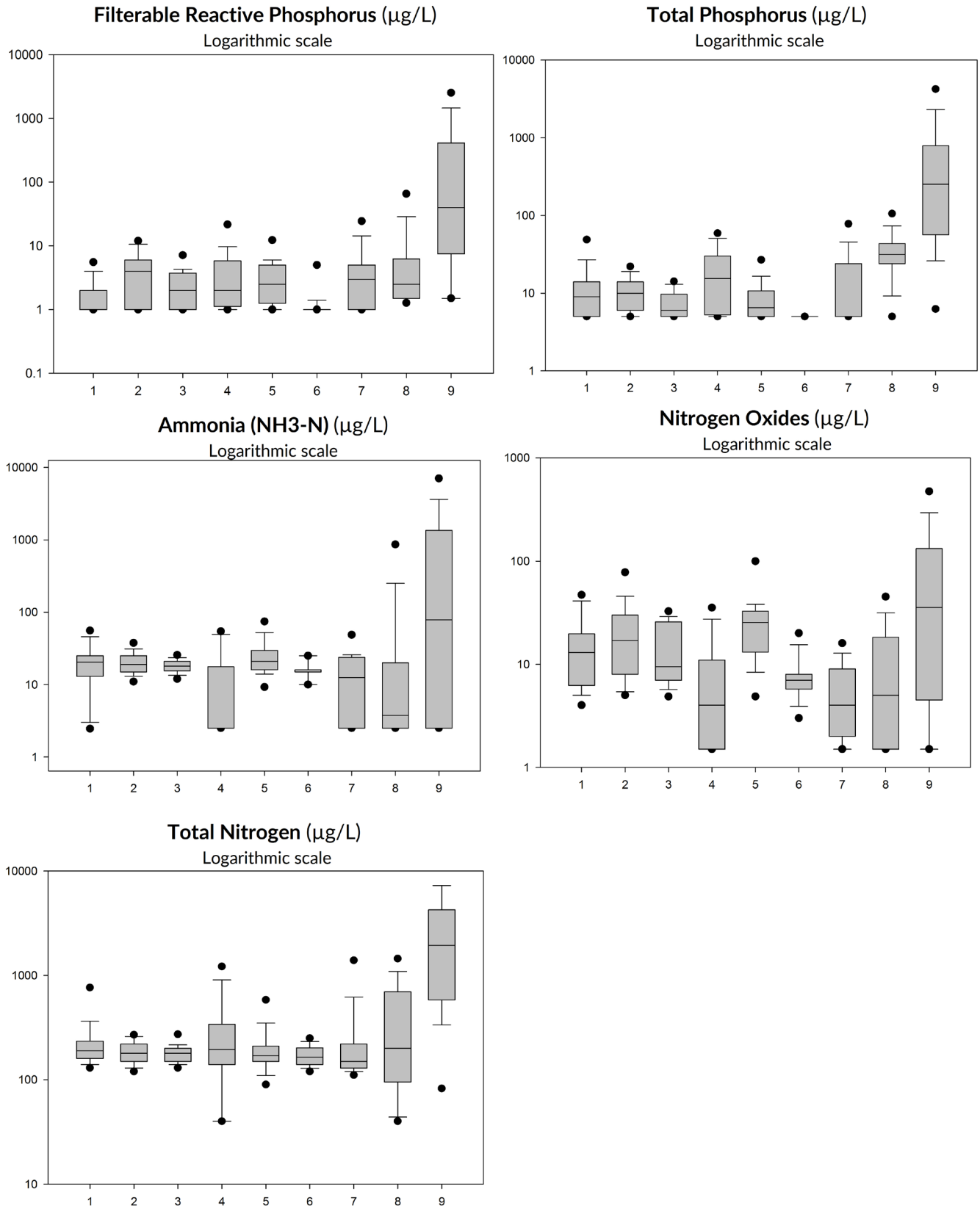
5.1 Darwin Harbour region

Figures 3 and 4 summarise the results of each water quality parameter monitored in the Darwin Harbour region for the period from 1 November 2014 to 30th October 2015.



1 - Elizabeth River, **2** - Blackmore River, **3** - West Arm, **4** - East Arm, **5** - Middle Harbour, **6** - Outer Harbour, **7** - Shoal Bay, **8** - Myrmidon Creek, **9** - Buffalo Creek.

Figure 3. Physico-chemical parameters and algal biomass measured in the Darwin Harbour region (Box plots show 5th, 10th, 25th, Median, 75th, 90th and 95th percentiles)



1 - Elizabeth River, **2** - Blackmore River, **3** - West Arm, **4** - East Arm, **5** - Middle Harbour, **6** - Outer Harbour, **7** - Shoal Bay, **8** - Myrmidon Creek, **9** - Buffalo Creek.

Figure 4. Nutrients measured in the Darwin Harbour region
(Box plots show 5th, 10th, 25th, Median, 75th, 90th and 95th percentiles)

For chlorophyll-a, nitrogen oxides, ammonia, total nitrogen, total phosphorus and filterable reactive phosphorus data was log10 transformed. This transformation was necessary to make results clear on the box plots, due to the wide variability of results between reporting zones and sites.

5.1.1. Dissolved Oxygen saturation

Median dissolved oxygen ranged from 103% (Outer Harbour) to 80% saturation (Myrmidon creek). Values for DO% were generally lower in the upper reaches of the harbour and higher in the outer zones such as the main body to outer harbour reporting zone. Results did not always comply with the WQO, for example elevated DO was observed in Outer Harbour (103%) however this departure was likely to be short lived. Elevated algal biomass in Buffalo Creek was associated with elevations at the surface.

5.1.2. Turbidity

Turbidity remained low across the estuary because measurements were mostly taken during the dry season conditions and neap tides. For most reporting zones turbidity remained under 10 NTU. A large proportion of sites indicated turbidity values lower than 5 NTU. The exception was Buffalo creek where excursions in turbidity were as high as 117 NTU, however the median value for the reporting year was lower at 21.3 NTU triggering the 4 NTU threshold.

5.1.3. pH

Median pH ranged from 7.8 (Blackmore Upper) to 8.1 in the Middle harbour zone with an overall minimum measured in the upper reaches of the Blackmore River. This limited range was typical of dry season conditions where negligible to no flow persists with the exception of the Blackmore River where spring-fed flows continue to discharge throughout the dry season. pH values largely reflected marine influences.

5.1.4. Salinity

Median salinities ranged from 32-36.6 ppt with lower salinities detected in the upper reaches of the Blackmore River, Elizabeth River and Buffalo Creek. The freshwater flows continue during the dry season in the Blackmore contributing to lower salinities. The Buffalo Creek system is subject to freshwater treated discharge from the Leanyer-Sanderson treatment plant and storm water during the wet season.

5.1.5. Temperature

Temperature ranged from 22 °C to 33 °C. Systems such as Elizabeth River, Blackmore River, Middle Harbour, Shoal Bay and West Arm had a narrow temperature range. Conversely systems such as Buffalo Creek, Myrmidon Creek and East Arm revealed a wider range of water temperatures. Temperatures were overall indicative of the dry season neap conditions sampled where the average ranged from 26-28 °C.

5.1.6. Chlorophyll-a

Median chlorophyll-a ranged from 0.6 μg/L in Outer Harbour and Shoal Bay and up to 35 μg/L in Buffalo Creek. Extremely high concentrations were observed in Buffalo Creek particularly in upper reach sites in association with treated wastewater entering the creek. Most systems recorded very low chlorophyll-a values (<4 μg/L) with higher algal biomass generally observed in upper reach sites and tidal creeks.

5.1.7. Nitrogen Oxides

Median NOx values ranged between 4 μg/L (East Arm and Shoal Bay) and 35 μg/L (Buffalo Creek) with highly variable minimum and maxima values across reporting zones of Darwin Harbour. High nitrate values were episodically observed in Myrmidon and Buffalo Creeks. Most other reporting zones had medians within water quality objectives with the exception of the middle harbour reporting zone (25.5 μg/L).

5.1.8. Ammonia

Median values for ammonia ranged between 2.5μg/L (Elizabeth River) and 78.8mg/L (Buffalo Creek). Significant extremes were observed in Myrmidon Creek and Buffalo Creek region where values as low as 2.5 μg/L and up to 7960 μg/L (7.96 mg/L) were recorded in Buffalo Creek.

5.1.9. Total Nitrogen

Median total nitrogen values ranged from 150 μg/L (Shoal Bay) to 1940 μg/L (Buffalo Creek). Although total nitrogen was not assessed as part of the nutrient suite for report card grading most sites met current WQO's. Total nitrogen was typically observed to be higher in the upper reaches of main systems and within tidal creeks.

5.1.10. Total Phosphorus

Total phosphorus for all reporting zones with the exception of Buffalo Creek and Myrmidon Creek met WQO's with median's ranging between 5-24 μg/L. The median for Buffalo Creek was 106 μg/L. Although elevated concentrations were recorded in Blessers Creek (East Arm reporting zone), the median value remained within the reporting benchmark or WQO's.

5.1.11. Filterable Reactive Phosphorus

Filterable reactive phosphorus, the soluble fraction of phosphorus was low across Darwin Harbour. Median values ranged from 1 μg/L to 4 μg/L for all reporting zones with the exception of Buffalo Creek (40 μg/L) exceeding locally derived WQO's. Extremes for FRP were observed in systems associated with licensed wastewater discharge such as Buffalo Creek, Myrmidon Creek and Blessers Creek, a tidal creek in the East Arm reporting zone.

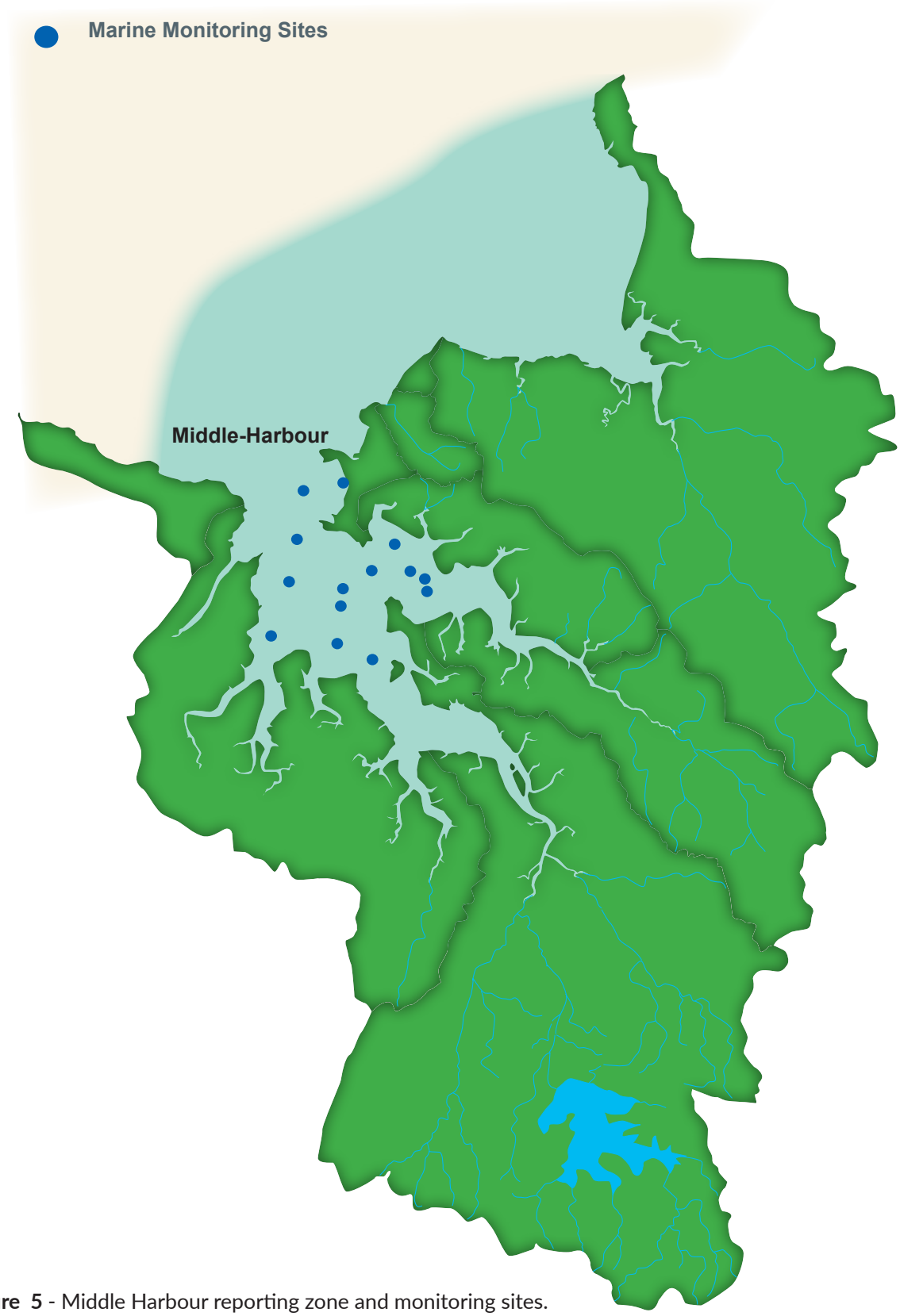


Figure 5 - Middle Harbour reporting zone and monitoring sites.

5.2 Middle Harbour

The eastern part of Middle Harbour receives stormwater runoff from Darwin's urban area. Monitoring locations extend from the East Arm boundary across to the western side of the harbour and south towards Channel Island. The area is a busy conduit for shipping traffic and marine services.

Figure 6 summarises the results of all water quality parameters measured at the Middle Harbour monitoring sites.

Table 5 reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 5 - Summary of water quality parameters measured in Middle Harbour.

Indicators	Water Quality Objectives	Middle Arm			
		min-max	Median	20th and 80th percentiles	
pH	7.0-8.5	7.5-8.6	8.1	8.0	8.3
Dissolved Oxygen (% sat)	80-100	80-108.7	99.6	90.9	105.3
Turbidity (NTU)	<4	0.8-8.3	2.7	2.0	4.4
Chlorophyll-a (µg/L)	<2	0.3-3.06	0.7	0.6	1.3
NOx (µg/L)	<20	4-143	25.5	12.7	36.3
Ammonia (µg/L)	<20	1-93.0	21.0	16.0	34.1
Total Nitrogen (µg/L)	<270	90-650	170.0	140.0	213.0
Total Phosphorus (µg/L)	<20	5.0-37	6.5	5.0	12.6
Filterable Reactive Phosphorus (µg/L)	<5	1.0-14	2.5	1.0	6.0
2015 Rating	***B***				

The water quality parameter of nutrients did not comply with WQO's for the mid estuary category: Water quality at the Middle Harbour reporting zone is in very good condition.

No specific spatial or temporal trend has been identified in Middle Harbour for the parameters studied over the last year. Last reporting year the Middle Harbour rated a 'B' with departures for dissolved oxygen. The 2015 median values were mostly compliant with local benchmarks with the exception of nutrients.

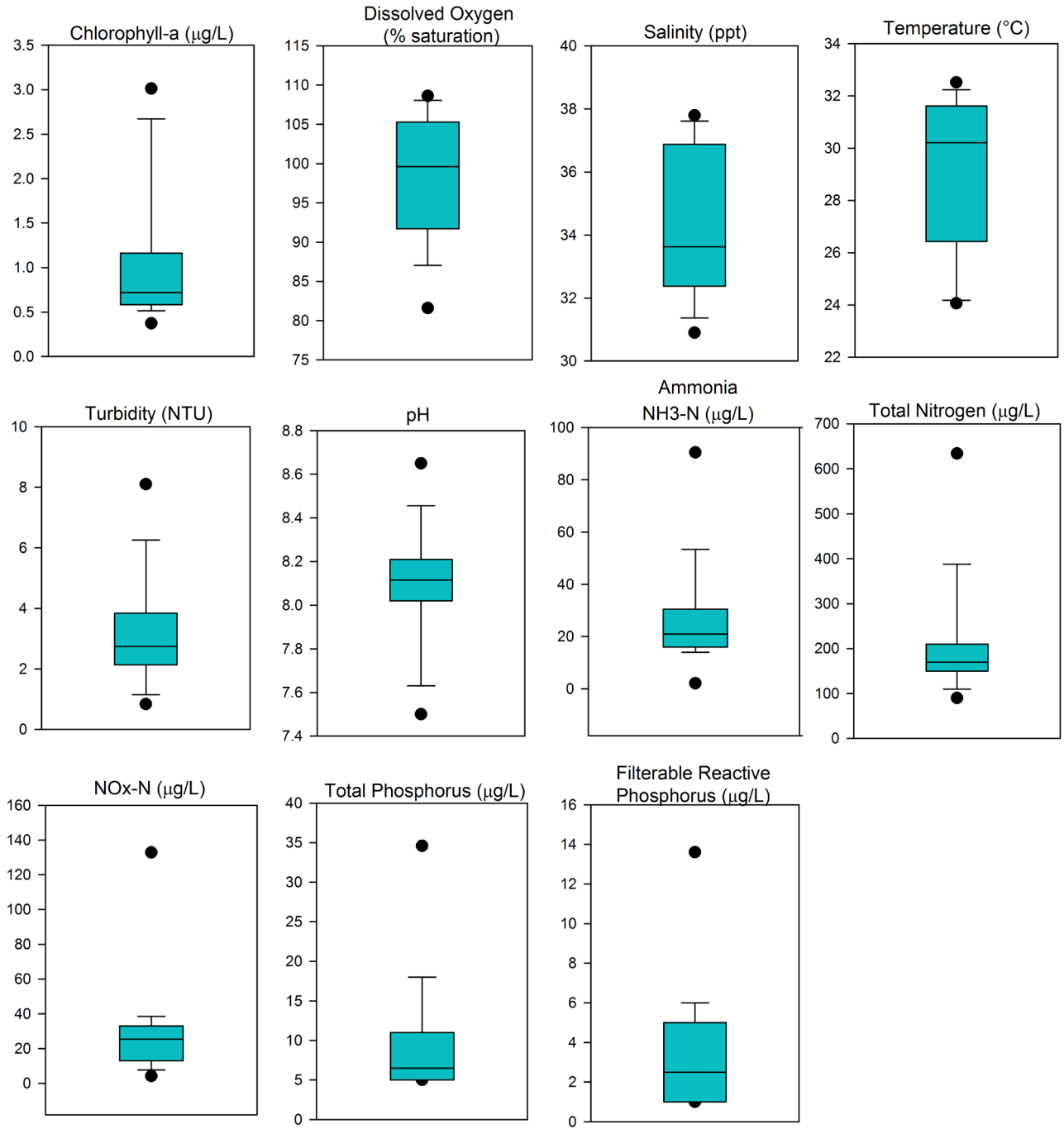


Figure 6. Water quality indicators measured in the Middle Harbour reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

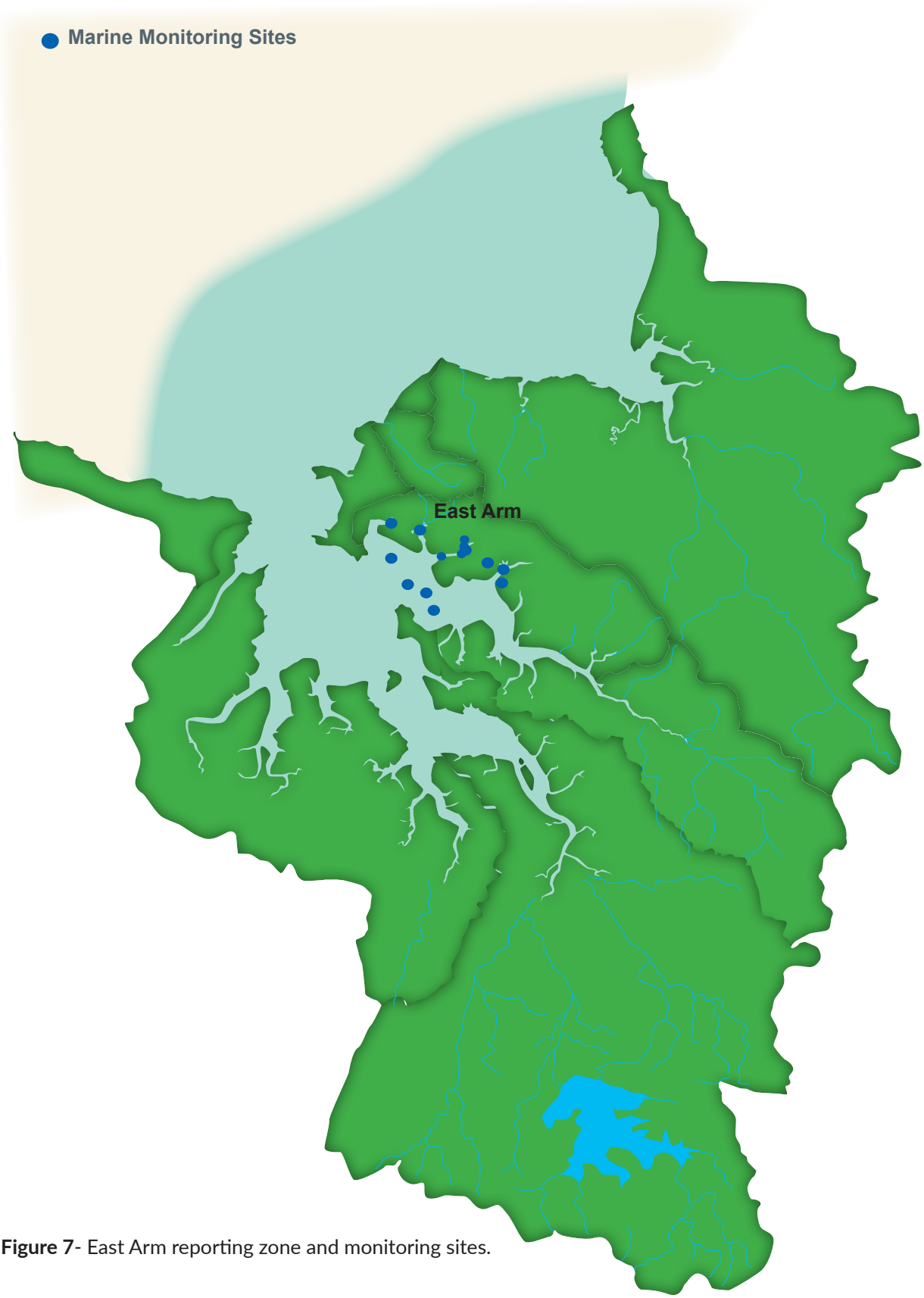


Figure 7- East Arm reporting zone and monitoring sites.

5.3 East Arm

A relatively large part of the catchment of East Arm is principally urbanised, and includes the East Arm wharf, marine support services and industrial areas.

Treated wastewater discharge to Blessers creek which is in the East Arm reporting area. During the wet season high sediment, nutrient and other pollutant loads are received from urbanised areas. Sediment monitoring has shown there is minor impact from urban land-use, and overall low metal and nutrient concentrations in the sediments (Munksgaard et al. 2013).

Figure 8 summarises the results of each water quality parameter measured at the East Arm monitoring sites.

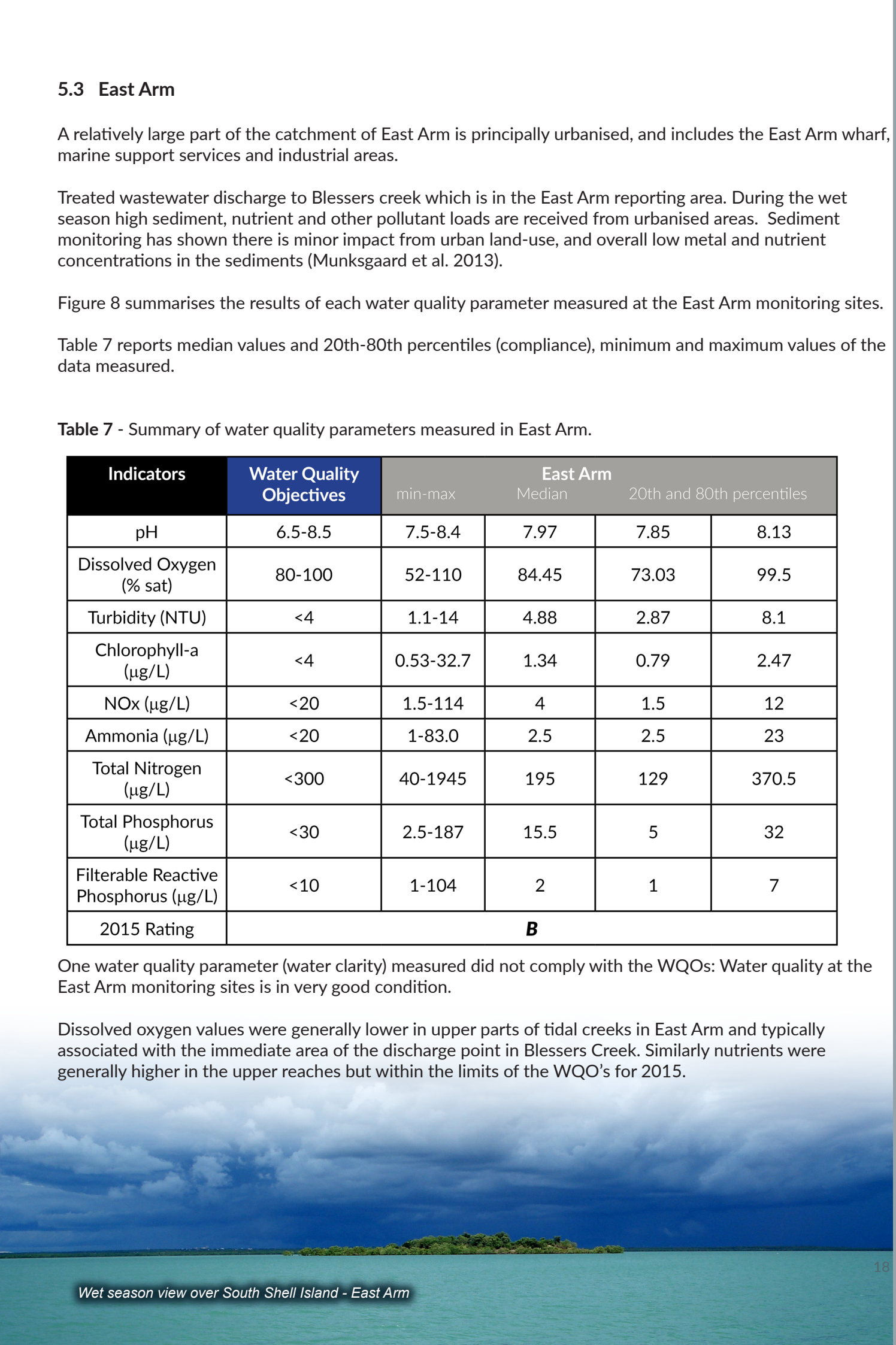
Table 7 reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 7 - Summary of water quality parameters measured in East Arm.

Indicators	Water Quality Objectives	East Arm			
		min-max	Median	20th and 80th percentiles	
pH	6.5-8.5	7.5-8.4	7.97	7.85	8.13
Dissolved Oxygen (% sat)	80-100	52-110	84.45	73.03	99.5
Turbidity (NTU)	<4	1.1-14	4.88	2.87	8.1
Chlorophyll-a (µg/L)	<4	0.53-32.7	1.34	0.79	2.47
NOx (µg/L)	<20	1.5-114	4	1.5	12
Ammonia (µg/L)	<20	1-83.0	2.5	2.5	23
Total Nitrogen (µg/L)	<300	40-1945	195	129	370.5
Total Phosphorus (µg/L)	<30	2.5-187	15.5	5	32
Filterable Reactive Phosphorus (µg/L)	<10	1-104	2	1	7
2015 Rating	***B***				

One water quality parameter (water clarity) measured did not comply with the WQOs: Water quality at the East Arm monitoring sites is in very good condition.

Dissolved oxygen values were generally lower in upper parts of tidal creeks in East Arm and typically associated with the immediate area of the discharge point in Blessers Creek. Similarly nutrients were generally higher in the upper reaches but within the limits of the WQO's for 2015.



Wet season view over South Shell Island - East Arm

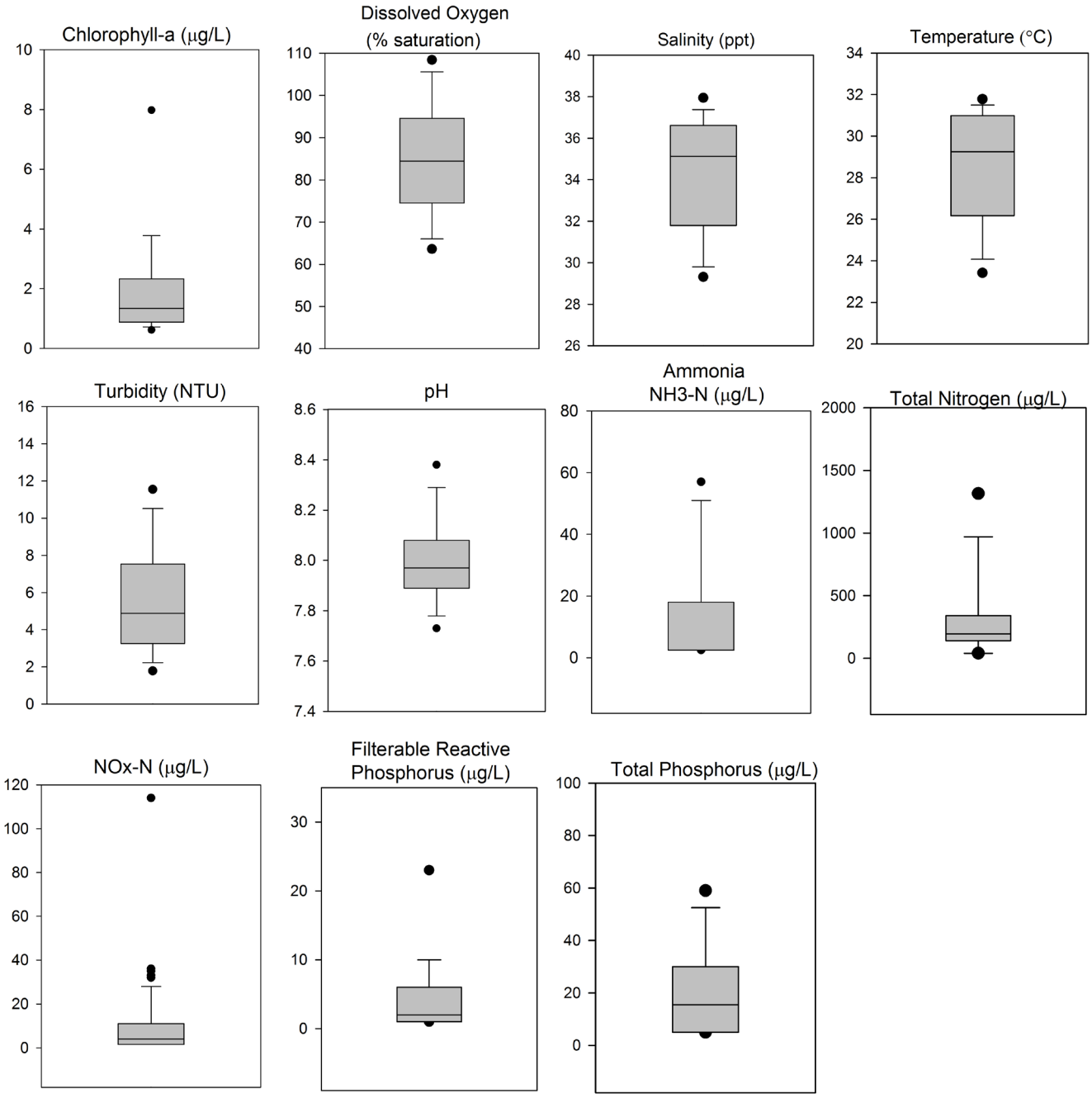


Figure 8. Water quality indicators measured in the East Arm reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

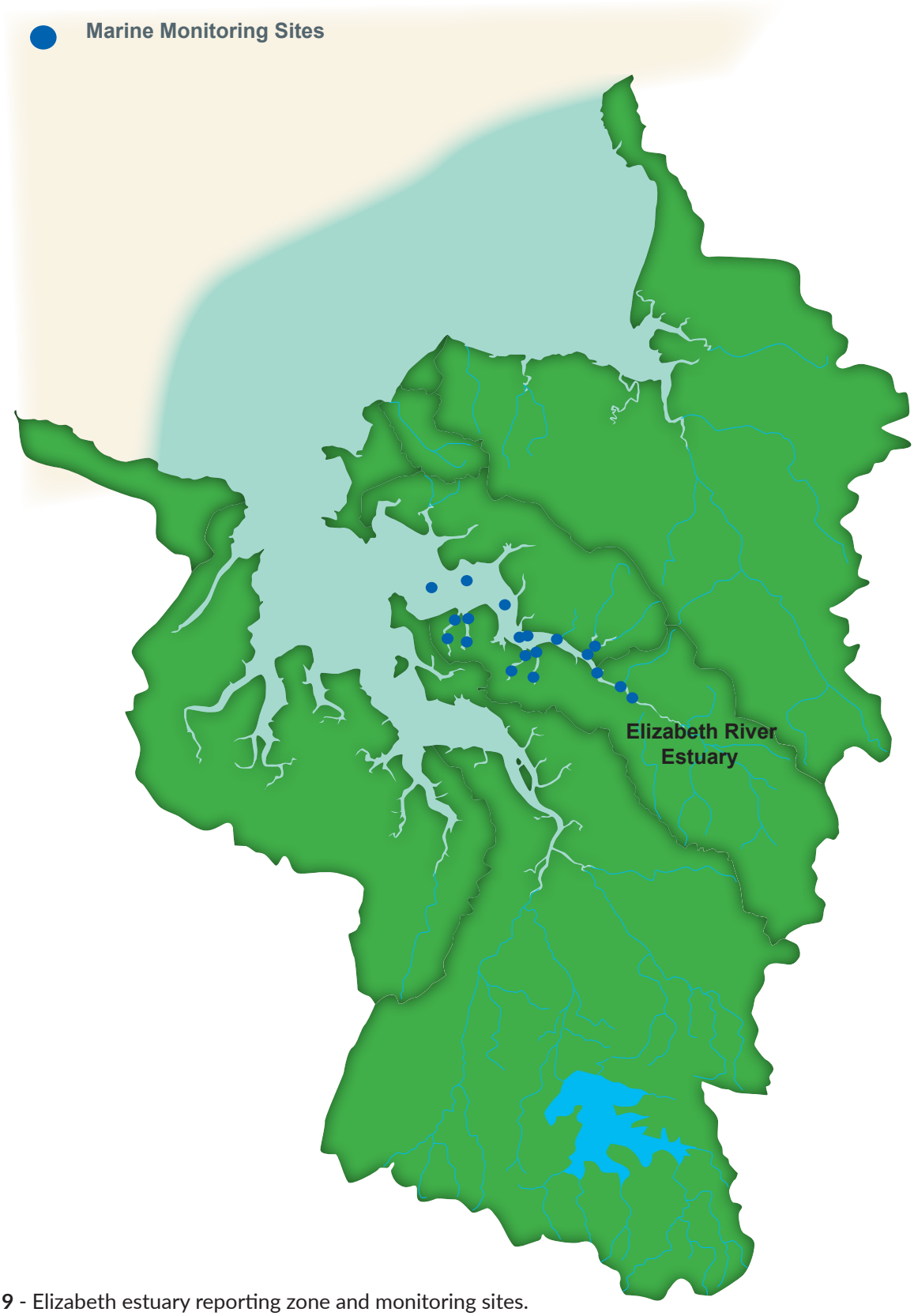


Figure 9 - Elizabeth estuary reporting zone and monitoring sites.

5.4 Elizabeth River Estuary

The estuary is characterised by a relatively long residence time in the upper reaches compared to outer and middle parts of the harbour. The catchment area around the estuary is subject to increasing commercial and urban development with the mid to outer reaches characterised by port activities and other industrial development.

Elizabeth River estuary indirectly receives licensed wastewater discharge from Myrmidon Creek, and sediment and nutrient loads from diffuse sources during the wet season.

Figure 10 summarises the results of each water quality parameter measured at the Elizabeth River Estuary monitoring sites.

Table 8 below reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 8 - Summary of water quality parameters measured in Elizabeth River estuary

Indicators	Water Quality Objectives	Elizabeth River			
		min-max	Median	20th and 80th percentiles	
pH	6.5-8.5	6.9-8.45	7.9	7.7	8.0
Dissolved Oxygen (% sat)	80-100	62 -110	91.2	83.3	97.8
Turbidity (NTU)	<4	1.6 - 21	3.4	2.6	5.2
Chlorophyll-a (µg/L)	<4	0.6 -14.7	1.5	1.0	2.8
NOx (µg/L)	<20	3.0-93	13	6	22
Ammonia (µg/L)	<20	1.0-91	20.5	11.1	26
Total Nitrogen (µg/L)	<300	120-1010	190	150	250
Total Phosphorus (µg/L)	<30	5-130	9	5	16.9
Filterable Reactive Phosphorus (µg/L)	<10	1.0-13	1	1	2
2015 Rating	***B***				

All but the water quality parameter of nutrients complied with the WQOs: Water quality within the reporting zone of the Elizabeth River estuary is in very good condition.

Dissolved oxygen and pH measured in upper parts were generally lower compared to those measured in more open parts of the harbour. Similar gradients of higher concentration in the upper reaches of the estuary and tidal creeks have been reported previously (Fortune, 2015a). A turbidity maxima is also typically observed in the upper reaches, this becomes particularly pronounced during the wet season and spring tides across Darwin Harbour.

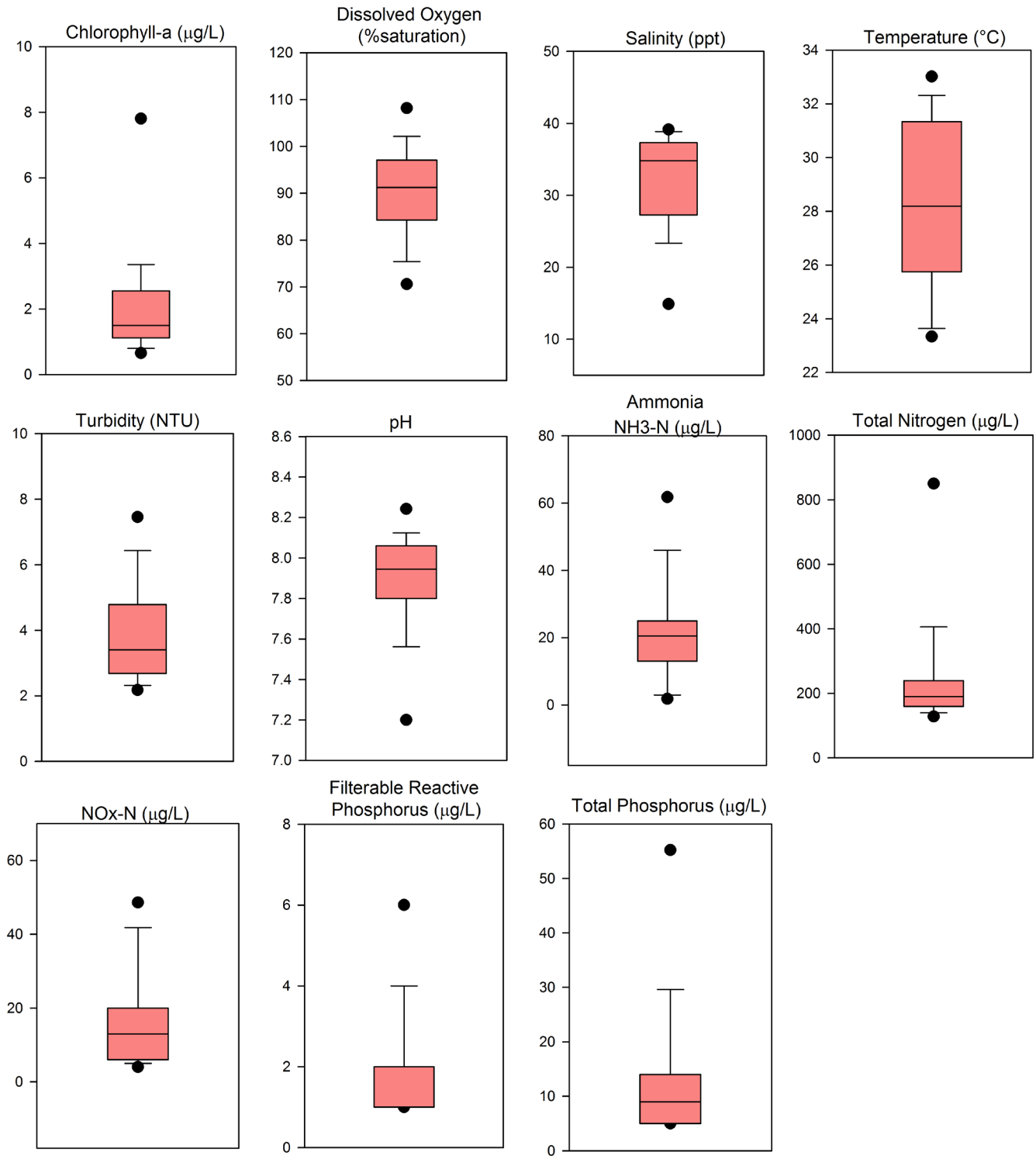


Figure 10. Water quality indicators measured in the Elizabeth Estuary reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

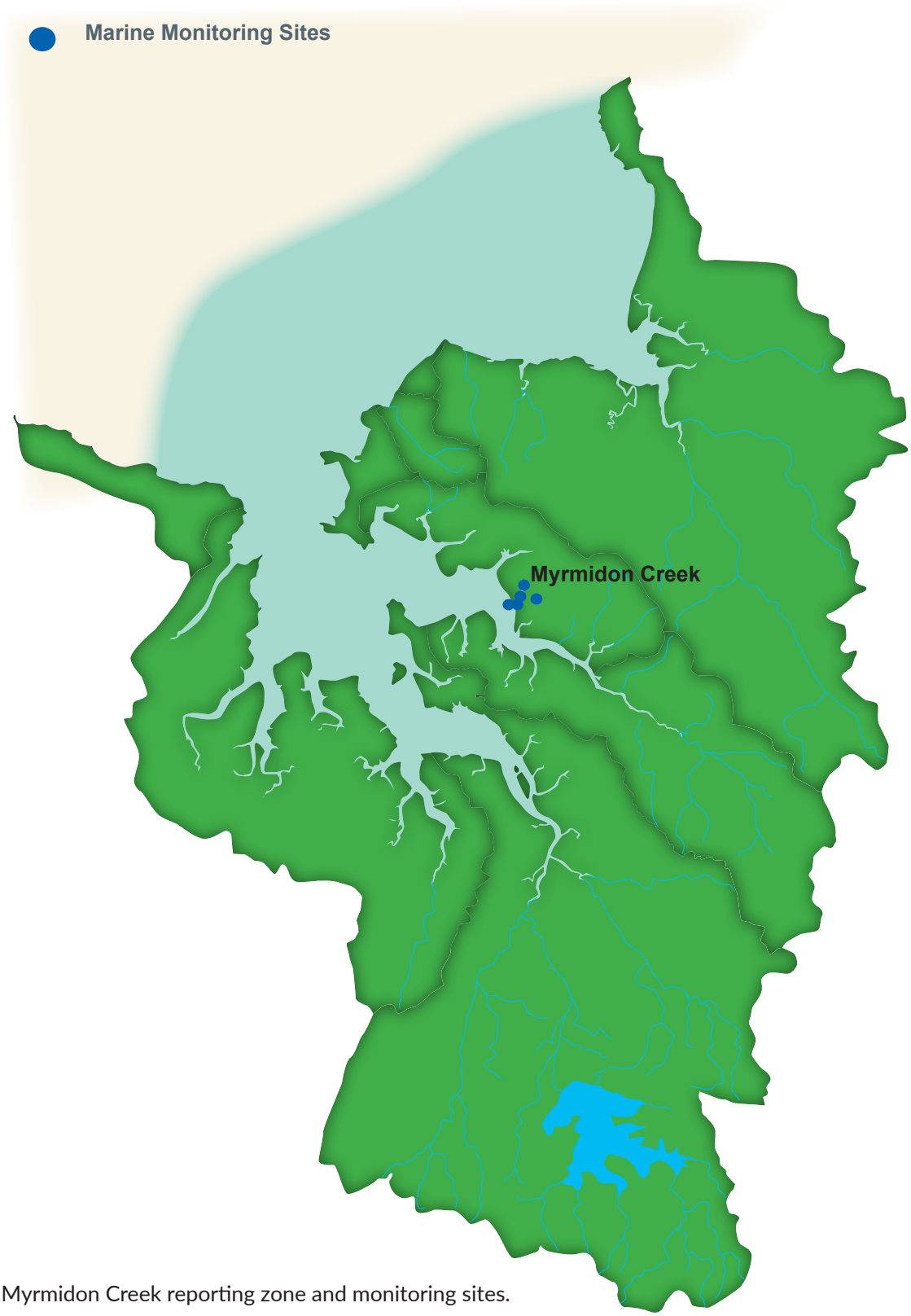


Figure 11 - Myrmidon Creek reporting zone and monitoring sites.

5.5 Myrmidon Creek

Myrmidon Creek receives discharge from a sewage treatment plant which services Palmerston and surrounding areas. The influence of the discharge entering the creek appears to be largely confined with no discernable impact to water quality detected downstream at the mouth.

Pollutant loads from rural and urban areas during the wet season enter the estuary from the upper reaches where mixed land uses prevail.

Figure 12 summarises the results of water quality parameters measured at the Myrmidon Creek monitoring sites. Much of this data has been provided by the Power and Water Corporation.

Table 9 reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 9 - Summary of water quality parameters measured in Myrmidon Creek.

Indicators	Water Quality Objectives	Myrmidon Creek			
		min-max	Median	20th and 80th percentiles	
pH	6.5-8.5	7.43-8.45	7.95	7.8	8.0
Dissolved Oxygen (% sat)	80-100	66.8-103	80.85	73.4	87.2
Turbidity (NTU)	<4	2.6-36.6	6.0	4.7	10.1
Chlorophyll-a (µg/L)	<4	0.8-26.7	2.7	1.7	4.0
NOx (µg/L)	<20	1.5-238	5	1.5	22
Ammonia (µg/L)	<20	2.5-1720	3.75	2.5	47.5
Total Nitrogen (µg/L)	<300	40-2250	200	90	840
Total Phosphorus (µg/L)	<30	5-228.5	31.5	22.5	49.5
Filterable Reactive Phosphorus (µg/L)	<10	1-280	2.5	1.5	10
2015 Rating	***B***				

One water quality parameters (turbidity) measured did not comply with the determined benchmark: Water quality at the Myrmidon Creek monitoring zone is in very good condition.

The highest values of ammonia, total nitrogen and total phosphorus were measured at sites closest to the discharge point in Myrmidon Creek. However these conditions appear to be transitional with the main channel of the system returning to background condition within a short period of time. This is possibly a result of effective mixing. Turbidity was higher than the designated benchmark.

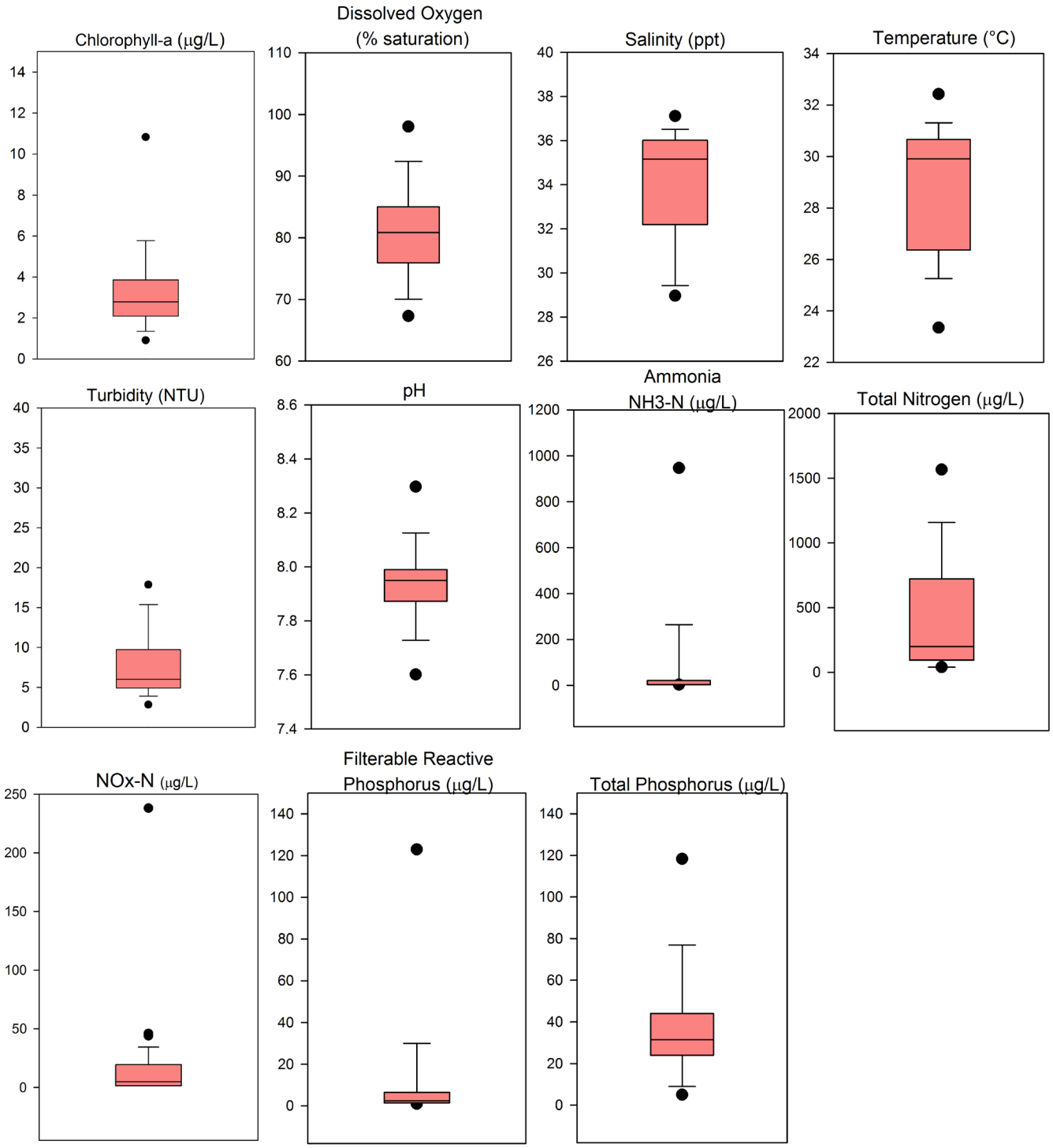


Figure 12. Water quality indicators measured in the Myrmidon Creek reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

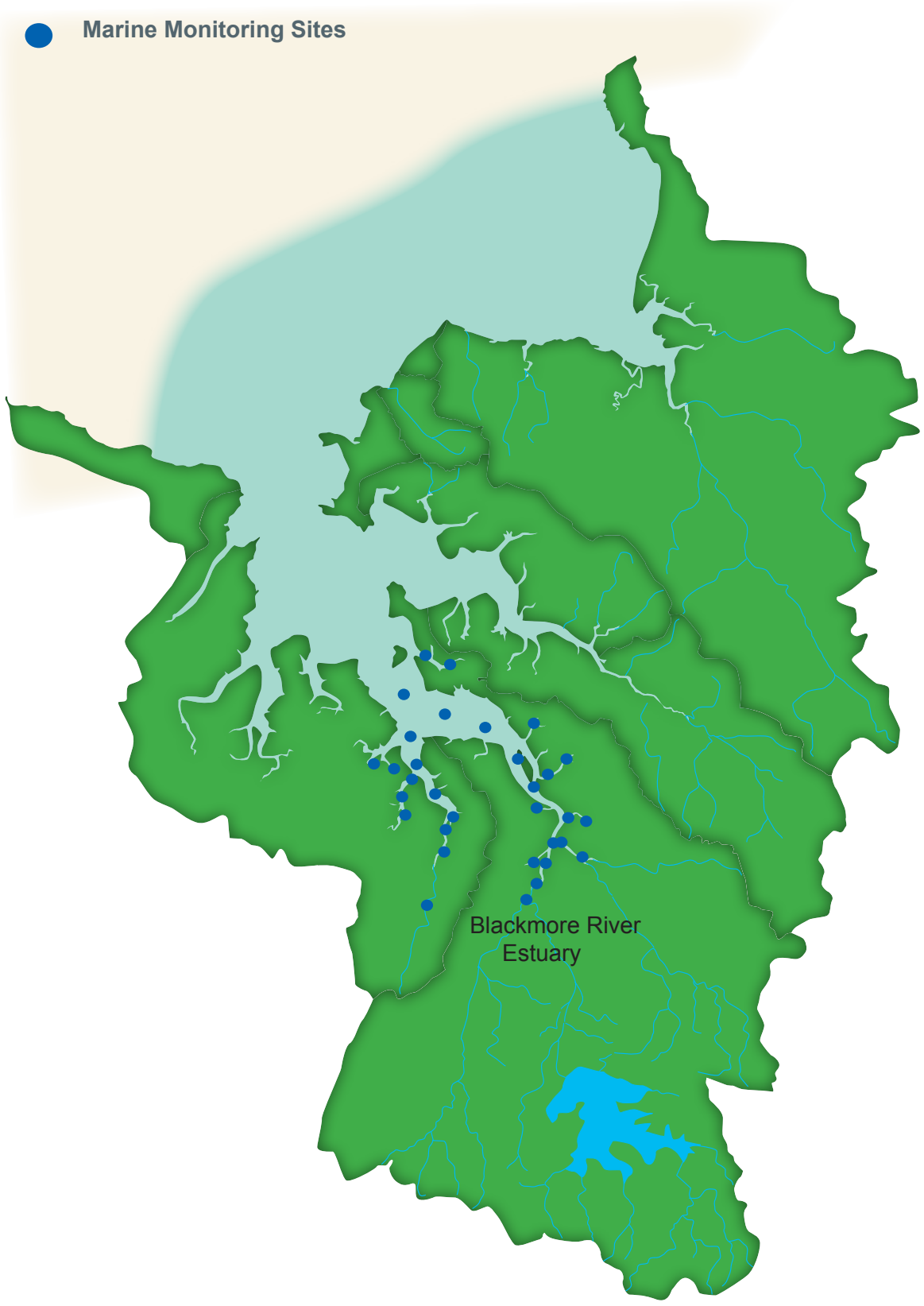


Figure 13 - Blackmore River estuary reporting zone and monitoring sites.

5.6 Blackmore River Upper

The estuary is characterised by a relatively long residence time in the upper reaches compared to outer and middle parts of the harbour.

Blackmore River Estuary receives occasional discharges from licensed aquaculture operations, and sediment and nutrient loads from diffuse sources in the wet season. The upper reaches are also subject to persistent freshwater flows from springs which continue to flow during the dry season in addition to flows maintained in Darwin River downstream of the Darwin River Dam.

Figure 14 summarises the results of each water quality parameter measured at the Blackmore River Estuary monitoring sites.

Table 10 below reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 10 - Summary of water quality parameters measured in Blackmore River estuary

Indicators	Water Quality Objectives	Blackmore River			
		Min-max	median	20th and 80th percentiles	
pH	6.5-8.5	6.8-8.32	7.9	7.7	8.1
Dissolved Oxygen (% sat)	80-100	67-109	90.4	81.8	98.3
Turbidity (NTU)	<4	1.1-16.1	4.2	2.7	6.1
Chlorophyll-a (µg/L)	<4	0.23-6.28	1.4	0.8	2.4
NOx (µg/L)	<20	3.0-124.0	17.0	8.0	31.0
Ammonia (µg/L)	<20	5.0-54	19.0	15.0	27.0
Total Nitrogen (µg/L)	<300	80-480	180.0	140.0	230.0
Total Phosphorus (µg/L)	<30	5.0-37.0	10.0	6.0	14.9
Filterable Reactive Phosphorus (µg/L)	<10	1.0-22.0	4.0	1.0	7.0
2015 Rating			***B***		

The water quality parameter of water clarity did not comply with the WQOs: Water quality in the Blackmore River estuary reporting zone is in very good condition.

The lowest pH and dissolved oxygen values were measured in upper parts of the estuary.

Dissolved oxygen, ammonia, total nitrogen and total phosphorus measured in upper parts of the estuary were generally higher compared to those measured in more open parts and indicated strong gradients decreasing with distance along the estuary. Chlorophyll-a and turbidity is generally lower during the dry season months in comparison to the wet season where water quality can fluctuate widely.

Mangrove lined tidal creek on the Blackmore River, Darwin Harbour.

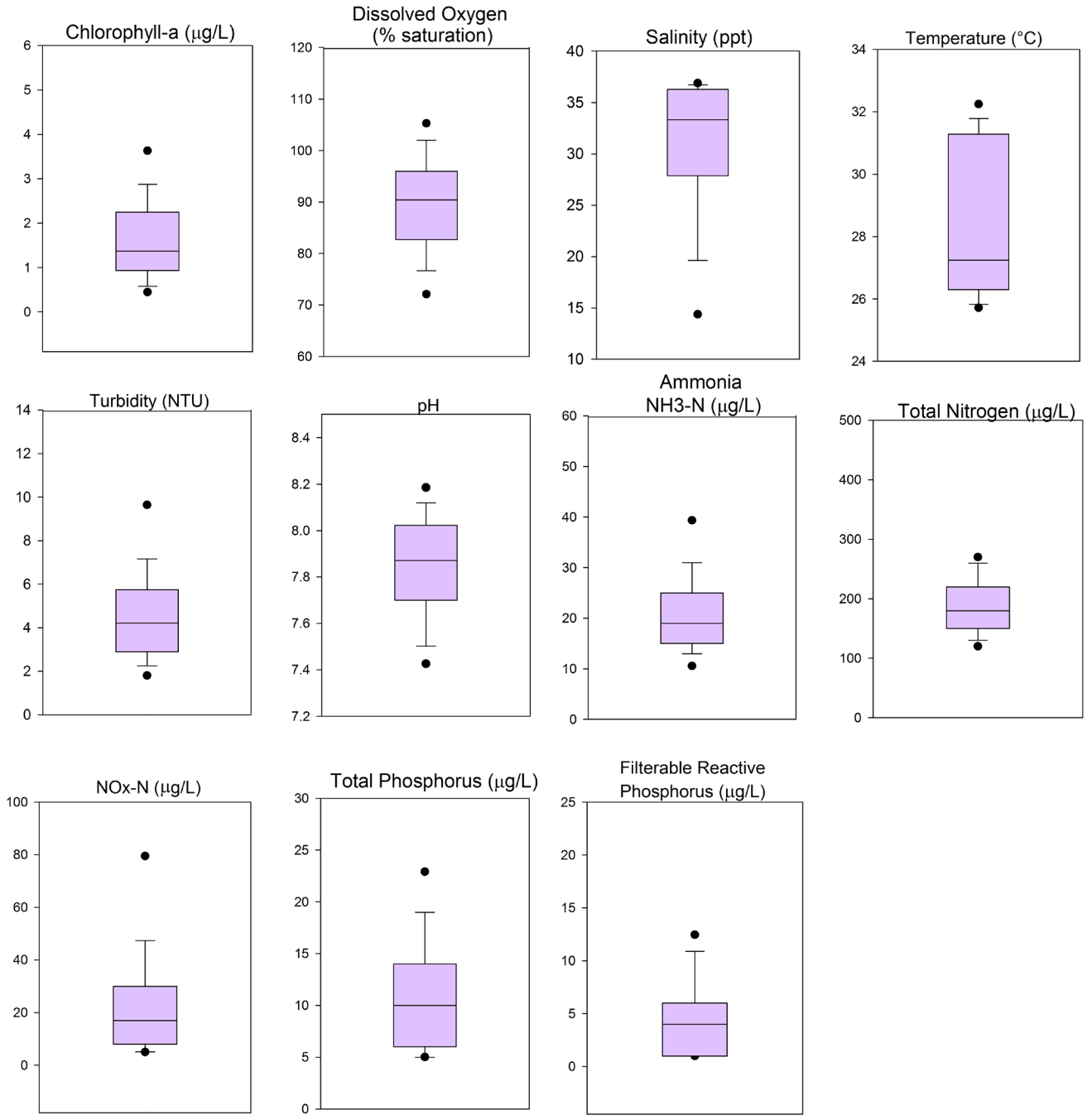


Figure 14. Water quality indicators measured in the Blackmore River estuary reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

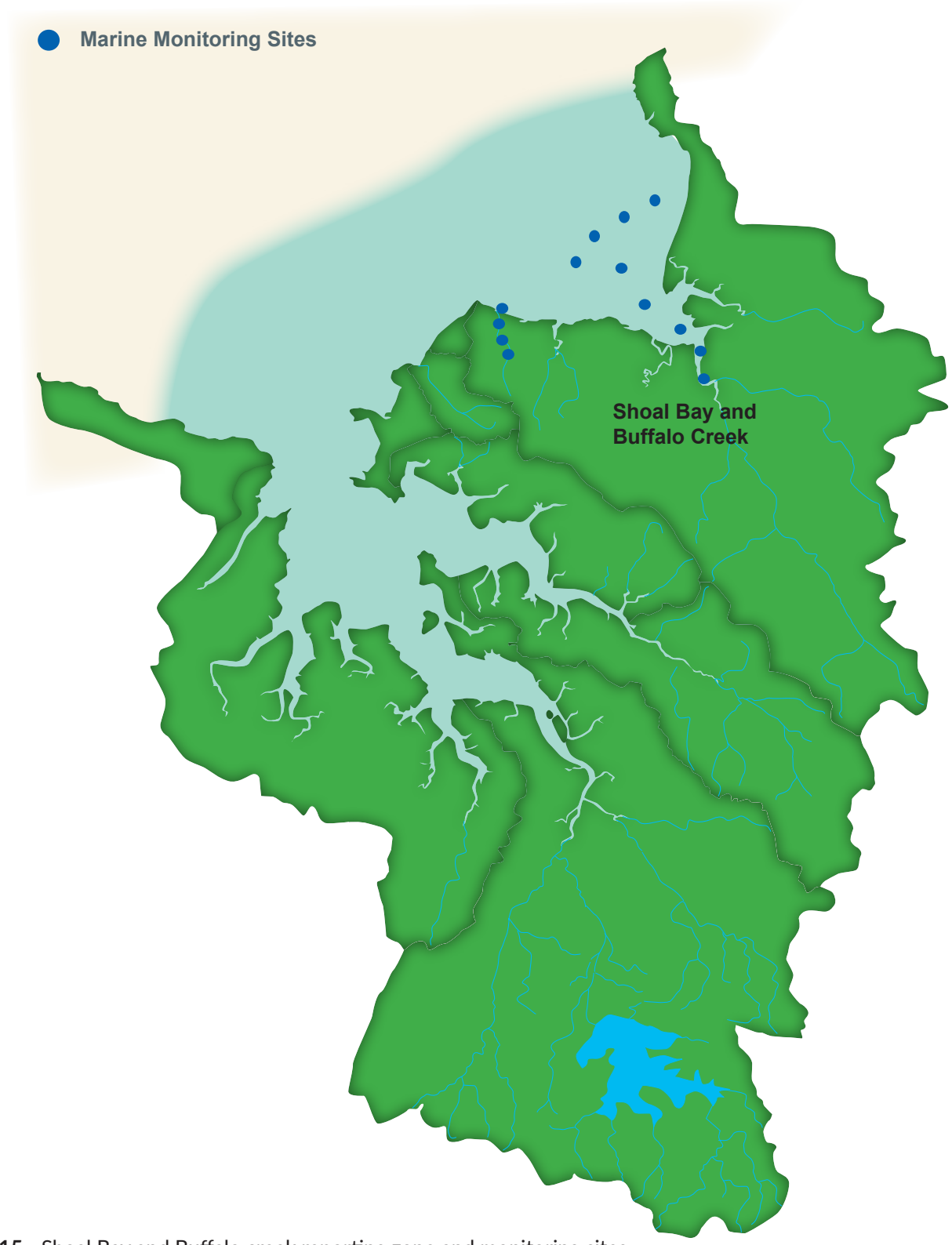


Figure 15 - Shoal Bay and Buffalo creek reporting zone and monitoring sites.

5.7 Shoal Bay

The area is a shallow embayment with a number of sandbars along the coastal fringe and entrance to tidal creeks. Shoal Bay receives sediments and nutrient loads from the Howard River catchment during the wet season. A number of smaller mangrove-lined creeks flow to Shoal Bay, these include King, Micket and Buffalo Creeks.

Figure 16 summarises the results of water quality parameters measured at the Shoal Bay monitoring sites.

Table 11 reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 11 - Summary of water quality parameters measured in Shoal Bay.

Indicators	Water Quality Objectives	Shoal Bay			
		Min-max	median	20th and 80th percentiles	
pH	7-8.5	7.5-8.5	8.1	7.7	8.5
Dissolved Oxygen (% sat)	80-100	85-116	102.5	99.6	105.7
Turbidity (NTU)	<4	0.7-117	2.7	2.0	6.3
Chlorophyll-a (µg/L)	<4	0.14-37	0.7	0.3	3.4
NOx (µg/L)	<10	1.5-19	4.0	2.0	10.0
Ammonia (µg/L)	<20	2.5-50	12.5	2.5	24.0
Total Nitrogen (µg/L)	<440	90-1840	150.0	130.0	229.0
Total Phosphorus (µg/L)	<20	5-131	5.0	5.0	24.9
Filterable Reactive Phosphorus (µg/L)	<10	1.0-25	3.0	1.0	5.0
2015 Rating	***A***				

All water quality parameters complied with the WQOs: Water quality at the Shoal Bay monitoring sites is in excellent condition.

Dissolved oxygen (DO) can fluctuate widely over short temporal scales particularly with changing tides. Elevations above guidelines can be associated with the natural variation observed in the region. Revision of water quality objectives is needed to better accommodate this natural variation. Sometimes elevated DO can be associated with high algal biomass (chlorophyll-a).

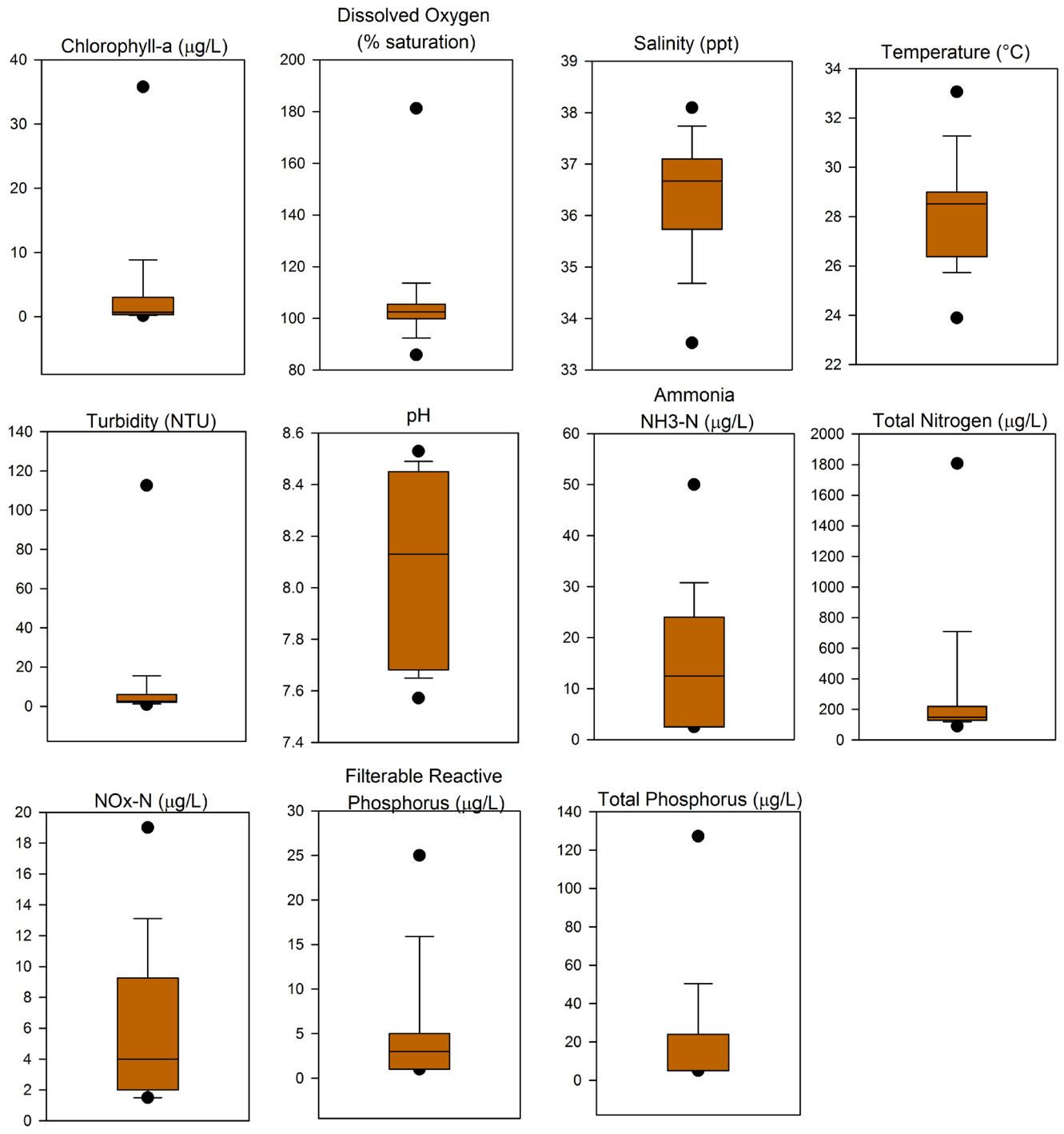


Figure 16. Water quality indicators measured in the Shoal Bay reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

5.8 Buffalo Creek

The area is characterized by long residence times and poor flushing due to a sand bar at the creek's mouth.

Buffalo Creek receives discharge from the Leanyer-Sanderson Wastewater Treatment Plant, and pollutant loads from urban areas during the wet season.

Figure 17 summarises the results of water quality parameters measured at the Buffalo Creek monitoring sites. This data is collected by the Power and Water Corporation in conjunction with waste discharge license monitoring requirements.

Table 12 reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured in Buffalo Creek.

Table 12 - Summary of water quality parameters measured in Buffalo Creek

Indicators	Water Quality Objectives	Buffalo Creek			
		Min-max	median	20th and 80th percentiles	
pH	6.5-8.5	7.1-8.4	7.8	7.5	8.1
Dissolved Oxygen (% sat)	80-100	2.5-236	87.7	56.7	105.1
Turbidity (NTU)	<4	0.1-114	21.4	7.2	34.1
Chlorophyll-a (µg/L)	<4	0.4-425	35.9	3.5	100.3
NOx (µg/L)	<20	1.5-654	35.5	3.1	197.0
Ammonia (µg/L)	<20	2.5-7960	78.5	2.5	1684.4
Total Nitrogen (µg/L)	<300	80-14650	1940.0	482.0	4559.5
Total Phosphorus (µg/L)	<30	5.0-4660	253.0	43.2	945.3
Filterable Reactive Phosphorus (µg/L)	<10	1.5-2975	40.0	5.5	603.0
2015 Rating	***E***				

Four water quality parameters measured (water clarity, algae, nutrients and dissolved oxygen) did not comply with the WQOs: Water quality at the Buffalo Creek reporting zone is in poor condition.

The highest values of chlorophyll-a, ammonia, total nitrogen, total phosphorus and filterable reactive phosphorus were measured at sites closest to the Buffalo Creek outfall.

Salt water Crocodile (Crocodylus porosus) on mudflats of Buffalo Creek.

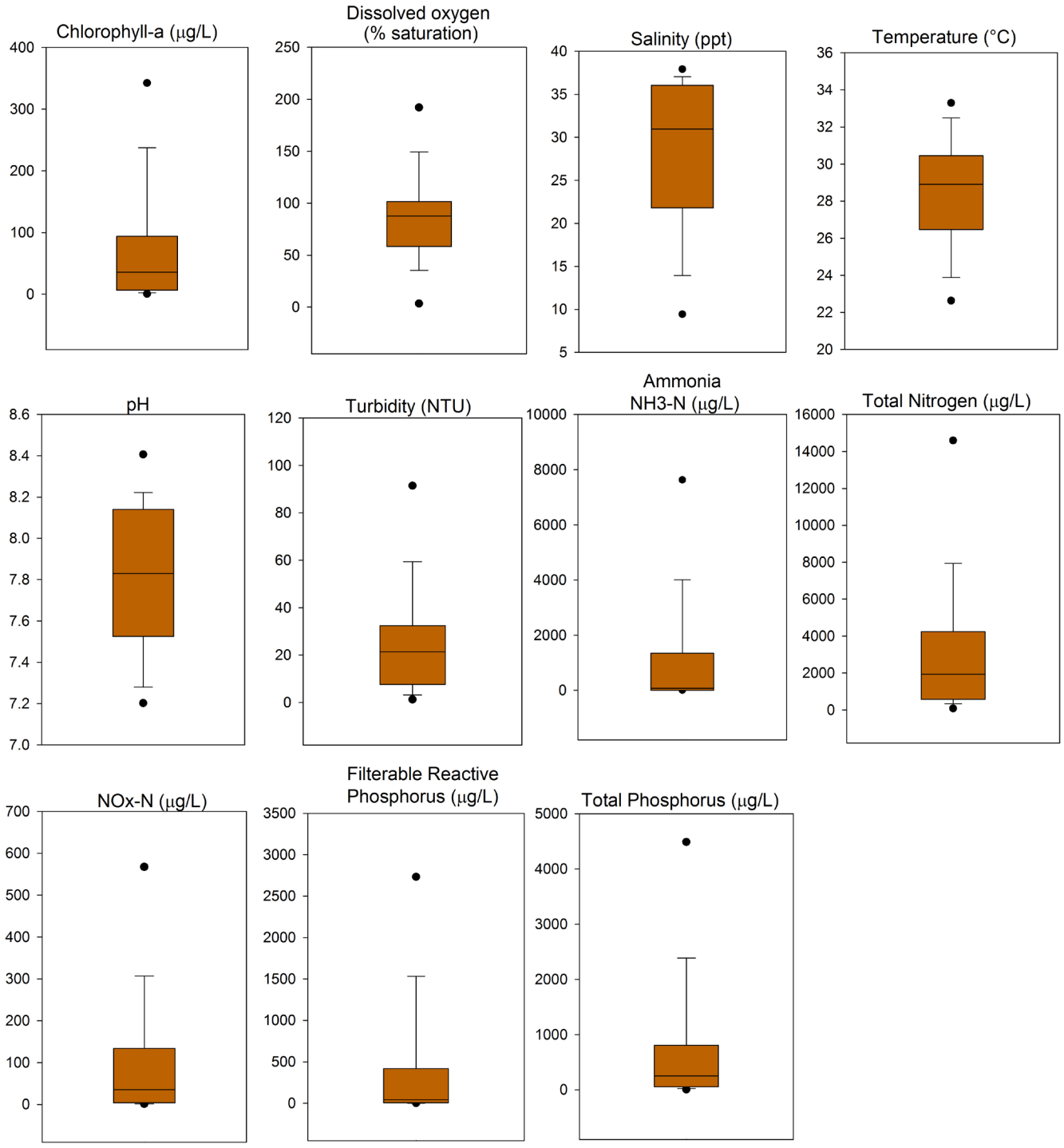


Figure 17. Water quality indicators measured in the Buffalo Creek reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

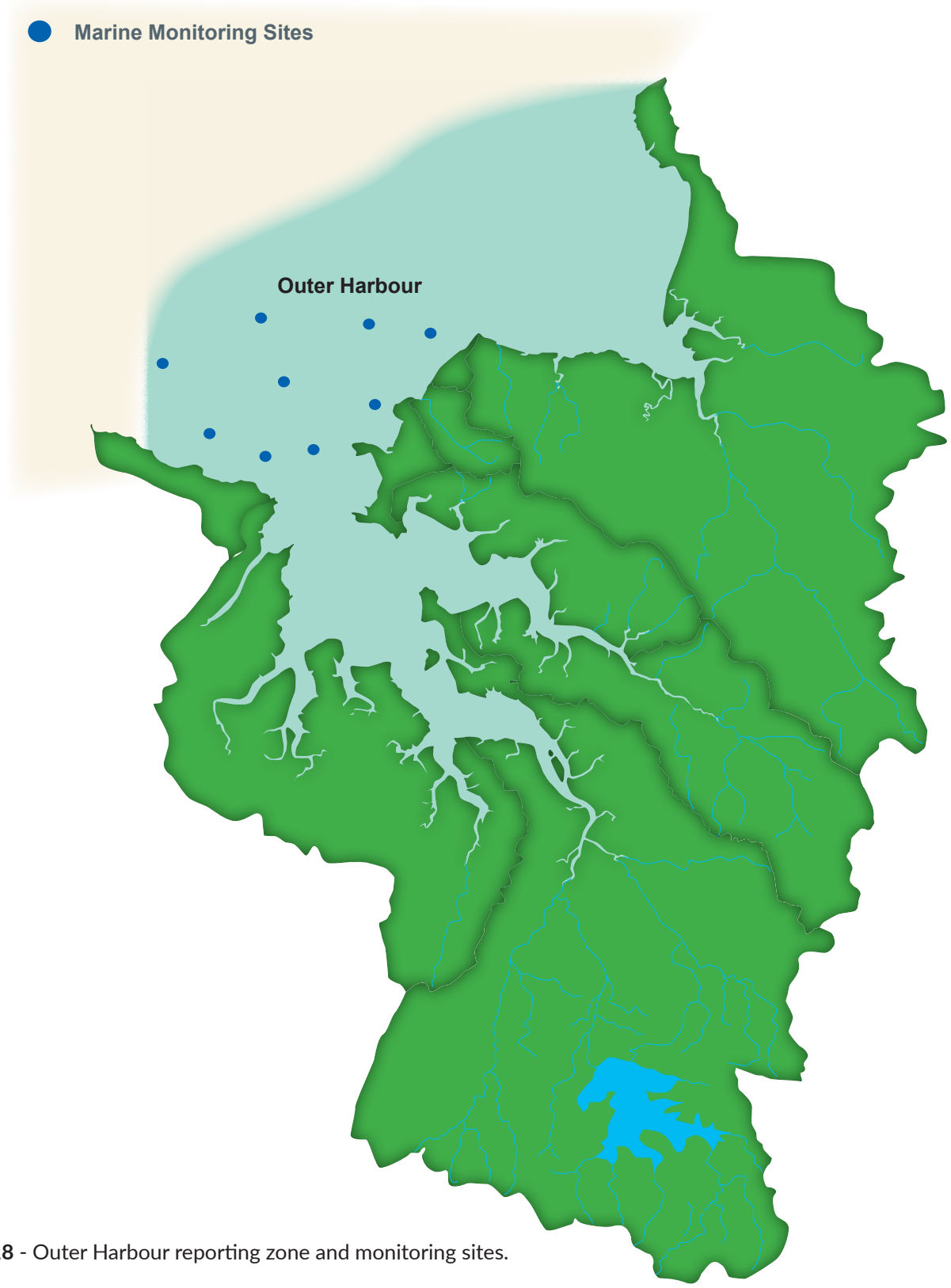


Figure 18 - Outer Harbour reporting zone and monitoring sites.

5.9 Outer Harbour

The area is a well-mixed system open to coastal exchange. Effluent from the Ludmilla Wastewater Treatment Plant is discharged to this part of the Harbour at the East Point outfall. Given the large tidal modulation and open waters, this discharge appears to be readily dispersed most of the time.

Figure 19 summarises the results of water quality parameters measured at Outer Harbour monitoring sites.

Table 13 reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 13 - Summary of water quality parameters measured in the Outer Harbour

Indicators	Water Quality Objectives	Outer Harbour			
		min-max	Median	20th and 80th percentiles	
pH	7.0-8.5	7.5-8.1	7.81	7.54	8.1
Dissolved Oxygen (% sat)	80-100	95.5 -108	103.2	98.5	105.6
Turbidity (NTU)	<4	1.5-11.3	5.02	3.83	8.87
Chlorophyll-a (µg/L)	<1	0.23-1.23	0.68	0.37	0.87
NOx (µg/L)	<10	3.0-20.0	7	5.1	8
Ammonia (µg/L)	<20	10.0-25.0	16	15	16
Total Nitrogen (µg/L)	<440	120-250	165	140	209
Total Phosphorus (µg/L)	<20	5.0-5.0	5	5	5
Filterable Reactive Phosphorus (µg/L)	<10	1.0-5.0	1	1	1
2015 Rating	***B***				

One water quality parameter (turbidity) measured did not comply with the WQOs: Water quality at the Outer Harbour monitoring zone is in very good condition.

During the sampling period of 2015 dry season conditions in the outer harbor were particularly windy. These gusts can produce strong currents and eddies which generate turbid conditions affecting water clarity.

Hermit crab amongst the fine seagrasses of Vesty's beach -Darwin Harbour

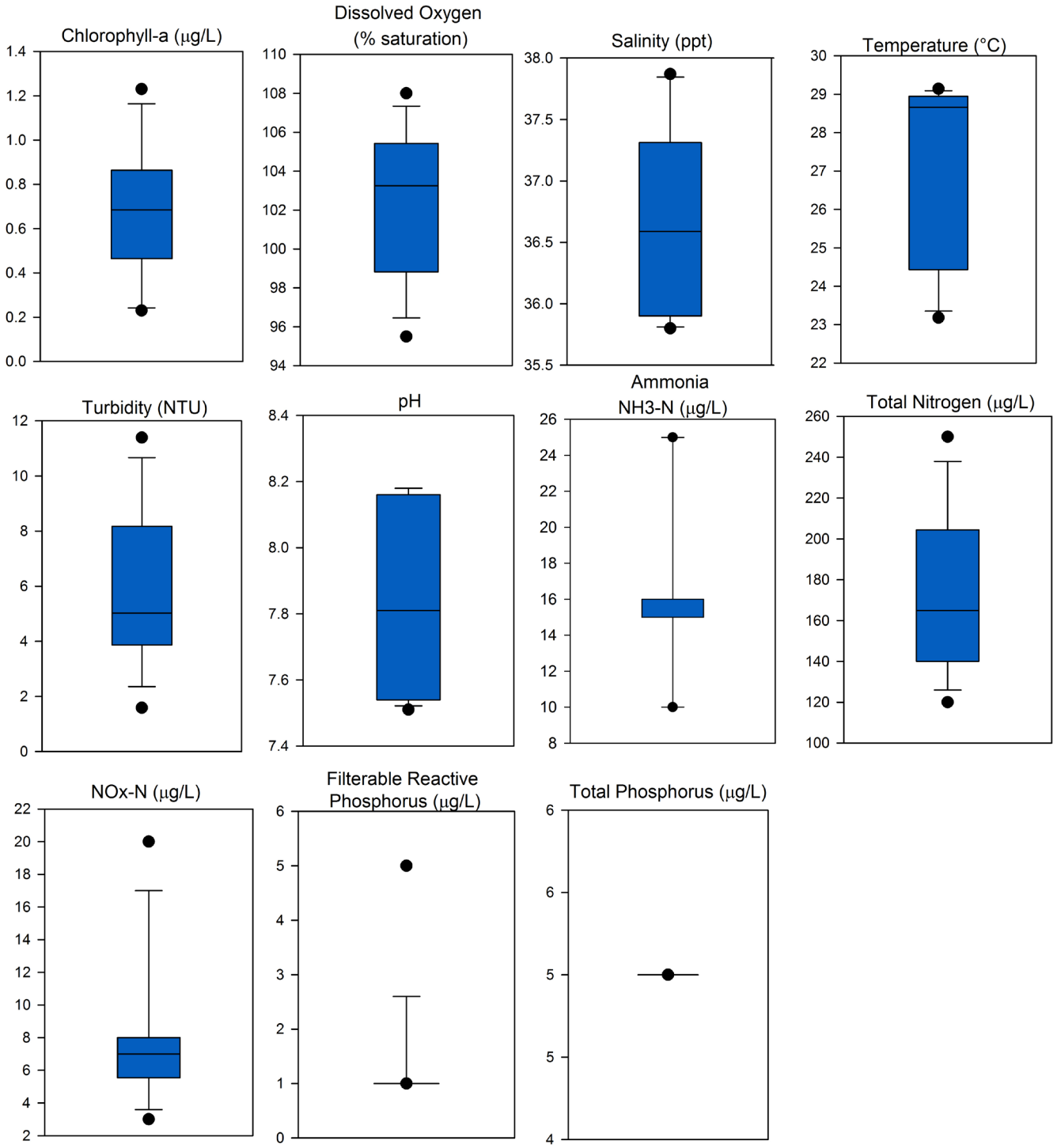


Figure 19. Water quality indicators measured in the Outer Harbour reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

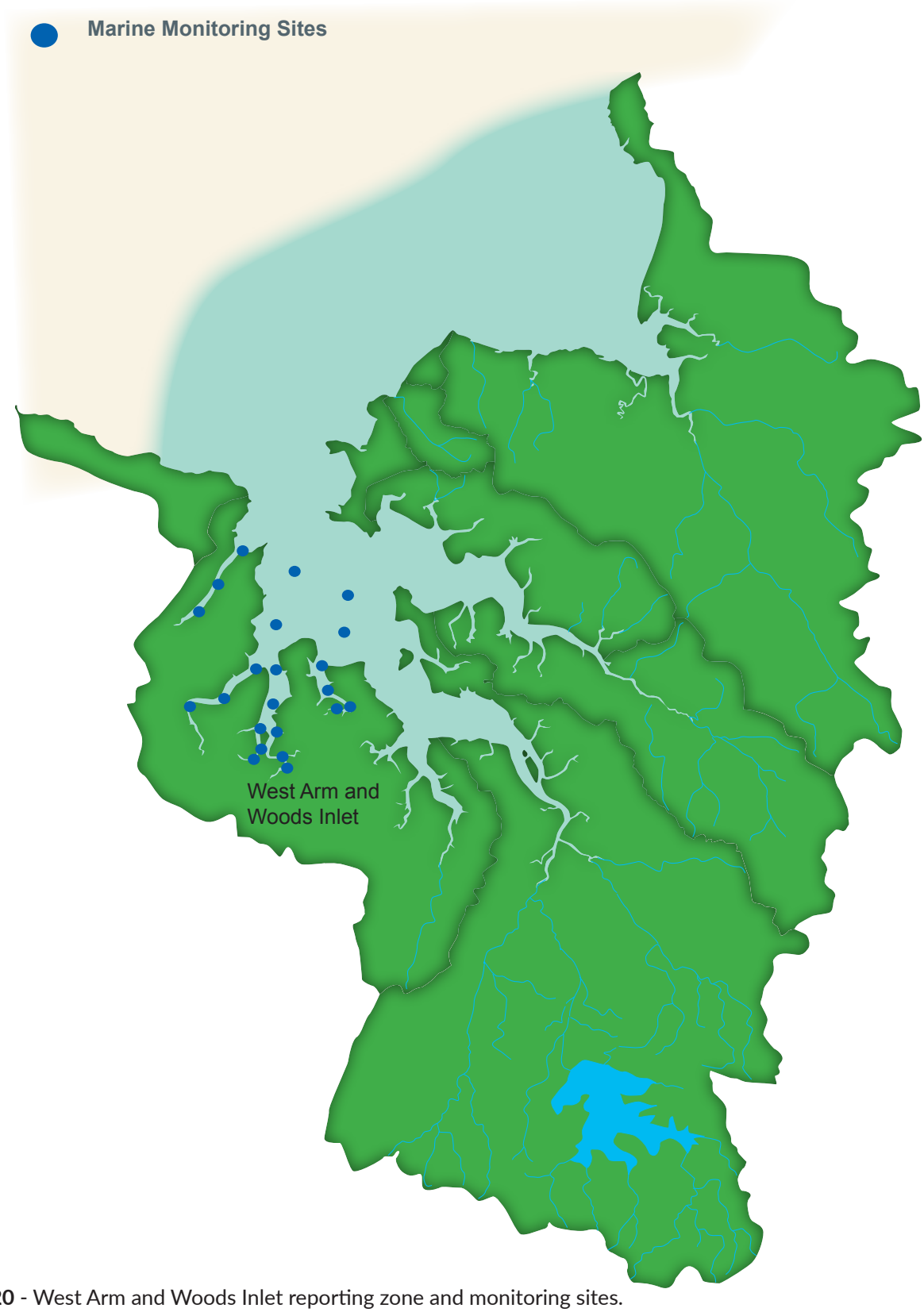


Figure 20 - West Arm and Woods Inlet reporting zone and monitoring sites.

5.10 West Arm

The Arm has extensive mangrove habitat, inter-tidal mudflats and large areas that are exposed on spring tides. The West Arm reporting zone includes a series of large tidal creeks and includes Woods inlet. The western boundary of Darwin Harbour comprises only minor development (small rural blocks of Cox Peninsula) with flows constrained to wet season run-off from a largely intact undisturbed catchment.

West Arm is considered to be undisturbed and typically used as 'reference' condition in Darwin Harbour. Figure 21 summarises the results of each water quality parameter measured.

Table 14 reports median values and 20th-80th percentiles (compliance), minimum and maximum values of the data measured.

Table 14 - Summary of water quality parameters measured in West Arm

Indicators	Water Quality Objectives	West Arm Min-max	median	20th and 80th percentiles	
pH	6.5-8.5	7.3-8.4	8.0	7.9	8.3
Dissolved Oxygen (% sat)	80-100	71-105	89.1	79.8	96.6
Turbidity (NTU)	<4	1.1-7.8	4.2	2.7	5.6
Chlorophyll-a (µg/L)	<4	0.21-3.42	1.1	0.7	2.1
NOx (µg/L)	<20	4.0-48	9.5	7.0	26.3
Ammonia (µg/L)	<20	10.0-35	18	15	22
Total Nitrogen (µg/L)	<300	80-360	180	150	203
Total Phosphorus (µg/L)	<30	5-19.0	6	5	10
Filterable Reactive Phosphorus (µg/L)	<10	1.0-9.0	2	1	4
2015 Rating	***B***				

All but the parameter of water clarity did not comply with the WQOs: Water quality within the West Arm monitoring zone is in very good condition.

No specific spatial or temporal trend has been identified in West Arm for the parameters studied over the last year maintaining very good water quality condition. The windy weather conditions during the dry season may have also influenced this zone of the harbour stimulating more turbid conditions during sampling.

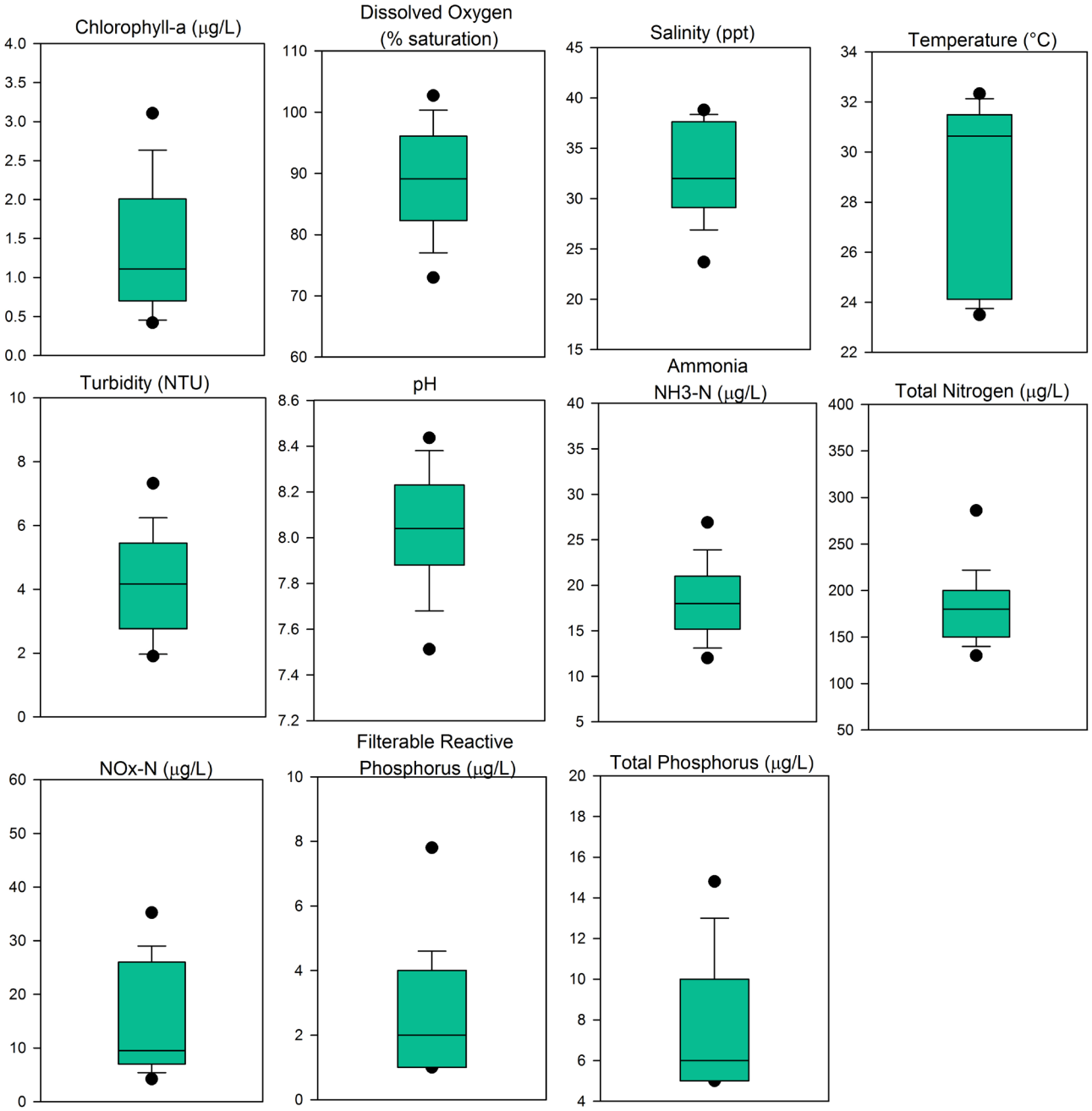


Figure 21. Water quality indicators measured in the West Arm reporting zone. Box plots show 5th, 10th, 25th, Median, 75th, 90th, and 95th percentiles.

6. Conclusion

For the 2015 reporting period (1 November 2014 – 30th October 2015) the water quality of the Darwin Harbour region was very good to excellent with the exception of Buffalo Creek. West Arm, Elizabeth River estuary, Blackmore River estuary, Outer Harbour, East Arm and Middle Harbour were graded B, with very good water quality. Shoal Bay, was graded an A with excellent water quality for the 2015 reporting year.

Buffalo Creek was an E (very poor) for the 2015 reporting year. This small system which enters Shoal Bay has had a long history of low grades due to continued treated wastewater discharge and the hydrodynamic constraints within the creek contributing to poor flushing and long residence times in the upper reaches.

Dissolved oxygen revealed significant variation in the 2015 reporting year. However these departures did not pose any need for further investigation and were more indicative of natural variation typically observed with tidal and spatial changes (Mauraud, 2013).

There has been no major change in the water quality of Darwin Harbour since reporting commenced. The system overall remains largely in very good condition with only small localised areas subject to degradation.

Potential sources of pollution to the waterways of Darwin Harbour include sediments, nutrients and other pollutants such as metals not included in the Report Card but reported elsewhere (Munskgaard et al. 2013; Munksgaard and Fortune, 2015; Fortune, 2015b). All these compounds can come from both 'point' and 'diffuse' sources, emanating from a specific location (i.e. sewage treatment plant) or from a wide area (i.e. stormwater during the wet season). These nutrient and sediment loads can have varying impact on water quality and have a more observable influence in the upper reaches of the estuary and smaller tidal creeks at the interface of the catchment.

The influence of the sewage treatment plant wastewater discharge is clear with the highest values for total nitrogen, total phosphorus, ammonia and filterable reactive phosphorus measured at sites adjacent to respective outfalls, particularly in Buffalo Creek. These systems represent extremes in water quality, however their influence remains localised and is not detected more broadly in the harbour.

Seasonal variations (dry vs wet season) and spatial variations (upper vs outer sites) have been previously identified as important factors driving water quality, amongst others (Fortune, 2015a). Clear gradients for many indicators are typical of the wet-dry macrotidal estuary given the extremes in physical forcings and seasonality.

Results from previous years have varied slightly but differences may be due to the location and the number of the sites sampled, the frequency and the time of the sampling event, the method and parameters used for the grade calculation and natural ecological processes affecting the environment.

7. References

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Rhizophora stylosa mangrove community - Buffalo Creek, Shoal Bay.

Sampling events and tidal stage for 2015 reporting year

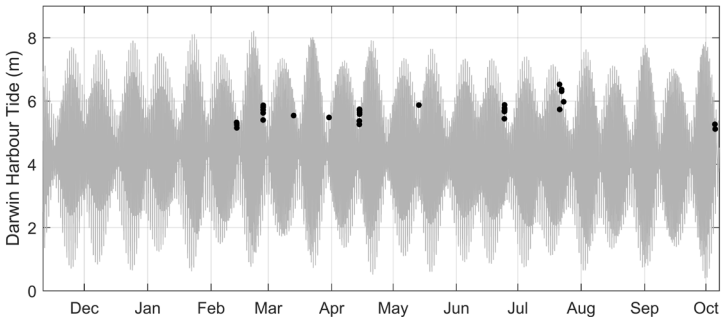

Figure 22 . Middle Harbour sampling times and tidal regime.

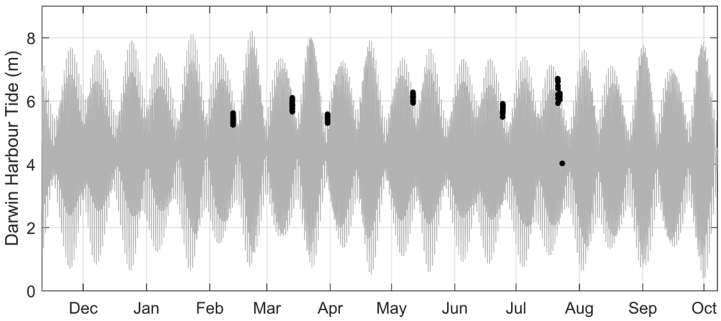

Figure 23. Elizabeth River sampling times and tidal regime.

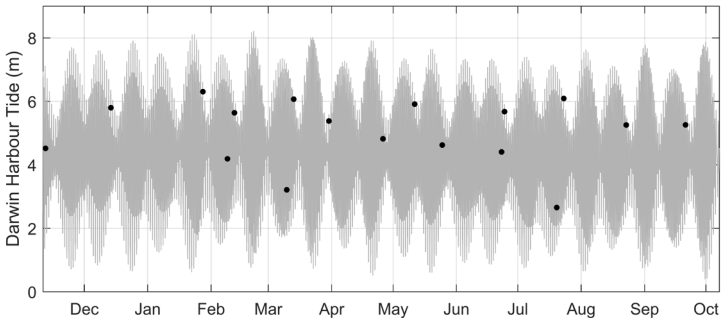

Figure 24. Myrmidon Creek sampling times and tidal regime.

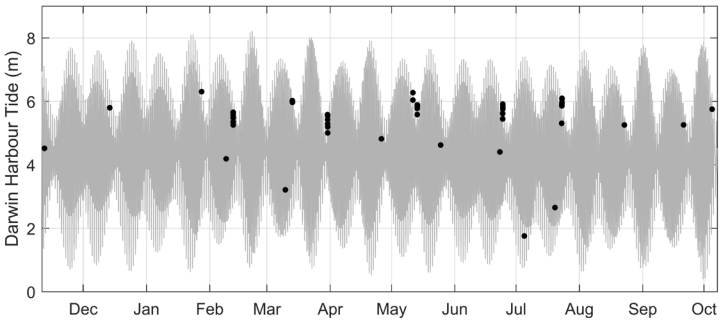

Figure 25. East Arm sampling times and tidal regime.

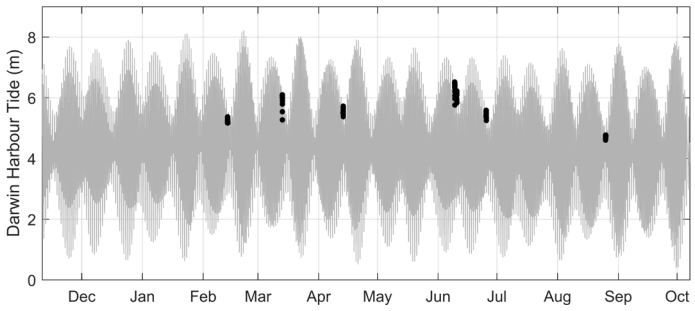

Figure 26. Blackmore River sampling times and tidal regime.

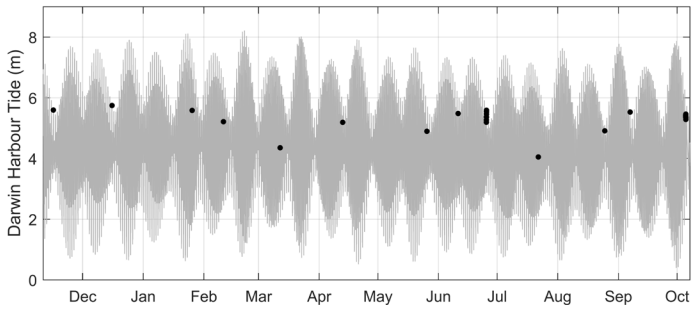

Figure 27. Shoal Bay sampling times and tidal regime.

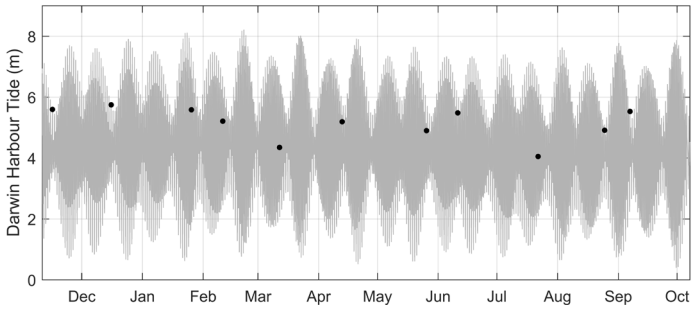

Figure 28. Buffalo Creek sampling times and tidal regime.

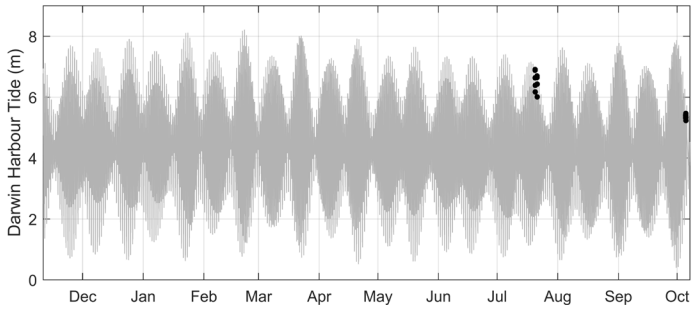

Figure 29. Outer Harbour sampling times and tidal regime.

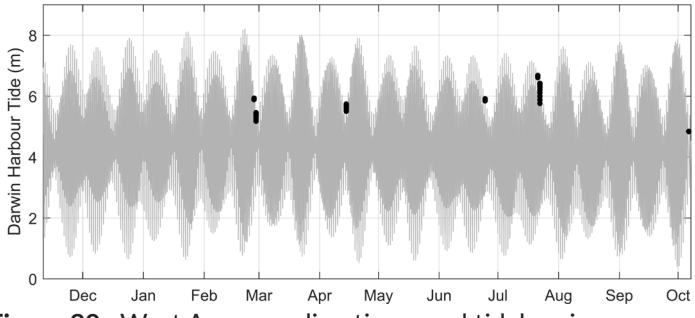

Figure 30. West Arm sampling times and tidal regime.

Each plot represents time and tidal stage of sampling events (black dots) at each reporting zone. Most sampling undertaken by the Aquatic Health Unit is standardised for neap tide however sampling by the Power and Water Corporation is aligned with monitoring for discharge licence requirements and not necessarily constrained to tide.

NORTHERN TERRITORY GOVERNMENT

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