GOVERNMENT OF
WESTERN AUSTRALIA

Cockburn Sound Annual Environmental Monitoring Report 2017–18

Assessment against the Environmental Quality Objectives and Criteria set in the State Environmental (Cockburn Sound) Policy

Cockburn Sound Management Council

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This publication is available at the Cockburn Sound Management Council's website < www.der.wa.gov.au/about-us/cockburn-sound-management-council > *or for those with special needs it can be made available in alternative formats such as audio, large print, or Braille.*

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Executive Summary

The Cockburn Sound marine area is managed by an environmental quality management framework established by the Environmental Protection Authority (EPA) through the State Environmental (Cockburn Sound) Policy 2015 (Government of Western Australia 2015). An essential component of the framework is environmental quality monitoring. This provides data for the measurement of environmental performance against the Cockburn Sound Environmental Quality Criteria (EQC) as described in the Environmental Quality Criteria Reference Document for Cockburn Sound (EPA 2015). The Cockburn Sound Management Council reports annually to the Minister for Environment on the environmental quality monitoring results for Cockburn Sound with specific reference to the Cockburn Sound EQC. This report presents the findings of the environmental quality monitoring for the period from 1 July 2017 to 30 June 2018.

Environmental Value: Ecosystem Health

Nutrient enrichment and phytoplankton biomass

The relevant Environmental Quality Guidelines (EQG) for nutrient enrichment and phytoplankton biomass (measured as chlorophyll α) were met at all of the Cockburn Sound water quality monitoring sites with the exception of the Jervoise Bay Northern Harbour site. A more detailed assessment of the Jervoise Bay Northern Harbour site found that the site met the Environmental Quality Standard (EQS) for phytoplankton biomass (measured as chlorophyll α).

With the exception of Mangles Bay and Jervoise Bay, median seagrass shoot densities at seagrass monitoring sites in Cockburn Sound were higher in 2018 than in 2017. However, seagrass shoot densities at the Warnbro Sound seagrass reference sites continued to decline, with a complete loss of seagrass at the 2.0 m depth site. The decline in shoot densities has been attributed to sediment erosion and potentially toxic sediment sulfides that have been found in the seagrass tissues (Fraser et al. 2016b).

Other physical and chemical stressors

The EQG for dissolved oxygen concentration were not met in the bottom waters at four water quality monitoring sites in Cockburn Sound on one or more sampling occasions. The four water quality monitoring sites did meet the EQS for dissolved oxygen concentration. No deaths of marine organisms were reported during the periods when low dissolved oxygen concentrations were recorded during the 2017–18 non river-flow sampling period.

Dissolved oxygen concentrations were also measured by the Water Corporation in the bottom waters at three monitoring sites in Cockburn Sound in July 2017, October 2017, December 2017 and May 2018. The Water Corporation monitoring site located in the High Protection Area - South and another site in the High Protection Area - North did not meet the high protection EQG for dissolved oxygen concentration in December 2017 and May 2018, respectively. Both sites did meet the high protection EQS for dissolved oxygen concentration.

Dissolved oxygen concentrations were measured by Fremantle Ports in the bottom waters at three sites around the Kwinana Bulk Jetty (KBJ) and three sites around the Kwinana Bulk Terminal (KBT) on 16 February 2018. The moderate protection EQG for dissolved oxygen concentration was met at all six sites.

With the exception of localised elevated salinities in bottom waters at two sites (CS9 and CS12) in the Moderate Protection Area – Eastern Sound, the EQC for protecting the marine ecosystem from the effects of the other physical and chemical stressors were met. The exceedances at sites CS9 and CS12 most likely reflect localised effects due to the sites close proximity to the saline water discharge from the Perth Seawater Desalination Plant.

The surface and bottom waters at all 18 water quality monitoring sites in Cockburn Sound met the relevant ‘Temperature’ and ‘pH’ EQG.

Toxicants in marine waters

Water samples from the marine waters around the KBT and KBJ were analysed for a range of toxicants, including ammonia, total recoverable hydrocarbons (TRHs) and benzene, toluene, ethylbenzene and xylene (BTEX). Concentrations of the toxicants in these samples were below the relevant EQG values or, where there are no EQG values, ‘low reliability value’ (LRV).

Toxicants in sediments

The EQC for toxicants in sediments were generally met in those areas where sampling and analysis were undertaken over the 2017–18 monitoring period. The exceptions were one slightly elevated concentration of mercury recorded in a sediment sample collected at KBT and elevated concentrations of mercury and cadmium in a sediment sample at KBJ, which has been attributed to the sampling method. Elevated concentrations of tributyltin (TBT), a highly toxic biocide previously used in anti-fouling paint, were also found in the KBJ sediment samples. An analysis of the elevated TBT sediment samples showed low bioavailability of the TBT. It is likely that the elevated TBT concentrations were a result of historical contamination.

There were no known reports of deaths of marine organisms during the 2017–18 reporting period that were attributed to anthropogenically-sourced stress.

These environmental monitoring results indicate that there is a high degree of certainty that the Environmental Quality Objective ‘Maintenance of ecosystem integrity’ is being achieved in Cockburn Sound.

Environmental Value: Fishing and Aquaculture

Water and shellfish tissue sampling was undertaken as part of the Western Australian Shellfish Quality Assurance Program (WASQAP). Water samples from two sites around KBT exceeded the EQG for faecal pathogens in water, but met the relevant EQS. The EQG for algal biotoxins, which are the ‘Alert’ levels that trigger management action in the WASQAP, were exceeded three times in July 2017 and once in January 2018 at the Southern Flats harvesting area.

The EQG for algal biotoxins were also exceeded twice, once in July 2017 and once in January 2018, at the Kwinana Grain Terminal harvesting area. The exceedances at the Southern Flats harvesting area triggered shellfish flesh testing for amnesic shellfish poisoning (ASP) biotoxin. The ASP testing did not find the biotoxin present in the tissue samples. As the Kwinana Grain Terminal harvesting area was closed at the time of the exceedance, no shellfish flesh testing was triggered. An analysis of toxicants in mussels from three KBJ and three KBT sites by Fremantle Ports found that toxicants in the mussels’ flesh were below the relevant EQG or EQS.

The assessment of dissolved oxygen and pH measured at four water monitoring sites close to the shellfish harvesting areas in Cockburn Sound found that the relevant EQG for the maintenance of aquaculture production were met at these sites.

Based on these findings, there is a high degree of certainty that the Environmental Quality Objectives for fishing and aquaculture were achieved during the reporting period.

Environmental Value: Recreational and Aesthetics

There were no recorded exceedances of the EQC for the Environmental Quality Objectives 'Maintenance of primary contact recreation values' and 'Maintenance of secondary contact recreation values'. Therefore, there is a high degree of certainty that the Environmental Quality Objectives were achieved and the waters are safe for recreational activities.

Environmental Value: Industrial Water Supply

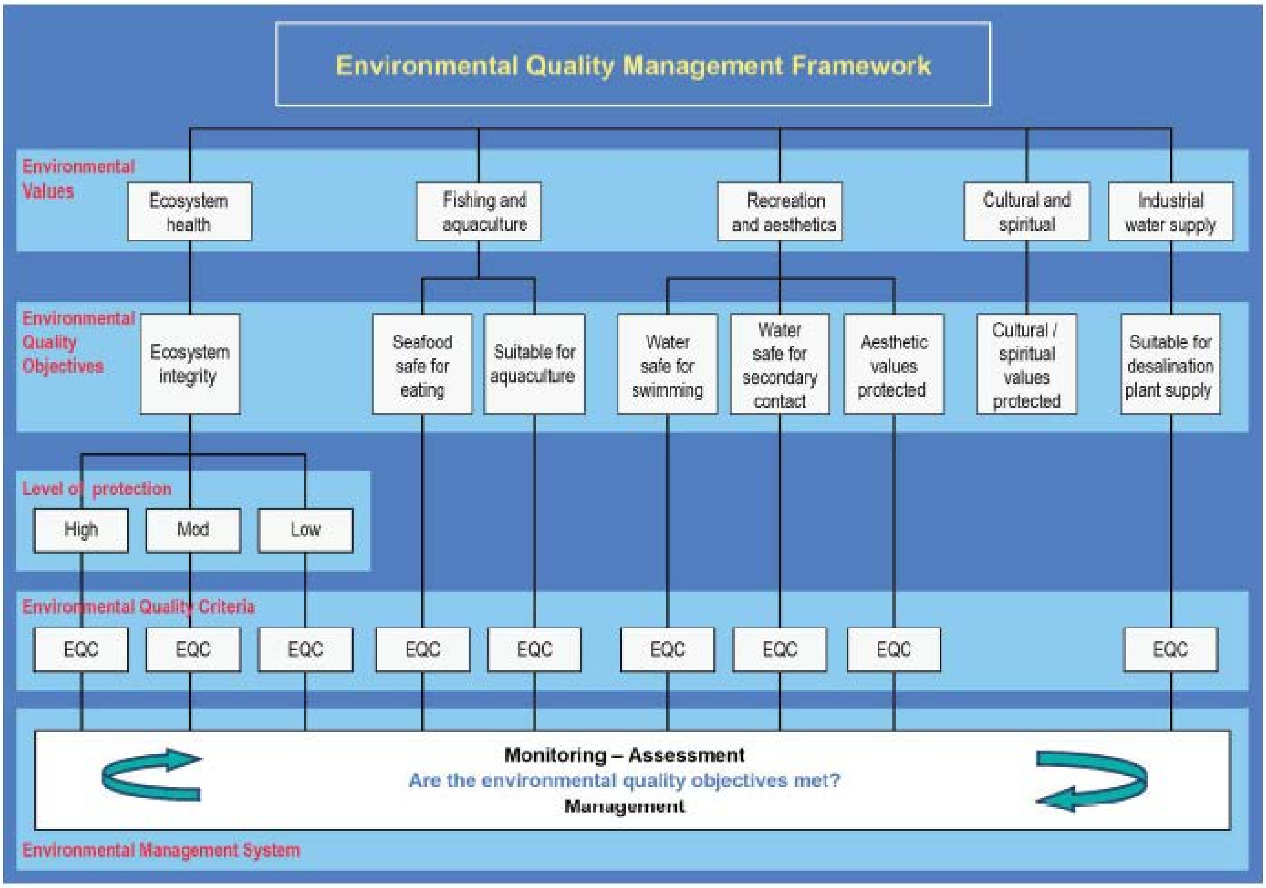
The results from the 2017–18 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant indicated there were minor exceedances of the EQG for Total Suspended Solids. The suitability of the quality of the intake seawater for the desalination process was not considered to have been compromised. Therefore, there is a high degree of certainty that the Environmental Quality Objective for industrial water supply has been achieved during the reporting period.

1. Introduction

The Cockburn Sound Management Council (Council) reports annually to the Minister for Environment on the results of environmental monitoring of the Cockburn Sound marine area and the extent to which the results meet the Environmental Quality Objectives and Environmental Quality Criteria in the *State Environmental (Cockburn Sound) Policy 2015*. This report presents the results for the 2017–18 monitoring period.

1.1 Environmental Quality Management Framework for Cockburn Sound

The Environmental Protection Authority (EPA) has established an environmental quality management framework for Cockburn Sound (Figure 1) through the *State Environmental (Cockburn Sound) Policy 2015* (Government of Western Australia 2015). This framework for Cockburn Sound's environmental quality management has been in place since 2005 under the first *State Environmental (Cockburn Sound) Policy 2005* (Government of Western Australia 2005). The objective of the environmental quality management framework is to maintain the Cockburn Sound's environmental quality in order to protect the integrity and biodiversity of the marine ecosystems, and current and projected future societal uses of these waters, from the effects of pollution, waste discharges and deposits (EPA 2017).



Source: Environmental Protection Authority (2017)

Figure 1. Environmental quality management framework for Cockburn Sound.

The environmental quality management framework is underpinned by:

- Environmental Values that recognise the importance of the marine environment for key uses that require protection from the effects of pollutants, waste discharges and deposits. One ecological and four social Environmental Values have been identified for protection in Cockburn Sound.
- Environmental Quality Objectives that identify the environmental quality needed to protect the Environmental Values that the community wants protected, and guide decision making and provide the common goals for management. Eight measureable Environmental Quality Objectives have been defined to support the five Environmental Values.
- Environmental Quality Criteria (EQC) for each Environmental Quality Objective, which provide the quantitative benchmarks against which environmental quality and the performance of environmental management can be measured. The EPA has defined EQC for Cockburn Sound to enable assessment of whether the environmental quality meets the objectives set in the State Environmental Policy.
- Monitoring and managing to ensure the Environmental Quality Objectives are achieved and/or maintained in the long-term in the areas for which they have been designated.

There are two types of EQC:

1. Environmental Quality Guidelines (EQG) are threshold numerical values or narrative statements which, if met, indicate there is a high degree of certainty that the associated Environmental Quality Objective has been achieved and the Environmental Values protected. If the EQG are not met, there is an increased risk that the associated Environmental Quality Objective may not be achieved and the Environmental Values are at risk. This triggers a requirement for more comprehensive assessment against an Environmental Quality Standard.
2. Environmental Quality Standards (EQS) are threshold numerical values or narrative statements that indicate a level beyond which there is a significant risk that the associated Environmental Quality Objective has not been achieved and that the Environmental Values are at risk. Investigation of the cause is needed and an adaptive management response is triggered if the exceedance continues.

The EQC that support the State Environmental Policy, and the decision schemes that explain how they are applied, are documented in the EPA's *Environmental Quality Criteria Reference Document for Cockburn Sound* (Reference Document; EPA 2017).

1.2 Monitoring Programs for Measuring Environmental Performance

An essential component of the environmental quality management framework is the implementation of appropriate monitoring programs to provide data for measuring environmental performance against the EQC (EPA 2017). The *Manual of Standard Operating Procedures for Environmental Monitoring against the Cockburn Sound Environmental Quality Criteria* (Standard Operating Procedures) (EPA 2005) specifies how samples should be collected and analysed, as well as how the results should be assessed against the EQC.

Under the State Environmental Policy responsibility for monitoring against the EQC is shared across a number of public authorities, based on their roles and responsibilities. Not all parameters for all environmental quality criteria are, or need to be, monitored on a regular basis, with relevant public authorities to determine what monitoring should be undertaken based on an assessment of risks and impacts. To facilitate the compilation and reporting of data and the adoption of appropriate responses, each year public authorities provide the results of that monitoring to the Council.

The environmental quality indicators that were measured through the monitoring programs for comparison against the EQC for Cockburn Sound, as well as the sources of these data, are summarised in Tables 1a and 1b.

The results are summarised and discussed in this report in the context of meeting the Environmental Quality Objectives and EQC for Cockburn Sound and encompass:

- maintenance of ecosystem integrity (Section 2);
- maintenance of seafood safe for human consumption (Section 3);
- maintenance of aquaculture (Section 3);
- maintenance of primary and secondary contact recreation values and aesthetic values (Section 4); and
- maintenance of water quality for industrial use (Section 5).

Ensuring that the quality of the waters of Cockburn Sound is sufficient to protect ecosystem integrity, protect the quality of seafood, allow people to recreate safely and maintain aesthetic values, may go some way towards maintaining cultural values with regards to the Environmental Value ‘Cultural and Spiritual’ (EPA 2017). It is more difficult to define spiritual values in terms of environmental quality requirements.

Table 1a. Environmental quality indicators and data sources reported in 2017–18.

<table>
<tr><th>Environmental Quality Objective</th><th colspan="2">Environmental Quality Criteria</th><th>Indicator</th><th>Data Source</th></tr>
<tr><td rowspan="11">Maintenance of ecosystem integrity</td><td rowspan="2">Physical and Chemical Stressors</td><td>Nutrients</td><td>Nutrient enrichment
• Chlorophyll a concentration
• Light attenuation coefficient
• Seagrass shoot density
• Seagrass lower depth limit
Phytoplankton biomass</td><td>Department of Water and Environmental Regulation (DWER)</td></tr>
<tr><td>Other physical and chemical stressors</td><td>Dissolved oxygen concentration
Water temperature
Salinity
pH</td><td>DWER, Water Corporation, Fremantle Ports, Department of Primary Industries and Regional Development (DPIRD)</td></tr>
<tr><td rowspan="4">Toxicants
(marine waters)</td><td>Metals and metalloids</td><td>Copper, Lithium, Manganese</td><td rowspan="4">DWER, Fremantle Ports</td></tr>
<tr><td>Non-metallic inorganics</td><td>Ammonia</td></tr>
<tr><td>Organics</td><td>Benzene, toluene, ethylbenzene, xylene (BTEX)</td></tr>
<tr><td>Oils and petroleum hydrocarbons</td><td>Total recoverable hydrocarbons (TRHs)</td></tr>
<tr><td rowspan="5">Toxicants
(sediments)</td><td>Metals and metalloids</td><td>Arsenic, Cadmium, Chromium, Copper, Lead, Lithium, Manganese, Mercury, Selenium Zinc</td><td rowspan="5">Fremantle Ports</td></tr>
<tr><td>Organometallics</td><td>Tributyltin (TBT), dibutyltin (DBT), monobutyltin (MBT)</td></tr>
<tr><td>Organics</td><td>Polycyclic aromatic hydrocarbons (PAHs)</td></tr>
<tr><td>Oils and petroleum hydrocarbons</td><td>TRHs</td></tr>
<tr><td>PFAS</td><td>PFOA, PFOS, PFHxS</td></tr>
</table>

Table 1b. Environmental quality indicators and data sources reported in 2017–18.

Environmental Quality Objective	Environmental Quality Criteria		Indicator	Data Source
Maintenance of seafood safe for human consumption	Biological contaminants		Faecal pathogens in water *Escherichia coli* (*E. coli*) in shellfish flesh Algal biotoxins	WA Shellfish Quality Assurance Program (WASQAP - Blue Lagoon Mussels), DPIRD
	Chemicals	Metals	Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Selenium, Zinc	WASQAP (Blue Lagoon Mussels), Fremantle Ports
		Organic chemicals	Polychlorinated biphenyls (PCBs) PAHs	
		Organometallics	TBT, DBT, MBT	
		Pesticides	Organochlorine pesticides (including Aldrin and Dieldrin, Benzene hexachloride [BHC], Chlordane, Dichlorodiphenyltrichloro-ethane [DDT], Dichloro-diphenyldichloroethylene [DDE] Dichlorodiphenyl-dichloroethane [DDD], Endosulfan, Heptachlor, Hexachlorobenzene [HCB]), Organophosphate pesticides (including Chlorpyrifos, Diazinon, Dichlorvos, Fenitrothion)	
Maintenance of aquaculture	Physical and chemical stressors		Dissolved oxygen, pH	DWER
	Toxicants	Non-metallic inorganic chemicals	Ammonia, Nitrate–Nitrite	DWER, Fremantle Ports
		Metals and metalloids	Copper, Manganese	
Maintenance of primary contact recreation values	Biological		Faecal pathogens	Department of Health (DoH)
	Physical		pH, Water clarity	DWER
	Toxic chemicals	Inorganic chemicals	Copper, Manganese, Nitrate–Nitrite	DWER, Fremantle Ports
		Organic chemicals	BTEX	
Maintenance of secondary contact recreation values	Biological		Faecal pathogens	DoH
	Physical and chemical		pH	DWER
			Toxic chemicals	DWER, Fremantle Ports
Maintenance of water quality for industrial use	Biological		*Escherichia coli* (*E. coli*)/ *Enterococci*	Water Corporation
	Physical and chemical		Temperature, pH, Dissolved oxygen, Total suspended solids, Hydrocarbons, Boron, Bromide	

2. Environmental Value: Ecosystem Health

2.1 Environmental Quality Objective

The Environmental Quality Objective for the Environmental Value 'Ecosystem Heath' is 'Maintenance of ecosystem integrity'. Ecosystem integrity is considered in terms of structure (for example the biodiversity, biomass and abundance of biota) and function (for example food chains and nutrient cycles) (EPA 2017). Achieving the Environmental Quality Objective is dependent on ensuring that environmental quality is maintained within acceptable levels.

2.2 Levels of Protection

The State Environmental Policy describes three levels of ecological protection (high protection, moderate protection and low protection) that apply to Cockburn Sound and where they apply spatially in the protected area so that overall ecological integrity can be maintained (Figure 2).

Most of Cockburn Sound is designated as having a high level of ecological protection (delineated as High Protection Area North [HPA-N] and High Protection Area South [HPA-S])[1] and the EQC for maintaining environmental quality at a high level apply.

The following areas have been designated as having a moderate level of ecological protection, where waste disposal and other societal uses preclude a high level of ecological protection: Careening Bay on Garden Island (Moderate Protection Area Careening Bay [MPA-CB]); and along the eastern margin of Cockburn Sound adjacent to the industrial area (Moderate Protection Area Eastern Sound [MPA-ES]). The EQC for maintaining environmental quality at a moderate level apply in these areas. The moderate level of ecological protection area on the eastern side of Cockburn Sound (MPA-ES) also includes several harbours and marinas, which are assessed individually (Moderate Protection Area Southern Harbour [MPA-SH] and Moderate Protection Area Northern Harbour [MPA-NH]).[2]

A few small areas around outfalls in Cockburn Sound (less than one per cent of the protected area) have been designated as having a low level of ecological protection. For these areas, EQG have been proposed for those toxicants identified as having the potential to adversely bioaccumulate or biomagnify.

The acceptance of different levels of ecological protection is based on the recognition that when managing environmental quality, other societal benefits also need to be considered (for example use of marine waters for receiving waste and the economic benefits of industrial development). These other benefits may preclude a high level of quality being achieved in some areas (EPA 2017). The levels of ecological protection represent the minimum acceptable level of environmental quality to be achieved through management of Cockburn Sound. They do not necessarily describe the current, or preferred, environmental condition of Cockburn Sound.

[1] In 2013, in recognition that the southern area of Cockburn Sound has different environmental characteristics to the northern, better flushed area, the Cockburn Sound Management Council began reporting on two separate areas within the existing High Ecological Protection Area (HEPA) for ecosystem health parameters.

[2] The Reference Document identifies that it may be appropriate to monitor a subset of indicators for some marinas and harbours depending on potential threats to environmental quality and the benthic habitats present (for example monitoring and assessment of chlorophyll *a* concentrations and light attenuation coefficients in a marina may be unnecessary if seagrass is not present).

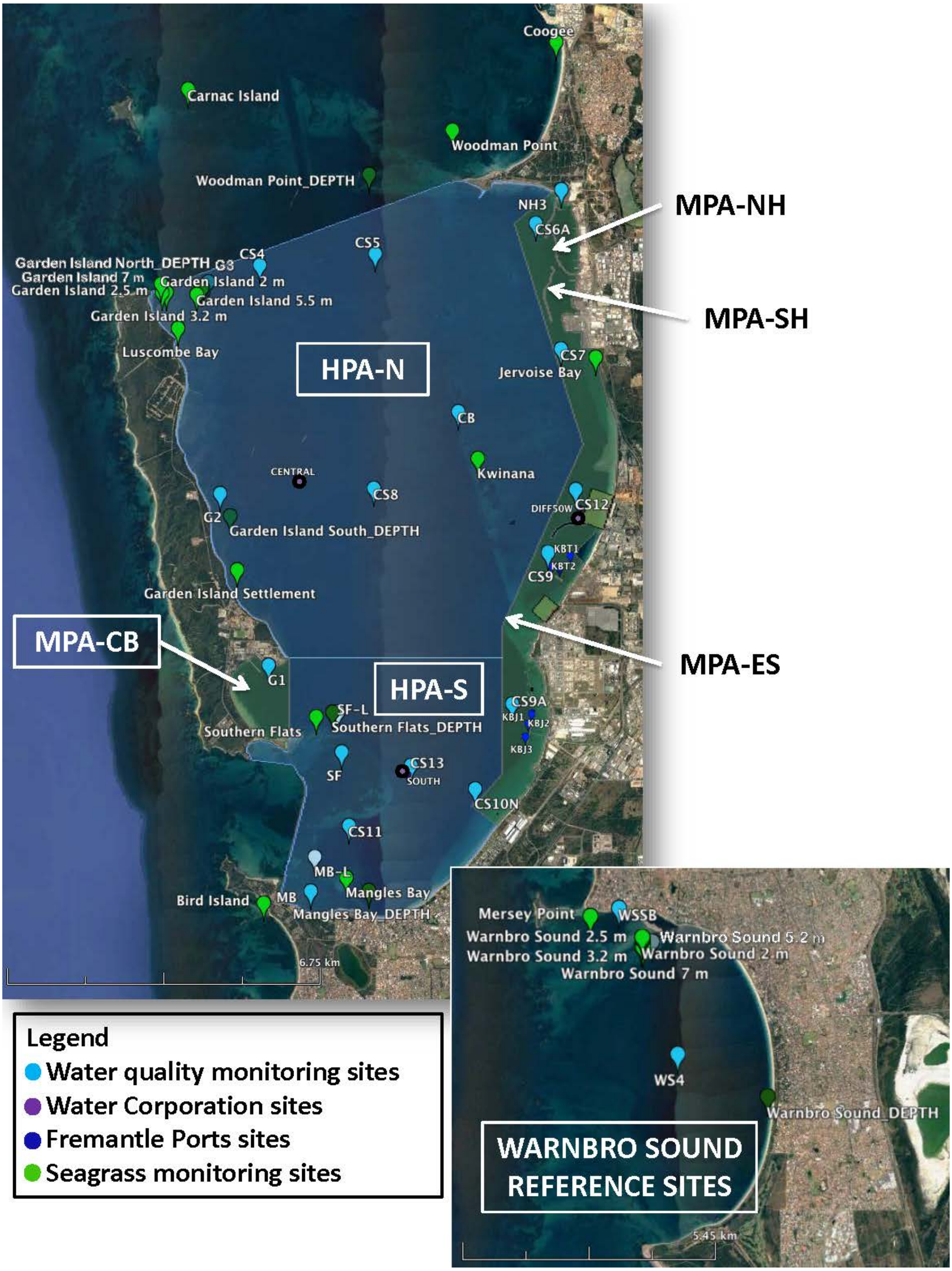


Figure 2. The ecological protection areas in Cockburn Sound and the location of water quality, sediment quality and seagrass monitoring sites in Cockburn Sound and reference sites in Warnbro Sound.

The details of the water quality, sediment contaminant and seagrass monitoring sites in each ecological protection area in Figure 2 are provided in Table 2 below.

Table 2. The high and moderate ecological protection areas for Cockburn Sound and the associated water quality, sediment contaminant and seagrass monitoring sites.

Ecological Protection Area	Water Quality Monitoring Sites	Seagrass Monitoring Sites	Toxicants in Sediment or Water Monitoring Sites
High Protection Area North (HPA-N)	CS4, CS5, CS8, G2, G3 and CB; Central	Garden Island 2.0 m, 2.5 m, 3.2 m, 5.5 m and 7.0 m; Luscombe Bay, Garden Island Settlement, Kwinana Garden Island North_DEPTH, Garden Island South_DEPTH	
High Protection Area South (HPA-S)	CS11, CS13, Southern Flats (SF/SF-L) and Mangles Bay (MB/MB-L); South *Light attenuation measured at MB-L (since December 2014) and SF-L (since December 2015) located close to the shallow sites*	Southern Flats, Mangles Bay	
Moderate Protection Area Careening Bay (MPA-CB)	G1		
Moderate Protection Area Eastern Sound (MPA-ES)	CS6A, CS7, CS9, CS9A, CS10N and CS12; DIFF50W	Jervoise Bay	Sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) monitored for toxicants in water and sediment
Moderate Protection Area Northern Harbour (MPA-NH)	Jervoise Bay Northern Harbour (NH3)		
Moderate Protection Area Southern Harbour (MPA-SH)	Not currently monitored		
Reference sites	WS4, WSSB/WSSB-L *Light attenuation measured at WSSB-L located close to the shallow site WSSB since December 2015*	Warnbro Sound (WS) 2.0 m, 2.5 m, 3.2 m, 5.2 m, 7.0 m Warnbro Sound_DEPTH Other seagrass sites outside Cockburn Sound which are also monitored: Coogee, Woodman Point, Carnac Island, Bird Island, Mersey Point, Woodman Point_DEPTH	

2.3 Water Quality and Sediment Quality Monitoring

Between 1 December 2017 and 26 March 2018 (the summer non river-flow period) Murdoch University's Marine and Freshwater Research Laboratory (MAFRL) took water samples to analyse water quality at 18 sites in Cockburn Sound and two reference sites in Warnbro Sound (Figure 2; Table 2). This was done on 16 occasions, generally at weekly intervals.

On each sampling occasion:

- A depth-integrated water sample was collected at each site for analysis of nutrients (ammonium, nitrate–nitrite, filterable reactive phosphorus, total nitrogen and total phosphorus) and chlorophyll *a*. The samples were processed in the field and stored on ice for transport to the laboratory. Samples were analysed using standard laboratory analytical procedures in accordance with the laboratory's quality system (AS ISO/IEC 17025) and the terms of the National Association of Testing Authorities, Australia (NATA) accreditation held by the laboratory.[3]
- At the deep sites CS13 and WS4, discrete surface and bottom samples were collected for nutrient analysis to identify differences in nutrient concentrations between the surface water and near the water-sediment interface.
- Physical-chemical parameters (water depth, water temperature, salinity, pH, turbidity, dissolved oxygen and chlorophyll *a* by fluorescence) were measured *in situ* at each site using a Sea-Bird Electronics SBE19*plus* V2 SeaCAT Profiler CTD (Conductivity, Temperature and Pressure) fitted with a SBE43 oxygen sensor, SBE18 pH sensor and a Turner Designs SCUFA combination fluorometer-turbidity sensor. The equipment was checked and calibrated prior to the commencement of sampling every week. Secchi depth was measured using a 20 centimetre (cm) diameter Secchi disc.
- Irradiance (light attenuation) was simultaneously measured using two underwater light sensors (Model LI-1400 Licor Inc.) to correct for changes in ambient conditions, with sensors positioned one metre (m) and seven metres below the surface. The light attenuation coefficient was calculated as:

$$\textit{Attenuation coefficient} = \frac{\log_{10}(\textit{Irradiance at 1 m}) - \log_{10}(\textit{Irradiance at 7 m})}{\textit{Depth Interval (6 m)}}$$

The Water Corporation undertook quarterly measurements (25 July 2017, 2 October 2017, 5 December 2017 and 17 May 2018) of the physical-chemical parameters dissolved oxygen, salinity and temperature as depth profiles through the water column. This was done at three sites in Cockburn Sound (South, Central, DIFF50W; Figure 2), as well as sites on Parmelia Bank and in Owen Anchorage.

Fremantle Ports undertook monitoring of toxicants in marine waters and sediments at three sites around the Kwinana Bulk Terminal (KBT1, KBT2 and KBT3; Figure 2) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2 and KBJ3; Figure 2). Water quality samples were collected on 16 February 2018 as well as measurements of the physical-chemical parameters dissolved oxygen, salinity and temperature as depth profiles through the water column.

At each site, water samples were collected from approximately 0.5 m below the

[3] The low-level method for ammonia is not covered under the laboratory's scope of accreditation, but has been validated to the same standards as all the other accredited methods.

surface and approximately 0.5 m above the seabed. The samples were processed in the field and stored on ice for transport to the laboratory. Samples were analysed by MAFRL for nutrients, chlorophyll *a* and filtered copper. Samples collected at the Kwinana Bulk Terminal sites were also analysed for lithium and filtered manganese. Samples were analysed by ChemCentre for total recoverable hydrocarbons (TRHs), benzene, toluene, ethylbenzene and xylene (BTEX).

Sediment samples were collected on 15 March 2018 at all six sites. Five 100 millimetre (mm) diameter sediment cores were collected within one square metre (m^2) at each site using polycarbonate corers. The top two centimetres of each core was separated and homogenised into one composite sample from each site. The sediment samples were stored on ice for transport to the laboratory. The samples were analysed by ChemCentre for Total Organic Carbon, metals (arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (tributyltin [TBT], dibutyltin [DBT] and monobutyltin [MBT]), polycyclic aromatic hydrocarbons (PAHs) and TRHs. Sediment samples collected at the Kwinana Bulk Terminal sites were also analysed for lithium and manganese.

Methods followed those outlined in the Standard Operating Procedures and standard laboratory analytical procedures were employed throughout. Laboratories with NATA-accredited methods (or laboratories with demonstrated Quality Assurance/Quality Control procedures in place) undertook the analyses.

2.4 Seagrass Monitoring

The University of Western Australia and the Department of Biodiversity, Conservation and Attractions undertook seagrass monitoring at 11 'potential impact' sites and two 'depth limit' sites in Cockburn Sound; five 'potential impact' sites and one 'depth limit' site outside Cockburn Sound in Owen Anchorage and the Shoalwater Islands Marine Park; and five reference sites and one 'depth limit' site in Warnbro Sound (Figure 2; Table 2). In 2017 two additional 'depth limit' sites were established at Mangles Bay and Southern Flats in HPA-S. The sites were monitored between February and March 2018.

The numbers of *Posidonia sinuosa*[4] and *Posidonia australis* shoots were recorded in each of 24 fixed 20 cm by 20 cm quadrats located along four[5] 10 m transects at each 'potential impact' and reference site. Shoot density data are normalised to one square metre (m^2). The height of the tallest shoot (maximum shoot height) and mean shoot height were measured in each quadrat. At each site, 10 one metre by one metre photographic quadrats were taken at a standard height (one metre) and at approximately one metre intervals along each transect, to provide a permanent record and allow for quantitative estimates of seagrass percentage cover.

At each of the six 'depth limit' sites, seagrass shoot density and canopy height were measured in quadrats located every two metres along three 20 m transects, which extend down the depth gradient of the seagrass meadow. The Lower Depth Limit (LDL) of seagrass distribution along each transect was recorded, as well as the depth at that point.

Monitoring was undertaken in accordance with Lavery and Gartner (2008) and the

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[4] Only counts of *Posidonia sinuosa* were assessed against the seagrass EQC. *Posidonia sinuosa* is one of the large meadow-forming and long-lived seagrass species in Cockburn Sound and is the dominant species at all of the monitoring sites.

[5] Except at Woodman Point and Warnbro Sound 3.2 m, where there are five transects.

Standard Operating Procedures.

2.5 Assessment against the 'Nutrient Enrichment' and 'Phytoplankton Biomass' Environmental Quality Criteria

The nutrient-related EQC address the issue of nutrient enrichment and were derived to achieve three key objectives:

- protection of the remaining seagrass meadows in Cockburn Sound;
- maintenance of a level of water quality that would enable seagrass meadows to re-establish along the eastern side of Cockburn Sound, including the Jervoise Shelf, to depths of up to 10 m; and
- minimisation of the occurrence and extent of phytoplankton blooms in Cockburn Sound (EPA 2017).

2.5.1 Re-calculation of the 2017–18 EQC for Chlorophyll *a*, Light Attenuation Coefficient, Phytoplankton Biomass and Seagrass Shoot Density

Chlorophyll *a*, Light Attenuation Coefficient and Phytoplankton Biomass

The EQC for chlorophyll *a*, light attenuation coefficient and phytoplankton biomass are based on 'rolling' percentiles and, consistent with Section 3.1.2 in the Reference Document, are re-calculated and updated each year. This was done using the monitoring results from the Warnbro Sound reference site (WS4) collected during 2017–18 and the five previous summers. Where the reference site data are outside the 'normal bounds',[6] new data are not incorporated into the historical reference dataset or used to recompute a new set of 'rolling' percentile-based EQG.

For the 2017–18 monitoring period, the chlorophyll *a* and light attenuation coefficient annual medians at WS4 were within their respective historical ranges (Table 3) and the 2017–18 data were therefore included in the re-calculation of the EQG (Table 4).

Table 3. Assessment of the 2017–18 chlorophyll *a* concentration and light attenuation coefficient (LAC) medians against the 20th and 80th percentiles of the WS4 historical dataset.

	Chlorophyll *a* (micrograms per litre [μg/L])	LAC ($\log_{10}$ m^{-1})
Historical dataset 20th percentile	0.40	0.066
Historical dataset 80th percentile	0.90	0.091
2017–18 median	0.65	0.076
Assessment	Met criteria specified in the Reference Document	Met criteria specified in the Reference Document
	2017–18 data included in the 2017–18 EQG calculations	

[6] If the median of the current year's reference site data is greater than the 80th percentile or lower than the 20th percentile of the historical dataset, it is accepted that the reference site data have shifted outside the 'normal bounds'.

Table 4. The 2017–18 high protection and moderate protection EQG for chlorophyll *a* concentration and light attenuation coefficient (LAC).

Indicator	High Protection Rolling 6-year 80th percentile	Moderate Protection Rolling 6-year 95th percentile
Chlorophyll *a* (µg/L)	1.10	1.80
LAC (log_{10} m^{-1})	0.096	0.114

Median chlorophyll *a* concentrations at the Warnbro Sound reference site WS4 were around 0.7 micrograms per litre (µg/L) in the late 1970s/early 1980s and 1990s and decreased to 0.4 µg/L in the mid-2000s. Since 2010–11, median chlorophyll *a* concentrations have varied between 0.6 µg/L and 0.85 µg/L.

Over the duration of the monitoring program there has been an increase in the occurrence of higher chlorophyll *a* concentrations reported at WS4. The highest recorded chlorophyll *a* concentration was 3.1 µg/L in 2016–17 and the second highest was 2.2 µg/L in 2012–13. In 2017-18, the highest recorded chlorophyll *a* concentration at WS4 was 1.1 µg/L, which was the lowest since 2010-11. Prior to 2010–11, a chlorophyll *a* concentration greater than 1.4 µg/L had been recorded on only one occasion (1.8 µg/L in 2002–03) since chlorophyll *a* concentrations were first measured at WS4.

There has been a corresponding increase in the EQG for chlorophyll *a* in recent years. The high protection EQG was:

- 0.7 µg/L in 2009–10;
- 0.8 µg/L in 2010–11 and 2011–12;
- 0.9 µg/L in 2012–13 and 2013–14;
- 1.0 µg/L in 2014–15 and 2015–16; and
- 1.1 µg/L in 2016-17.

This trend continued in 2017-18. The high protection EQG for chlorophyll *a* for this period was 1.1 µg/L.

The moderate protection EQG was:

- 1.0 µg/L in 2009–10;
- 1.2 µg/L in 2011–12 and 2012-13;
- 1.5 µg/L in 2013-14, 2014–15 and 2015–16; and
- 1.8 µg/L in 2016–17 and 2017–18.

The re-calculated EQC for phytoplankton biomass are presented in Table 5.

Table 5. The 2017–18 high protection and moderate protection EQC for phytoplankton biomass.

	High Protection Rolling 6-year median	Moderate Protection Rolling 6-year 80th percentile
Chlorophyll *a* (µg/L)	0.70	1.10
Conversion factor[7]	x 3	x 3
EQG	2.10	3.30

Seagrass shoot density

The EQS for *Posidonia sinuosa* shoot densities are based on 'rolling' four-year percentiles and, consistent with Section 3.1.2 in the Reference Document, are re-calculated and updated each year using the monitoring results for each monitored depth at the Warnbro Sound reference site. Seagrass shoot densities at the reference sites in Warnbro Sound have continued to exhibit significant declines in shoot density (Mohring and Rule 2014; Rule 2015; Fraser *et al*. 2016a, 2017; Fraser *et al.* 2018).

Mean shoot densities at Warnbro Sound (WS) 3.2 m and 5.2 m have shown a statistically significant (α=0.05) decline since 2006 (Fraser *et al.* 2018). At WS 2.5 m, the decline in mean shoot density approached significance (α=0.2). Similarly, median shoot densities at WS 3.2 m showed a statistically significant decline (α=0.05) since 2006 and at WS 2.5 m and 5.2 m, the decline in median shoot densities approached statistical significance (α=0.2). No significant trends in mean or median shoot densities were observed at 7.0 m for the period from 2006 to 2018.

Compared to the shoot densities recorded in 2017, mean shoot densities decreased at WS 2.5 m, 3.2 m and 7.0 m, but slightly increased at the WS 5.2 m (Fraser *et al*. 2018). At WS 3.2m, the mean shoot density in 2018 (310 shoots/m^2) was less than half of the mean shoot density in 2017 (657 shoots/m^2), which may have been in part due to the decrease in the number of quadrats observed with seagrass shoots at this site (from 21 quadrats in 2017 to 10 quadrats in 2018). There was a complete loss of seagrass in and around WS 2.0 m. The 2018 median shoot density at WS 2.5 m was the same as for 2017, while the median decreased at WS 3.2 m from 700 shoots/m^2 in 2017 to 425 shoots/m^2 and at WS 5.2 m, from 700 shoots/m^2 to 525 shoots/m^2. There was a slight decrease in the median shoot density from 250 shoots/m^2 in 2017 to 225 shoots/m^2 in 2018.

The Reference Document recommends that the EQS are calculated using 100 data points, which allows the first percentile to be calculated with a high degree of confidence (Lavery and McMahon 2011). The 'rolling' four-year percentiles for the Warnbro Sound 2.0 m site were calculated using data from 38 quadrats, which is considerably less than that recommended in the Reference Document.

The re-calculated EQS for each depth are presented in Table 6.

[7] The Reference Document sets out that the EQC is three times the median chlorophyll *a* concentration of the reference site for high ecological protection areas and three times the 80th percentile of chlorophyll *a* concentration at the reference site for moderate ecological protection areas.

Table 6. The 2018 high protection and moderate protection EQS for seagrass shoot density.

Reference Site	Rolling 4-year 20th percentiles of seagrass shoot density (shoots per square metre [shoots/m^2])	Rolling 4-year 5th percentiles of seagrass shoot density (shoots/m^2)	Rolling 4-year 1st percentiles of seagrass shoot density (shoots/m^2)
Warnbro Sound 2.0 m	500	299	71
Warnbro Sound 2.5 m	475	133	48
Warnbro Sound 3.2 m	260	75	25
Warnbro Sound 5.2 m	400	269	195
Warnbro Sound 7.0 m	100	50	25

The results of Mann-Kendall trend analyses of the EQS for seagrass shoot density are presented in Table 7. The 'rolling' four-year percentiles of seagrass shoot density showed significant downward trends at all of the reference sites except at WS 5.2 m. The downward trends were statistically significant ($\alpha = 0.05$) for the 'rolling' four-year 20th percentiles reported for WS 2.0 m, 3.2 m and 7.0 m; 5th percentiles reported for WS 2.0 m, 2.5 m and 7.0 m; and 1st percentiles reported for WS 2.0 m, 2.5 m and 3.2 m.

Table 7. Results of Mann-Kendall trend analyses of the high protection and moderate protection EQS for seagrass shoot density.

Reference Site	Rolling 4-year 20th percentiles of seagrass shoot density (shoots per square metre [shoots/m^2])		Rolling 4-year 5th percentiles of seagrass shoot density (shoots/m^2)		Rolling 4-year 1st percentiles of seagrass shoot density (shoots/m^2)	
	Mann-Kendall Statistic	*p*-value (two-tailed test)	Mann-Kendall Statistic	*p*-value (two-tailed test)	Mann-Kendall Statistic	*p*-value (two-tailed test)
Warnbro Sound 2.0 m	-0.79	**0.002**	-0.80	**0.0002**	-0.74	**0.0008**
Warnbro Sound 2.5 m	-0.37	*0.1*	-0.73	**0.0008**	-0.90	**0.00004**
Warnbro Sound 3.2 m	-0.48	**0.027**	-0.37	*0.1*	-0.76	**0.0008**
Warnbro Sound 5.2 m	-0.28	0.23	-0.22	0.33	-0.38	*0.09*
Warnbro Sound 7.0 m	-0.76	**0.0008**	-0.56	**0.013**	-0.30	0.24

Note: *p*-values < 0.05 are shown in bold; *p*-values < 0.2 are shown in italics.

Sediment erosion and the development of 'blow outs' have been identified as potential causes of the decline in shoot densities at the Warnbro Sound reference sites, with some sites (e.g. WS 2.0 m) experiencing rapid erosion that has resulted in the loss of transects (Mohring and Rule 2014; Rule 2015). Sand scour was identified in 2005 (two years after the reference sites were established) as a possible cause of the significant declines in shoot densities recorded at WS 2.0 m (Lavery and Westera 2005). Significant decreases in shoot densities at WS 3.2 m were also reported in 2005. Relatively high levels of intrusion of potentially toxic sediment sulfides into seagrass tissues have been reported at the reference sites which may also be contributing to the declines observed at these sites (Fraser *et al.* 2016b).

2.5.2 Assessment of Compliance with the 'Nutrient enrichment' EQC

Chlorophyll *a* and Light Attenuation

Chlorophyll *a* concentrations and light attenuation coefficients were recorded at the 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.3; Figure 2). They were assessed against the 'Nutrient enrichment' EQG (EQG A, Table 1a, Reference Document) over the 2017-18 non river-flow period:

High protection: *The median chlorophyll a concentration/light attenuation coefficient in HPA-N and HPA-S during the 2017–18 non river-flow period is not to exceed a chlorophyll a concentration of 1.10 µg/L or a light attenuation coefficient of 0.096 log_{10} m^{-1}.*

Moderate protection: *The median chlorophyll a concentration/light attenuation coefficient in MPA-ES and MPA-CB during the 2017–18 non river-flow period is not to exceed a chlorophyll a concentration of 1.80 µg/L or a light attenuation coefficient of 0.114 log_{10} m^{-1}.*

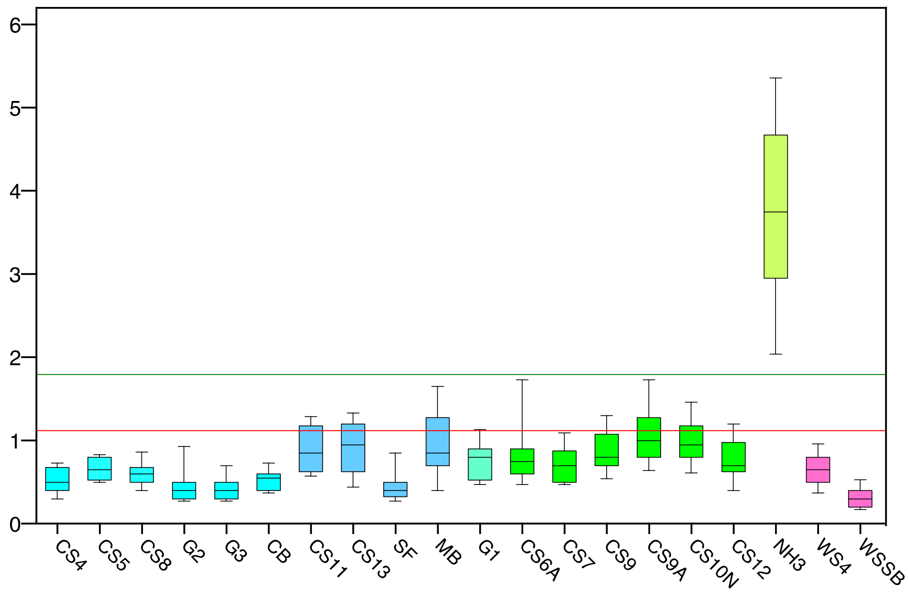
The results are presented in Table 8 and Figures 3, 4, 5 and 6. The 'Nutrient enrichment' EQG for chlorophyll *a* and light attenuation were met in HPA-N, HPA-S, MPA-CB, and MPA-ES.

Table 8. Assessment of chlorophyll *a* concentrations and light attenuation coefficients (LAC) against the 'Nutrient enrichment' EQG for each ecological protection areas and 18 individual sites (2017–18).

Ecological Protection Area	Site	Chlorophyll *a* (µg/L)			LAC (log_{10} m^{-1})			Assessment
		2017–18 EQG	2017–18 Site median	2017–18 Ecological Protection Area median	2017–18 EQG	2017–18 Site median	2017–18 Ecological Protection Area median	
HPA-N	CS4	1.1	0.5	0.5	0.096	0.075	0.077	EQG met
	CS5		0.65			0.077		
	CS8		0.6			0.077		
	CB		0.55			0.092		
	G2		0.4			0.080		
	G3		0.4			0.073		
HPA-S	CS11	1.1	0.85	0.7	0.096	0.092	0.086	EQG met
	CS13		0.95			0.085		
	SF		0.4			0.080		
	MB/MB-L		0.85			0.091		
MPA-CB	G1	1.8	0.8	0.8	0.114	0.087	0.087	EQG met
MPA-ES	CS10N	1.8	0.95	0.8	0.114	0.097	0.099	EQG met
	CS12		0.7			0.092		
	CS6A		0.75			0.103		
	CS7		0.7			0.111		
	CS9		0.8			0.093		
	CS9A		1.0			0.110		
MPA-NH	NH3	N/A	3.8	3.8	N/A	0.151	0.151	N/A

Note: 'N/A' indicates that the 'Nutrient enrichment' EQG were not applied due to the absence of macro-benthic primary producers.

The highest chlorophyll *a* concentrations and light attenuation coefficients were recorded at Jervoise Bay Northern Harbour (NH3) in MPA-NH; however, due to the absence of macro-benthic primary producers (for example seagrass) within the harbour, the 'Nutrient enrichment' EQG were not applied in this area. This is consistent with the Reference Document which considers that it may be appropriate to monitor a subset of indicators for some marinas and harbours depending on the potential threats to environmental quality and the benthic habitats present (for example monitoring and assessment of light attenuation coefficients and chlorophyll *a* concentrations in a marina may be unnecessary if seagrass is not present).



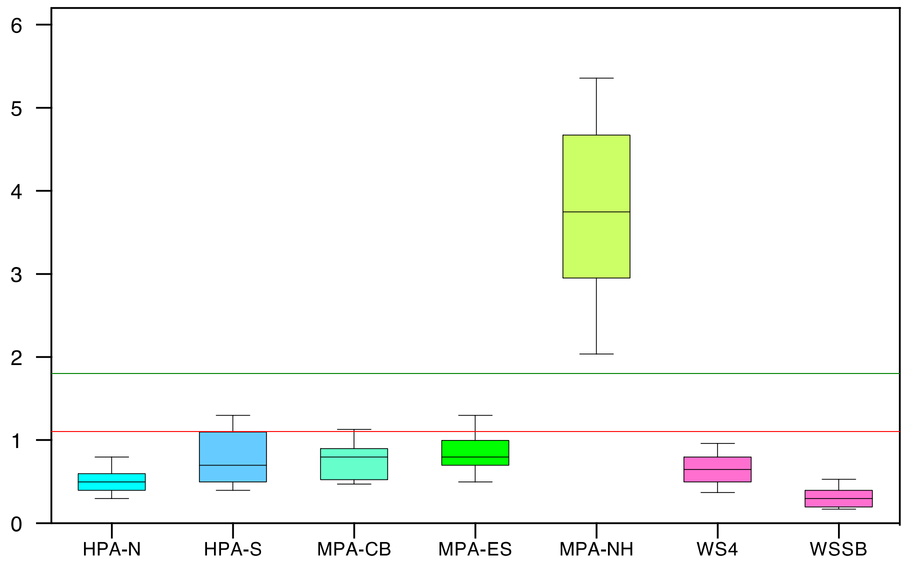
Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bars = HPA-N water quality monitoring sites; dark blue bars = HPA-S sites; blue/green bar = MPA-CB site; bright green bars = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2.

(3) Red line = high protection EQG; green line = moderate protection EQG.

Figure 3. Median chlorophyll *a* concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.

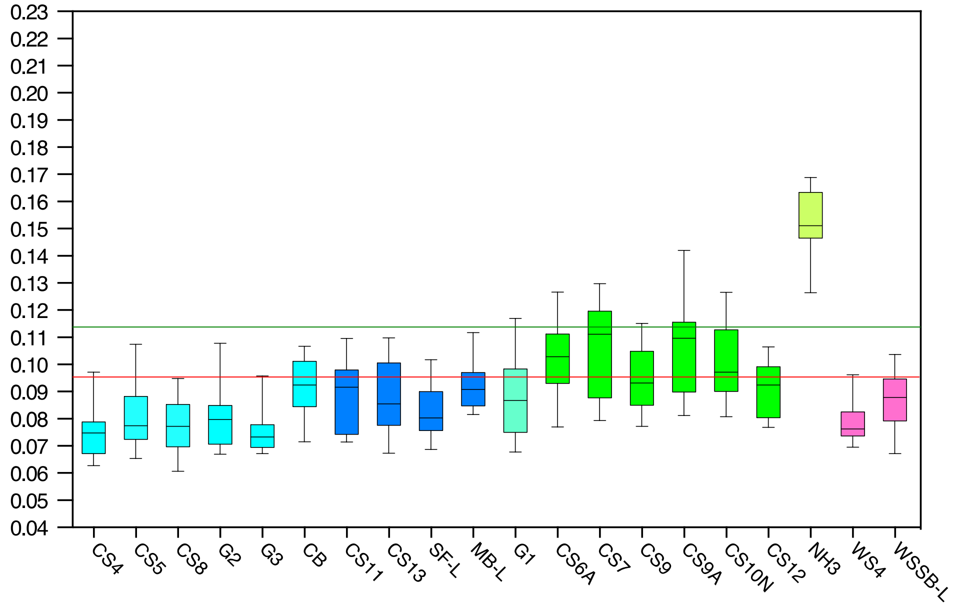


Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Red line = high protection EQG; green line = moderate protection EQG.

Figure 4. Median chlorophyll *a* concentration for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2017 to March 2018.



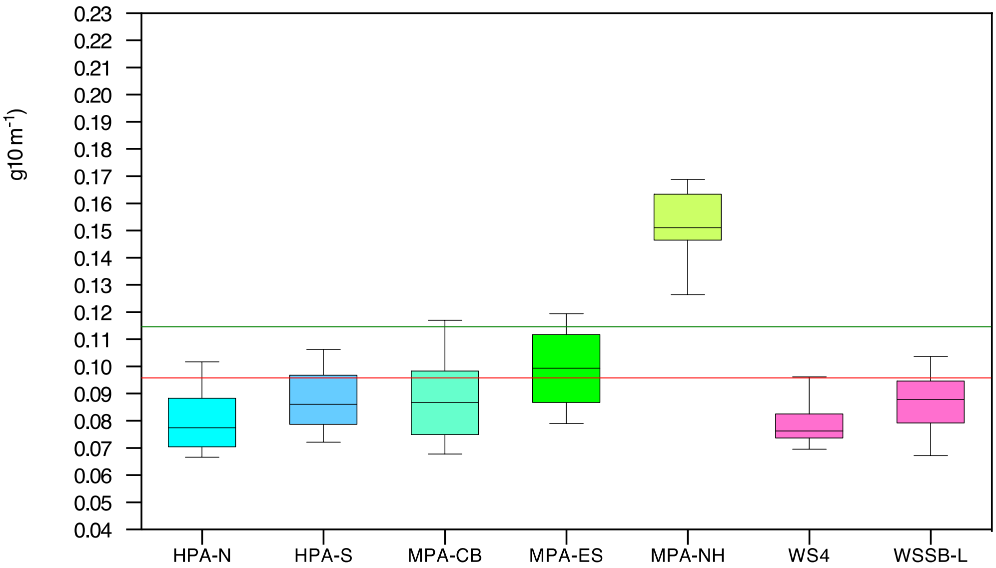
Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bars = HPA-N water quality monitoring sites; dark blue bars = HPA-S sites; blue/green bar = MPA-CB site; bright green bars = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2.

(3) Red line = high protection EQG; green line = moderate protection EQG.

Figure 5. Median light attenuation coefficient at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.



Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Red line = high protection EQG; green line = moderate protection EQG.

Figure 6. Median light attenuation coefficient for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2017 to March 2018.

There has been a significant reduction in dissolved inorganic nutrient concentrations since the 2006 to 2007 season (Keesing *et al.* 2016; Cossington and Wienczugow 2017, 2018; Appendix B). This is attributed to a reduction in nutrient inputs from external sources, including the diversion of industrial wastewater and the discharge from wastewater treatment plants into the Sepia Depression Ocean Outlet Landline (SDOOL) in 2005; improvements in groundwater through remediation; and a reduction in groundwater recharge due to less than average long-term rainfall.

Information on nutrient concentrations (total nitrogen, nitrate–nitrite, ammonium, total phosphorus and filterable reactive phosphorus) at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound over the 2017–18 non river-flow period is presented in Appendix A. Information on variations and trends over time in nutrient concentrations is included in Appendix B and in chlorophyll *a* concentrations and light attenuation coefficients in Appendix C.

Assessment against the Environmental Quality Standard

Although the 'Nutrient enrichment' EQG were met at HP-N, HP-S, MPA-CB and MPA-ES, an assessment against the 'Nutrient enrichment' Environmental Quality Standard (EQS) was conducted for comparison to the 2017 seagrass shoot density and lower depth limits (LDLs) results.

EQS(i) Seagrass shoot density

While the 'Nutrient enrichment' EQG were not exceeded in a second consecutive year, the median seagrass shoot densities for 2016 to 2018 at the Southern Flats (approximately 2.5 m depth) and Mangles Bay (approximately 3.2 m depth) monitoring sites located in HPA-S and the Jervoise Bay (approximately 2.5 m depth) monitoring site located in MPA-ES, were compared against the 'absolute minimum' seagrass shoot densities (Table 9) and the ‘rolling’ four-year 20th (high protection) or 5th (moderate protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites (Table 10).

At all three sites, the median shoot densities recorded in 2016 and 2017 were higher than the ‘absolute minimum’ seagrass shoot densities recorded at the relevant reference sites (Table 9). In 2018, the median shoot densities decreased at Mangles Bay and Jervoise Bay and were lower than the ‘absolute minimum’ seagrass shoot densities. The median shoot density at the Southern Flats remained higher than the ‘absolute minimum’ seagrass shoot density.

At Southern Flats the median shoot density in 2018 was higher than the 2017 median shoot density and the ‘rolling’ four-year 20th percentile (Table 10). The 2018 median shoot densities at Mangles Bay and Jervoise Bay were lower than in 2017. The 2018 median shoot density at Mangles Bay was lower than the ‘rolling’ four-year 20th (high protection) percentile, while the 2018 median shoot density at Jervoise Bay was higher than the ‘rolling’ four-year 5th (moderate protection) percentile.

Table 9. Assessment of median seagrass shoot density at Southern Flats, Mangles Bay and Jervoise Bay seagrass monitoring sites for three consecutive years against the ‘absolute minimum’ seagrass shoot densities.

Ecological Protection Area	Year	Seagrass Monitoring Site	Depth	Absolute minimum seagrass shoot density (shoots/m^2)	Median shoot density (shoots/m^2)
HPA-S	2016	Southern Flats	2.0 – 3.0 m	500	1,125
	2017	Southern Flats	2.0 – 3.0 m	500	563
	2018	Southern Flats	2.0 – 3.0 m	500	900
	2016	Mangles Bay	3.0 – 4.0 m	171	325
	2017	Mangles Bay	3.0 – 4.0 m	171	325
	2018	Mangles Bay	3.0 – 4.0 m	171	**150**
MPA-ES	2016	Jervoise Bay	2.0 – 3.0 m	275	513
	2017	Jervoise Bay	2.0 – 3.0 m	275	300
	2018	Jervoise Bay	2.0 – 3.0 m	275	**175**

Note: text in bold indicates a shoot density less than the ‘absolute minimum’ seagrass shoot density.

Table 10. Assessment of median seagrass shoot density at Southern Flats, Mangles Bay and Jervoise Bay seagrass monitoring sites for three consecutive years against the ‘rolling’ four-year 20^{th} (high protection) or 5^{th} (moderate protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites.

Ecological Protection Area	Year	Seagrass Monitoring Site	Reference Site	Rolling 4-year 20^{th} or 5^{th} percentile (shoots/m^2)	Median shoot density (shoots/m^2)
HPA-S	2016	Southern Flats	WS 2.5 m	690	1,125
	2017	Southern Flats	WS 2.5 m	615	**563**
	2018	Southern Flats	WS 2.5 m	475	900
	2016	Mangles Bay	WS 3.2 m	280	325
	2017	Mangles Bay	WS 3.2 m	325	325
	2018	Mangles Bay	WS 3.2 m	260	**150**
MPA-ES	2016	Jervoise Bay	WS 2.5 m	358	513
	2017	Jervoise Bay	WS 2.5 m	296	300
	2018	Jervoise Bay	WS 2.5 m	133	175

Note: text in bold indicates a shoot density less than the ‘rolling’ four-year percentile.

EQS(ii) Seagrass shoot density

For assessment against the ‘Nutrient enrichment’ EQS(ii), the 2018 median seagrass shoot densities at the Southern Flats, Mangles Bay and Jervoise Bay monitoring sites were compared against the ‘rolling’ four-year 5^{th} (high protection) or 1^{st} (moderate protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites (Table 11). The EQS(ii) was met at all three sites.

Table 11. Assessment of median seagrass shoot density at Southern Flats, Mangles Bay and Jervoise Bay seagrass monitoring sites against the ‘rolling’ four-year 5^{th} (high protection) or 1^{st} (low protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites.

Ecological Protection Area	Year	Seagrass Monitoring Site	Reference Site	Rolling 4-year 5^{th} or 1^{st} percentile (shoots/m^2)	Median shoot density (shoots/m^2)	Assessment
HPA-S	2018	Southern Flats	WS 2.5 m	133	900	EQS(ii) met
	2018	Mangles Bay	WS 3.2 m	75	150	EQS(ii) met
MPA-ES	2018	Jervoise Bay	WS 2.5 m	25	175	EQS(ii) met

EQS(iii) Lower Depth Limit

The assessment against the ‘Nutrient enrichment’ EQS(iii) involves analysis of the Lower Depth Limit (LDL) of seagrass meadows at a ‘depth limit’ site relative to the baseline depth. The LDL decreased (i.e. was shallower) at Garden Island North and Woodman Point in 2018 compared to 2017, while the LDL increased (i.e. was deeper) at Garden Island South (Fraser *et al*., 2018). The LDL was not recorded at Warnbro Sound depth transect in 2018.

Two new depth transect sites were established in 2017—one at Mangles Bay and one at Southern Flats. Between 2017 and 2018, the LDL increased (i.e. became deeper) from 5.2 m to 9.2 m at the Mangles Bay depth transect site and decreased (i.e. became shallower) from 7.9 m to 7.5 m at the Southern Flats depth transect site. The mean LDL of seagrass at the Garden Island South and Woodman Point 'depth limit' sites were significantly deeper in 2018 compared to the baseline LDL for each site (Table 12). The EQS(iii) was met at all the 'depth limit' sites. Note there are no 'depth limit' sites in MPA-ES.

Table 12. Mean baseline and 2018 Lower Depth Limit (LDL) at the Garden Island North, Garden Island South, and Woodman Point 'depth limit' sites and the results of *t*-tests for differences in the LDL at each site.

Ecological Protection Area	Depth Limit Site	Mean Baseline Lower Depth Limit (m)	Mean 2018 Lower Depth Limit (m)	*P* (one-tail)	Assessment
HPA-N	Garden Island North	9.8	10.0	0.22	EQS(iii) met
	Garden Island South	7.6	11.3	**< 0.001**	EQS(iii) met
Outside Cockburn Sound	Woodman Point	8.4	10.5	**< 0.001**	EQS(iii) met
Reference Site	Warnbro Sound	8.7	-	N.A.	N.A.

Note: *p*-values < 0.05 are shown in bold.

Seagrass Shoot Density at other Sites within and outside Cockburn Sound

With the exception of Mangles Bay and Jervoise Bay, median seagrass shoot densities at the monitoring sites in Cockburn Sound were higher in 2018 than in 2017 (Table 13).

Table 13. Median seagrass shoot densities at seagrass monitoring sites inside and outside Cockburn Sound and at the Warnbro Sound reference sites.

Ecological Protection Area	Site	2016 median shoot density (shoots/m^2)	2017 median shoot density (shoots/m^2)	2018 median shoot density (shoots/m^2)
HPA-N	Garden Island Settlement	1,575	550	750
	Kwinana	513	625	700
	Garden Island 2.0 m	1,525	613	738
	Garden Island 2.5 m	800	600	688
	Garden Island 3.2 m	713	625	688
	Garden Island 5.5 m	825	338	550
	Garden Island 7.0 m	650	388	550
	Luscombe Bay	775	563	1000
HPA-S	Southern Flats	1,125	563	900
	Mangles Bay	325	325	**150**
MPA-ES	Jervoise Bay	513	300	**175**
Sites outside Cockburn Sound	Coogee	488	300	425
	Bird Island	650	575	325
	Mersey Point	800	550	563
	Carnac Island	775	613	838
	Woodman Point	525	600	**175**
Warnbro Sound Reference Sites	Warnbro Sound 2.0 m	700	788	**0**
	Warnbro Sound 2.5 m	913	725	725
	Warnbro Sound 3.2 m	850	700	**425**
	Warnbro Sound 5.2 m	888	475	525
	Warnbro Sound 7.0 m	263	250	**225**

Note: text in bold indicates a shoot density less than the 2017 median shoot density.

The median shoot densities at Mangles Bay and Jervoise Bay were less than half the densities recorded in 2016. Median shoot densities were also lower in 2018 than in 2017 at Woodman Point and at three of the reference sites in Warnbro Sound, with complete loss of seagrass at the Warnbro Sound 2.0 m reference site.

Median shoot densities at each of the seagrass monitoring sites in HPA-N were compared with the 'absolute minimum' seagrass shoot densities and the 'rolling' four-year 20th percentiles of seagrass shoot densities at the relevant Warnbro Sound reference sites (Table 14). Median shoot densities at sites outside Cockburn Sound were also compared with the relevant 'absolute minimum' seagrass shoot densities and the 'rolling' four-year 20th percentiles of seagrass shoot densities at the reference sites.

Table 14. Comparison of median seagrass shoot density at eight seagrass monitoring sites in Cockburn Sound and five sites outside Cockburn Sound against the 'absolute minimum' and 'rolling' four-year percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites.

Ecological Protection Area	Seagrass Monitoring Site	Reference Site	Absolute minimum seagrass shoot density (shoots/m^2)	Rolling 4-year 20th percentile (shoots/m^2)	2018 median shoot density (shoots/m^2)
HPA-N	Garden Island Settlement	WS 2.0 m	666	500	750
	Kwinana	WS 5.2 m	419	400	700
	Garden Island 2.0 m	WS 2.0 m	666	500	738
	Garden Island 2.5 m	WS 2.5 m	500	475	688
	Garden Island 3.2 m	WS 3.2 m	171	260	688
	Garden Island 5.5 m	WS 5.2 m	419	400	550
	Garden Island 7.0 m	WS 7.0 m	59	100	550
	Luscombe Bay	WS 2.0 m	666	500	1000
Sites outside Cockburn Sound	Coogee	WS 5.2 m	419	400	425
	Bird Island	WS 2.0 m	666	500	**325**
	Mersey Point	WS 3.2 m	171	260	563
	Carnac Island	WS 5.2 m	419	400	838
	Woodman Point	WS 2.5 m	500	475	**175**

Note: text in bold indicates a shoot density less than the 'absolute minimum' and/or the 'rolling' four-year percentile.

Median seagrass shoot densities at the eight monitoring sites in Cockburn Sound were above both the 'absolute minimum' shoot density and the 'rolling' four-year 20th percentile of shoot density at the relevant Warnbro Sound reference sites (Table 14).

Median seagrass shoot densities at Mersey Point, Carnac Island and Coogee were above the 'absolute minimum' shoot density and the 'rolling' four-year 20th percentile of shoot density at the relevant Warnbro Sound reference sites (Table 14). At the shallower sites, Bird Island (approximately a depth of 2.0 m) and Woodman Point (approximately a depth of 2.5 m), the median shoot densities were below the 'absolute minimum' shoot density and the 'rolling' four-year 20th percentile of shoot density at the relevant Warnbro Sound reference sites.

Information on trends over time in seagrass shoot densities is included in Appendix D.

Phytoplankton Biomass

Phytoplankton biomass (measured as chlorophyll *a*) was recorded at the 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.3; Figure 2). This was assessed against the ‘Phytoplankton biomass’ EQG (EQG C, Table 1a, Reference Document) over the 2017-18 non river-flow period:

High protection:

i. *Median phytoplankton biomass in HPA-N and HPA-S is not to exceed 2.10 µg/L on any occasion during the 2017–18 non river-flow period.*

ii. *Phytoplankton biomass at any site is not to exceed 2.10 µg/L on 25% or more occasions during the 2017–18 non river-flow period.*

Moderate protection:

i. *Median phytoplankton biomass in MPA-ES is not to exceed 3.30 µg/L on more than one occasion during the 2017–18 non river-flow period.*

ii. *Phytoplankton biomass at any site is not to exceed 3.30 µg/L on 50% or more occasions during the 2017–18 non river-flow period.*

The results of the assessment against the EQG are presented in Tables 15 and 16. The high protection ‘Phytoplankton biomass’ EQG(i) and EQG(ii) were met at all sites in HPA-N, HPA-S and MPA-ES during the 2017-18 non river-flow period (Tables 15 and 16). The ‘Phytoplankton biomass’ EQG(ii) was met at the site G1 in MPA-CB, but was not met at the site NH3 in Jervoise Bay (MPA-NH).

Table 15. Assessment of median chlorophyll *a* concentrations in HPA-N, HPA-S and MPA-ES on each sampling occasion during the 2017–18 non river-flow period against the ‘Phytoplankton biomass’ EQG(i).

Sampling date	HPA-N Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	HPA-S Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	MPA-ES Chlorophyll *a* concentration (µg/L) EQG: 3.30 µg/L
1/12/2017	0.4	0.6	0.7
8/12/2017	0.5	0.7	0.9
15/12/2017	0.4	0.7	0.8
22/12/2017	0.4	0.6	0.7
5/01/2018	0.4	0.5	0.5
15/01/2018	0.8	0.7	0.9
22/01/2018	0.4	1.0	0.6
29/01/2018	0.6	1.1	1.0
5/02/2018	0.6	1.1	1.0
12/02/2018	0.5	0.7	0.7
19/02/2018	0.5	0.7	0.8
26/02/2018	0.6	0.9	0.7
5/03/2018	0.5	0.7	0.8
12/03/2018	0.5	0.9	1.2
19/03/2018	0.6	1.2	1.1
26/03/2018	0.8	1.4	1.0
Assessment	EQG(i) met in HPA-N, HPA-S and MPA-ES on all sampling occasions during the 2017–18 non river-flow period		

Table 16. Assessment of chlorophyll *a* concentrations at 18 water quality monitoring sites in Cockburn Sound during the 2017–18 non river-flow period against the 'Phytoplankton biomass' EQG(ii).

Ecological Protection Areas	Site	2017–18 EQG	Number of sampling occasions	Number of occasions EQG was exceeded	Per cent (%) of occasions EQG was exceeded	Assessment
HPA-N	CS4	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	16	0	0%	EQG(ii) met
	CS5		16	0	0%	EQG(ii) met
	CS8		16	0	0%	EQG(ii) met
	CB		16	0	0%	EQG(ii) met
	G2		16	0	0%	EQG(ii) met
	G3		16	0	0%	EQG(ii) met
HPA-S	CS11	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	16	0	0%	EQG(ii) met
	CS13		16	0	0%	EQG(ii) met
	SF		16	0	0%	EQG(ii) met
	MB		16	0	0%	EQG(ii) met
MPA-CB	G1	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	16	0	0%	EQG(ii) met
MPA-ES	CS10N	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	16	0	0%	EQG(ii) met
	CS12		16	0	0%	EQG(ii) met
	CS6A		16	0	0%	EQG(ii) met
	CS7		16	0	0%	EQG(ii) met
	CS9		16	0	0%	EQG(ii) met
	CS9A		16	0	0%	EQG(ii) met
MPA-NH	NH3	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	16	**9**	**56.3%**	EQG(ii) exceeded

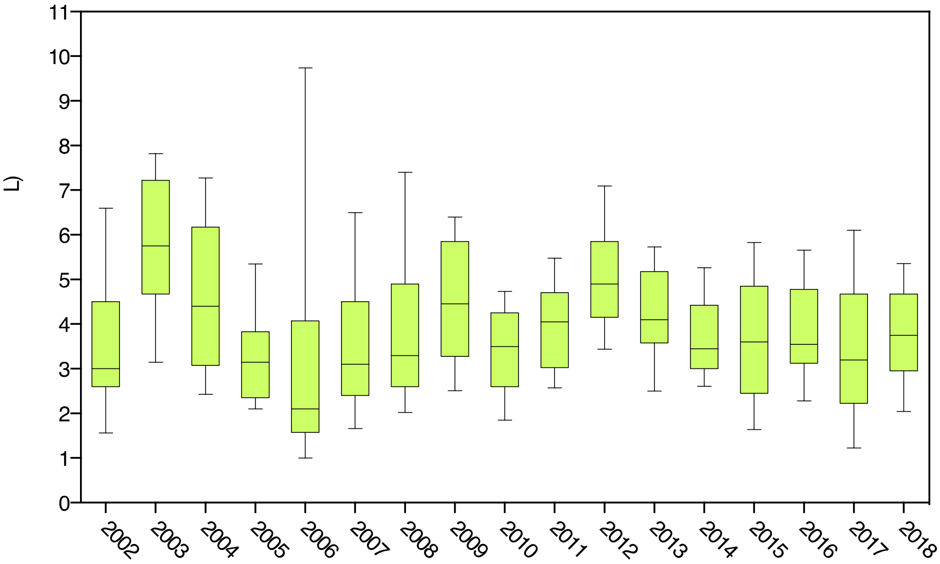
Note: numbers in bold indicates an exceedance of the EQG.

In Cockburn Sound, the chlorophyll *a* concentrations ranged from 0.2 µg/L which was recorded at site SF (HPA-S) on 1 December 2017, site G2 (HPA-N) on 5 January 2018 and site G3 (HPA-N) on 8 December 2017, to 5.5 µg/L which was recorded at the site NH3 (MPA-NH) on 26 February 2018. The chlorophyll *a* concentrations at the two reference sites in Warnbro Sound ranged from 0.1 µg/L at site WSSB on 5 January 2018 to 1.1 µg/L at site WS4 on 26 March 2018.

The highest chlorophyll *a* concentration recorded in HPA-N was 1.0 µg/L at the sites G2 and CS8 on 15 January 2018. The highest chlorophyll *a* concentration recorded in HPA-S was 2.0 µg/L at Mangles Bay on 29 January 2018.

The moderate protection 'Phytoplankton biomass' EQG(ii) was exceeded at the site NH3 (MPA-NH) on nine of the 16 sampling occasions. The exceedances ranged from 3.6 µg/L to 5.5 µg/L on 1 December 2017 and 26 February 2018, respectively. The moderate protection 'Phytoplankton biomass' EQG(ii) has only been met once since reporting began in 2003, which was during the 2016-2017 non river-flow period.

The median chlorophyll *a* concentrations at NH3 since 2002 are presented in Figure 7.



Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure 7. Median chlorophyll *a* concentrations at the Jervoise Bay Northern Harbour site (NH3).

Assessment against the Environmental Quality Standard

EQS(ii) 'Phytoplankton biomass' at the Jervoise Bay Northern Harbour (NH3)

The 'Phytoplankton biomass' EQG(ii) was not met at the site NH3 which triggers more detailed assessment against the moderate protection 'Phytoplankton biomass' EQS(ii) (EQS C(ii), Table 1a, Reference Document):

> *Phytoplankton biomass at NH3 is not to exceed 3.30 µg/L on 50% or more occasions during the non river-flow period and in two consecutive years.*

The results are presented in Table 17. Assessment of phytoplankton biomass at NH3 during the non river-flow period for two consecutive years indicates that phytoplankton biomass exceeded 3.30 µg/L on 50 per cent or more occasions in 2017–18, but not in 2016–17. The 'Phytoplankton biomass' EQS(ii) was therefore met.

Table 17. Assessment of chlorophyll *a* concentrations at Jervoise Bay Northern Harbour (NH3) against the moderate protection '*Phytoplankton biomass*' EQS(ii) over two consecutive years (2016–17 and 2017-18).

Site	Year	EQS	Number of occasions EQS was exceeded	Per cent (%) of occasions EQS was exceeded	Assessment
NH3	2016–17	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	7 (out of 16)	43.75%	EQS met
	2017–18	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	9 (out of 16)	56.25%	

2.6 Assessment against the Environmental Quality Criteria for Other Physical and Chemical Stressors

2.6.1 Dissolved Oxygen Concentration

Measurements of dissolved oxygen concentrations (% saturation) were recorded in the bottom waters[8] at the 18 water quality monitoring sites in Cockburn Sound (Section 2.3; Figure 2). They were assessed against the 'Dissolved Oxygen concentration' EQG (EQG D, Table 1a, Reference Document) over the 2017–18 non river-flow period:

High protection	*The median dissolved oxygen concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 90% saturation.*
Moderate protection	*The median dissolved oxygen concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 80% saturation.*

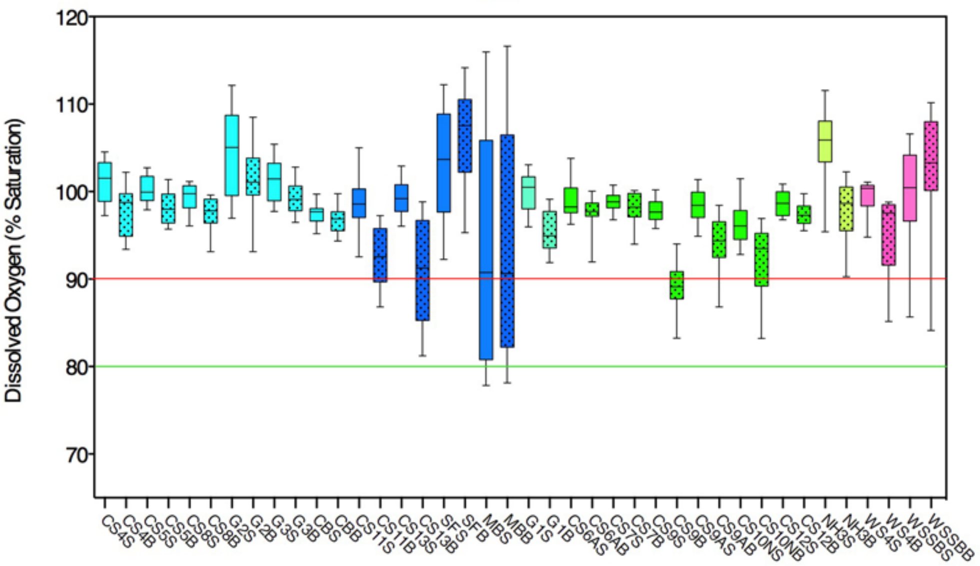
The results of the assessment against the EQC are presented in Table 18 and Figure 8. Measurements were made at approximately weekly intervals during the non river-flow period. Therefore, the dissolved oxygen concentrations recorded at each site on each sampling occasion, rather than median concentrations, were compared against the EQC.

Dissolved oxygen concentrations in the bottom waters at four of the 18 monitoring sites in Cockburn Sound were below the high (90% saturation) and moderate (80% saturation) protection 'Dissolved Oxygen concentration' EQG on between one and eight occasions during the 2017–18 non river-flow period.

[8] Waters within 50 centimetre (cm) of the sediment surface.

Table 18. Assessment of dissolved oxygen concentrations (% saturation) in the bottom waters at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the 2017–18 non river-flow period against the 'Dissolved Oxygen concentration' EQC.

Ecological Protection Area	Site (approximate depth)	Number of sampling occasions	No. of occasions EQG was not met	No. of occasions EQS(i) was not met	Assessment
HPA-N	CS4 (21 m)	16	0	-	EQG met
	CS5 (19 m)	16	0	-	EQG met
	CS8 (20 m)	16	0	-	EQG met
	CB (9.5 m)	16	0	-	EQG met
	G2 (10 m)	16	1	0	EQG not met; EQS(i) met
	G3 (13 m)	16	0	-	EQG met
HPA-S	CS11 (18 m)	16	6	0	EQG not met, EQS(i) met
	CS13 (20.5 m)	16	7	0	EQG not met, EQS(i) met
	SF (3.5 m)	16	0	-	EQG met
	MB (1.5 m)	16	8	0	EQG not met, EQS(i) met
MPA-CB	G1 (15 m)	16	0	-	EQG met
MPA-ES	CS10N (14 m)	16	0	-	EQG met
	CS12 (10 m)	16	0	-	EQG met
	CS6A (10.5 m)	16	0	-	EQG met
	CS7 (10.5 m)	16	0	-	EQG met
	CS9 (13 m)	16	0	-	EQG met
	CS9A (16.5 m)	16	0	-	EQG met
MPA-NH	NH3 (10 m)	16	0	-	EQG met
Reference Sites	WS4 (17.5 m)	16	3 < 90%	0 < 60%	N/A
	WSSB (2.5 m)	16	2 < 90%	0 < 60%	N/A



Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bars = HPA-N water quality monitoring sites; dark blue bars = HPA-S sites; blue/green bars = MPA-CB site; bright green bars = MPA-ES sites; pale green bars = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Plain bars and site label 'S' = surface waters; spotted bars and site label 'B' = bottom waters.

(3) Red line = high protection EQG (90% saturation); green line = moderate protection EQG (80% saturation).

Figure 8. Median dissolved oxygen concentrations (% saturation) in surface and bottom waters at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.

Low dissolved oxygen concentrations were recorded at three HPA-S sites (CS11, CS13 and MB) on 22 January 2018 and 12 February 2018. Low dissolved oxygen concentrations were also recorded at Mangles Bay (MB) on all four occasions in March 2018. Concentrations below 80% saturation were recorded at Mangles Bay on 15 January, 12 February and 26 March 2018.

Both Warnbro Sound reference sites recorded low dissolved oxygen concentrations on 15 January 2018. Concentrations below 90% saturation were recorded at WS4 over three consecutive occasions between the end of December and mid-January 2018. The lowest dissolved oxygen concentrations were recorded on 5 January 2018 at WS4 (84% saturation) and 26 March 2018 at WSSB (76% saturation), which was the lowest recorded at any of the 18 water quality monitoring sites.

The revised EQG for dissolved oxygen is more stringent than the EQG for dissolved oxygen in the *Environmental Quality Criteria Reference Document for Cockburn Sound (2003 – 2004)* (2005 Reference Document; EPA 2005). In the 2005 Reference Document the ambient value for dissolved oxygen concentrations in bottom waters was required to be greater than the specified per cent dissolved oxygen saturation at any site for a 'defined period of not more than six weeks' (rather than 'over a period of no more than one week') for the EQG to be met.

Review of the incidence of low dissolved oxygen concentrations in bottom waters at the 18 water quality monitoring sites in Cockburn Sound indicates that, over the past ten non river-flow periods (2008–09 onwards), the 'Dissolved Oxygen concentration'

EQG have not been met at all of the sites (with the exception of CS12) on one or more occasions during each non river-flow period (Table 19). The high protection ‘Dissolved Oxygen concentration’ EQG has not been met in the non river-flow period on between one and 11 occasions at sites in HPA-S. The greatest number of occurrences of low dissolved oxygen concentrations have been at deeper sites in HPA-S (CS11 and CS13) and HPA-N (CS4, CS5 and CS8).

The 2017-18 non river-flow period had the lowest number of low dissolved oxygen occurrences in HPA-N during the ten years, while sites in HPA-S continued to show the same trends as in previous years, with Mangles Bay (MB) having the greatest number of occurrences of low dissolved oxygen in 2017-18.

Since 2008–09, dissolved oxygen concentrations less than 90% saturation have been recorded on between one and six occasions at the two reference sites in Warnbro Sound, with the greatest number of occurrences at the deeper site WS4 (Table 19).

Table 19. Number of occasions during each non river-flow period since 2008–09 when dissolved oxygen concentrations (% saturation) in the bottom waters at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound did not meet the ‘Dissolved Oxygen concentration’ EQG.

Ecological Protection Area	Site (approximate depth)	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
HPA-N	CS4 (21 m)	3	1	2	2	1	0	1	3	6	0
	CS5 (19 m)	1	0	2	3	0	1	0	2	3	0
	CS8 (20 m)	3	1	3	3	1	1	0	6	6	0
	CB (9.5 m)	1	0	0	1	0	1	0	0	0	0
	G2 (10 m)	3	0	2	1	0	0	1	0	1	1
	G3 (13 m)	2	0	0	1	1	0	1	2	2	0
HPA-S	CS11 (18 m)	9	5	7	4	5	4	10	8	11	6
	CS13 (20.5 m)	9	9	8	2	6	4	6	9	11	7
	SF (3.5 m)	0	2	1	0	0	1	2	2	0	0
	MB (1.5 m)	-	4	4	3	4	2	6	3	7	8
MPA-CB	G1 (15 m)	0	0	0	0	0	0	0	1	0	0
MPA-ES	CS10N (14 m)	2	1	2	1	0	2	0	3	2	0
	CS12 (10 m)	0	0	0	0	0	0	0	0	0	0
	CS6A (10.5 m)	0	0	0	0	0	0	0	1	1	0
	CS7 (10.5 m)	0	0	1	2	1	0	0	0	1	0
	CS9 (13 m)	0	0	3	1	0	0	0	1	3	0
	CS9A (16.5 m)	0	0	3	0	1	1	0	0	3	0
MPA-NH	NH3 (10 m)	0	1	1	3	1	0	0	0	4	0
Reference Sites	WS4 (17.5 m)	2	5	3	2	5	6	3	6	6	3
	WSSB (2.5 m)	5	3	2	0	1	0	1	4	2	2

The results of the assessment of the dissolved oxygen concentrations in bottom waters measured quarterly over the 2017–18 monitoring period at the three Water Corporation sites in Cockburn Sound, and two sites located outside Cockburn Sound, are presented in Table 20. The high protection ‘Dissolved Oxygen concentration’ EQG was not met on one occasion at the site Central and on one occasion at the site South. The high protection ‘Dissolved Oxygen concentration’ EQS(i) was met at both of these sites.

Table 20. Assessment of dissolved oxygen concentrations (% saturation) in the bottom waters at the three Water Corporation monitoring sites in Cockburn Sound against the 'Dissolved Oxygen concentration' EQC.

Ecological Protection Area	Site (approximate depth)	July 2017	October 2017	December 2017	May 2018
HPA-N	Central (21 m)	EQG met	EQG met	EQG met	EQG not met; EQS(i) met
HPA-S	South (20 m)	EQG met	EQG met	EQG not met; EQS(i) met	EQG met
MPA-ES	DIFF50W (10 m)	EQG met	EQG met	EQG met	EQG met
Sites outside Cockburn Sound	Parmelia Bank (7 m)	> 90%	> 90%	> 90%	> 90%
	Owen Anchorage (14 m)	> 90%	> 90%	> 90%	> 90%

The moderate protection 'Dissolved Oxygen concentration' EQG was met in the bottom waters at the three sites around the Kwinana Bulk Terminal[9] and at the three sites around the Kwinana Bulk Jetty[10] surveyed by Fremantle Ports on 16 February 2018.

Assessment against the Environmental Quality Standard

The 'Dissolved Oxygen concentration' EQG were not met at four of the water quality monitoring sites which triggers more detailed assessment against the high protection and moderate protection 'Dissolved Oxygen concentration' EQS (EQS D, Table 1a, Reference Document):

High protection:

- *i. The median dissolved oxygen concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 60% saturation.*
- *ii. No significant change beyond natural variation in any ecological or biological indicators that are affected by poorly oxygenated water unless that change can be demonstrably linked to a factor other than oxygen concentration.*
- *iii. No deaths of marine organisms resulting from deoxygenation.*

Moderate protection:

- *i. The median dissolved oxygen concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 60% saturation.*
- *ii. No persistent (i.e. ≥ 4 weeks) and significant change beyond natural variation in any ecological or biological indicators that are affected by poorly oxygenated water unless that change can be demonstrably linked to a factor other than oxygen concentration.*
- *iii. No deaths of marine organisms resulting from deoxygenation.*

The dissolved oxygen concentrations in the bottom waters at four of the 18 water quality monitoring sites were below the 'Dissolved Oxygen concentration' EQS(i)

[9] Depths varied between approximately 10.5 metres to 11.5 metres.
[10] Depths varied between approximately 12 metres and 16.5 metres.

(Table 18). The dissolved oxygen concentration recorded at G2 in HPA-N was 90%. The dissolved oxygen concentrations recorded at CS11 and CS13 in HPA-S were all greater than 80%, except for one occasion (22 January 2018) when 79% saturation was recorded at CS13. Similarly, Mangles Bay (MB) had only three occurrences of dissolved oxygen concentrations at or below 80%—80% saturation recorded on 15 January 2018, 79% saturation recorded on 12 February, and 77% saturation recorded on 26 March 2018. The high protection 'Dissolved Oxygen concentration' EQS(i) was met at all four sites.

The waters of Cockburn Sound are generally well mixed and well oxygenated (Department of Environmental Protection 1996; D.A. Lord & Associates Pty Ltd 2001; Hart and Church 2006). There are periods, mostly during late summer and autumn, when low dissolved oxygen concentrations may be experienced for short periods of time, in particular in the deeper waters at the southern end of Cockburn Sound.

There were no reports to the Cockburn Sound Management Council of deaths of marine organisms during the periods when low dissolved oxygen concentrations were recorded over the 2017–18 non river-flow period that may have been attributed to deoxygenation ('Dissolved Oxygen concentration' EQS(iii)).

2.6.2 Water Temperature

Measurements of surface[11] and bottom[12] water temperatures were recorded at the 18 water quality monitoring sites[13] (Section 2.3; Figure 2). They were assessed against the 'Water Temperature' EQG (EQG E, Table 1a, Reference Document) over the 2017–18 non river-flow period:

High protection:	*Median temperature at an individual site over the 2017–18 non river-flow period, measured according to the Standard Operating Procedures, is not to exceed the 80th percentile of the natural temperature range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period.*
Moderate protection:	*Median temperature at an individual site over the 2017–18 non river-flow period, measured according to the Standard Operating Procedures, is not to exceed the 95th percentile of the natural temperature range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period.*

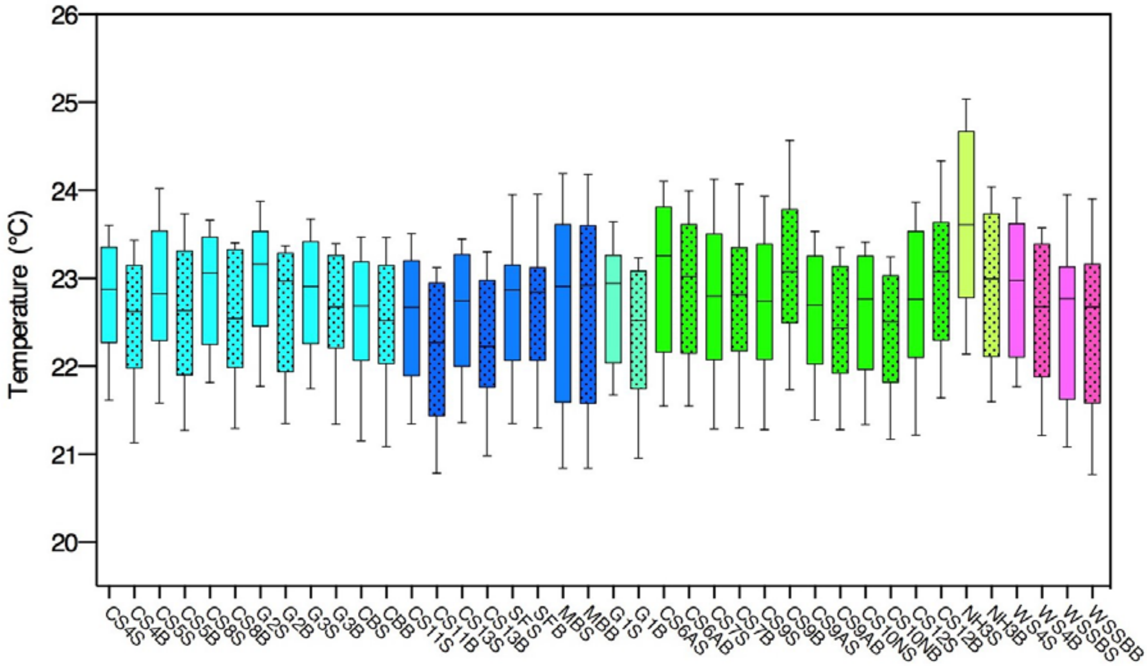
The results of the assessment against the EQG are presented in Table 21. Median surface and bottom water temperatures at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound are shown in Figure 19. At all sites, the median surface and bottom water temperatures recorded over the 2017–18 non river-flow period met the 'Temperature' EQG.

[11] Measured at 50 cm below the water surface.
[12] Measured at 50 cm above the sediment surface.
[13] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2017).

Table 21. Assessment of median surface and bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound over the 2017–18 non river-flow period against the 'Temperature' EQG.

Ecological Protection Area	Site	Temperature (° C)				Assessment
		2017–18 EQG (Surface)	2017–18 median (Surface)	2017–18 EQG (Bottom)	2017–18 median (Bottom)	
HPA-N	CS4	≤ 23.63	22.87	≤ 23.50	22.62	EQG met
	CS5		22.82		22.64	EQG met
	CS8		23.06		22.55	EQG met
	CB		22.69		22.52	EQG met
	G2		23.16		22.97	EQG met
	G3		22.91		22.68	EQG met
HPA-S	CS11	≤ 23.63	22.67	≤ 23.50	22.27	EQG met
	CS13		22.74		22.22	EQG met
	SF	≤ 23.16	22.87	≤ 23.20	22.84	EQG met
	MB		22.91		22.92	EQG met
MPA-CB	G1	≤ 23.90	22.94	≤ 23.57	22.52	EQG met
MPA-ES	CS10N	≤ 23.90	22.77	≤ 23.57	22.51	EQG met
	CS12		22.76		23.07	EQG met
	CS6A		23.26		23.02	EQG met
	CS7		22.80		22.82	EQG met
	CS9		22.74		23.07	EQG met
	CS9A		22.70		22.43	EQG met
MPA-NH	NH3	≤ 23.90	23.61	≤ 23.57	22.99	EQG met

Note: Sites MB (approximately 1.3 m depth) and SF (approximately 3.5 m depth) were assessed against the reference site WSSB (approximately 2.4 m depth).



Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bars = HPA-N water quality monitoring sites; dark blue bars = HPA-S sites; blue/green bars = MPA-CB site; bright green bars = MPA-ES sites; pale green bars = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Plain bars and site label 'S' = surface waters; spotted bars and site label 'B' = bottom waters.

Figure 9. Median surface and bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.

Information on variations and trends over time in water temperatures in Cockburn Sound is included in Appendix E.

2.6.3 Salinity

Measurements of surface[14] and bottom[15] water salinities were recorded at the 18 water quality monitoring sites[16] (Section 2.3; Figure 2). They were assessed against the 'Salinity' EQG (EQG F, Table 1a, Reference Document) over the 2017–18 non river-flow period:

High protection: *Median salinity at an individual site over the 2017–18 non river-flow period, measured according to the Standard Operating Procedures, is not to deviate beyond the 20th and 80th percentiles of the natural salinity range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period.*

Moderate protection: *Median salinity at an individual site over the 2017–18 non river-flow period, measured according to the Standard Operating Procedures, is not to deviate beyond the 5th and 95th percentiles of the natural salinity range measured at*

[14] Measured at 50 cm below the water surface.

[15] Measured at 50 cm above the sediment surface.

[16] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2017).

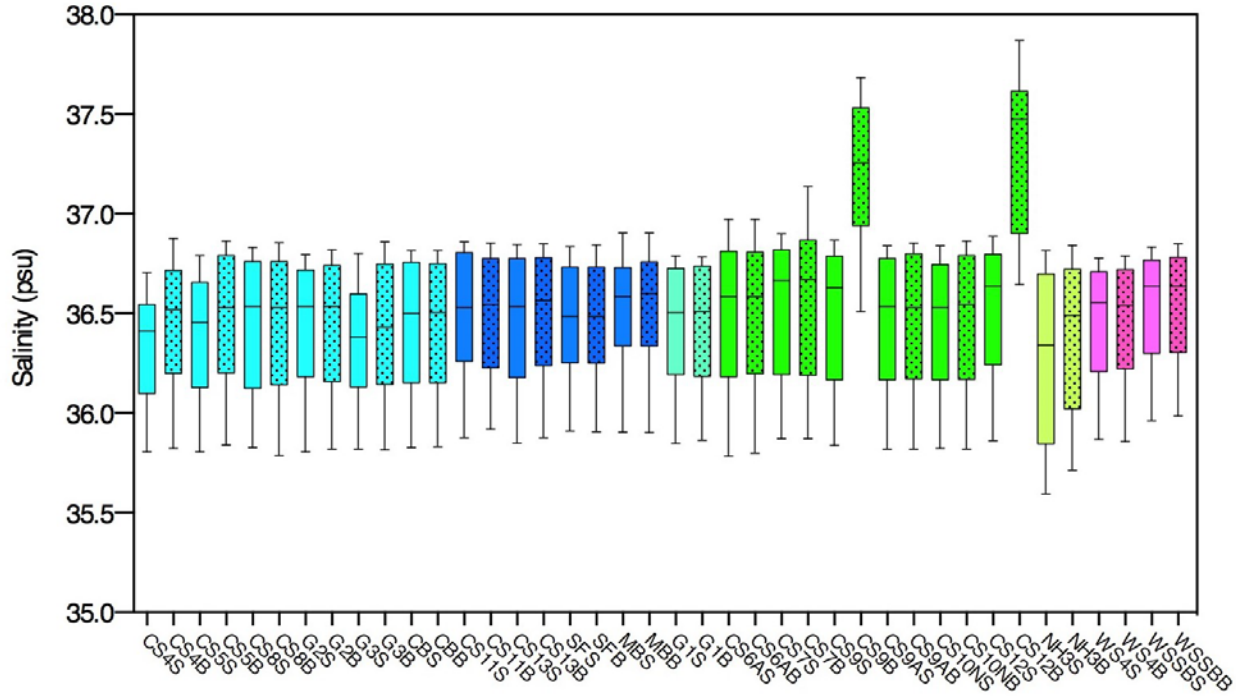
the Warnbro Sound reference sites WS4 or WSSB for the same period.

The results of the assessment against the EQG are presented in Table 22. Median surface and bottom water salinities at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound are shown in Figure 10. The median surface and bottom water salinities recorded over the 2017–18 non river-flow period met the 'Salinity' EQG at all sites with the exception of the bottom waters at CS9 and CS12 in MPA-ES. Elevated median salinities were recorded in the bottom waters at CS9 and CS12.

Table 22. Assessment of median surface and bottom salinities at 18 water quality monitoring sites in Cockburn Sound over the 2017–18 non river-flow period against the 'Salinity' EQG.

Ecological Protection Area	Site	Salinity (practical salinity units [psu])				Assessment
		2017–18 EQG (Surface)	2017–18 median (Surface)	2017-18 EQG (Bottom)	2017–18 median (Bottom)	
HPA-N	CS4	36.14 ≤ x ≤ 36.71	36.41	36.16 ≤ x ≤ 36.72	36.52	EQG met
	CS5		36.45		36.53	EQG met
	CS8		36.53		36.53	EQG met
	CB		36.50		36.50	EQG met
	G2		36.53		36.53	EQG met
	G3		36.38		36.43	EQG met
HPA-S	CS11	36.14 ≤ x ≤ 36.71	36.53	36.16 ≤ x ≤ 36.72	36.55	EQG met
	CS13		36.54		36.56	EQG met
	SF	36.26 ≤ x ≤ 36.77	36.48	36.26 ≤ x ≤ 36.79	36.48	EQG met
	MB		36.58		36.60	EQG met
MPA-CB	G1	35.87 ≤ x ≤ 36.78	36.50	35.86 ≤ x ≤ 36.79	36.51	EQG met
MPA-ES	CS10N	35.87 ≤ x ≤ 36.78	36.53	35.86 ≤ x ≤ 36.79	36.55	EQG met
	CS12		36.63		**37.47**	EQG not met in bottom waters
	CS6A		36.59		36.59	EQG met
	CS7		36.67		36.67	EQG met
	CS9		36.63		**37.25**	EQG not met in bottom waters
	CS9A		36.54		36.53	EQG met
MPA-NH	NH3	35.87 ≤ x ≤ 36.78	36.34	35.86 ≤ x ≤ 36.79	36.49	EQG met

Note: Sites MB (approximately 1.3 m depth) and SF (approximately 3.5 m depth) assessed against the reference site WSSB (approximately 2.4 m depth); text in bold indicates an exceedance of the EQ**G.**



Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bars = HPA-N water quality monitoring sites; dark blue bars = HPA-S sites; blue/green bars = MPA-CB site; bright green bars = MPA-ES sites; pale green bars = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Plain bars and site label 'S' = surface waters; spotted bars and site label 'B' = bottom waters.

Figure 10. Median surface and bottom water salinities at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.

The results of the assessment of salinity in bottom waters measured quarterly over the 2017–18 monitoring period at the three Water Corporation sites in Cockburn Sound, and two sites located outside Cockburn Sound, are presented in Table 23. Slightly elevated salinities were recorded in bottom waters at DIFF50W, located 50 metres west of the Perth Seawater Desalination Plant diffuser, in July 2017, October 2017, December 2017 and May 2018 compared to Central and South in Cockburn Sound, and Parmelia Bank and Owen Anchorage located outside Cockburn Sound.

Table 23. Bottom water salinities (practical salinity units [psu]) recorded at the three Water Corporation monitoring sites in Cockburn Sound and two sites outside Cockburn Sound.

Ecological Protection Area	Site	July 2017	October 2017	December 2017	May 2018
HPA-N	Central	35.28	34.96	35.79	36.40
HPA-S	South	35.29	34.85	35.81	36.27
MPA-ES	DIFF50W	35.77	35.70	36.49	36.87
Sites outside Cockburn Sound	Parmelia Bank	35.28	35.02	35.71	35.77
	Owen Anchorage	35.27	35.06	35.72	35.78

Assessment against the Environmental Quality Standard

The moderate protection 'Salinity' EQG was not met in the bottom waters at CS9 and CS12 which triggers more detailed assessment against the moderate protection 'Salinity' EQS (EQS F, Table 1a, Reference Document):

i. *No persistent (i.e. ≥ 4 weeks) and significant change beyond natural variation in any ecological or biological indicators that are affected by changing salinity unless that change can be demonstrably linked to a factor other than salinity stress.*

ii. *No deaths of marine organisms resulting from anthropogenically-sourced salinity stress.*

Median bottom water salinities at CS9 and CS12 were higher than the 'Salinity' EQG by less than one practical salinity unit (psu) and were below the default moderate protection salinity trigger value[17] in the Reference Document. The risk of a persistent and significant change beyond natural variation in any ecological or biological indicators as a result of elevated salinity is therefore considered to be low ('Salinity' EQS(i)).

Median bottom salinities at CS9 and CS12 have exceeded the 'Salinity' EQG since the 2006–07 monitoring period. These exceedances possibly reflect localised effects due to the proximity of the sites to the saline water discharge from the Perth Seawater Desalination Plant, which commenced operation in late 2006.

There were no known reports of deaths of marine organisms over the 2017–18 non river-flow period that may have been attributable to anthropogenically-sourced salinity stress ('Salinity' EQS(ii)).

2.6.4 pH

Measurements of surface[18] and bottom[19] water pH were recorded at the 18 water quality monitoring sites[20] (Section 2.3; Figure 2). They were assessed against the 'pH' EQG (EQG G, Table 1a, Reference Document) over the 2017–18 non river-flow period:

High protection: *Median pH at an individual site over the 2017–18 non river-flow period, measured according to the Standard Operating Procedures, is not to deviate beyond the 20th and 80th percentiles of the natural pH range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period.*

Moderate protection: *Median pH at an individual site over the 2017–18 non river-flow period, measured according to the Standard Operating Procedures, is not to deviate beyond the 5th and 95th percentiles of the natural pH range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period.*

[17] Moderate protection bottom waters = 37.94 practical salinity units (the median of suitable reference site data ± 1.4; 36.54 + 1.4).
[18] Measured at 50 cm below the water surface.
[19] Measured at 50 cm above the sediment surface.
[20] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2017).

The results of the assessment against the EQG are presented in Table 24. At all sites, the median surface and bottom water pH recorded over the 2017–18 non river-flow period met the 'pH' EQG. There were no significant differences in pH in the surface and bottom waters between any of the water quality monitoring sites (Cossington and Wienczugow 2018).

Table 24. Assessment of median surface and bottom pH at 18 water quality monitoring sites in Cockburn Sound over the 2017–18 non river-flow period against the 'pH' EQG.

Ecological Protection Area	Site	pH (pH units)				Assessment
		2017–18 EQG (Surface)	2017–18 median (Surface)	2017–18 EQG (Bottom)	2017–18 median (Bottom)	
HPA-N	CS4	8.2 ≤ x ≤ 8.3	8.2	8.2 ≤ x ≤ 8.3	8.2	EQG met
	CS5		8.2		8.2	EQG met
	CS8		8.2		8.2	EQG met
	CB		8.2		8.2	EQG met
	G2		8.2		8.2	EQG met
	G3		8.2		8.2	EQG met
HPA-S	CS11	8.2 ≤ x ≤ 8.3	8.2	8.2 ≤ x ≤ 8.3	8.2	EQG met
	CS13		8.2		8.2	EQG met
	SF	8.2 ≤ x ≤ 8.3	8.2	8.2 ≤ x ≤ 8.3	8.3	EQG met
	MB		8.2		8.2	EQG met
MPA-CB	G1	8.1 ≤ x ≤ 8.4	8.2	8.1 ≤ x ≤ 8.3	8.2	EQG met
MPA-ES	CS10N	8.1 ≤ x ≤ 8.4	8.2	8.1 ≤ x ≤ 8.3	8.2	EQG met
	CS12		8.2		8.2	EQG met
	CS6A		8.2		8.2	EQG met
	CS7		8.2		8.2	EQG met
	CS9		8.2		8.2	EQG met
	CS9A		8.2		8.2	EQG met
MPA-NH	NH3	8.1 ≤ x ≤ 8.4	8.2	8.1 ≤ x ≤ 8.3	8.2	EQG met

Note: Sites MB (approximately 1.3 m depth) and SF (approximately 3.5 m depth) assessed against the reference site WSSB (approximately 2.4 m depth).

2.7 Assessment against the Environmental Quality Criteria for Toxicants in Marine Waters

2.7.1 Non-metallic Inorganics (Ammonia) in Marine Waters of Cockburn Sound

Over the 2017–18 non river-flow period, concentrations of ammonium recorded in the depth-integrated water samples collected at each of the 18 water quality monitoring sites in Cockburn Sound (Section 2.3; Figure 2) varied from below the analytical limit of reporting (< 0.5 micrograms nitrogen per litre [µg N/L]) recorded at most sites on one or more occasions, to 18 µg N/L at CS9A and 22 µg N/L at CS10 in MPA-ES on 26 March 2018. The highest concentration recorded in bottom waters at CS13 in HPA-S was 16 µg N/L.

The Reference Document (Table 2a) specifies that the 95th percentile of the sample concentrations from a single site or a defined area (either from one sampling run or all samples over an agreed period of time) should not exceed the EQG values.

The 95th percentile of the ammonium concentrations at sites in HPA-N varied between 2.2 µg N/L and 3.5 µg N/L and between 3.7 µg N/L and 5.1 µg N/L at sites in HPA-S, all below the high protection EQG value for toxic effects of 500 µg/L for ammonia. The

95th percentile of the ammonium concentrations at sites in MPA-ES varied between 3.0 µg N/L and 16.0 µg N/L, below the moderate protection EQG value for toxic effects of 1,200 µg/L for ammonia. Similarly, at G1 in MPA-CB and Jervoise Bay Northern Harbour (NH3) in MPA-NH, where the 95th percentiles of the ammonium concentrations were 3.3 µg N/L and 3.5 µg N/L, respectively.

2.7.2 Toxicants in Marine Waters around the Kwinana Bulk Terminal and Kwinana Bulk Jetty

Surface marine water samples were collected in February 2018 at six sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) in MPA-ES (Section 2.3; Figure 2). The samples were analysed for ammonia, filtered copper, total recoverable hydrocarbons (TRHs), benzene, toluene, ethylbenzene and xylene (BTEX). The Kwinana Bulk Terminal samples were also analysed for lithium and filtered manganese.

The Reference Document identifies that, ideally, a minimum of five samples is required for comparison with the EQG and where less than 20 samples have been taken, the maximum sample concentration should be less than the guideline. Given the small sample size, concentrations of contaminants in the water samples collected at each of the sites were compared against the relevant EQG values or, where there is no EQG value available, against the relevant 'low reliability value' (LRV).

Concentrations of copper and ammonia were below the relevant EQG values for toxic effects at all the sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty (Table 25). Concentrations of manganese at sites around the Kwinana Bulk Terminal were below the LRV. There is no EQG value or LRV for lithium. Concentrations of BTEX were below the analytical limits of reporting and below the relevant EQG values or LRVs. Concentrations of TRHs were below the analytical limits of reporting.

Table 25. Assessment of toxicants in surface waters sampled at three sites around the Kwinana Bulk Terminal (KBT) and three sites around the Kwinana Bulk Jetty (KBJ) against the moderate protection EQG or LRV for 'Toxicants in marine waters'.

Toxicant (µg/L)	EQG/LRV (µg/L)	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Ammonia	EQG: 1,200	5	4	4	5	15	< 3
Copper (filtered)	EQG: 3.0	0.3	0.8	1.0	0.7	0.5	0.6
Manganese (filtered)	LRV: 80[1]	1.0	1.0	1.1	Not measured		
Lithium	-	180	180	180	Not measured		
Benzene	EQG: 900	< 1	< 1	< 1	< 1	< 1	< 1
Toluene	LRV: 230	< 1	< 1	< 1	< 1	< 1	< 1
Ethylbenzene	LRV: 5.0[1]	< 1	< 1	< 1	< 1	< 1	< 1
Xylene	m-xylene LRV: 75[1] p-xylene LRV: 200[1] o-xylene LRV: 350[1]	< 2	< 2	< 2	< 2	< 2	< 2
Total BTEX	-	< 5	< 5	< 5	< 5	< 5	< 5
Total Recoverable Hydrocarbons (C10–C36)	LRV: 7[1, 2]	< 250	< 250	< 250	< 250	< 250	< 250
Total Toxicity of Mixture (TTM)	If TTM>1, mixture exceeded water quality guideline	< 1	< 1	< 1	< 1	< 1	< 1

Notes: '<' signifies the result is less that the limit of quantitation for the method.

(1) High protection LRV (there is no moderate protection LRV)
(2) LRV for Total Petroleum Hydrocarbons.

At all sites, the Total Toxicity of the Mixture (TTM)[21], based on the effects of ammonia, copper and benzene, was below one (Table 25). The combined additive effect of these contaminants was therefore not expected to result in adverse effects on marine flora or fauna in the vicinity of the sampling sites.

2.8 Assessment against the Environmental Quality Criteria for Toxicants in Sediments

Surface (top two centimetres) sediment samples were collected at sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) in MPA-ES in March 2018 (Section 2.3; Figure 2). The samples were analysed for Total Organic Carbon, metals (arsenic, cadmium, chromium, copper, lead, lithium[22], manganese, mercury and zinc), non-metals (selenium and phosphorus), organotins (tributyltin [TBT], dibutyltin [DBT] and monobutyltin [MBT]), polycyclic aromatic hydrocarbons (PAHs), total recoverable hydrocarbons (TRHs), perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA).

The concentrations of contaminants in sediments were compared against the EQG (Table 3, Reference Document):

A. *Median total contaminant concentration in sediments from a single site or defined sampling area should not exceed the environmental quality guideline value for high, moderate and low ecological protection areas.*

B. *Total contaminant concentration at individual sample sites should not exceed the environmental quality guideline re-sampling trigger.*

The median concentrations of arsenic, chromium, copper, lead and zinc in both sampling areas were below the relevant EQG values (Table 26). Elevated concentrations of cadmium and mercury were recorded in one of the Kwinana Bulk Jetty samples (KBJ1). A slightly elevated concentration of mercury was recorded in one of the Kwinana Bulk Terminal samples (KBT1). The median concentrations of cadmium and mercury in sediments at the Kwinana Bulk Jetty and mercury in sediments at the Kwinana Bulk Terminal were below the EQG value. The concentrations of both toxicants at KBJ1 and KBT1 were below the EQG re-sampling trigger. There are no EQG values for lithium, manganese and selenium.

After normalisation to 1% Total Organic Carbon[23], median concentrations of TBT in the Kwinana Bulk Terminal samples were below the EQG value (Table 26). Elevated concentrations of TBT were recorded in the three Kwinana Bulk Jetty samples. The concentrations of TBT at KBJ1 and KBJ2 were below the EQG re-sampling trigger value. As the TBT concentration at KBJ3 was above the EQG re-sampling trigger value, an elutriate analysis was conducted to determine the bioavailability of the toxicant, the results of which showed low bioavailability. It is most likely that the elevated TBT concentrations were a result of historical contaminants in the sediments

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[21] TTM = $\Sigma (C_i/EQG_i)$, where C_i is the concentration of the 'i'th component in the mixture and EQG is the guideline for that component.

[22] Lithium and manganese only sampled in sediments at the Kwinana Bulk Terminal.

[23] Consistent with the Reference Document, where Total Organic Carbon concentrations were within the range of 0.5% to 10%, the concentrations of organometallic/organic contaminants were normalised to 1% organic carbon before assessing against the EQG. Note that contaminant concentrations less than the analytical limit of reporting were not normalised.

being released during the sediment sampling process.

There are no ECG values for the TBT break-down products DBT or MBT (Table 26). The significant concentrations of DBT in the Kwinana Bulk Terminal and Kwinana Bulk Jetty samples suggest ongoing degradation of TBT in these areas. All three Kwinana Bulk Terminal samples had a Butylin Degradation Index (BDI) equal to or greater than one, suggesting that the TBT originally deposited in this area had been degraded into DBT and MBT (Table 26). The BDI for the Kwinana Bulk Jetty samples were below one as a result of the elevated TBT concentrations in this sampling area.

The median concentrations of PAHs were below the relevant EQG values (Table 26). The concentrations of PAHs in all the samples from both sampling areas were below the EQG values. There are no EQG values for TRHs, however, the concentrations of TRHs at all of the sites were below the analytical limit of reporting. The concentrations of PFOS and PFOA were also below the analytical limit of reporting at all of the sites.

Table 26. Assessment of toxicants in sediment collected from sites around the Kwinana Bulk Terminal (KBT) and the Kwinana Bulk Jetty (KBJ) against the EQG and the re-sampling trigger for 'Toxicants in sediments'.

Chemical (milligrams per kilogram [mg/kg])	Environmental Quality Criteria		Kwinana Bulk Terminal				Kwinana Bulk Jetty			
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median
Metals										
Arsenic	20	70	5.6	4.8	3.7	4.8	4.6	2.1	2.6	2.6
Cadmium	1.5	10	0.1	0.1	0.1	0.1	**2.3**	0. 5	0.4	0.5
Chromium	80	370	33	30	9.5	30	37	15	18	18
Copper	65	270	17	18	5	17	11	3	7	7
Lead	50	220	12	10	3	10	8	2	4	4
Lithium	-	-	14	14	3	14	Not measured			
Manganese	-	-	43	36	140	43	Not measured			
Mercury	0.15	1	**0.16**	0.12	0.02	0.12	**0.23**	0.05	0.11	0.11
Selenium	-	-	0.37	0.35	0.11	0.35	0.64	0.30	0.32	0.32
Zinc	200	410	61	23	10	23	71	73	14	14
Organotins (µg Sn/kg normalised to 1% TOC)										
Tributyltin	5	70	0.7	1.7	3.7	1.7	**7.8**	**15.8**	**157.1**	15.8
Dibutyltin	-	-	1.0	1.6	8.0	1.6	3.3	3.1	3.6	3.3
Monobutyltin	-	-	0.1	0.1	2.9	0.1	0.9	0.7	0.5	0.7
Butylin Degradation Index (BDI)	-	-	1.5	1.0	2.9	-	0.6	0.2	0.02	-
Organics (mg/kg normalised to 1% TOC)										
Acenaphthene	0.016	0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Acenaphthelene	0.044	0.64	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Anthracene	0.085	1.1	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Benzo(a)anthracene	0.261	1.6	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Benzo(a)pyrene	0.43	1.6	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Chrysene	0.384	2.8	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Dibenzo(a,h)anthracene	0.063	0.26	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Fluoranthene	0.6	5.1	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Fluorene	0.019	0.54	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Naphthalene	0.16	2.1	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Phenathrene	0.24	1.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Pyrene	0.665	2.6	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Total Recoverable Hydrocarbons (C10–C36)	-	-	<200	<200	<200	<200	<200	<200	<200	<200
Total Perfluorooctane sulfonate	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002

Chemical (milligrams per kilogram [mg/kg])	Environmental Quality Criteria		Kwinana Bulk Terminal				Kwinana Bulk Jetty			
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median
Total Perfluorooctanoic acid	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002

2.9 Conclusion

With respect to nutrient enrichment, the 2017-18 monitoring results indicate that there is a high degree of certainty that the Environmental Quality Objective 'Maintenance of ecosystem integrity' is being achieved in Sound. The 'Nutrient enrichment' EQG were met in the High Protection Areas (HPA-N and -S) and the Moderate Protection Areas (MPA-CB, -ES and –NH). The 'Nutrient enrichment' EQG for chlorophyll *a* and light attenuation were met in these environmental protection areas. The 'Phytoplankton biomass' EQG were met at all sites in these environmental protection areas except at Jervoise Bay Northern Harbour (NH3) in the Moderate Protection Area Northern Harbour (MPA-NH). Due to the uncertainty as to whether the Environmental Quality Objective had been achieved in respect to MPA-NH, a more detailed assessment against the EQS was triggered for NH3 in MPA-NH. The assessment found that the EQS was met at NH3 in MPA-NH.

While there have been improvements in nutrient concentrations in the water in Cockburn Sound, seagrass shoot densities have continued to decline at some sites in Cockburn Sound (Appendix D). Environmental factors other than a nutrient enrichment-related reduction in light availability at the seafloor are likely to be contributing to the seagrass decline or lack of recovery in Cockburn Sound. Seagrass at sites on the east coast of Garden Island where the largest declines have been recorded (Fraser *et al.* 2017) have some of the most depleted ratios of the two most common stable isotopes of sulfur ($\delta^{34}S$) in their tissues, indicating this area is being impacted by intrusion of sedimentary sulfides (Fraser *et al*. 2016b). Research currently being undertaken by the University of Western Australia is investigating whether low nocturnal dissolved oxygen concentrations at the Garden Island sites are making the seagrass more vulnerable to sulfide intrusion, or if sediment conditions (including the composition of the sediment microbial community) is contributing to these patterns (Fraser *et al*. 2017, Olsen *et al*. 2018).

The 'Dissolved Oxygen concentration' EQG were not met in the bottom waters at four of the 18 water quality monitoring sites in Cockburn Sound on one or more occasions over the 2017–18 non river-flow period. The 'Dissolved Oxygen concentration' EQS(i) was met at these four sites (G2 in HPA-N; and CS11, CS13 and MB in HPA-S). There were no reports of deaths of marine organisms during the periods when low dissolved oxygen concentrations were recorded over the 2017–18 non river-flow period that may have been attributable to deoxygenation.

With the exception of localised elevated salinities in bottom waters at two MPA-ES sites (CS9 and CS12), the EQC for protecting the marine ecosystem from the effects of the other physical and chemical stressors were met. The EQC for toxicants in sediments and marine waters were generally met in those areas where sampling and analysis were undertaken over the 2017–18 monitoring period. The exceptions were one slightly elevated concentration of mercury recorded in a sediment sample collected at the Kwinana Bulk Terminal and elevated concentrations of mercury and cadmium in a sediment sample from the Kwinana Bulk Jetty, which can be attributed to the sampling method. There were no known reports of deaths of marine organisms during the 2017–18 reporting period that were attributed to anthropogenically-sourced stress.

The results from the 2017–18 monitoring programs in Cockburn Sound indicate that there is a low risk that the Environmental Quality Objective 'Maintenance of ecosystem integrity' is not being achieved in most of Cockburn Sound. Cockburn Sound is likely to experience further pressures in the future, particularly from urbanisation and industrial and infrastructure development along the coast. There is limited understanding of the ecological resilience of Cockburn Sound's marine ecosystem to these pressures (Cockburn Sound Management Council 2018).

2.9.1 Warnbro Sound Reference Sites

Warnbro Sound in the Shoalwater Islands Marine Park was originally selected as the most appropriate reference area for Cockburn Sound due to its relatively undisturbed state compared with the Sound. Over the years, Warnbro Sound has become increasingly impacted population growth and development. The Cockburn Sound marine area is facing similar pressures (BMT Western Australia 2018).

The EQC for chlorophyll *a*, light attenuation coefficient and phytoplankton biomass are derived using data collected from one reference site in the central basin of Warnbro Sound during 'typical' summer conditions over a rolling six-year period. The EQG for chlorophyll *a* have been increasing in recent years, reflecting an increased occurrence of higher chlorophyll *a* concentrations. This has had the effect of increasing the trigger for investigation of elevated chlorophyll *a* concentrations in Cockburn Sound. The causes of this change in chlorophyll *a* concentrations at the reference site are not clear and require further investigation.

The EQS for seagrass shoot density are derived using data collected from five reference sites in the Safety Bay region of Warnbro Sound. Seagrass shoot densities at the Warnbro Sound reference sites and, correspondingly the EQS for seagrass shoot density, have continued to show significant declines (Fraser *et al*. 2018). In 2018, significant declines in median shoot density were reported at three of the five reference sites, while only two (Woodman Point and Bird Island) of the monitoring sites located outside Cockburn Sound showed similar declines (Appendix D).

The Warnbro Sound reference sites are subject to sediment erosion and the development of 'blow outs' (Mohring and Rule 2014; Rule 2015) which are significantly affecting the integrity of these sites. Relatively high levels of intrusion of potentially toxic sediment sulfides into seagrass tissues have also been reported at the reference sites (Fraser *et al.* 2016b). This is indicative of environmental pressures on the seagrass at these sites which may be contributing to the observed declines in seagrass shoot density. These factors reduce the value of the Warnbro Sound sites as reliable reference sites for comparison with Cockburn Sound.

In response to the Expert Advisory Panel's recommendations of a review of the Cockburn Sound water quality monitoring programs in 2017, the Cockburn Sound Management Council is exploring alternatives to the current monitoring and reporting of water quality and seagrass shoot density at the Warnbro Sound reference sites. A cross-scale approach to seagrass monitoring has been suggested, which would greatly increase the understanding of the health and trends of the seagrass communities in Cockburn Sound at an individual, site and landscape scale.

The long-term shoot density measurements provided by the annual monitoring program give a valuable picture into changing benthic habitats in different areas across Cockburn Sound. These could be supplemented by regular (every 3-5 years) benthic mapping of the entirety of Cockburn Sound, to identify changes in areal coverage of benthos over larger spatial scales. At areas where shoot densities continue to decline, novel methods for seagrass monitoring such as microbial (Martin *et al*. 2019, Fraser *et al*. in prep) or genomic toolkits (Davey *et al*. 2016) could provide sub-lethal indicators of seagrass stress to a range of different stressors, including sulfide intrusion which is typically insidious and hard to detect. Work is ongoing at UWA to develop microbial toolkits for the monitoring and management of *Halophila ovalis* in the Swan River, and similar methods could be developed for *Posidonia sinuosa* in Cockburn Sound. Cross-scale seagrass monitoring would provide a much more comprehensive picture of the resilience of seagrass ecosystems to coastal development, climate change and other environmental stressors.

3. Environmental Value: Fishing and Aquaculture

3.1 Environmental Quality Objectives

The Environmental Quality Objectives for the Environmental Value 'Fishing and Aquaculture' are:

- 'Maintenance of seafood safe for human consumption' – seafood is safe for human consumption when collected or grown.
- 'Maintenance of aquaculture' – water is of a suitable quality for aquaculture purposes (EPA 2017).

The EQC for these Environmental Quality Objectives set a level of environmental quality that will ensure:

- there is a low risk of any effect on the health of human consumers of seafood; and
- the health and productivity of aquaculture species is maintained (EPA 2017).

To protect wild seafood populations from the effects of environmental contamination, the EQC for the 'Maintenance of ecosystem integrity' are recommended (EPA 2017).

3.2 Water Quality and Seafood Monitoring

For filter feeding shellfish (excluding scallops and pearl oysters), any assessment against the Environmental Quality Objective must use data collected from a comprehensive monitoring program consistent with the requirements of the *Western Australia Shellfish Quality Assurance Program (WASQAP) Operations Manual* (WASQAP Operations Manual; Department of Health 2017).

The WASQAP Operations Manual sets out the requirements for bacteriological monitoring (water and shellfish), phytoplankton and shellfish biotoxin monitoring, and the chemical analysis of shellfish in the shellfish growing areas in Cockburn Sound. Figure 11 shows the shellfish growing areas in Cockburn Sound. Mussel Aquaculture Closed Safety Zones are designated areas around recognised contamination points that should not be considered as potential sites for shellfish aquaculture. Blue Lagoon Mussels undertook sampling over the 2017–18 monitoring period as part of the WASQAP and it was administered by the Department of Health.

Between July 2017 and June 2018, water samples for bacteriological monitoring were collected on six occasions from five sites (SF6, SF8, SF9, SF10, SF11) in the Southern Flats harvesting area[24] and 12 occasions from five sites (KGT1, KGT2, KGT3, KGT4, KGT5) in the Kwinana Grain Terminal harvesting area.[25] Shellfish samples were also collected for bacteriological testing on 12 occasions from two Kwinana Grain Terminal sites (North and South) and on six occasions from one Southern Flats site. PathWest Laboratory analysed the samples.

Depth-integrated water samples for phytoplankton identification and enumeration were collected approximately twice monthly on scheduled dates (during periods when shellfish were being harvested) at one of the Kwinana Grain Terminal sites (KGT3) and one of the Southern Flats sites (SF11). Samples were collected from as close to the shellfish as possible and at the location where shellfish samples for flesh testing

[24] Harvesting area classified as 'approved' under the WASQAP Operations Manual.
[25] Harvesting area classified as 'conditionally approved' under the WASQAP Operations Manual.

were taken. Dalcon Environmental analysed the samples for specific groups of phytoplankton species that are known to potentially produce toxins which may be concentrated in shellfish. At the same time, composite samples of shellfish flesh were collected for biotoxin testing in the event the potentially toxic phytoplankton counts exceeded the 'Alert' level to initiate flesh testing for biotoxins for the particular species.

In addition, shellfish flesh samples were collected for routine screening for amnesic shellfish poisoning (ASP), diarrhoetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP) biotoxins in accordance with the *Marine Biotoxin Monitoring and Management Plan* (Department of Health 2016). Eight shellfish flesh samples were collected between October 2017 and June 2018 at Kwinana Grain Terminal harvesting area. Fifteen shellfish flesh samples were collected between July 2017 and June 2018 at the Southern Flats harvesting area.

Fremantle Ports undertook analysis of toxicants in mussels at three sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3; Figure 2) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3; Figure 2). They collected 15 mussels of uniform size (approximately 55–90 mm shell length) from the nearest suitable infrastructure (e.g. wharf pylons, ladders) on 29 March 2018. Mussel samples were analysed for metals (inorganic arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (tributyltin [TBT], dibutyltin [DBT] and monobutyltin [MBT]) and polycyclic aromatic hydrocarbons (PAHs). ChemCentre undertook the analyses for metals, organotins and PAHs.

Source: Department of Health (2017)

Figure 11. Sampling locations associated with shellfish harvesting areas in Cockburn Sound.

3.3 Assessment against the Seafood Safe for Human Consumption Environmental Quality Criteria

3.3.1 Assessment of Compliance with the 'Faecal pathogens in water' EQC

Thermotolerant coliform concentrations (expressed as Colony Forming Units/100 millilitres [CFU/100 mL]) were assessed against the 'Faecal pathogens in water' EQG (EQG A, Table 4, Reference Document):

> *The median faecal coliform concentration in samples from a single site must not exceed 14 CFU/100 mL and the estimated 90th percentile must not exceed 21 CFU/100 mL measured using the membrane filtration method.*

These concentrations were recorded at five sites in each of the harvesting areas in Cockburn Sound over the 2017-18 non river-flow period. The results of the assessment against the EQG are presented in Table 27. Over the 2017–18 monitoring period both components of the 'Faecal pathogens in water' EQG were met at all sites in the Southern Flats harvesting area and at three sites (KGT3, KGT4 and KGT5) in the Kwinana Grains Terminal harvesting area. The second component of the 'Faecal pathogens in water' EQG was not met at KGT1 and KGT2 in the Kwinana Grains Terminal harvesting area. As the median faecal coliform concentration did not exceed 70 CFU/100 ml and the estimated 90th percentile did not exceed 85 CFU/100 ml at KGT1 and KGT2, the 'Faecal pathogens in water' EQS was met at KGT1 and KGT2.

Table 27. Assessment of thermotolerant (faecal) coliforms in water samples collected from five sites in each of the two shellfish harvesting areas in Cockburn Sound between July 2017 and June 2018 against the 'Faecal pathogens in water' EQG.

Site	Median faecal coliform concentration (CFU/100 mL)	90th percentile faecal coliform concentration (CFU/100 mL)	Assessment
EQG	Median faecal coliform concentration ≤ 14 CFU/100 mL	90th percentile ≤ 21 CFU/100 mL	
KGT1	1.0	**22.5**	EQG not met
KGT2	2.0	**32.6**	EQG not met
KGT3	2.0	11.0	EQG met
KGT4	1.0	3.2	EQG met
KGT5	1.0	1.0	EQG met
SF6	2.0	4.2	EQG met
SF8	1.0	1.0	EQG met
SF9	3.5	5.5	EQG met
SF10	1.0	1.0	EQG met
SF11	1.5	1.9	EQG met

Note: Text in bold indicates an exceedance of the EQG.

3.3.2 Assessment of Compliance with the 'Algal biotoxins' EQC

Concentrations of toxic phytoplankton recorded in the two harvesting areas in Cockburn Sound over the 2017–18 monitoring period were assessed against the 'Algal biotoxins' EQG (Table 28).

Table 28. The phytoplankton levels that trigger management action.

Type of Toxin	Phytoplankton Species	Alert Level (cells/litre) (notify Department of Health)	Alert Level (cells/litre) (initiate flesh testing)
Paralytic shellfish poison	*Alexandrium catenella*	100	200
	Alexandrium minutum	100	200
	Alexandrium ostenfeldii	100	200
	Alexandrium tamarense	100	200
	Gymnodinium catenatum	500	1,000
Diarrhoetic shellfish poison	*Dinophysis acuminata*	1,000	1,000
	Dinophysis acuta	500	1,000
	Dinophysis caudata	500	1,000
	Dinophysis fortii	500	1,000
	Prorocentrum lima	500	500
Amnesic shellfish poison	*Pseudo-nitzschia seriata* group	50,000	50,000
	Pseudo-nitzschia delicatissima group	500,000	500,000
Neurotoxic shellfish poison	*Karenia brevis*	500	1,000
	Karenia/Karlodinium/Gymnodinium group	100,000	250,000

The ‘Algal biotoxins’ EQG are the phytoplankton ‘Alert’ levels that trigger management action identified in the WASQAP *Marine Biotoxin Monitoring and Management Plan 2016* (Department of Health 2016). The concentrations of toxic phytoplankton found in the water samples taken from the two harvesting areas are listed in Table 29.

On 5, 10 and 17 July 2017 and 8 January 2018, the cumulative densities of *Pseudo-nitzschia delicatissima* group and *Pseudo-nitzschia seriata* group exceeded 50,000 cells per litre (cells/L) at the Southern Flats harvesting area. An ‘Alert’ level to initiate flesh testing was exceeded on 5, 10 and 17 July 2017 at the Southern Flats harvesting area.

The cumulative densities of *Pseudo-nitzschia delicatissima* group and *Pseudo-nitzschia seriata* group exceeded 50,000 cells/L at the Kwinana Grain Terminal harvesting area on 10 July 2017 and 8 January 2018. An ‘Alert’ level to initiate flesh testing was exceeded on 10 July 2017. No samples were available from the Kwinana Grain Terminal harvesting area for 5, 17, 24 and 31 July 2017 as the harvesting area was in a commercial closure.

Table 29. Phytoplankton concentrations in water samples collected in the two shellfish harvesting areas in Cockburn Sound between July 2017 and June 2018.

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	Toxic algae recorded	Cell density (cells/L)	Cell density (cells/L)
05/07/2017	*Pseudo-nitzschia* delicatissima group	No sample	**609,600**
	Pseudo-nitzschia seriata group	No sample	**194,800**
10/07/2017	*Pseudo-nitzschia* delicatissima group	453,200	**1,388,000**
	Pseudo-nitzschia seriata group	**124,000**	**438,800**
17/07/2017	*Pseudo-nitzschia* delicatissima group	No sample	**590,800**
	Pseudo-nitzschia seriata group	No sample	**163,600**
24/07/2017	*Pseudo-nitzschia* delicatissima group	No sample	29,140
	Pseudo-nitzschia seriata group	No sample	6,570
31/07/2017	*Pseudo-nitzschia* delicatissima group	No sample	35,200
	Pseudo-nitzschia seriata group	No sample	12,200
14/08/2017	*Dinophysis acuminata*	100	100
	Pseudo-nitzschia delicatissima group	300	2,000
	Pseudo-nitzschia seriata group	100	600
28/08/2017	*Dinophysis acuminata*	100	70
	Pseudo-nitzschia delicatissima group	4,100	2,800
	Pseudo-nitzschia seriata group	4,100	600
11/09/2017	*Pseudo-nitzschia* delicatissima group	9,200	6,400
	Pseudo-nitzschia seriata group	3,200	4,800
26/09/2017	*Dinophysis acuminata*	50	40
9/10/2017	No toxic algae detected	-	-
23/10/2017	*Dinophysis acuminata*	90	60
	Pseudo-nitzschia delicatissima group	23,400	13,600
	Pseudo-nitzschia seriata group	7,000	3,200
6/11/2017	*Pseudo-nitzschia* delicatissima group	460	340
20/11/2017	*Dinophysis acuminata*	120	100
	Pseudo-nitzschia delicatissima group	2,860	4,460
4/12/2017	*Pseudo-nitzschia* delicatissima group	6,020	6,340
11/12/2017	*Pseudo-nitzschia* delicatissima group	26,460	22,560
	Pseudo-nitzschia seriata group	6,420	5,660
8/01/2018	*Pseudo-nitzschia* delicatissima group	22,030	24,410
	Pseudo-nitzschia seriata group	36,490	27,230
22/01/2018	*Pseudo-nitzschia* delicatissima group	12,200	13,210
12/02/2018	*Pseudo-nitzschia* delicatissima group	60	3,600
26/02/2018	No toxic algae detected	-	-
12/03/2018	*Phalacroma rotundatum*	Not detected	10
	Pseudo-nitzschia delicatissima group	530	230
9/04/2018	*Pseudo-nitzschia* delicatissima group	11,410	16,670
19/04/2018	*Dinophysis caudata* var pendiculata	30	30
	Prorocentrum rhathymum	70	50
	Pseudo-nitzschia delicatissima group	5,630	1,210
14/05/2018	*Dinophysis caudata* var pendiculata	10	20
	Prorocentrum rhathymum	10	10
	Pseudo-nitzschia delicatissima group	4,810	3,780
28/05/2018	*Prorocentrum rhathymum*	30	10
	Pseudo-nitzschia delicatissima group	5,290	4,720
12/06/2018	*Pseudo-nitzschia* delicatissima group	880	1,440
25/06/2018	*Pseudo-nitzschia* delicatissima group	1,280	1,120

Assessment against the Environmental Quality Standard

The exceedance of the 'Algal biotoxins' EQG in July 2017 at the Southern Flats harvesting area triggered shellfish flesh testing for amnesic shellfish poisoning (ASP) biotoxin. The results of the screening for ASP were negative.

As the harvesting area was closed for commercial reasons the exceedance of the 'Algal biotoxins' EQG on 10 July 2017 at the Kwinana Grain Terminal harvesting area did not trigger shellfish flesh testing.

Under WASQAP, routine monthly biotoxin screening was introduced in 2015 for all harvesting areas. All the samples for Cockburn Sound in the 2017–18 reporting period were negative for PSP, DSP and ASP biotoxins (Table 30).

Table 30. Results of monthly biotoxin screening in the 2017–18 reporting period.

Sampling date	Amnesic shellfish poison (ASP)		Diarrhoetic shellfish poison (DSP)		Paralytic shellfish poison (PSP)	
	EQS: < 20 mg/kg		EQS: < 0.2 mg/kg		EQS: < 0.8 mg/kg Saxitoxin equivalents	
	Kwinana Grain Terminal	Southern Flats	Kwinana Grain Terminal	Southern Flats	Kwinana Grain Terminal	Southern Flats
5/07/2017	-	Negative	-	-	-	-
10/07/2017	-	Negative	-	Negative	-	Negative
17/07/2017	-	Negative	-	-	-	-
24/07/2017	-	Negative	-	-	-	-
31/07/2017	-	Negative	-	-	-	-
14/08/2017	-	Negative	-	Negative	-	Negative
28/08/2017	-	Negative	-	-	-	-
11/09/2017	-	Negative	-	Negative	-	Negative
9/10/2017	Negative	Negative	Negative	Negative	Negative	Negative
23/10/2017	-	Negative	-	Negative	-	Negative
6/11/2017	Negative	Negative	Negative	Negative	Negative	Negative
20/11/2017	Negative	-	Negative	-	-	-
4/12/2017	Negative	Negative	Negative	Negative	Negative	Negative
11/12/2017	Negative	-	-	-	-	-
22/01/2018	Negative	-	Negative	-	Negative	-
12/02/2018	Negative	-	Negative	-	Negative	-
9/04/2018	-	Negative	-	Negative	-	Negative
14/05/2018	-	Negative	-	Negative	-	Negative
12/6/2018	Negative	Negative	Negative	Negative	Negative	Negative

Note: Two shellfish flesh samples were taken from the Southern Flats harvesting area on 12 June 2018.

3.3.3 Assessment of Compliance with the '*Escherichia coli* (*E. coli*) in Shellfish Flesh' EQS

Escherichia coli (*E. coli*) counts (expressed as Most Probable Number per gram [MPN/g]) recorded in the flesh of mussels collected at each of the sites in the harvesting areas in Cockburn Sound over the 2017–18 monitoring period were assessed against the '*E. coli* in shellfish flesh' EQS (EQS B, Table 4, Reference Document):

> *Shellfish destined for human consumption should not exceed a limit of 2.3 MPN E. coli/g of flesh (wet weight) in two or more representative samples out of five, and no single sample should exceed 7 MPN E. coli/g.*

The results of the assessment against the EQS are presented in Table 31. Both components of the EQS were met in both harvesting areas over the 2017–18 monitoring period.

Table 31. Assessment of *E. coli* counts in mussel flesh collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2017 and June 2018 against the '*E. coli* in shellfish flesh' EQS.

Sampling date	*E. coli* count (MPN/g)			Assessment
	Kwinana Grain Terminal (North)	Kwinana Grain Terminal (South)	Southern Flats	
EQG	2 or more representative samples out of 5 ≤ 2.3 MPN *E. coli*/g flesh and no single sample > 7 MPN *E. coli*/g			
10/07/2017	< 1.8	< 1.8	< 1.8	EQS met
14/08/2017	< 1.8	< 1.8		EQS met
28/08/2017	< 1.8	< 1.8		EQS met
11/09/2017	< 1.8	< 1.8	< 1.8	EQS met
9/10/2017	< 1.8	< 1.8		EQS met
6/11/2017	< 1.8	< 1.8	< 1.8	EQS met
4/12/2017	< 1.8	2		EQS met
7/12/2017	< 1.8	< 1.8		EQS met
22/01/2018	< 1.8	< 1.8	< 1.8	EQS met
9/04/2018	4	< 1.8	< 1.8	EQS met
14/05/2018	< 1.8	< 1.8	< 1.8	EQS met
12/6/2018	< 1.8	< 1.8		EQS met

Note: 1.8 E. coli MPN/g is the laboratory's lowest limit of detection for the analysis.

3.3.4 Assessment of Compliance with the 'Chemical concentration in seafood flesh' EQC

Concentrations of chemicals in mussel flesh were assessed against the 'Chemical concentration in seafood flesh' EQG (EQG C, Table 4, Reference Document):

Median chemical concentration in the flesh of seafood should not exceed the environmental quality guidelines:

Copper	*30 mg/kg*	*(molluscs)*
Selenium	*1.0 mg/kg*	*(molluscs)*
Zinc	*290 mg/kg*	*(oysters).*

Concentrations were also assessed against the 'Chemical concentration in seafood flesh' EQS (EQS D, EQS E and EQS F, Table 4, Reference Document):

Chemical concentrations (except for mercury) in the flesh of seafood should not exceed the environmental quality standards:

Arsenic (inorganic)	*1.0 mg/kg*	*(molluscs)*
Cadmium	*2.0 mg/kg*	*(molluscs)*
Lead	*2.0 mg/kg*	*(molluscs)*

Mercury concentration in the flesh of seafood should not exceed the environmental quality standard in accordance with Standard 1.4.1 Contaminants and natural toxicants of the Australia New Zealand Food Standards Code (Schedule 19 – Maximum levels of contaminants and natural toxicants):

Mercury 0.5 mg/kg (mean level) (molluscs).

Pesticide residue concentrations in the flesh of seafood should not exceed the maximum residue limits and extraneous residue limits in Schedules 20 and 21 respectively of the Australia New Zealand Food Standards Code.[26]

The results of the assessment against the EQC are presented in Table 32. Where there are EQC, the concentrations of metals in mussel flesh at sites in Cockburn Sound were all below the relevant EQG or EQS. The concentrations of PCBs, PAHs, organochlorine and organophosphate pesticides in mussel flesh were all below the analytical limits of reporting. In the case of PCBs and the organochlorine pesticides for which there are EQS, the analytical limits of reporting were equivalent to or below the relevant EQS.

[26] Maximum residue limits from Schedule 20 and Extraneous residue limits from Schedule 21 of the *Australia New Zealand Food Standards Code* (accessed on 12 July 2017).

Table 32. Assessment of chemicals in mussels collected at sites in Cockburn Sound against the 'Chemical concentration in seafood flesh' EQC.

Chemical (mg/kg)	Environmental Quality Criteria (mg/kg)		Kwinana Bulk Terminal (mg/kg)				Kwinana Bulk Jetty (mg/kg)				Kwinana Grain Terminal (mg/kg)	Southern Flats (mg/kg)
	EQG	EQS	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median		
Metals												
Arsenic (Total)	-	-	-	-	-	-	-	-	-	-	3.2	3.2
Arsenic (inorganic)[1]	-	**1.0**	< 0.05	< 0.05	< 0.05	-	< 0.05	< 0.05	< 0.05	-	0.32	0.32
Cadmium	-	**2.0**	0.10	0.12	0.10	-	0.14	0.12	0.13	-	0.19	0.19
Chromium	-	-	0.07	0.12	0.09	-	0.13	0.09	0.09	-	Not measured	
Copper	**30**	-	0.83	0.83	0.85	0.83	0.93	0.99	0.82	0.93	0.81	0.76
Lead	-	**2.0**	0.06	0.06	0.10	0.06	0.09	0.09	0.11	0.09	< 0.1	< 0.1
Mercury	-	**0.5 (mean level)**	< 0.01	< 0.01	< 0.01	-	0.01	< 0.01	< 0.01	-	< 0.01	< 0.01
Selenium	**1.0**	-	0.5	0.5	0.6	0.5	0.8	0.7	0.7	0.7	Not measured	
Zinc (EQG for oysters)	**290**	-	22	23	26	23	30	27	31	30	28	24
Tributyltin	-	-	< 0.001	< 0.001	< 0.001	-	0.0015	0.0016	< 0.001	-	Not measured	
Organics												
Polychlorinated Biphenyls (PCBs) (fish)	-	**0.5**	Not measured				Not measured				All < 0.01	All < 0.01
Polycyclic aromatic hydrocarbons (PAHs)	-	-	All below limits of reporting				All below limits of reporting				Not measured	
Organochlorine Pesticides												
Aldrin and Dieldrin	-	**0.1**[2]	Not measured				Not measured				Aldrin < 0.01 Dieldrin < 0.1	Aldrin < 0.01 Dieldrin < 0.1
BHC (sum of isomers of 1,2,3,4,5,6-hexachloro-cyclohexane, excluding gamma-isomer Lindane)	-	**0.01**[2]	Not measured				Not measured				BHC-α < 0.01 BHC-β < 0.01 BHC-δ < 0.01	BHC-α < 0.01 BHC-β < 0.01 BHC-δ < 0.01
Chlordane (sum of cis- and trans-chlordane)	-	**0.05**[2]	Not measured				Not measured				cis- < 0.01 trans- < 0.01	cis- < 0.01 trans- < 0.01
DDT (sum of p,p'-DDT, o,p'-DDT, p,p'-DDE and p,p'-DDD)	-	**1.0**[2]	Not measured				Not measured				pp-DDD < 0.01 pp-DDE < 0.01 pp-DDT < 0.01	pp-DDD < 0.01 pp-DDE < 0.01 pp-DDT < 0.01
Heptachlor (sum of heptachlor and heptachlor epoxide)	-	**0.05**[2]	Not measured				Not measured				Heptachlor < 0.01 Heptachlor epoxide < 0.01	Heptachlor < 0.01 Heptachlor epoxide < 0.01
Hexachlorobenzene (HCB)	-	**0.1**[2]	Not measured				Not measured				< 0.01	< 0.01
Lindane (BHC-gamma)	-	**1.0**[2]	Not measured				Not measured				< 0.01	< 0.01

Notes: '<' signifies the result is less that the limit of quantitation for the method.

1. 10% of total arsenic is assumed to be present as the inorganic form (Stewart and Turnbull 2015).
2. Extraneous Residue Limits for organochlorine pesticides in molluscs (*Australia New Zealand Food Standards Code*, Schedule 21 Extraneous residue limits, April 2017).

3.4 Assessment against the Maintenance of Aquaculture Production Environmental Quality Criteria

3.4.1 Assessment of Compliance with the 'Physical-chemical stressors' EQG

Dissolved oxygen and pH measured at four water quality monitoring sites close to the shellfish harvesting areas in Cockburn Sound (CS9A, CS10N, CS11 and CS13) over the 2017–18 non river-flow period (Section 2.3; Figure 2) were assessed against the 'Physical-chemical stressors' EQG (EQG A, Table 5, Reference Document):

> *The median of the sample concentrations from the defined sampling area on each sampling occasion over the 2017–18 non river-flow period should meet the following environmental quality guideline values:*
>
> *Dissolved oxygen* ≥ *5* mg/L
>
> *pH* *6–9.*

Dissolved oxygen (milligrams per litre [mg/L]) and pH were recorded in the surface waters and at the depth of the mussel lines (8–10 m) at all four sites. These depths represent the approximate greatest depths of the mussel lines in the Kwinana Grain Terminal harvesting area and the Southern Flats harvesting area.

The results are presented in Table 33. Median dissolved oxygen concentrations and pH of surface waters and at depth in the defined sampling area met the relevant EQG on all sampling occasions over the 2017–18 non river-flow period.

Table 33. Assessment of dissolved oxygen concentrations and pH in surface waters and at depth, measured at four sites adjacent to the shellfish harvesting areas in Cockburn Sound over the 2017–18 non river-flow period against the 'Physico-chemical stressors' EQG.

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
Surface waters dissolved oxygen (milligrams/litre [mg/L])	1/12/2017	7.2	7.0	7.5	7.3	7.3	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	8/12/2017	7.2	6.8	7.3	7.1	7.3		
	15/12/2017	7.1	7.1	7.0	7.1	7.1		
	22/12/2017	7.2	7.3	7.6	7.3	7.3		
	5/01/2018	6.9	6.8	6.9	6.9	6.9		
	15/01/2018	6.9	6.9	6.9	7.0	6.9		
	22/01/2018	6.8	6.5	6.7	6.9	6.8		
	29/01/2018	6.6	6.5	7.0	6.8	6.7		
	5/02/2018	6.9	6.5	6.8	7.1	6.9		
	12/02/2018	6.8	6.6	6.9	6.7	6.8		
	19/02/2018	6.7	6.5	6.3	6.8	6.6		
	26/02/2018	6.7	6.5	6.4	6.7	6.6		
	5/03/2018	6.8	6.9	6.9	7.0	6.9		
	12/03/2018	6.8	6.8	7.0	7.0	6.9		
	19/03/2018	6.9	6.9	6.8	6.9	6.9		
	26/03/2018	6.5	6.5	6.6	6.6	6.6		

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
Depth waters dissolved oxygen (mg/L)	1/12/2017	7.1	6.9	7.0	7.3	7.1	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	8/12/2017	7.2	6.9	7.0	6.6	7.0		
	15/12/2017	6.6	7.0	6.4	7.0	6.8		
	22/12/2017	6.7	6.8	7.1	6.4	6.8		
	5/01/2018	6.8	5.9	6.3	6.2	6.3		
	15/01/2018	6.3	6.2	6.7	6.4	6.4		
	22/01/2018	6.6	6.2	5.8	5.5	6.0		
	29/01/2018	6.6	6.2	6.5	6.8	6.6		
	5/02/2018	6.4	6.7	6.6	5.7	6.5		
	12/02/2018	6.7	6.5	6.2	6.0	6.4		
	19/02/2018	6.5	6.6	6.2	6.7	6.6		
	26/02/2018	6.6	6.5	6.4	6.6	6.6		
	5/03/2018	5.9	6.6	6.8	6.0	6.3		
	12/03/2018	6.2	5.7	6.5	5.9	6.1		
	19/03/2018	6.7	6.7	6.4	6.8	6.7		
	26/03/2018	6.6	6.4	6.6	6.5	6.6		
Surface waters pH	1/12/2017	8.2	8.2	8.3	8.2	8.2	6–9	EQG met on all sampling occasions and at all sites
	8/12/2017	8.2	8.2	8.2	8.2	8.2		
	15/12/2017	8.2	8.2	8.2	8.2	8.2		
	22/12/2017	8.2	8.2	8.2	8.2	8.2		
	5/01/2018	8.2	8.2	8.2	8.2	8.2		
	15/01/2018	8.2	8.2	8.2	8.2	8.2		
	22/01/2018	8.2	8.2	8.2	8.2	8.2		
	29/01/2018	8.2	8.2	8.3	8.2	8.2		
	5/02/2018	8.3	8.2	8.2	8.3	8.3		
	12/02/2018	8.3	8.3	8.3	8.3	8.3		
	19/02/2018	8.4	8.3	8.3	8.3	8.3		
	26/02/2018	8.2	8.2	8.2	8.2	8.2		
	5/03/2018	8.3	8.3	8.3	8.3	8.3		
	12/03/2018	8.3	8.3	8.3	8.3	8.3		
	19/03/2018	8.2	8.2	8.2	8.2	8.2		
	26/03/2018	8.2	8.2	8.2	8.2	8.2		
Depth waters pH	1/12/2017	8.2	8.2	8.2	8.2	8.2	6–9	EQG met on all sampling occasions and at all sites
	8/12/2017	8.2	8.2	8.2	8.2	8.2		
	15/12/2017	8.2	8.2	8.2	8.2	8.2		
	22/12/2017	8.2	8.2	8.2	8.2	8.2		
	5/01/2018	8.2	8.2	8.2	8.2	8.2		
	15/01/2018	8.2	8.2	8.2	8.2	8.2		
	22/01/2018	8.2	8.2	8.2	8.1	8.2		
	29/01/2018	8.2	8.2	8.2	8.2	8.2		
	5/02/2018	8.2	8.2	8.2	8.2	8.2		
	12/02/2018	8.3	8.3	8.3	8.3	8.3		
	19/02/2018	8.4	8.4	8.3	8.4	8.4		
	26/02/2018	8.2	8.2	8.2	8.2	8.2		
	5/03/2018	8.3	8.3	8.3	8.3	8.3		
	12/03/2018	8.3	8.2	8.3	8.2	8.3		
	19/03/2018	8.2	8.2	8.2	8.2	8.2		
	26/03/2018	8.2	8.2	8.2	8.2	8.2		

3.4.2 Assessment of Compliance with the 'Toxicants' EQG

Concentrations of ammonia and nitrate–nitrite measured at four water quality monitoring sites close to the shellfish harvesting areas in Cockburn Sound (CS9A, CS10N, CS11 and CS13) over the 2017–18 non river-flow period (Section 2.3; Figure 2) were assessed against the 'Toxicants' EQG for the maintenance of aquaculture production (EQG B, Table 5, Reference Document). On one occasion (16 February 2018) the concentrations of selected toxicants (ammonia, nitrate–nitrite, copper and manganese) in surface water samples were collected at sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) (Section 2.3; Figure 2). They were also assessed against the 'Toxicants' EQG for the maintenance of aquaculture production.

The Reference Document (Table 5) specifies that the 95th percentile of the sample concentrations from the defined sampling area (either from one sampling run or all samples over an agreed period of time, or from a single site over an agreed period of time) should not exceed the EQG values. Given the small sample size, concentrations of copper, manganese, ammonia and nitrate–nitrite in water samples collected at each of the Kwinana Bulk Terminal and Kwinana Bulk Jetty sites were assessed against the relevant 'Toxicants' EQG values.

The results are presented in Table 34. The toxicant concentrations recorded at all the sites were below the relevant EQG values.

Table 34. Assessment of concentrations of ammonia, nitrate–nitrite, copper and manganese at sites in the proximity of the shellfish harvesting areas in Cockburn Sound against the 'Toxicants' EQG.

<table>
<tr><th rowspan="2">Site</th><th colspan="3">Ammonia (µg N/L)</th><th colspan="3">Nitrate–Nitrite (µg N/L)</th><th colspan="2">Copper (µg/L)</th><th colspan="2">Manganese (µg/L)</th></tr>
<tr><th>EQG</th><th>Surface</th><th>Bottom</th><th>EQG</th><th>Surface</th><th>Bottom</th><th>EQG</th><th>Surface</th><th>EQG</th><th>Surface</th></tr>
<tr><td>KBT1</td><td rowspan="10">≤1,000</td><td>5</td><td>32</td><td rowspan="10">Nitrite-N ≤100 Nitrate-N ≤100,000</td><td>3</td><td>6</td><td rowspan="10">≤5</td><td>0.3</td><td rowspan="10">≤10</td><td>1.0</td></tr>
<tr><td>KBT2</td><td>4</td><td>12</td><td>2</td><td>5</td><td>0.8</td><td>1.0</td></tr>
<tr><td>KBT3</td><td>4</td><td>11</td><td>3</td><td>7</td><td>1.0</td><td>1.1</td></tr>
<tr><td>KBJ1</td><td>5</td><td>27</td><td>6</td><td>7</td><td>0.7</td><td>Not measured</td></tr>
<tr><td>KBJ2</td><td>15</td><td>8</td><td>6</td><td>< 2</td><td>0.5</td><td>Not measured</td></tr>
<tr><td>KBJ3</td><td>< 3</td><td>9</td><td>< 2</td><td>3</td><td>0.6</td><td>Not measured</td></tr>
<tr><td>CS13</td><td>4.1</td><td>16.0</td><td>2</td><td>4</td><td>Not measured</td><td>Not measured</td></tr>
<tr><td>CS9A</td><td colspan="2">95th percentile = 13.5</td><td colspan="2">95th percentile = 4</td><td>Not measured</td><td>Not measured</td></tr>
<tr><td>CS10N</td><td colspan="2">95th percentile = 16.0</td><td colspan="2">95th percentile = 4</td><td>Not measured</td><td>Not measured</td></tr>
<tr><td>CS11</td><td colspan="2">95th percentile = 5.1</td><td colspan="2">95th percentile = 3</td><td>Not measured</td><td>Not measured</td></tr>
<tr><td colspan="4">Assessment</td><td colspan="7">EQG met at all sites</td></tr>
</table>

3.5 Conclusions

Based on the results from the 2017–18 monitoring programs in Cockburn Sound, there is a high degree of certainty that the Environmental Quality Objectives 'Maintenance of seafood safe for human consumption' and 'Maintenance of aquaculture' have been achieved in the 'approved' and 'conditionally approved' shellfish harvesting areas in southern Cockburn Sound. There is no information available from other areas in Cockburn Sound or for wild shellfish or fish.

Accredited quality assurance monitoring programs based on the requirements of the WASQAP Operations Manual are currently conducted for ‘approved’ and ‘conditionally approved’ shellfish harvesting areas in southern Cockburn Sound where shellfish are grown commercially for the food market. The Department of Health (2010, 2016) recommends only eating shellfish harvested commercially under strict quality assurance monitoring programs.

4. Environmental Value: Recreation and Aesthetics

4.1 Environmental Quality Objectives

The Environmental Quality Objectives for the Environmental Value ‘Recreation and Aesthetics’ are:

- ‘Maintenance of primary contact recreation values’ – primary contact recreation (for example swimming) is safe to undertake.
- ‘Maintenance of secondary contact recreation values’ – secondary contact recreation (for example boating) is safe to undertake.
- ‘Maintenance of aesthetic values’ – the aesthetic values are protected (EPA 2017).

The EQC for these Environmental Quality Objectives set a level of environmental quality that will ensure:

- people undertaking primary contact recreational activities where the participant comes into frequent direct contact with the water, either as part of the activity or accidentally, are protected from ill effects caused by poor water quality;
- people undertaking secondary contact recreational activities where the participant comes into direct contact with the water infrequently, either as part of the activity or accidentally, are protected from ill effects caused by poor water quality; and
- the visual amenity of the waters of Cockburn Sound is maintained (EPA 2017).

4.2 Water Quality Monitoring

The cities of Cockburn, Kwinana, and Rockingham undertook bacterial water sampling at a number of popular recreational beaches (program sites) around Cockburn Sound in the 2017–18 monitoring period (Figure 12). The Department of Health administered the sampling. A minimum collection of 65 samples between November and early May (the time of year when most people participate in recreational activities) over five consecutive years is encouraged at these program sites. This is based on the Department of Health’s revised approach of the National Health and Medical Research Council’s (2008) recommendation of 100 samples collected over five consecutive years. The Department of Health’s recommendation of a minimum of 65 samples is equivalent to 13 samples per season (equivalent to approximately one sample collected each fortnight). This minimum number of samples is recommended to maintain statistical confidence when assigning a site classification (beach grades) following the National Health and Medical Research Council (2008) guidelines.[27]

In addition, local governments monitor other sites (reference sites) for their own purposes outside of the program sites, generally at less frequent intervals (for example five or less samples per season).

PathWest Laboratory analysed samples for enterococci, the bacterial indicator recommended by the National Health and Medical Research Council (2008).

[27] For further information regarding beach grades refer to the Department of Health’s website: http://ww2.health.wa.gov.au/Articles/A_E/Beach-grades-for-Western-Australia

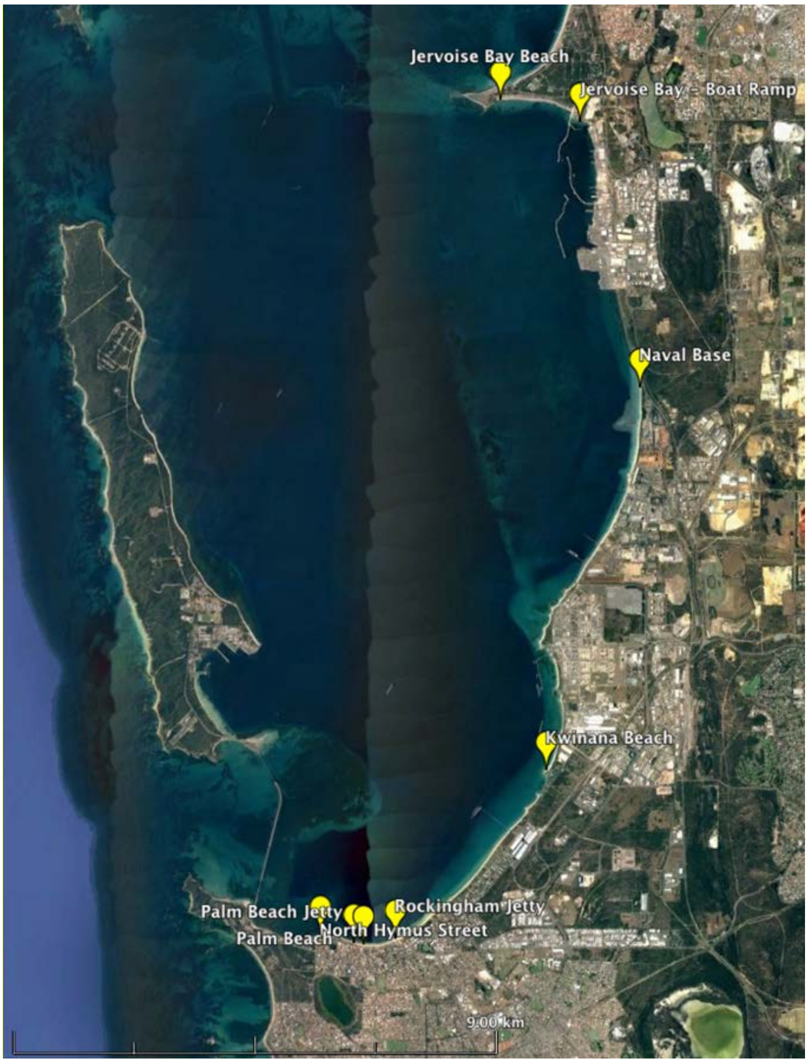


Figure 12. Sampling locations associated with recreational beaches in Cockburn Sound.

4.3 Assessment against the Maintenance of Primary and Secondary Contact Recreation Environmental Quality Criteria

4.3.1 Assessment of Compliance with the 'Faecal Pathogens' EQG

Enterococci counts (expressed as Most Probable Number per 100 millilitres [MPN/100 mL]) recorded at each of eight locations around Cockburn Sound over the 2017–18 monitoring period were assessed against the 'Faecal pathogens' EQG for primary contact recreation (EQG A, Table 6, Reference Document):

> *The 95th percentile bacterial count of marine waters should not exceed 200 enterococci/100 mL.*

Enterococci counts were also assessed against the 'Faecal pathogens' EQG for secondary contact recreation (EQG A, Table 7, Reference Document):

> *The 95th percentile bacterial count of marine waters should not exceed 2,000 enterococci/100 mL.*

The results are presented in Table 35. The 'Faecal pathogens' EQG for both primary and secondary contact recreation were met at all of the sites monitored over the

2017–18 monitoring period. Only one site (Jervoise Bay Beach) met the minimum sample size of 65 samples collected over a five year period.

Table 35. Assessment of the 95th percentile of enterococci counts (samples collected between 2013–14 and 2017–18) at eight locations around Cockburn Sound against the 'Faecal pathogens' EQG.

Location	Type of Site	Number of measurements	EQG		Rolling 5-year 95th percentile of enterococci counts (MPN/100 ml)
			Primary contact	Secondary contact	
North Hymus Street[1]	Program	59	200	2,000	85
Jervoise Bay Beach	Program	66			95
Rockingham Beach + Jetty[1]	Program	55			160
Palm Beach Jetty[1]	Program	60			175
Naval Base[1]	Program	35			34
Kwinana Beach[1]	Program	33			60
Jervoise Bay Boat Ramp[1]	Reference	61			45
Palm Beach[1]	Reference	27			38
Assessment		Primary contact and secondary contact recreation EQG met at all sites			

1 Sample size did not meet the minimum number of samples required for analysis, therefore results must be treated with caution.

Note: The 95th percentiles were calculated using the Western Australian Department of Health's Enterotester V200. The Enterotester is a Microsoft® Excel template predicated on a risk management approach to recreational water surveillance (Lugg *et al*. 2012) and is the method used by the Western Australian Department of Health.

4.3.2. Assessment of Compliance with the 'Physical' EQG

Water clarity and pH recorded at each of the 18 water quality monitoring sites over the 2017–18 non river-flow period (Section 2.3; Figure 2) were assessed against the 'Physical' EQC for primary contact recreation (EQG D and EQS E, Table 6, Reference Document):

Water clarity EQG: *To protect the visual clarity of waters used for swimming, the horizontal sighting of a 200 mm diameter black disc should exceed 1.6 m.*[28]

pH EQS: *The median of the sample concentrations from the area of concern (either from one sampling run or from a single site over an agreed period of time) should not exceed the range of 5–9 pH units.*

pH was also assessed against the 'Physical' EQG for secondary contact recreation (EQG E, Table 7, Reference Document):

pH EQG: *The median of the sample concentrations from a defined sampling area (either from one sampling run or from a single site over an agreed period of time) should not exceed the range of 5–9 pH units.*

The results are summarised in Table 36. Water clarity and pH met the relevant 'Physical' EQC for primary and secondary contact recreation at all the sites.

[28] The former Office of the Environmental Protection Authority (now the Department of Water and Environmental Regulation) advised that in marine waters it is considered reasonable to use vertical Secchi disc measurements.

Table 36. Assessment of pH and water clarity (Secchi disc) at 18 water quality monitoring sites in Cockburn Sound over the 2017–18 non river-flow period against the 'Physical' EQC for primary and secondary contact recreation.

Site	pH EQC	Median pH (surface)	Median pH (bottom)	Water Clarity EGG	Range of Secchi disc measurements (m ± 0.1 m)	Assessment
CS4	Not to exceed the range of 5–9 pH units	8.2	8.2	>1.6 m	7.0 – 13.0	EQC met at all sites
CS5		8.2	8.2		5.1 – 12.9	
CS6A		8.2	8.2		4.9 – 10.3	
CS7		8.2	8.2		4.8 – 10.4	
CS8		8.2	8.2		4.8 – 11.0	
CS9		8.2	8.1		5.3 – 9.5	
CS10N		8.2	8.2		5.2 – 12.7	
CS11		8.2	8.2		5.2 – 10.5	
CS12		8.2	8.2		5.2 – 9.7	
CS13		8.2	8.2		5.2 – 10.8	
CS9A		8.2	8.2		3.1 – 9.1	
CB		8.2	8.2		4.9 – 9.5	
G1		8.2	8.2		5.0 – 9.9	
G2		8.2	8.2		5.2 – 9.8	
G3		8.2	8.2		6.1 – 12.9	
SF		8.2	8.2		5.0 – 11.8	
MB		8.2	8.2		5.1 – 8.0	
NH3		8.2	8.2		2.8 – 4.5	

4.3.3. Assessment of Compliance with the 'Toxic Chemicals' EQC

In general, the levels of toxicants required to impact on the health of people recreating in marine waters are greater than the levels necessary to protect ecosystem health. The toxicant concentrations were below the relevant ecosystem health EQC (refer to Section 2.7). The waters can therefore also be considered safe for human recreation.

4.4 Indicators of Aesthetic Quality

Cockburn Sound is highly valued by the community for its ecological, recreational and aesthetic attributes and EQC have been developed to protect the aesthetic values of the Sound (EPA 2017). Many of the guidelines for aesthetic quality are subjective and relate to the general appreciation and enjoyment of Cockburn Sound by the community as a whole. Factors such as whether observations of aesthetic quality are in a location or of an intensity likely to trigger community concern, and whether any impacts on aesthetic quality are transient, persistent or regular events, are therefore considered.

In the vicinity of each of the 18 water quality monitoring sites on each of the 16 sampling occasions over the December 2017 to March 2018 non river-flow period (Section 2.3; Figure 2), MAFRL undertook qualitative observations of the following indicators of aesthetic quality:

- nuisance organisms;
- algal blooms;
- faunal deaths;
- water clarity;
- colour variation;

- surface films (for example oil and petrochemical films on the water);
- surface or submerged debris (for example grain and litter); and
- odours.

The results are summarised in Table 37.

Grain was observed on the water surface at CS10N adjacent to the Kwinana Grain Jetty on seven occasions and at CS9 and CS13 on one occasion each over the 2017–18 non river-flow period. Odours were reported at sites adjacent to the industrial area on the eastern shore of Cockburn Sound (CB, CS9, CS9A and CS12) on eight occasions and at CS10N adjacent to the Kwinana Grain Terminal on one occasion.

Algal blooms were observed at sites adjacent to the industrial area on the eastern shore of Cockburn Sound (CB, CS9, CS9A and CS12) and CS10N adjacent to the Kwinana Grain Terminal. The algal blooms were observed on one occasion at CS9A (26 March 2018), CS12 (15 December 2017) and CS10N (19 February 2018). Algal blooms were observed on two occasions at CB and CS9 (8 December 2017 and 15 December 2017). Algal blooms were also observed on 8 December 2017 at CS7 and 15 December 2017 at CS7, CS8, G1, G2 and Jervoise Bay Northern Harbour (NH3).

Algal blooms were observed at the Jervoise Bay Northern Harbour site on nine out of the ten days that algal blooms were observed. Impacts on water clarity and water colour were also observed on these occasions.

Algal blooms were observed at one Warnbro Sound reference site (WS4) on 19 February 2018.

Table 37. Qualitative observations of indicators of aesthetic quality at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound over the 2017–18 non river-flow period.

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour variation	Surface films or oils	Surface or submerged debris	Odours
1/12/2017	CS7, CS12, CS9, NH3 (surface phytoplankton scum)	NH3	-	NH3 (algal blooms)	NH3 (algal blooms)	-	CB, WSSB, WS4, G1,CS8, G2, G3, CS4, CS5 (algae); CS10N (grain)	CS12 (industrial odours)
8/12/2017	CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, G1, CS8, G2, CS5, NH3 (surface phytoplankton scum); G1 (algae)	CS7, CB, CS9	-	CS7 and CB (algal blooms)	CS7, CB, CS12, CS9, CS5 (milky green)	MB	G1 (seagrass)	CS12 (industrial odours); CS9A (hydrocarbons)
15/12/2017	CS7, CB, CS12, CS9, G1, NH3 (surface phytoplankton scum)	CS7, CB, CS12, CS9, G1, CS8, G2, NH3	-	CS7, CB, CS12, CS9, G1, CS8, G2, NH3 (algal blooms)	CS7, CB, CS12, CS9, G1, CS8, G2, NH3 (milky green)	-	CB, CS12, CS11, MB, SF, WSSB, WS4, G1,CS8, G2, G3 (algae)	-
22/12/2017	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, SF, G1, CS8, G2, NH3 (surface phytoplankton scum)	NH3	-	NH3 (algal blooms)	NH3 (algal blooms)	-	CS10N (grain); WSSB, WS4, G2, G3, CS4, CS5 (algae); SF (seagrass)	-
5/01/2018	CS7, CB, CS12, CS9, CS9A, CS10N, CS13, NH3 (surface phytoplankton scum)	NH3	-	NH3 (algal blooms)	NH3 (algal blooms)	-	CS12, WSSB, WS4 (algae); CS13, CS11 (seagrass); CS9 and CS10N (grain)	-
15/01/2018	CS6A, CS9, NH3 (surface phytoplankton scum)	NH3	-	CS9A (tug wash); NH3 (algal blooms)	CS9A (tug wash); NH3 (algal blooms)	-	-	CS12 (industrial odours)
22/01/2018	CS6A, CS7, CB, CS12, CS9, CS9A (surface phytoplankton scum); NH3 (algal blooms)	NH3	-	NH3 (algal blooms)	NH3 (algal blooms)	CS12	WSSB, WS4, G1, CS8, G2 (seagrass)	-
29/01/2018	CS6A, CS7, CB, CS12, CS9, CS9A, CS13, CS11, WS4, G1,CS8, G2, CS5 (surface phytoplankton scum)	-	-	CS9A, CS10N, WS4, NH3	CS9A, CS10N, WS4 (milky green); NH3 (green)	-	CS13 (grain); SF (seagrass and algae); G2 (seagrass)	CB, CS12, CS9A (industrial odours)
5/02/2018	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, CS8, CS5, NH3 (surface phytoplankton scum)	-	-	-	NH3 (green)	-	CS10N (grain); CS11 (seagrass and algae)	-
12/02/2018	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, G1	G1, NH3	-	G1, NH3 (algal blooms)	G1, NH3 (algal blooms)	-	CS6A, CS7, CB, SF, CS5 (seagrass and algae); CS10N	-

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour variation	Surface films or oils	Surface or submerged debris	Odours
	(surface phytoplankton scum)						(grain); MB (seagrass)	
19/02/2018	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, WS4, CS8, CS5, NH3 (surface phytoplankton scum)	CS10N, WS4, CS5, NH3	-	CS10N, WS4, CS5, NH3 (algal blooms)	CS10N, WS4, CS5, NH3 (algal blooms)	-	WSSB, WS4 (seagrass); CS10N (grain)	CS12 and CS9 (oil odour)
26/02/2018	CS6A, CS7, CB, CS12, CS13, MB, CS8, G2, G3, CS4, CS5, NH3 (surface phytoplankton scum)	-	-	-	NH3 (green)	-	WSS4, G2, G3 (seagrass)	-
5/03/2018	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, SF, WS4, CS8 (surface phytoplankton scum)	-	-	-	NH3 (green)	-	MB, SF, G1, CS4 (seagrass)	CS12, CS9A (industrial odours)
12/03/2018	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, WS4, CS8, G3, CS5, NH3 (surface phytoplankton scum)	-	-	-	CS6A, CS7, CB, CS9A, NH3 (green)	-	MB, SF (seagrass)	CS12 (industrial odours)
19/03/2018	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, WS4, G1, G2, G3, NH3 (surface phytoplankton scum)	-	-	CS7 (tug wash)	NH3 (green)	-	SF, WSB, CS8 (seagrass)	CS12 (industrial odours)
26/03/2018	CS9A, CS11, NH3 (surface phytoplankton scum)	CS9A, CS11, NH3	-	CS9A (tug wash and algal blooms); CS11, NH3 (algal blooms)	CS9A, CS11, NH3 (green)	-	CS10N (grain)	CS10N (grain odour)

4.5 Conclusions

Based on the results from the 2017–18 monitoring programs in Cockburn Sound, there were no recorded exceedances of the EQC for the Environmental Quality Objectives ‘Maintenance of primary contact recreation values’ and ‘Maintenance of secondary contact recreation values’. There is, therefore, a high degree of certainty that the Environmental Quality Objectives have been achieved and the waters are safe for recreational activities.

5. Environmental Value: Industrial Water Supply

5.1 Environmental Quality Objective

The Environmental Quality Objective for the Environmental Value ‘Industrial Water Supply’ is:

- ‘Maintenance of water quality for industrial use’ – water is of suitable quality for industrial use (EPA 2017).

The Perth Seawater Desalination Plant (Desalination Plant), located in the industrial zone along the eastern shore of Cockburn Sound, takes seawater from Cockburn Sound and utilises reverse osmosis to produce drinking water for the Perth metropolitan area. The Desalination Plant produces 18 per cent of Perth’s water supply. Seawater quality is fundamental to the operation of the Desalination Plant. Seawater quality determines the level of pre-treatment of seawater required to ensure optimal performance of the reverse osmosis system and to prevent fouling and scaling.

A reduction in the quality of the incoming seawater would have a significant impact on the pre-treatment requirements, and potentially the efficiency of the reverse osmosis membranes, resulting in additional costs in producing drinking water. As there are significant development pressures in this area, water quality criteria have been defined for the intake seawater to ensure the efficacy of the desalination process and that the quality of the desalinated water is maintained (Table 9, Reference Document).

No other guidelines have been defined for industrial water use (EPA 2017).

5.2 Perth Seawater Desalination Plant Intake Water Quality Monitoring

The Water Corporation undertakes real-time continuous monitoring of a suite of parameters including temperature, pH, dissolved oxygen and hydrocarbons in the intake seawater. The Water Corporation also monitors other parameters in the intake seawater via a routine sampling program. Parameters relevant to the water quality criteria include total suspended solids (TSS) and bacterial indicators, which were monitored weekly; and boron and bromide, which were monitored quarterly. Sampling for the bacterial indicator *Escherichia coli* (*E. coli*) was replaced with sampling for *Enterococci* in May 2017, as this gives a more robust pathogen indicator in saltwater. For water quality parameters, water samples were collected by an in-house process chemist and analysed by accredited laboratories.

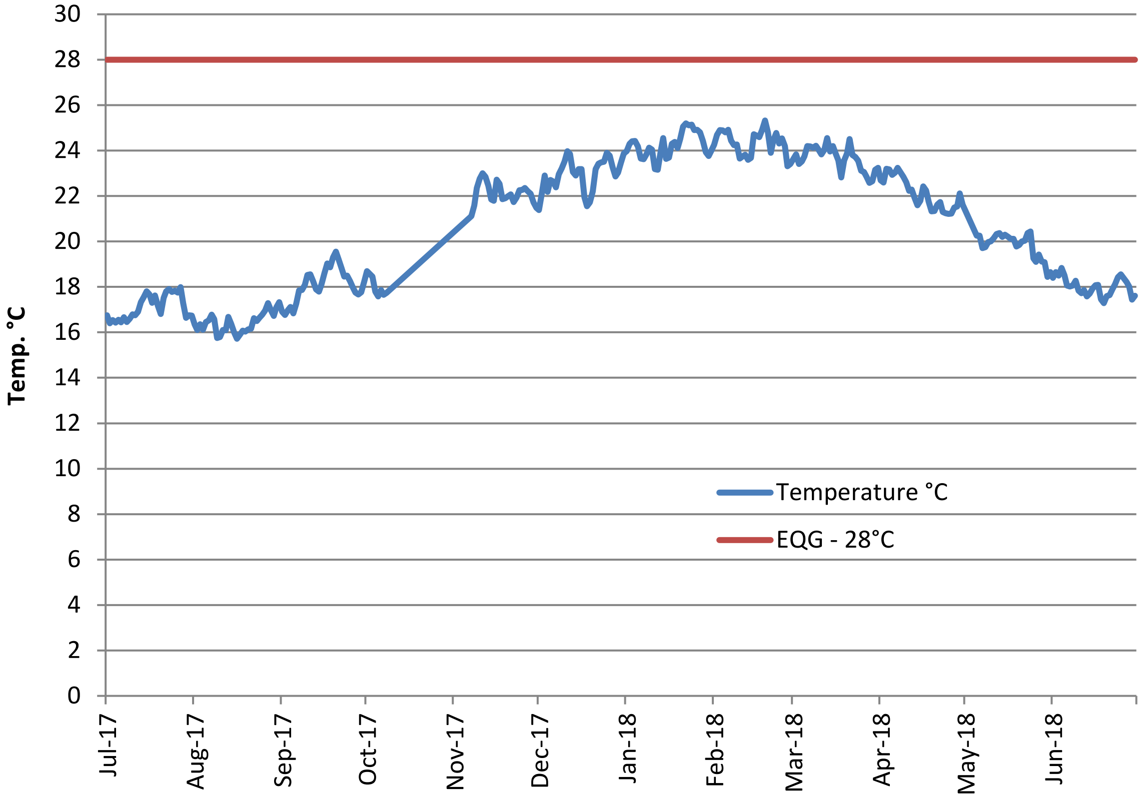
5.3 Assessment against the Environmental Quality Criteria for Maintenance of Water Quality for Desalination Plant Intake Water

5.3.1 Biological Indicators

Enterococci did not exceed the EQG of 32 Colony Forming Units per 100 millilitres (CFU/100 mL) on any sampling occasion over the July 2017 to June 2018 monitoring period. *Enterococci* was generally under the Limit of Reporting (LOR) of <10 CFU/100mL. The highest recording during the reporting period was 20 CFU/100mL which was recorded on two occasions.

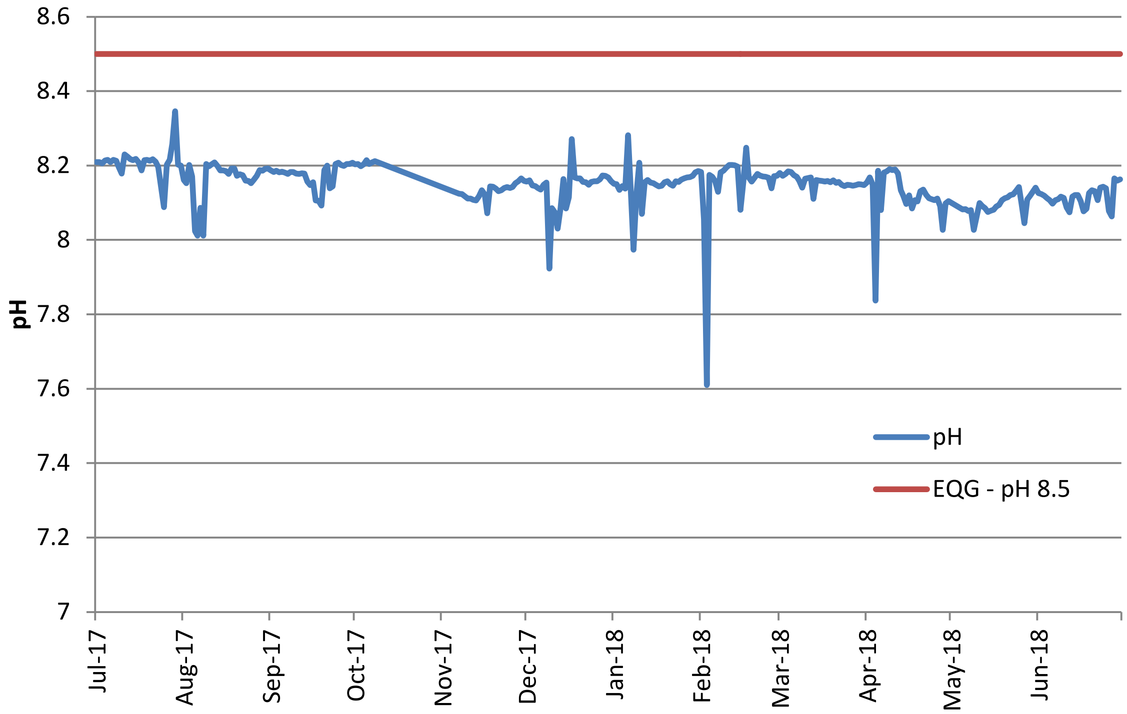
5.3.2 Physical and Chemical Indicators

Over the 2017–18 monitoring period, the temperature of the intake seawater was below the EQG of 28°C (Figure 13) and pH was below the EQG of 8.5 (Figure 14). Dissolved oxygen concentrations were above the EQG of 2 milligrams per litre (mg/L) over the monitoring period (Figure 15).



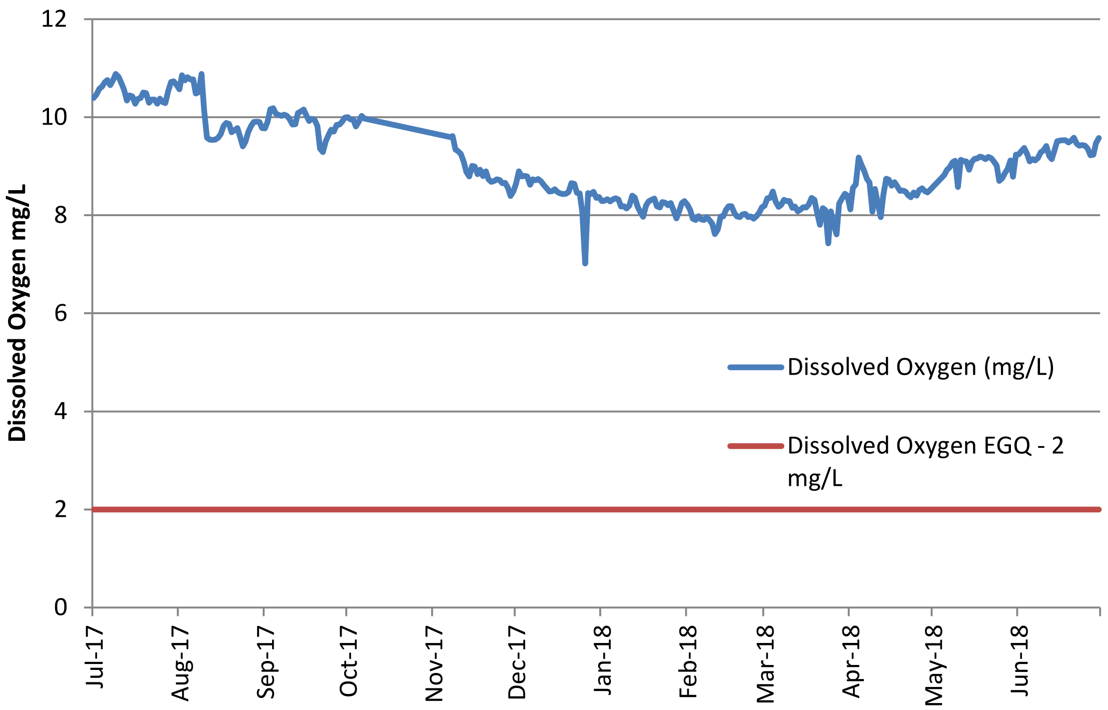
Note: Data recorded during scheduled plant shutdowns has been removed, as the data is not representative of seawater quality (Data removed from 09/10/17 – 06/11/17 and 01/05/18 – 04/05/18).

Figure 13. Daily average temperature of the intake seawater over the 2017–18 monitoring period.



Note: Data recorded during scheduled plant shutdowns has been removed, as the data is not representative of seawater quality (Data removed from 09/10/17 – 06/11/17 and 01/05/18 – 04/05/18).

Figure 14. Daily average pH of the intake seawater over the 2017–18 monitoring period.



Note: Data recorded during scheduled plant shutdowns has been removed, as the data is not representative of seawater quality (Data removed from 09/10/17 – 06/11/17 and 01/05/18 – 04/05/18).

Figure 15. Daily average dissolved oxygen concentration of the intake seawater over the 2017–18 monitoring period.

The 'rolling' four-week median concentration of TSS exceeded the EQG of 4.5 mg/L from mid-November to late December, from mid to late April, and from mid to late June (Figure 16). There were two individual exceedances of the EQG of 9mg/L in March and June. The two individual exceedances did not have a significant impact on the operation of the plant.

The Water Corporation advised that the dosing of coagulant in the Desalination Plant's pre-treatment process is automated to adjust to variance in TSS up to the Desalination Plant's operational limit of 9 mg/L.

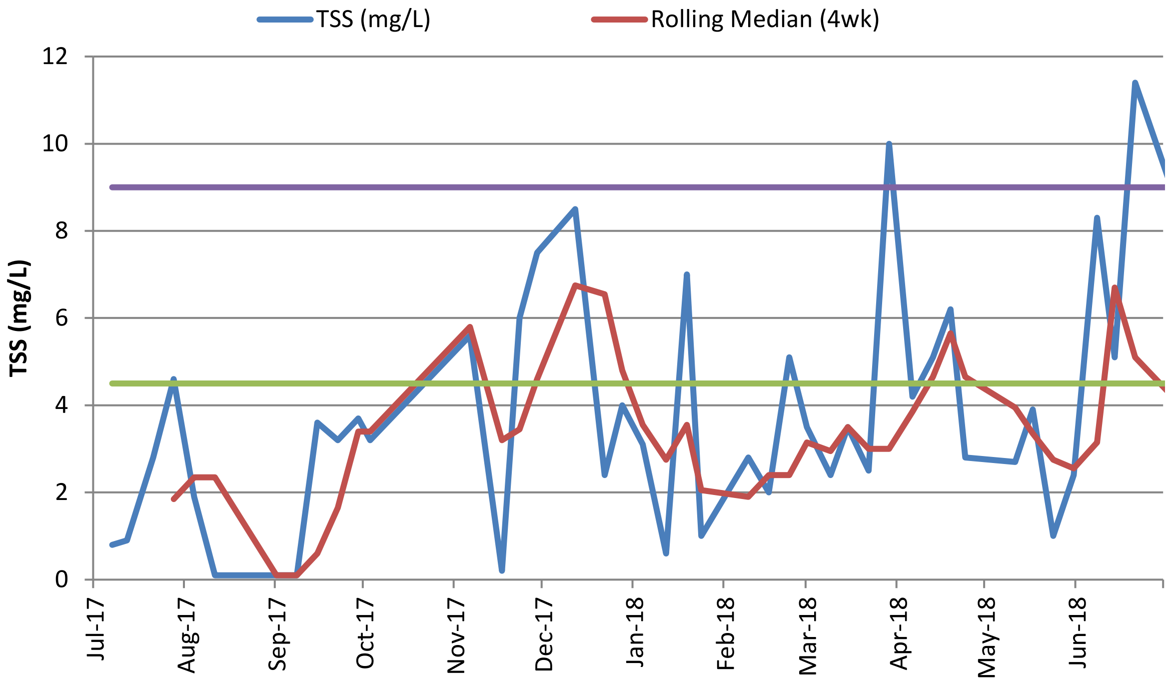


Figure 16. Weekly and 'rolling' four-weekly median total suspended solids (TSS) concentration in the intake seawater over the 2017–18 monitoring period.

Over the 2017–18 monitoring period, hydrocarbon concentrations in the intake seawater did not exceed the Water Corporation's limit, nor did boron or bromide concentrations exceed the EQG of 5.2 and 77 mg/L respectively (Table 38). The Water Corporation advised that boron is removed by the reverse osmosis process.

Table 38. Quarterly concentrations of boron and bromide in the intake seawater over the 2017–18 monitoring period.

Sampling Occasion	Boron (mg/L)		Bromide (mg/L)	
	EQG	Concentration	EQG	Concentration
July 2017	5.2	4.2	77	54
October 2017		4.3		63
January 2018		4.6		62
April 2018		4.3		68

The Water Corporation advised that it did not report a significant reduction in efficiency of the desalination process or a significant increase in the maintenance requirements demonstrably caused by the variance in the intake seawater quality during the 2017–18 monitoring period. Natural variation in the quality of the intake seawater was observed by the Water Corporation over the 2017–18 monitoring period, as in previous years. However, these variances had minimal effect on the operation of the desalination plant.

5.4 Conclusions

The results from the 2017–18 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant indicated there were minor exceedances of the EQG for Total Suspended Solids (TSS). The suitability of the quality of the intake seawater for the desalination process was not considered to have been compromised. There is therefore a high degree of certainty that the Environmental Quality Objective has been achieved during the reporting period.

Glossary

Absolute minimum	Historical baseline 5th percentile (high protection) and first percentile (moderate protection) values for seagrass shoot density at the Warnbro Sound reference sites during the first four years of monitoring prior to 2005.
Anthropogenic	Resulting from, or relating to, the influence of human beings on nature.
Approved shellfish harvesting area	A shellfish harvesting area classified as 'approved' for harvesting or collecting shellfish for direct marketing.
Baseline Lower Depth Limit (LDL)	Mean of the lower depth limit measurements from 2000 to 2002 (three years) at each seagrass 'depth limit' site.
Butyltin Degradation Index (BDI)	The relationship between tributyltin (TBT) and its breakdown products dibutyltin (DBT) and monobutyltin (MBT) provides an indication of how recently contamination occurred. BDI = (DBT + MBT)/TBT (Garg *et al*. 2009). A BDI of 1.0 indicates that half the TBT has broken down into DBT and MBT (in other words TBT in the sediment has reached its half-life).
Chlorophyll *a*	A complex molecule that is able to capture sunlight and convert it into a form that can be used for photosynthesis (a process which uses solar energy to convert carbon dioxide and water into carbohydrate). The concentration of chlorophyll *a* in water is used as a measure of phytoplankton biomass.
Conditionally approved shellfish harvesting area	The classification of a shellfish harvesting area which meets 'approved' harvesting area criteria for a predictable period. The period depends upon established performance standards specific in a management plan. A 'conditionally approved' area is closed when it does not meet the 'approved' harvesting area criteria.
Contaminant	Any physical, chemical or biological substance or property which is introduced into the environment. Does not imply any effect.
$\delta^{34}S$ (delta 34 S)	Standardised method for reporting measurements of the ratio of the two most common stable isotopes of sulfur, ^{34}S:^{32}S, as measured in a sample against the equivalent ratio in a known reference standard. Deviation from the international standard, which is set at δ0.00, is expressed as the $\delta^{34}S$ (a ratio in per million [$^{o}/_{oo}$]). Positive values indicate greater levels of ^{34}S and negative values greater levels of ^{32}S in a sample.
Dissolved Inorganic Nutrients	Dissolved inorganic nutrient concentrations in seawater are made up of soluble inorganic nitrogen compounds consisting of dissolved nitrite, nitrate and ammonia in solution. Dissolved phosphorus in seawater is made up of both soluble organic phosphorus and inorganic ortho-phosphate ions. Most soluble forms of nitrogen and phosphorus are readily available for uptake by phytoplankton and in high concentrations can give rise to phytoplankton blooms.

Environmental Quality Criteria (EQC)	The numerical values (for example cadmium 0.7 µg/L) or narrative statements (for example the 95th percentile of the bioavailable contaminant concentration in the test samples should not exceed the Environmental Quality Guideline value) that serve as benchmarks to determine whether a more detailed assessment of environmental quality is required (Environmental Quality Guidelines), or whether a management response is required (Environmental Quality Standards).
Environmental Quality Guideline (EQG)	A numerical value or narrative statement which, if met, indicates there is a high probability that the associated Environmental Quality Objective has been achieved.
Environmental Quality Management Framework	Provides the context within which management of existing activities and decisions about future activities occurs. The management framework does this by confirming the environmental objectives and establishing ambient environmental limits and triggers.
Environmental Quality Objective	A specific management goal for a part of the environment, which is either ecologically based (by describing the desired level of health of the ecosystem) or socially based (by describing the environmental quality required to maintain specific human uses).
Environmental Quality Standard (EQS)	A numerical value or narrative statement which, if not met, indicates a high probability that the associated Environmental Quality Objective has not been achieved and a management response is triggered.
Environmental Value	A particular value or use of the marine environment that is important for a healthy ecosystem or for public benefit, welfare, safety or health and which requires protection from the effects of pollution, environmental harm, waste discharge and deposits. There are two types of environmental value: ecological and social.
Extraneous residue limit	The maximum concentration of a pesticide residue or contaminant arising from environmental sources (including former agricultural use) other than the direct or indirect use of a pesticide or contaminant substance that is legally permitted or accepted in a food.
High level of ecological protection	Allows for small changes in the quality of water, sediment or biota (such as small changes in contaminant concentrations with no resultant detectable changes beyond natural variation in the diversity of species and biological communities, ecosystem processes and abundance/biomass of marine life).
Light attenuation in water	The exponential decay of light intensity with increasing depth due to absorption and scattering. A large light attenuation coefficient means that light is quickly “attenuated” (i.e. weakened) as it passes through the water column; a small light attenuation coefficient means that the water is relatively transparent to light.
Low level of	Allows for large changes in the quality of water, sediment or biota

ecological protection	(such as large changes in contaminant concentrations that could cause large changes beyond natural variation in the diversity of species and biological communities, rates of ecosystem processes and abundance/biomass of marine life, but which do not result in bioaccumulation/biomagnification in near-by high ecological protection areas).
Low reliability value (LRV)	For a number of toxicants where there are insufficient toxicological data to develop reliable guideline trigger levels, low reliability values have been derived to give guidance in the absence of any higher reliability guidelines being available. LRVs should not be used as default guideline trigger values. However, it is assumed that if ambient concentrations fall below the LRV then there is low risk of ecological impact. If concentrations are above a LRV it does not necessarily mean an impact is likely. Exceedance of a LRV does not trigger mandatory assessment against the Environmental Quality Standards, but does signal that the possibility of ecological impact should be considered, particularly if further increases beyond the LRV are likely.
Lower Depth Limit (LDL)	The maximum depth and distance at which seagrass shoots are observed within a one metre belt either side of the transect line. The objective of this measure is to identify the position of the boundary of a seagrass bed, and, by reference to the baseline and/or reference conditions, to establish the magnitude and direction of change (in other words, gain or loss) of seagrass meadow.
Mann-Kendall trend analysis	The Mann-Kendall trend analysis is a non-parametric statistical test to detect a monotonic upward or downward trend in the variable of interest over time.
Marine biotoxins	Toxic compounds produced by some species of phytoplankton.
Maximum residue limit	The highest concentration of a chemical residue that is legally permitted or accepted in a food.
Mean shoot height	The 80th percentile of shoot heights within quadrats. The tallest 20% of shoots inside a quadrat were excluded and the height of the tallest remaining shoots measured. Mean shoot height is measured as long leaves are often necrotic for much of their length and maximum height may not be an accurate measure of canopy height within each quadrat.
Median	A measure used in statistics representing the 'middle' number in a sequence of numbers that has been arranged from the smallest value to the largest value. The main advantage of the median compared to the average or mean of a data set, is that is it not influenced so much by very large or very small values and is therefore considered to be more representative of the majority of values in a data set.
Moderate level of	Allows for moderate changes in the quality of water, sediment or biota (such as moderate changes in contaminant concentrations

ecological protection	that could cause small changes beyond natural variation in ecosystem processes and abundance/biomass of marine life, but no detectable changes from the natural diversity of species and biological communities).
Non river-flow period	The main period for nutrient-related monitoring in Cockburn Sound. This is over summer when river flow is minimal and nutrient concentrations are most stable.
Normalisation	A procedure to adjust concentrations of contaminants in sediments for the influence of natural variability in sediment composition, in particular for grain size, organic matter content and mineralogy.
Nutrients	Elements or compounds, such as nitrogen and phosphorus, that are essential for organic growth and development.
Percentile	A measure used in statistics whereby the p^{th} percentile of a distribution of data is the value that is greater than or equal to *p*% of all the values in the distribution. For example the 80^{th} percentile is greater than or equal to 80% of all values; conversely, 80% of all values are less than or equal to the 80^{th} percentile.
Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)	A group of synthetic fluorine-containing chemicals used in heat, stain and water resistant products (such as non-stick cookware, specialised textiles, Scotchgard™) and were used in fire-fighting foams. PFAS are highly persistent in the environment, moderately soluble, can be transported long distances and transfer between soil, sediment, surface water and groundwater. They have been shown to be toxic to some animals and, because they break down very slowly, can bioaccumulate and biomagnify in some wildlife, including fish. This means that fish and animals higher in the food chain may accumulate higher concentrations of PFAS in their bodies. Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are two of the best-known PFAS and are contaminants of emerging concern in Australia and internationally. They have been identified in the environment at a number of known and suspected contaminated sites in Western Australia.
Phytoplankton	Single-celled plants and other photosynthetic organisms (including cyanobacteria, diatoms and dinoflagellates) that live in the water column.
Public Authority	A Minister of the Crown acting in their official capacity, department of the Government, state agency or instrumentality, local government or other person, whether corporate or not, who or which under the authority of a written law administers or carries on for the benefit of the State, or any district or other part thereof, a social service or public utility.
Re-sampling trigger	Where the total concentration of a contaminant in individual sediment sample sites exceeds the environmental quality guideline re-sampling trigger, additional sampling of that potentially contaminated site will generally be required to better define the area

	of high concentration.
Seagrass	Submerged flowering plants that mainly occur in shallow marine areas and estuaries.
Shellfish	Under the *Western Australia Shellfish Quality Assurance Program (WASQAP) Operations Manual 2015* (Department of Health 2015) shellfish means all edible species of molluscan bivalves such as oysters, clams, scallops, pipis and mussels, either shucked or in the shell, fresh or frozen, whole or in part or processed. The definition does not include spat, scallops or *Pinctada* spp. where the consumed product is only the adductor mussel.
Social Value	A particular value or use of the marine environment that is important for public benefit, welfare, safety or health and which requires protection from the effects of pollution, environmental harm, waste discharges and deposits.
State Environmental Policy (SEP)	A State Environmental Policy is a non-statutory instrument developed by the Environmental Protection Authority (EPA) under the *Environmental Protection Act 1986*. It is a flexible policy instrument which is developed through public consultation and adopted on a whole-of-government basis.
Total Nutrients	In seawater the total nitrogen and total phosphorus concentrations are made up of a combination of soluble and insoluble organic and inorganic compounds. The organic nutrients incorporate all organic particulate matter, including phytoplankton, zooplankton, bacteria and organic surface films on re-suspended sediments, detrital matter and some soluble organic compounds. The inorganic nitrogen compounds consist of dissolved nitrite, nitrate and ammonia in solution. Inorganic phosphorus is made up of dissolved inorganic ortho-phosphates.
Total Toxicity of the Mixture (TTM)	An interpretive tool used for estimating the potential toxicity of mixtures of up to five toxicants, where the interactions are simple and predictable. If the total toxicity of the mixture exceeds one, the mixture has exceeded the water quality guideline. TTM = $\sum(C_i)/EQG_i)$, where C_i is the concentration of the ‘i’th component in the mixture and EQG_i is the guideline for that component.

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Appendix A: 2017–18 Nutrient Concentrations

Total nitrogen concentrations over the 2017–18 non river-flow period varied between 90 micrograms per litre (µg/L) recorded at four sites in Cockburn Sound (CS12, CS5, G1 and SF) and one reference site in Warnbro Sound (WS4) and 210 µg/L recorded at Mangles Bay (MB) in HPA-S on 19 March 2018 (Cossington and Wienczugow 2018). Total phosphorus concentrations varied between 11 µg/L at the Warnbro Sound reference site WS4 on 19 March 2018 and 23 µg/L at Mangles Bay (MB) in HPA-S on 19 March 2018.

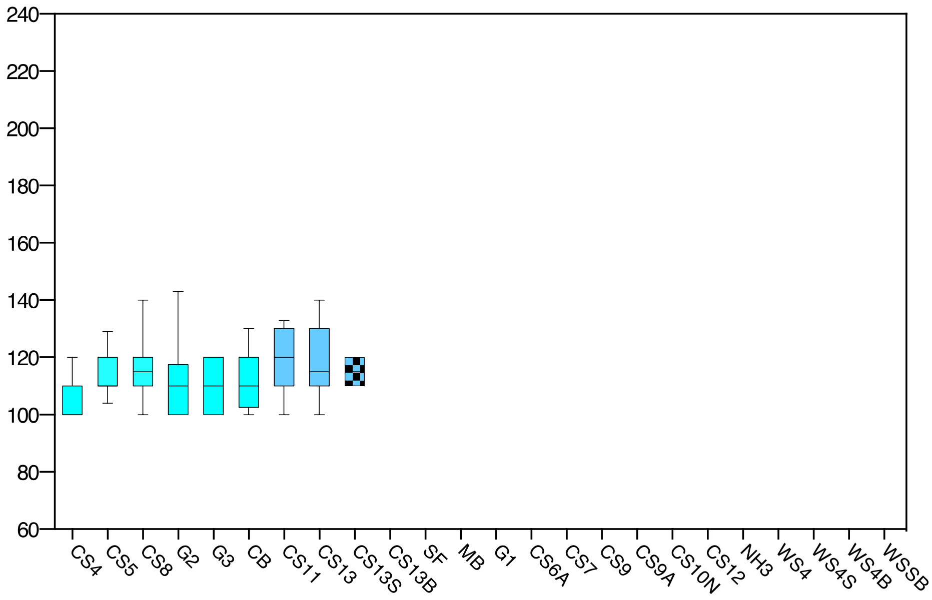
The highest median total nitrogen concentrations were recorded at NH3 (160 µg/L) in MPA-NH, where an elevated median chlorophyll *a* concentration was also reported, and Mangles Bay (MB; 150 µg/L) in HPA-S (Figure A.1; Cossington and Wienczugow 2018). Median total nitrogen concentrations at NH3 and MB were significantly[29] higher than those recorded at most of the other sites in Cockburn Sound and Warnbro Sound. Other sites with elevated median total nitrogen concentrations included CS9A (130 µg/L) and CS10N (130 µg/L) in MPA-ES.

The highest median total phosphorus concentrations were recorded at NH3 (18 µg/L) and MB (18 µg/L) (Figure A.2; Cossington and Wienczugow 2018). Other sites with elevated median total phosphorus concentrations included CS9A (16 µg/L) and CS10N (17 µg/L) in MPA-ES and CS11 (16 µg/L) and CS13 (16 µg/L) in HPA-S.

The lowest median total nitrogen and total phosphorus concentrations were generally recorded at sites in the central, northern and north-western areas of Cockburn Sound (for example CB, G2, G3, CS4 and CS5) which also generally had lower median chlorophyll *a* concentrations.

Significantly higher median total nitrogen and total phosphorus concentrations were recorded in bottom waters than in surface waters at CS13 (surface waters: median total nitrogen: 115 µg/L, median total phosphorus: 15 µg/L; bottom waters: median total nitrogen: 125 µg/L, median total phosphorus: 17 µg/L) and the Warnbro Sound reference site WS4 (surface waters: median total nitrogen: 110 µg/L, median total phosphorus: 12 µg/L; bottom waters: median total nitrogen: 130 µg/L, median total phosphorus: 15 µg/L) (Figures A.1 and A.2).

[29] Results of non-parametric Kruskal-Wallis one-way analysis of variance by ranks with Dunn's *post hoc* test. Results identified as being significant are those with a p value of less than 0.05 (that is $\alpha < 0.05$).

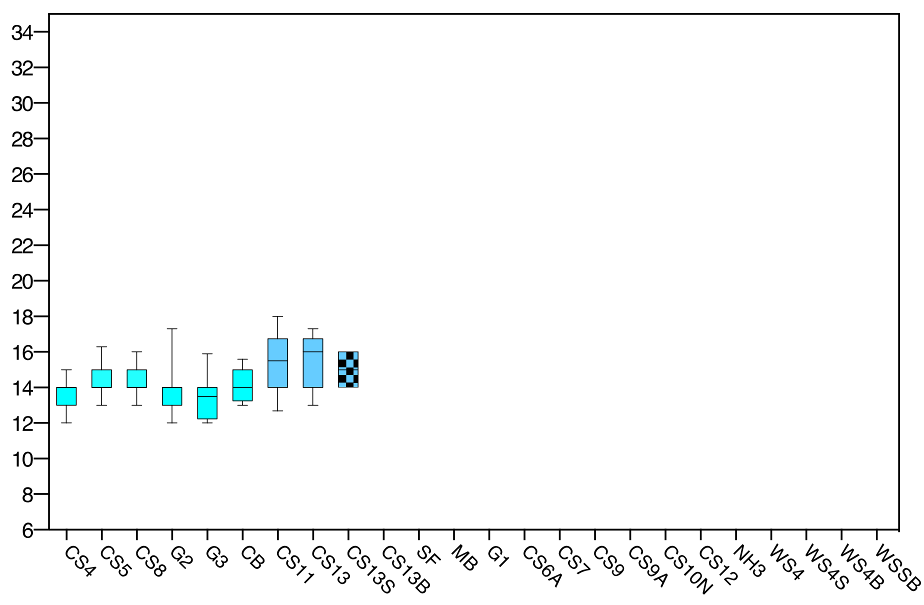


Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bar = HPA-N sites; dark blue bar = HPA-S sites; blue/green bar = MPA-CB site; bright green bar = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Hatched bars = concentrations in discrete surface (S) and bottom (B) waters.

Figure A.1. Median total nitrogen concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.



Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bar = HPA-N sites; dark blue bar = HPA-S sites; blue/green bar = MPA-CB site; bright green bar = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Hatched bars = concentrations in discrete surface (S) and bottom (B) waters.

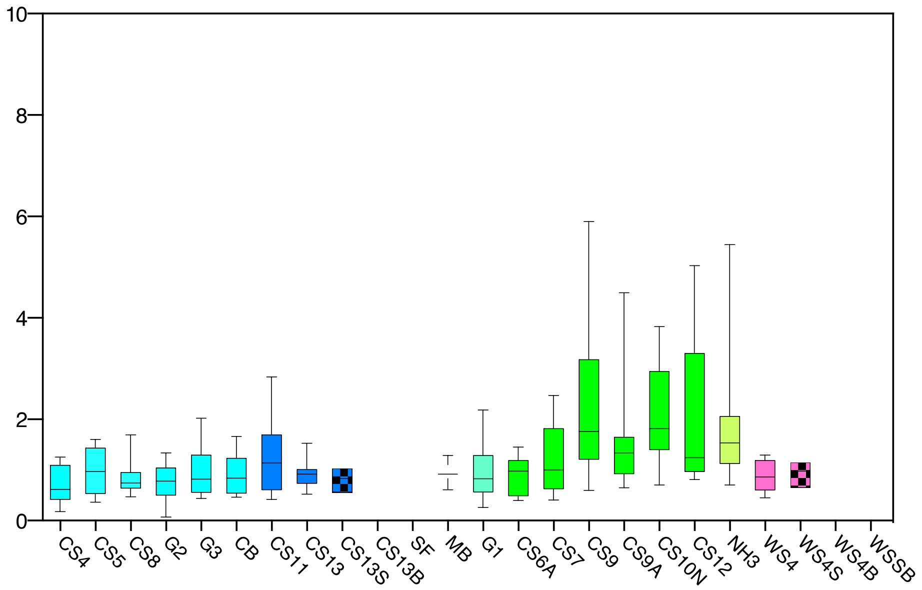
Figure A.2. Median total phosphorus concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.

Nitrate–nitrite concentrations ranged from less than the analytical reporting limit (< 2 µg/L) which was recorded at all sites on numerous occasions, to 9 µg/L at NH3 in MPA-NH on 26 March 2018. Median nitrate–nitrite concentrations were below the analytical reporting limit at all sites (Figure A.3; Cossington and Wienczugow 2018).

Ammonium concentrations ranged from less than the analytical reporting limit (< 0.5 µg/L) which was recorded at most sites on one or more occasions, to 18 µg/L at CS9A and 22 µg/L at CS10N on 26 March 2018. The highest median ammonium concentrations were recorded at Mangles Bay (MB; 1.8) in HPA-S, and CS9A (2.0 µg/L), CS9 (2.4 µg/L) and CS10N (6.3 µg/L) in MPA-ES (Figure A.4; Cossington and Wienczugow 2018). The median ammonium concentrations at CS10N was significantly higher than at a number of the Cockburn Sound sites, the exception of sites CB, SF, MB, CS12, CS9 and CS9A.

Filterable reactive phosphorus concentrations ranged from less than the analytical reporting limit (< 2 µg/L) which was recorded at most sites and 5 µg/L at five sites (CS9A, CS10N, CS11, SF and MB) on numerous occasions. The highest median filterable reactive phosphorus concentration (3.9 µg/L) was recorded at CS10N (Figure A.5; Cossington and Wienczugow 2018).

Median nitrate–nitrite concentrations were significantly lower in surface waters than bottom waters at the reference site WS4 and CS13 (Figure A.3). Median ammonium and filterable reactive phosphorus concentrations were significantly higher in bottom waters than in surface waters at both CS13 and the reference site WS4 (Figure A.4 and Figure A.5).

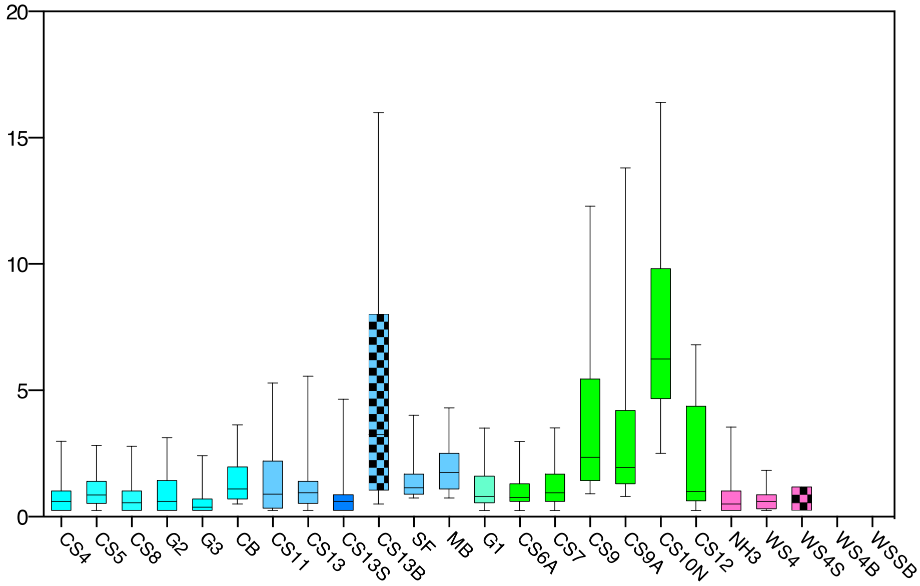


Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bar = HPA-N sites; dark blue bar = HPA-S sites; blue/green bar = MPA-CB; bright green bar = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Hatched bars = concentrations in discrete surface (S) and bottom (B) waters.

Figure A.3. Median nitrate–nitrite concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.



Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Light blue bar = HPA-N sites; dark blue bar = HPA-S sites; blue/green bar = MPA-CB site; bright green bar = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Hatched bars = concentrations in discrete surface (S) and bottom (B) waters.

Figure A.4. Median ammonium concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.

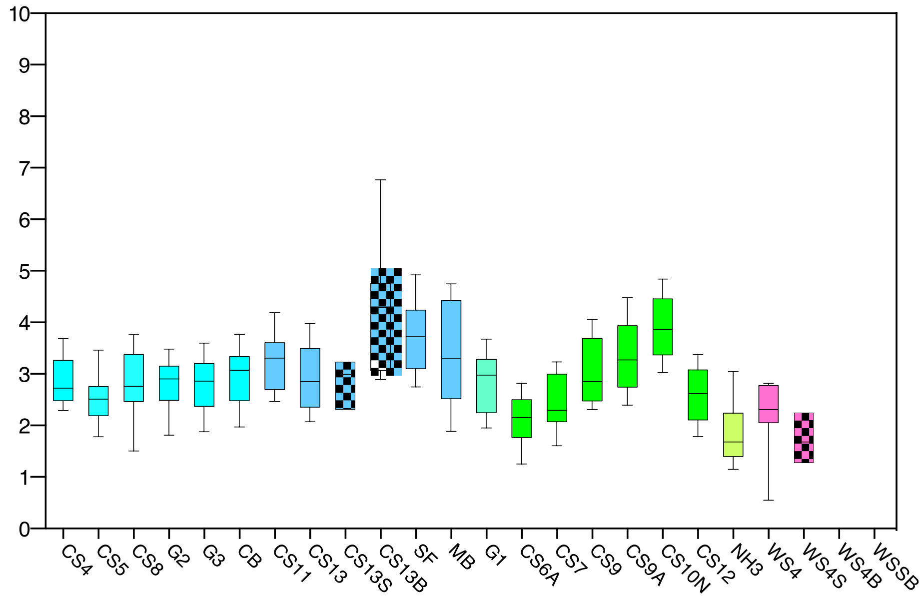
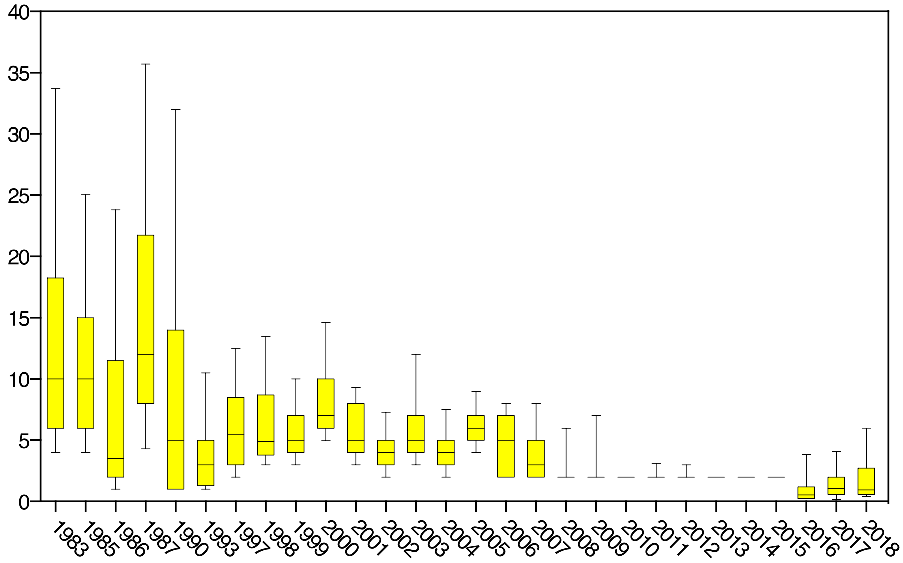


Figure A.5. Median filterable reactive phosphorus concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2017 to March 2018.

Appendix B: Variations and Trends over Time in Nutrient Concentrations

Median non river-flow period ammonium concentrations in Cockburn Sound have declined from the 1980's to the 1990's and 2000's, and again from around 2008 onwards (Figure B1; Cossington and Wienczugow 2018). The variability between sites within years has also decreased over that time. The median ammonium concentrations at Cockburn Sound historical sites (i.e. CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11) in 2018 were not significantly different to the median concentrations recorded in the period from 2008 to 2017, but were significantly lower than earlier years.



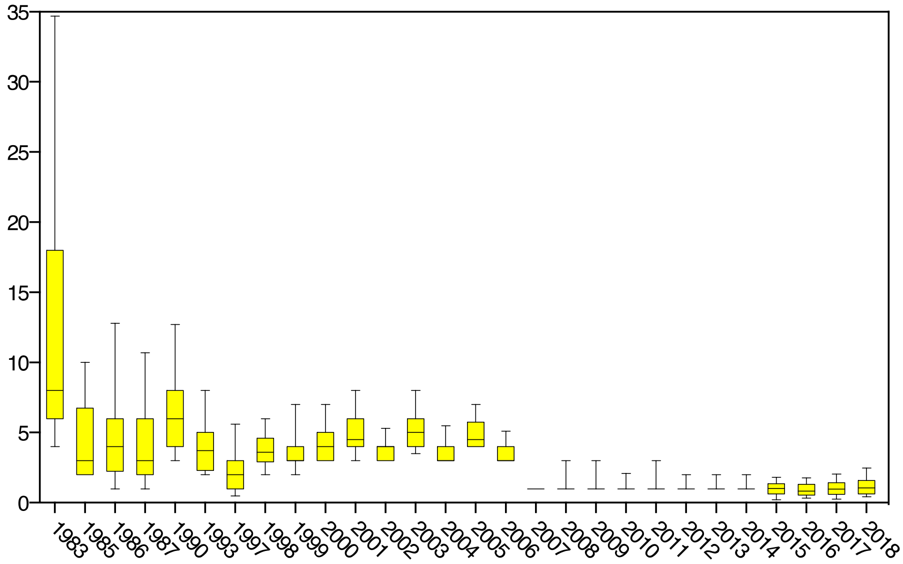
Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) The results in 2016 and 2017 are from the low ammonium method adopted in 2015–16 to improve the detection of ammonium below 3 micrograms per litre (µg/L).

Figure B.1. Median ammonium concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2018.

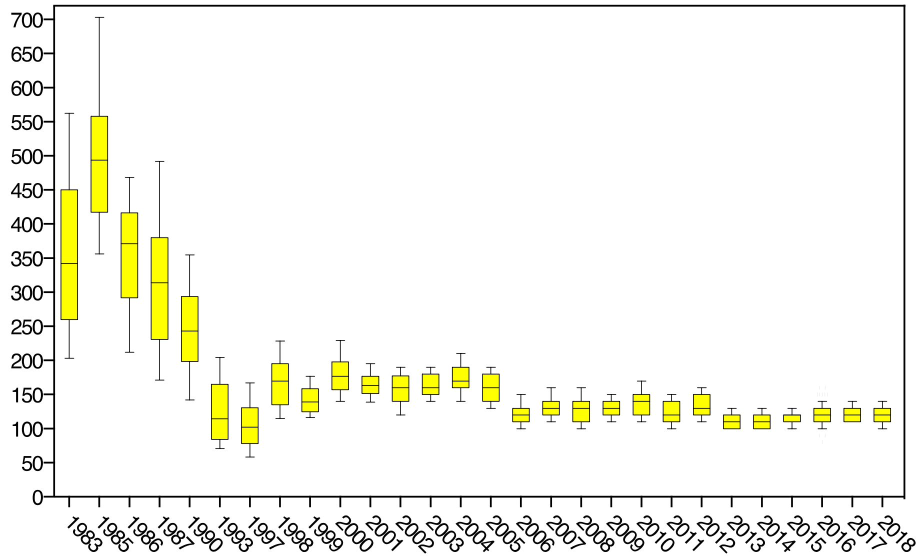
Median non river-flow period nitrate–nitrite concentrations were highest in the early 1980s, with the lowest concentrations recorded since 2006–07 (Figure B2; Cossington and Wienczugow 2018). The variability in nitrate–nitrite concentrations between sites within each year has also decreased over time. The median nitrate-nitrite concentrations at the Cockburn Sound historical sites in the 2017-2018 non river-flow season were not significantly different from the concentrations recorded from 2006–07 to 2016–17, but were significantly lower than concentrations recorded prior to 2006-07.



Note: The ‘box’ represents the 25th and 75th percentiles and the ‘whiskers’ the 10th and 90th percentiles.

Figure B.2. Median nitrate–nitrite concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2018.

Median non river-flow period total nitrogen concentrations have generally decreased since monitoring began in Cockburn Sound, as has the variability within years (Figure B.3; Cossington and Wienczugow 2018). The median total nitrogen concentrations at the Cockburn Sound historical sites in 2017–18 were not significantly different to the median total nitrogen concentrations recorded in 1992–93, 1996–97, 2005–06, 2008–09, 2010–11, 2012—13 to 2016–17. Median concentrations in 2017–18 were significantly lower than for the other years when total nitrogen was measured. Plots of median total nitrogen concentrations at each site over time are presented in Figure B.4.



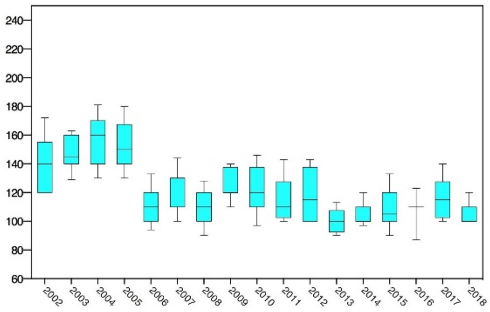
Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

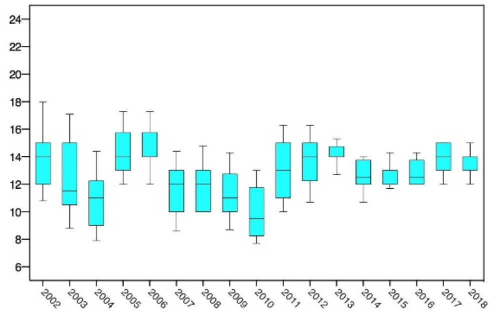
Figure B.3. Median total nitrogen concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2018.

Site **Total Nitrogen (µg/L)** **Total Phosphorus (µg/L)**

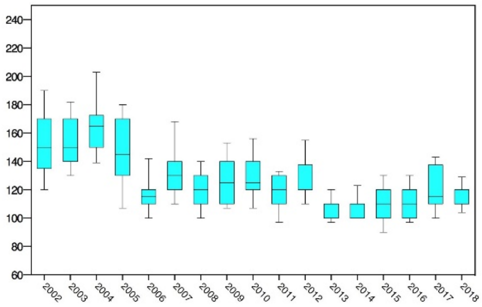
High Ecological Protection Area - North

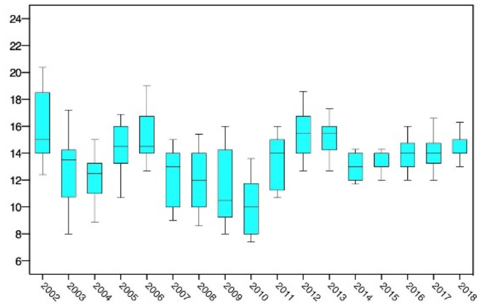
CS4



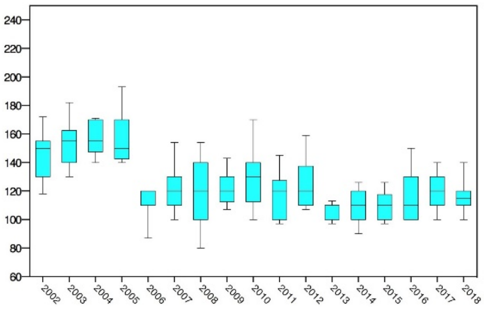


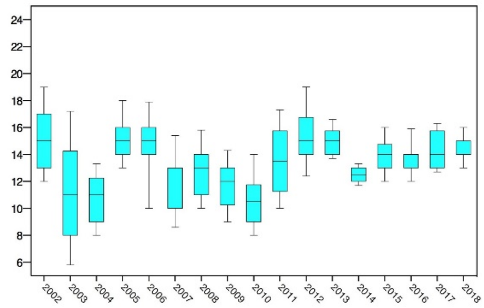
CS5



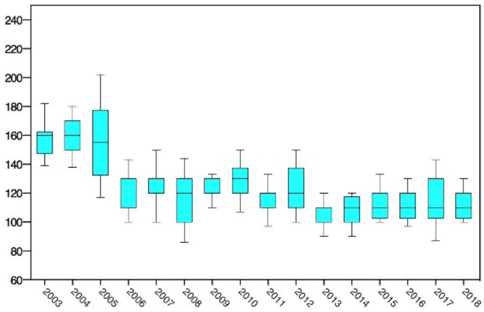


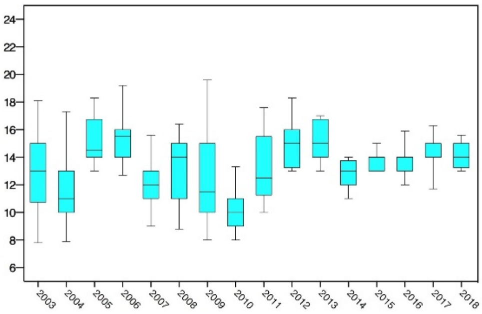
CS8



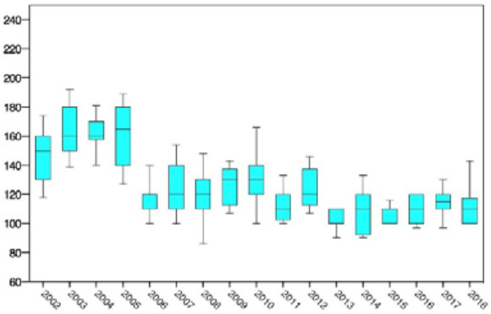


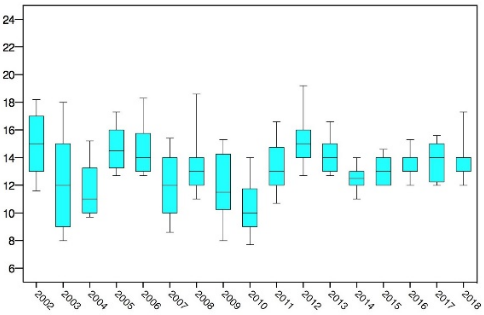
CB





G2

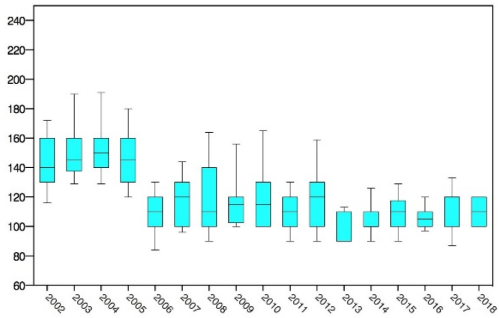


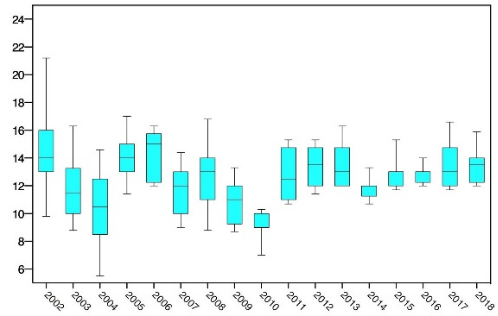


Site	Total Nitrogen (µg/L)	Total Phosphorus (µg/L)

High Ecological Protection Area - North

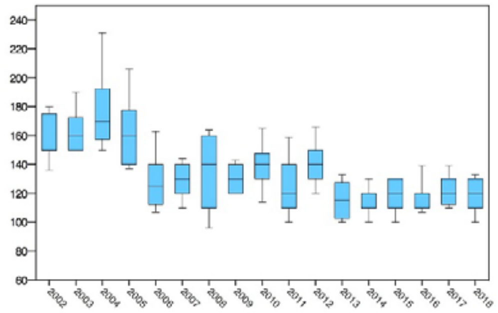
G3

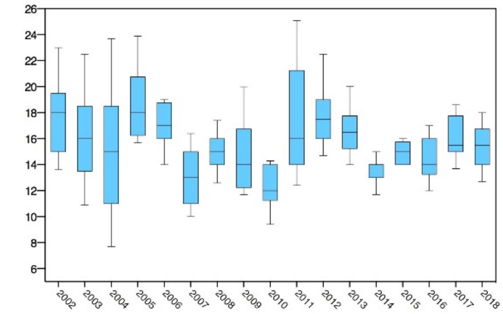




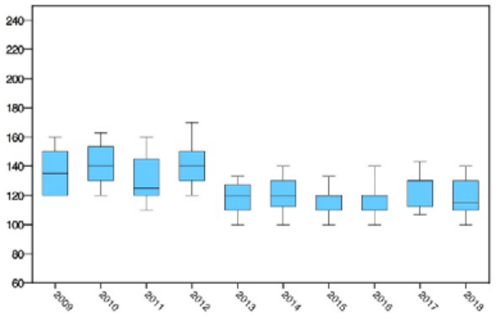
High Ecological Protection Area - South

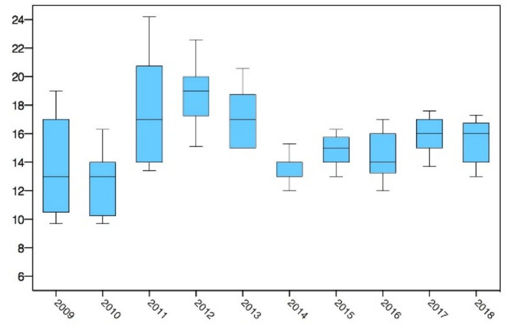
CS11



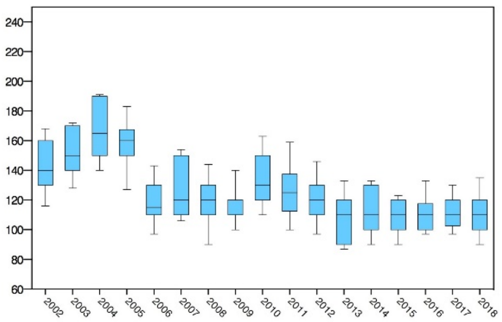


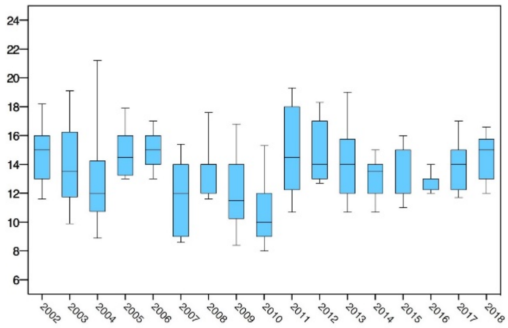
CS13



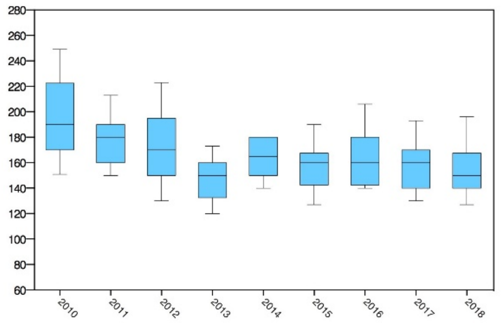


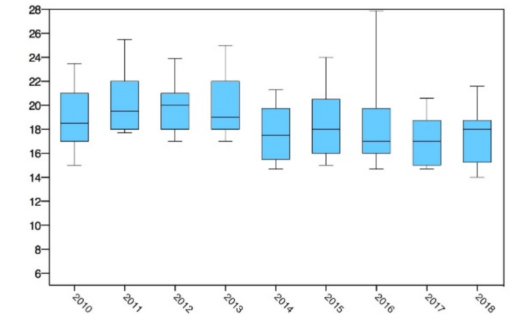
SF





MB

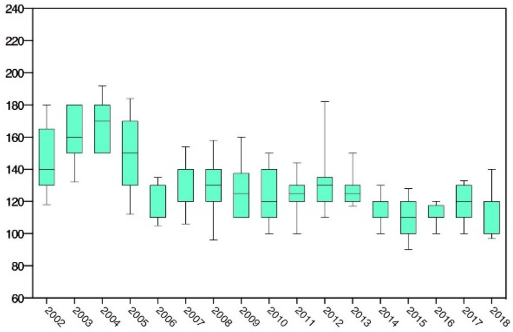


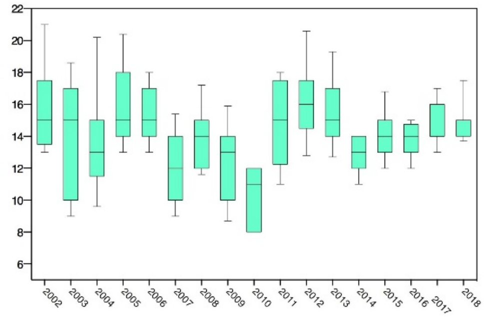


Site	Total Nitrogen (µg/L)	Total Phosphorus (µg/L)

Moderate Ecological Protection Area – Careening Bay

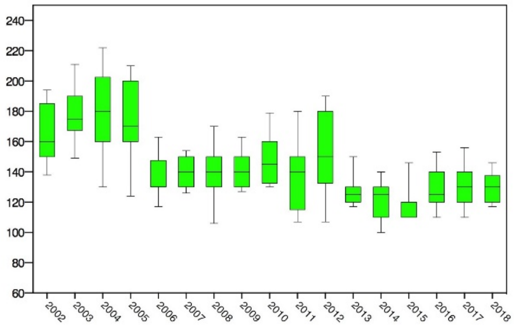
G1

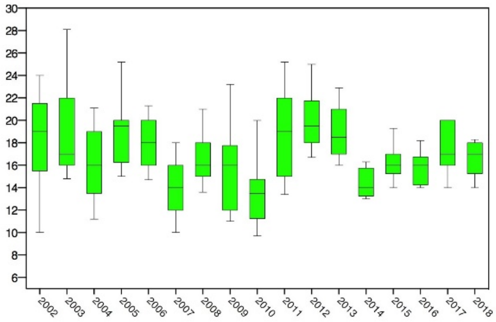




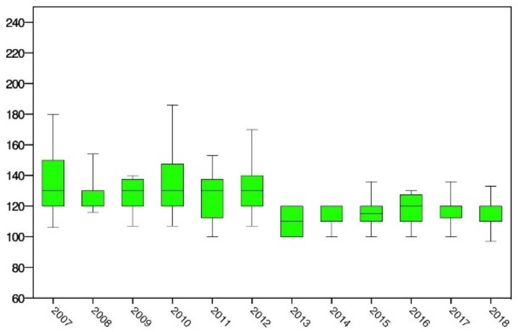
Moderate Ecological Protection Area – Eastern Sound

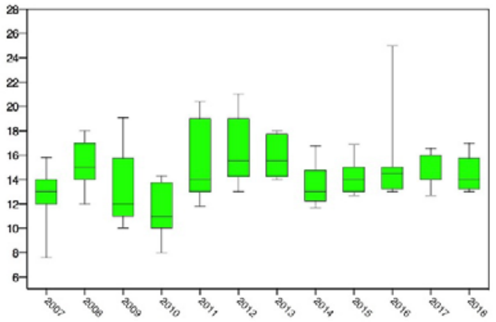
CS10N



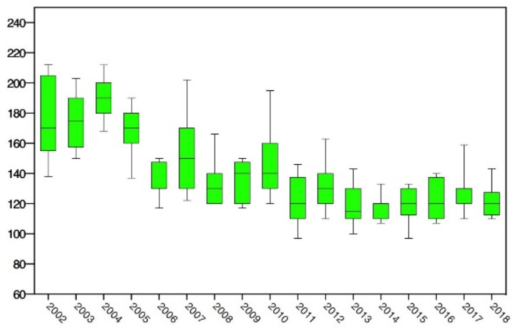


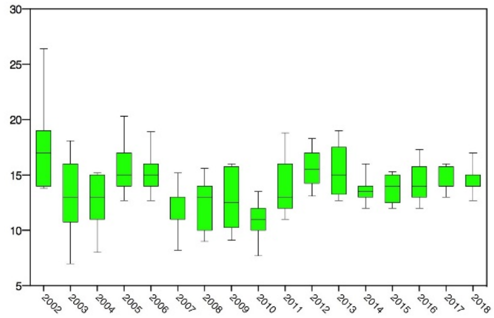
CS12



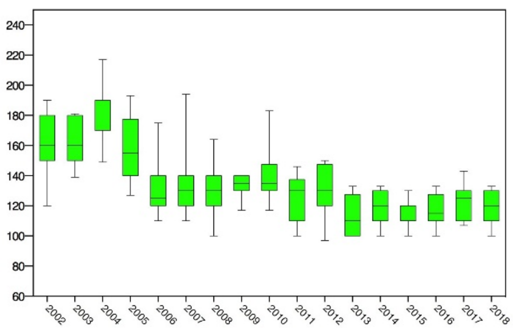


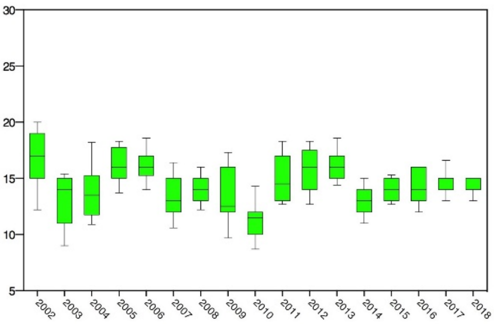
CS6A





CS7





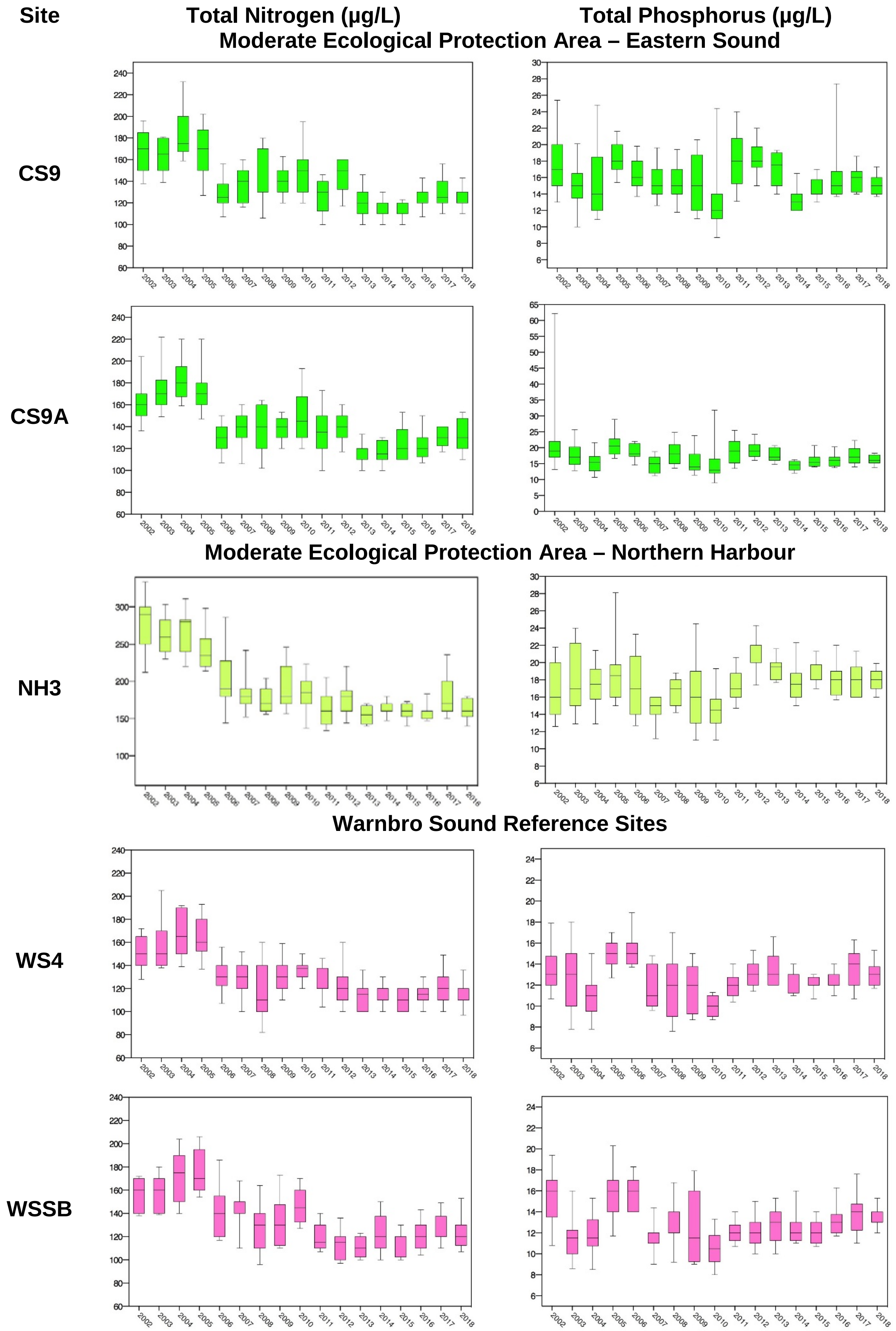
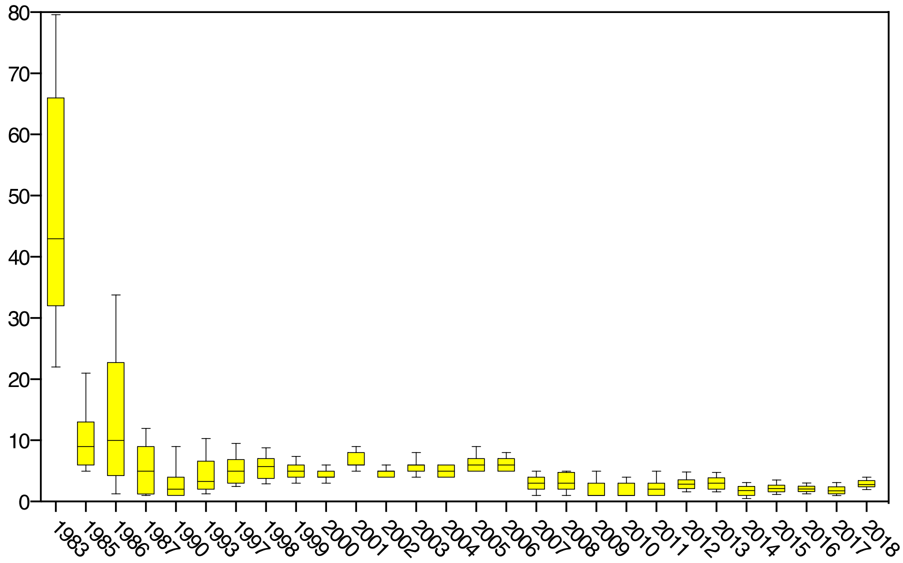


Figure B.4. Median total nitrogen and total phosphorus concentrations at the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound. The 'box' represents the 25th and 75th percentiles and the 'whiskers', the 10th and 90th percentiles.

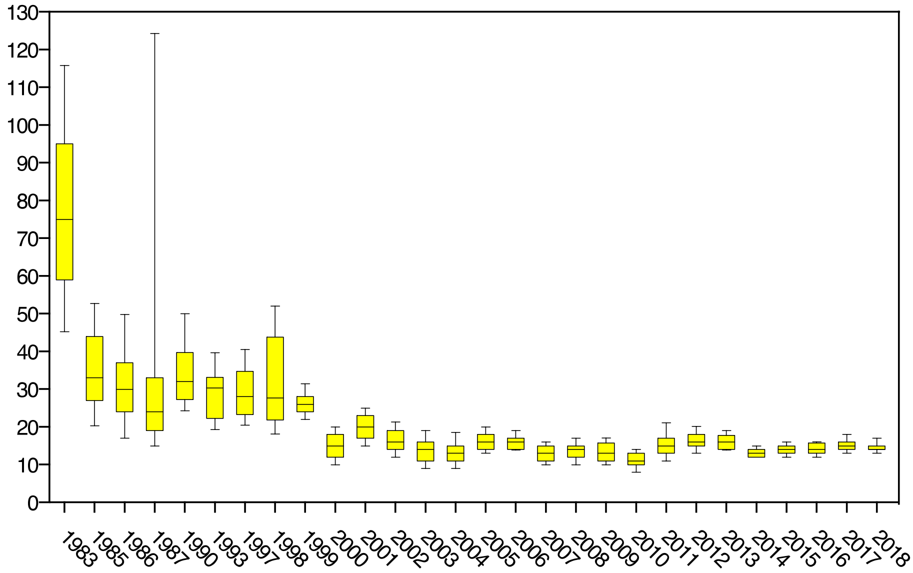
Median non river-flow period filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 have decreased over the past 35 years, although concentrations have generally remained unchanged over the past 12 years (Figure B.5; Cossington and Wienczugow 2018). The median filterable reactive phosphorus concentrations at these sites were significantly higher in 2017-18 than in 2013-14. There were no significant differences for the periods from 2006-07 to 2012-13 and from 2015-16 to 2016-17. The median filterable reactive phosphorus concentrations in 2017–18 were significantly lower than in all years prior to 2006–07, with the exception of 1990 and 1993, where there were no significant differences.



Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure B.5. Median filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2018.

Median non river-flow period total phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 have decreased significantly since monitoring began, although concentrations have remained relatively constant over the last 12 years with some year-to-year fluctuation (Figure B.6; Cossington and Wienczugow 2018). The median total phosphorus concentrations in 2017–18 were significantly lower than in the 1980s and 1990s and not significantly different from subsequent years with the exception of 2000–01, which had significantly lower median concentrations, and 2009–10, which had significantly higher median concentrations. Plots of median total phosphorus concentrations at each site over time are presented in Figure B.4.

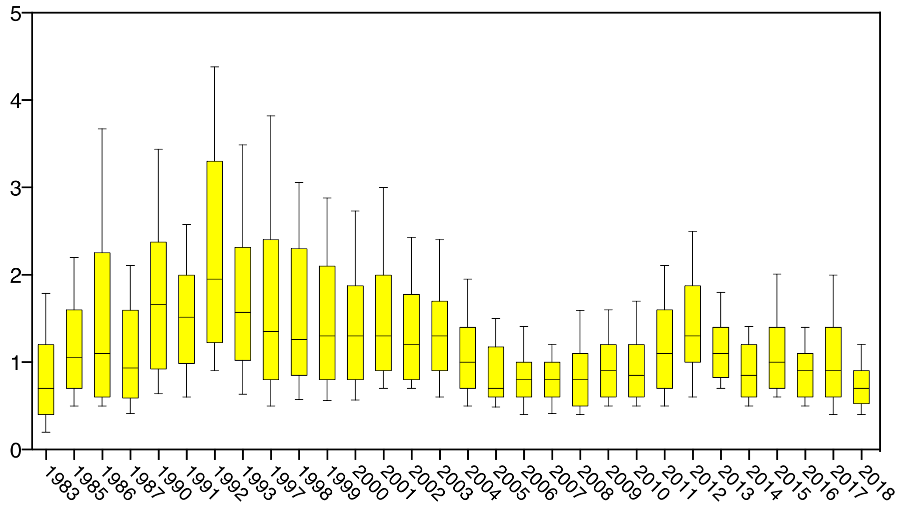


Note: The ‘box’ represents the 25th and 75th percentiles and the ‘whiskers’ the 10th and 90th percentiles.

Figure B.6. Median total phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2018.

Appendix C: Variations and Trends over Time in Chlorophyll *a* Concentrations and Light Attenuation

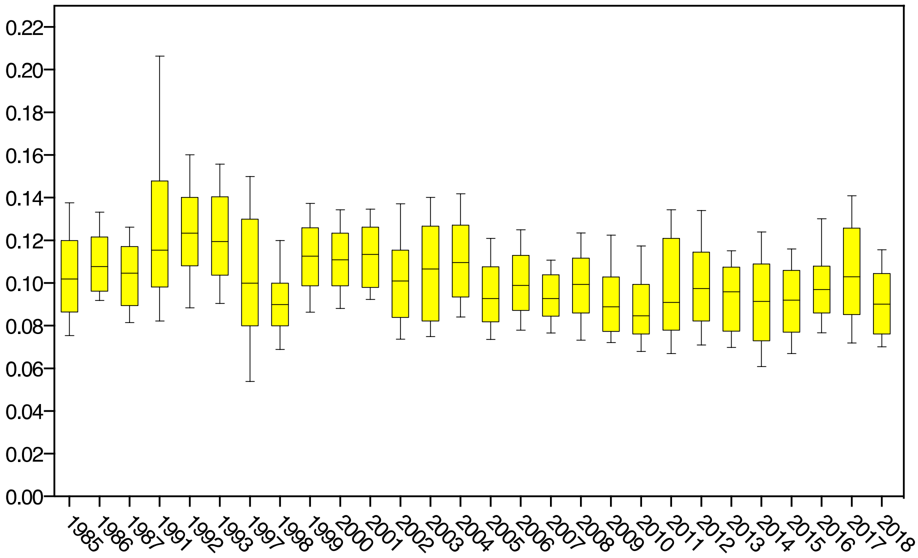
Median chlorophyll *a* concentrations in Cockburn Sound generally increased from the 1980s to the 1990s, remained high in the early 2000s, decreased during the mid-2000s, increased between 2010–11 and 2012–13 and then decreased again (Figure C.1; Cossington and Wienczugow 2018). The median chlorophyll *a* concentration in 2017–18 was not significantly different to the concentrations reported in 1982–83, but was found to be significantly lower than concentrations reported between 1984–85 and 2003–04, from 2010-11 to 2012-13, and in 2014-15 and 2016-17.



Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure C.1. Median chlorophyll *a* concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2018.

There were similar trends in median light attenuation coefficients (LAC), which generally increased to the early 1990s, decreased in the mid-2000s, with a slight increase between 2010–11 and 2012–13, and again in 2016–17 (Figure C.2). The median LAC in 2017–18 was significantly lower than the median LAC reported between 1984-85 and 1992-93, from 1998–99 to 2000-01, and in 2002–03, 2003-04, and 2016-17. There were no significant differences for any of the other years.



Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

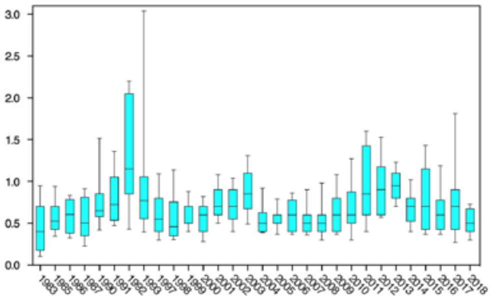
Figure C.2. Median light attenuation coefficients at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1985 to 2018.

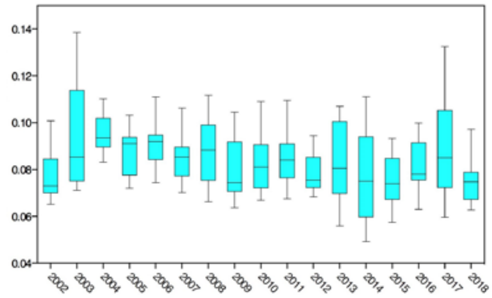
Plots of median chlorophyll *a* concentrations and median light attenuation coefficients at each site over time are presented in Figure C.3.

Site	Chlorophyll *a* (µg/L)	Light Attenuation Coefficient ($\log_{10}$ m^{-1})

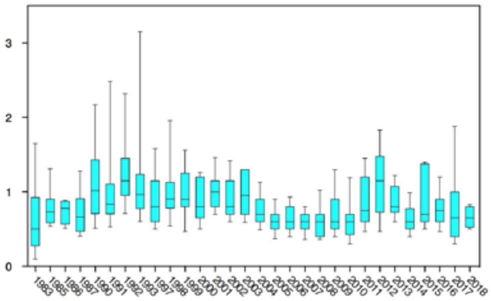
High Ecological Protection Area - North

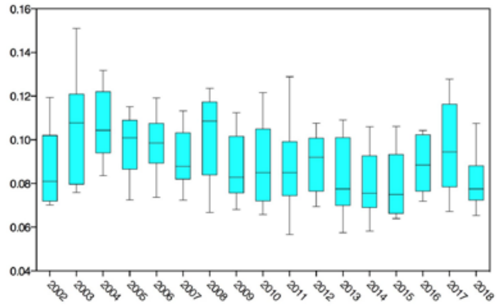
CS4



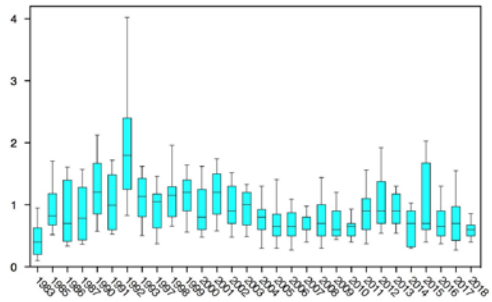


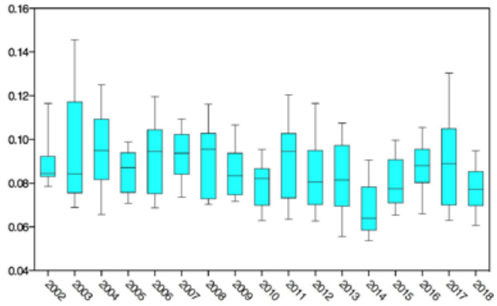
CS5



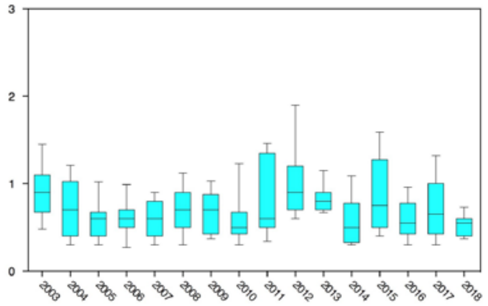


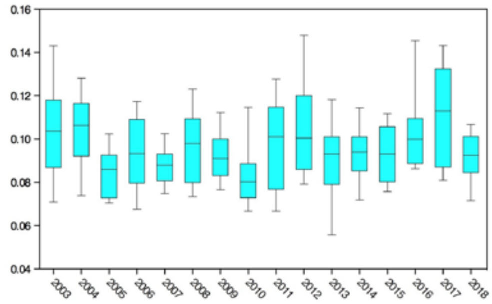
CS8



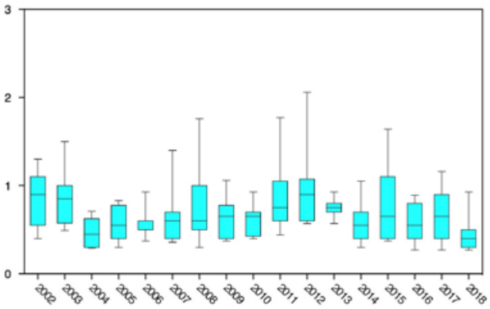


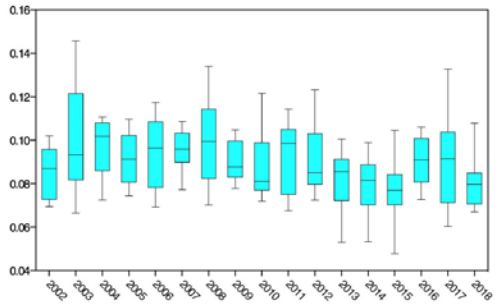
CB

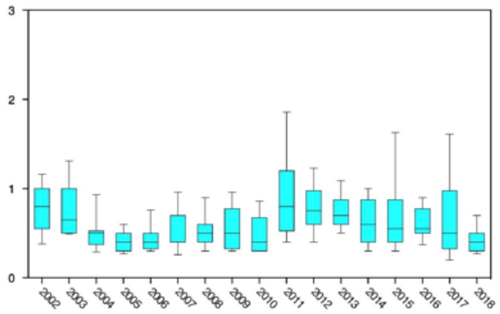
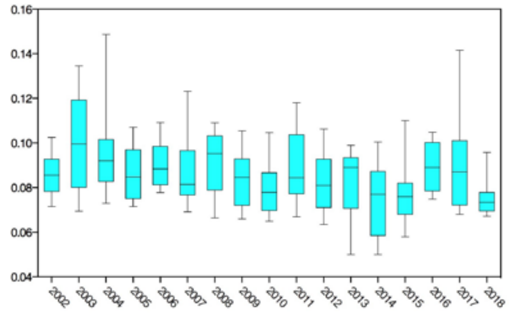
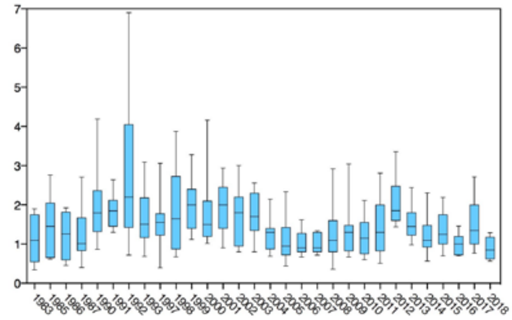
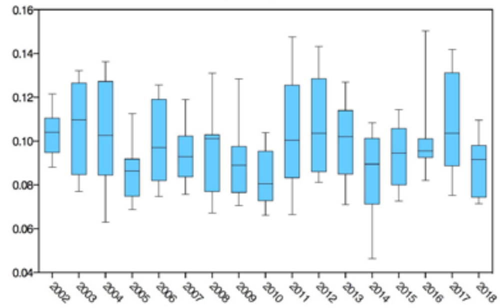
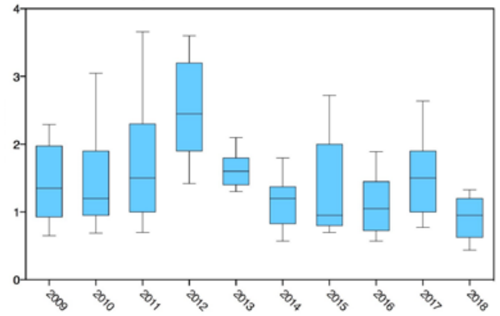
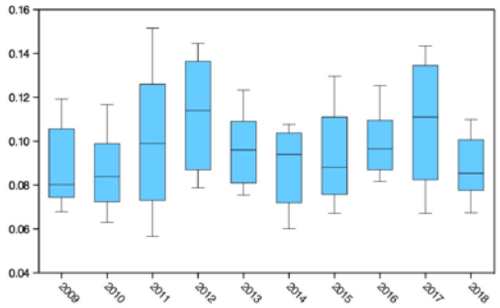
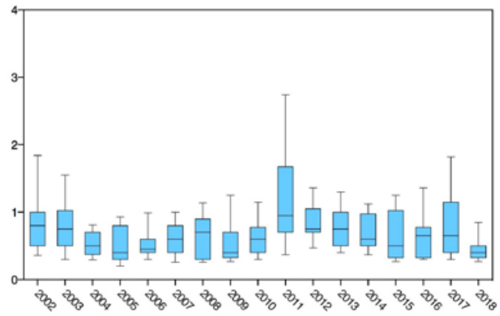
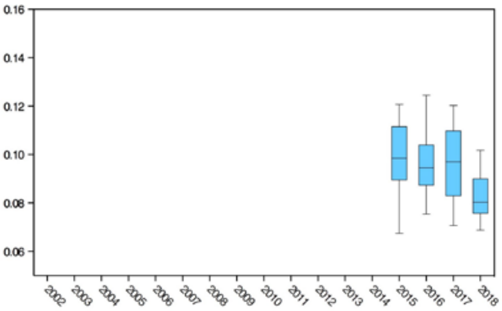
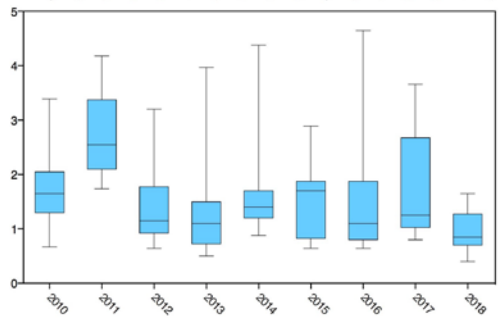
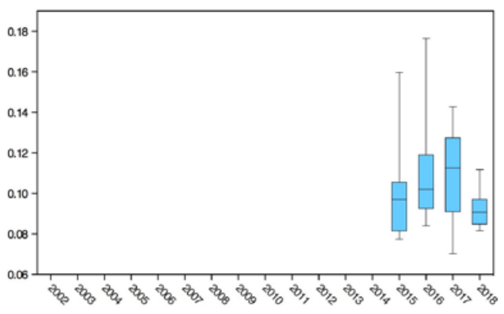




G2



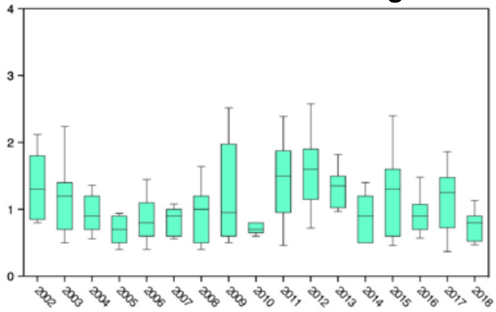


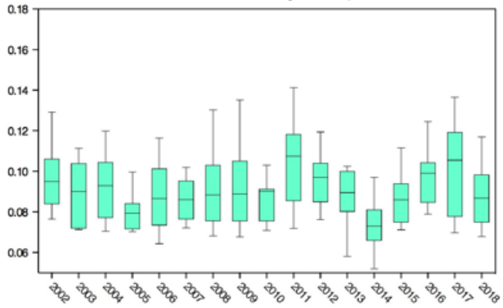
Site	Chlorophyll *a* (μg/L)	Light Attenuation Coefficient ($\log_{10}$ m^{-1})
High Ecological Protection Area - North		
G3		
High Ecological Protection Area - South		
CS11		
CS13		
SF		
MB		

Site	Chlorophyll *a* (µg/L)	Light Attenuation Coefficient (log_{10} m^{-1})

Moderate Ecological Protection Area – Careening Bay

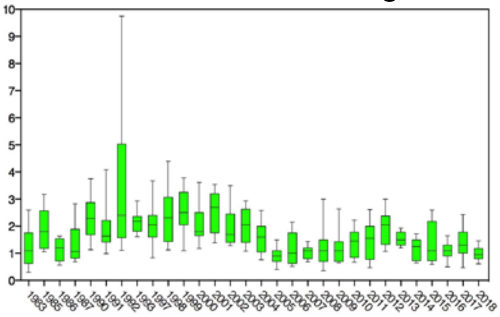
G1

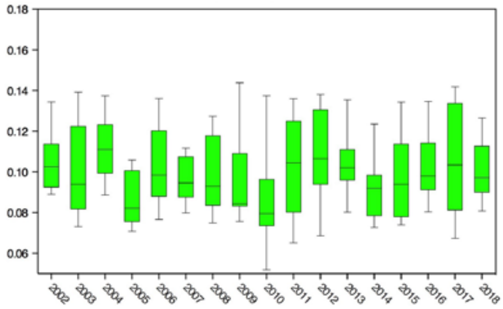




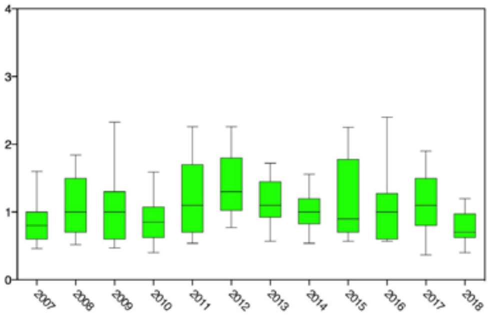
Moderate Ecological Protection Area – Eastern Sound

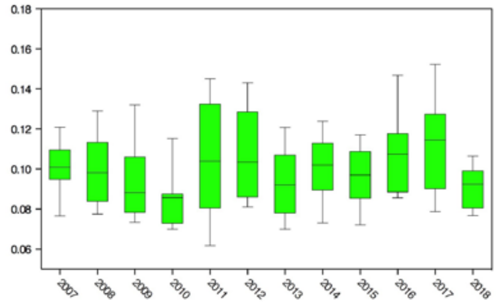
CS10N



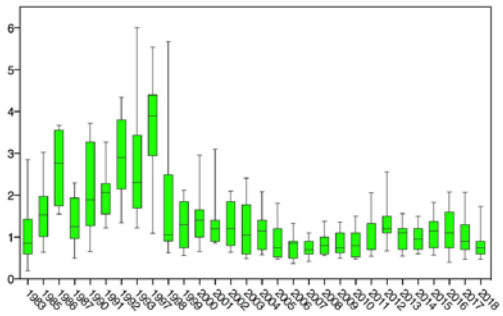


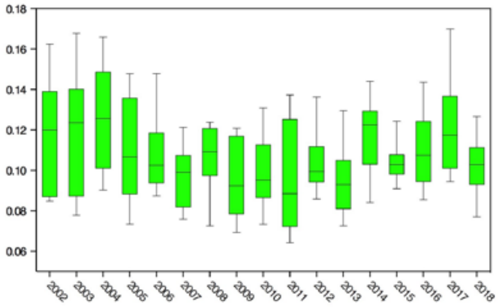
CS12



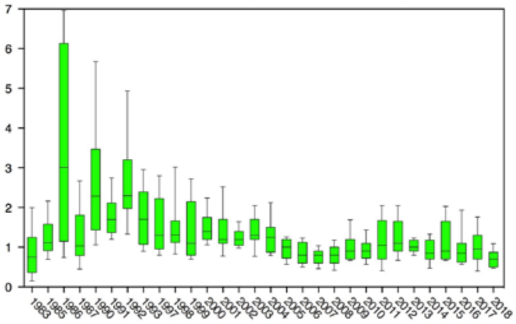


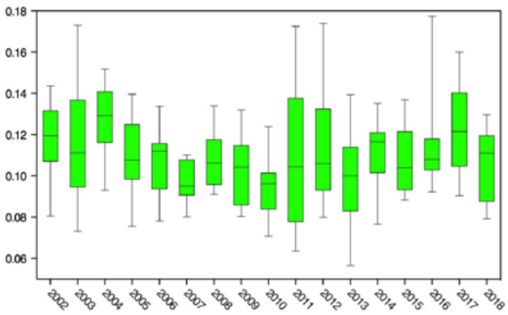
CS6A





CS7





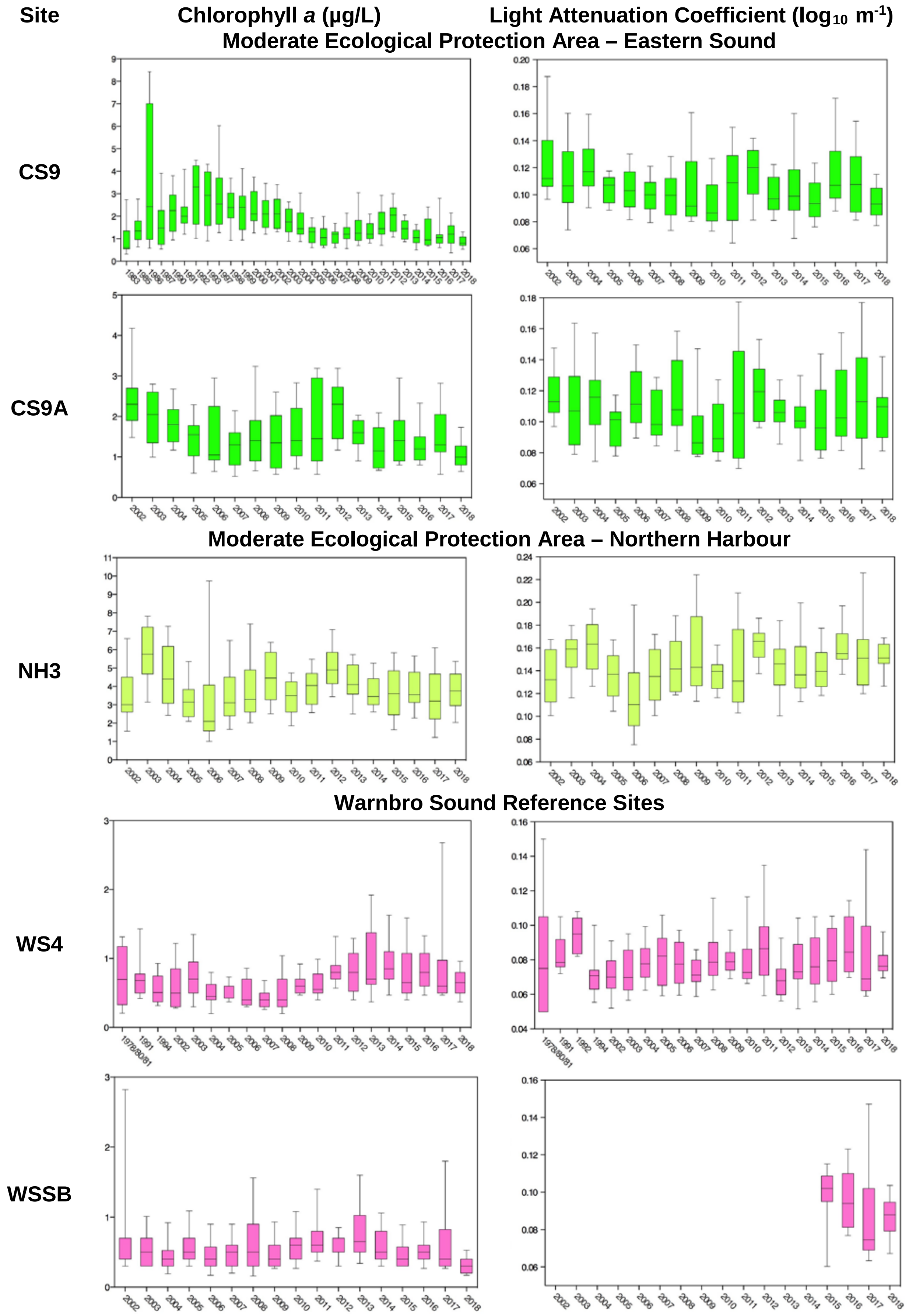


Figure C.3. Median chlorophyll *a* concentrations and light attenuation coefficients at the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound. The 'box' represents the 25th and 75th percentiles and the 'whiskers', the 10th and 90th percentiles.

Appendix D: Temporal Trends in Seagrass Shoot Density and Lower Depth Limits of Seagrass Distribution

The results of the Mann-Kendall trend analyses of mean and median *Posidonia sinuosa* shoot densities at each of the 11 seagrass monitoring sites in Cockburn Sound, the five sites outside Cockburn Sound and the five reference sites in Warnbro Sound are presented in Table D.1. Plots of mean and median shoot density at each site over time are presented in Figure D.1.

Table D.1. Results of Mann-Kendall trend analyses of mean and median *Posidonia sinuosa* shoot densities at the seagrass monitoring sites in and around Cockburn Sound and the reference sites in Warnbro Sound.

Ecological Protection Area	Site	Seagrass Shoot Density (shoots/m^2)			
		Mean shoot density		Median shoot density	
		Mann-Kendall Statistic	*p*-value (two-tailed test)	Mann-Kendall Statistic	*p*-value (two-tailed test)
HPA-N	Garden Island 2.0 m	-0.09	0.69	-0.09	0.69
	Garden Island 2.5 m	0.02	0.96	0.04	0.85
	Garden Island 3.2 m	-0.26	*0.18*	-0.27	*0.16*
	Garden Island 5.5 m	-0.57	**0.003**	-0.56	**0.003**
	Garden Island 7.0 m	-0.18	0.34	-0.23	0.24
	Luscombe Bay	-0.03	0.95	-0.12	0.62
	Garden Island Settlement	-0.39	*0.08*	-0.31	*0.16*
	Kwinana	-0.36	*0.08*	-0.46	**0.03**
HPA-S	Southern Flats	-0.25	*0.19*	-0.27	*0.16*
	Mangles Bay	-0.32	*0.13*	-0.25	0.24
MPA-ES	Jervoise Bay	-0.45	**0.03**	-0.46	**0.02**
Sites Outside Cockburn Sound	Carnac Island	0.08	0.76	0.08	0.76
	Coogee	-0.33	*0.15*	-0.33	*0.17*
	Woodman Point	-0.39	*0.08*	-0.12	0.62
	Bird Island	-0.26	0.25	-0.30	*0.18*
	Mersey Point	-0.23	0.30	-0.16	0.50
Reference Sites	Warnbro Sound 2.0 m	-0.54	**0.0056**	-0.50	**0.012**
	Warnbro Sound 2.5 m	-0.32	*0.10*	-0.27	*0.16*
	Warnbro Sound 3.2 m	-0.50	**0.008**	-0.48	**0.012**
	Warnbro Sound 5.2 m	-0.38	**0.04**	-0.35	*0.07*
	Warnbro Sound 7.0 m	-0.14	0.51	-0.23	0.29

Note: *p*-values < 0.05 are shown in bold; *p*-values < 0.2 are shown in italics.

There were significant (α = 0.05) downward trends in mean and median shoot densities at Garden Island 5.5 m and Jervoise Bay, and in median shoot density at Kwinana. There were potential[30] downward trends (α = 0.2) in mean and median shoot densities at Garden Island Settlement, Garden Island 3.2 m, Southern Flats, and in mean shoot density at Mangles Bay and Kwinana. There were no significant increases in shoot density reported at any site.

There were no significant trends in mean or median shoot densities at any of the five monitoring sites outside Cockburn Sound (Coogee, Carnac Island, Woodman Point,

[30] Trends are assessed as 'significant trends' at α = 0.05 and 'potential trends' at α = 0.2. This ensures that potential declining trends that are not statistically significant are nevertheless identified early on as a potential future issue.

Mersey Point, Bird Island). There were potential downward trends in mean and median shoot densities at Coogee, median shoot density at Bird Island and mean shoot density at Woodman Point.

Significant downward trends in mean and median shoot densities were recorded at two of the reference sites (Warnbro Sound 2.0 m and Warnbro Sound 3.2 m) and in mean shoot density at one site (Warnbro Sound 5.2 m). There were potential downward trends in mean and median shoot densities recorded at Warnbro Sound 2.5 m and median shoot density at Warnbro Sound 5.2 m.

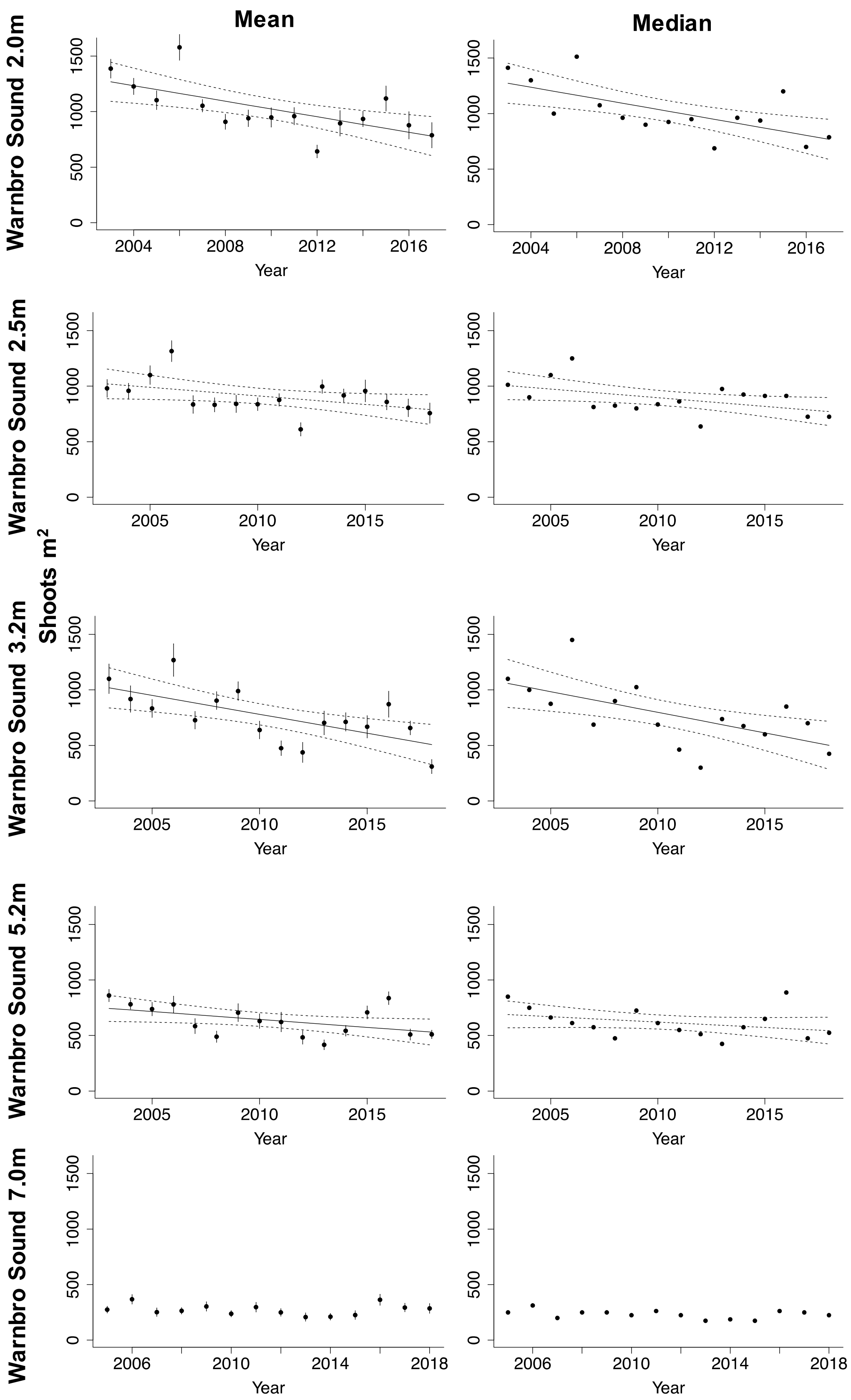


Figure D.1. Trends in mean (± standard error) and median shoot densities at five reference sites in Warnbro Sound. Note that there was no seagrass present in and around Warnbro Sound 2.0 m. Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.

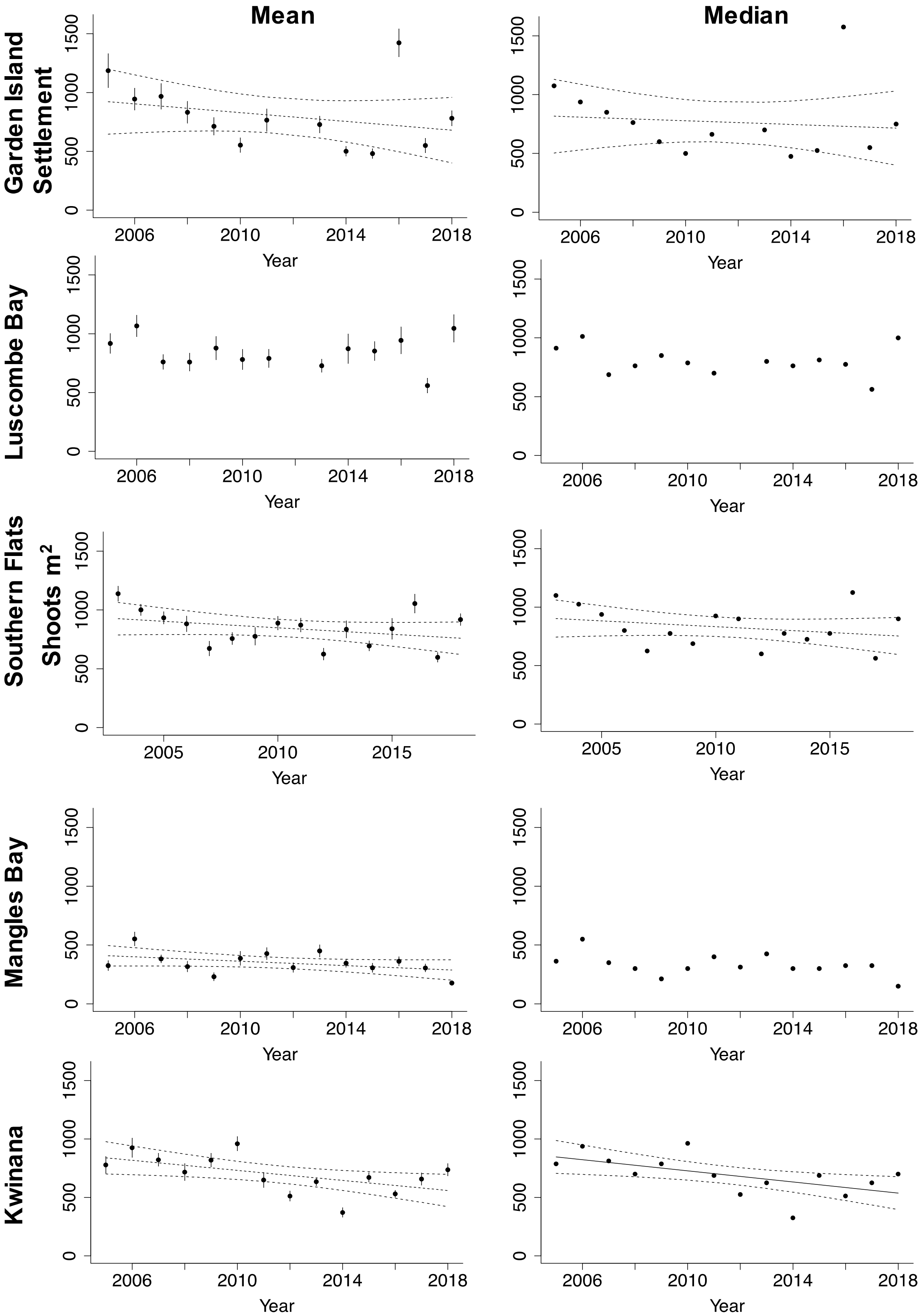
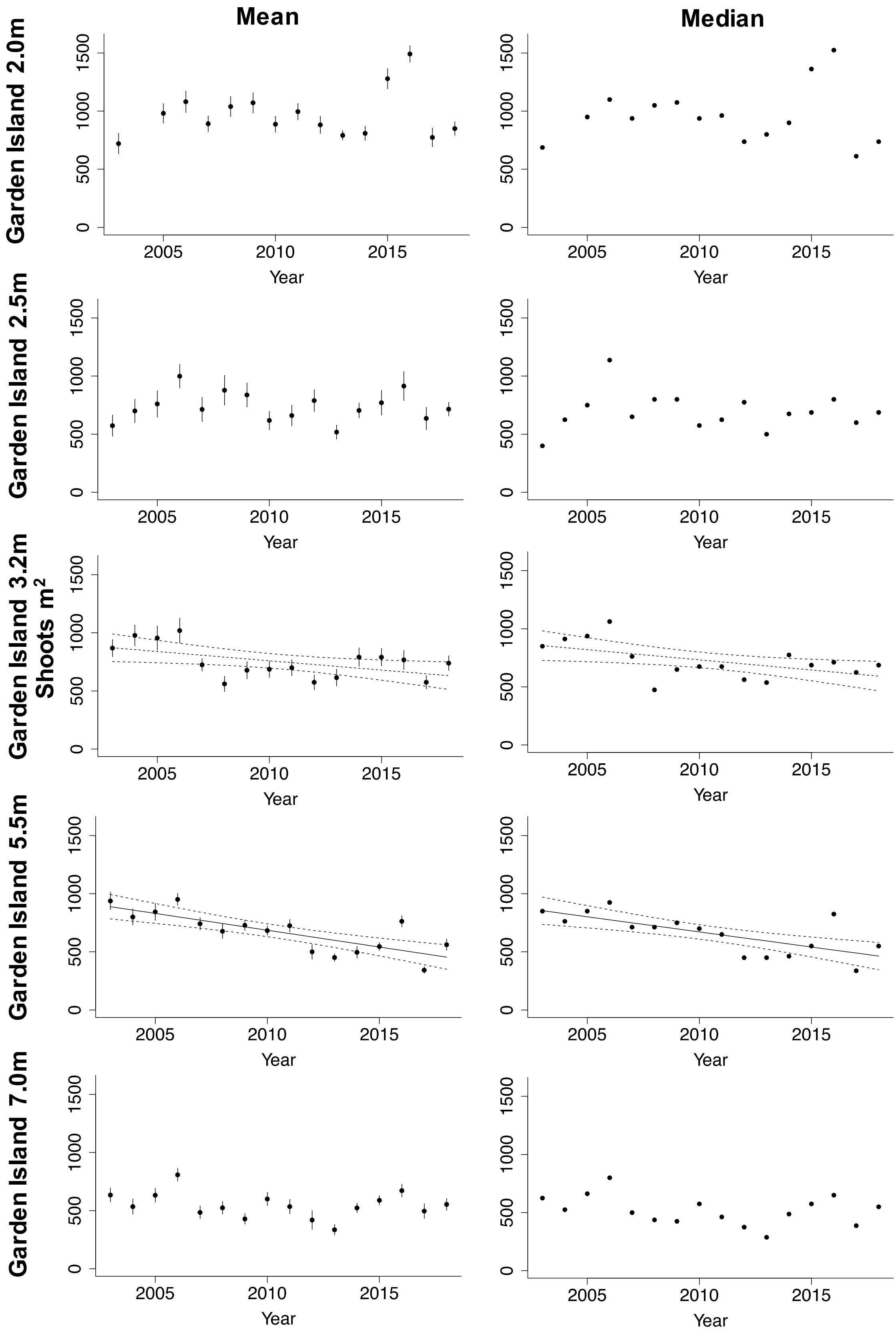
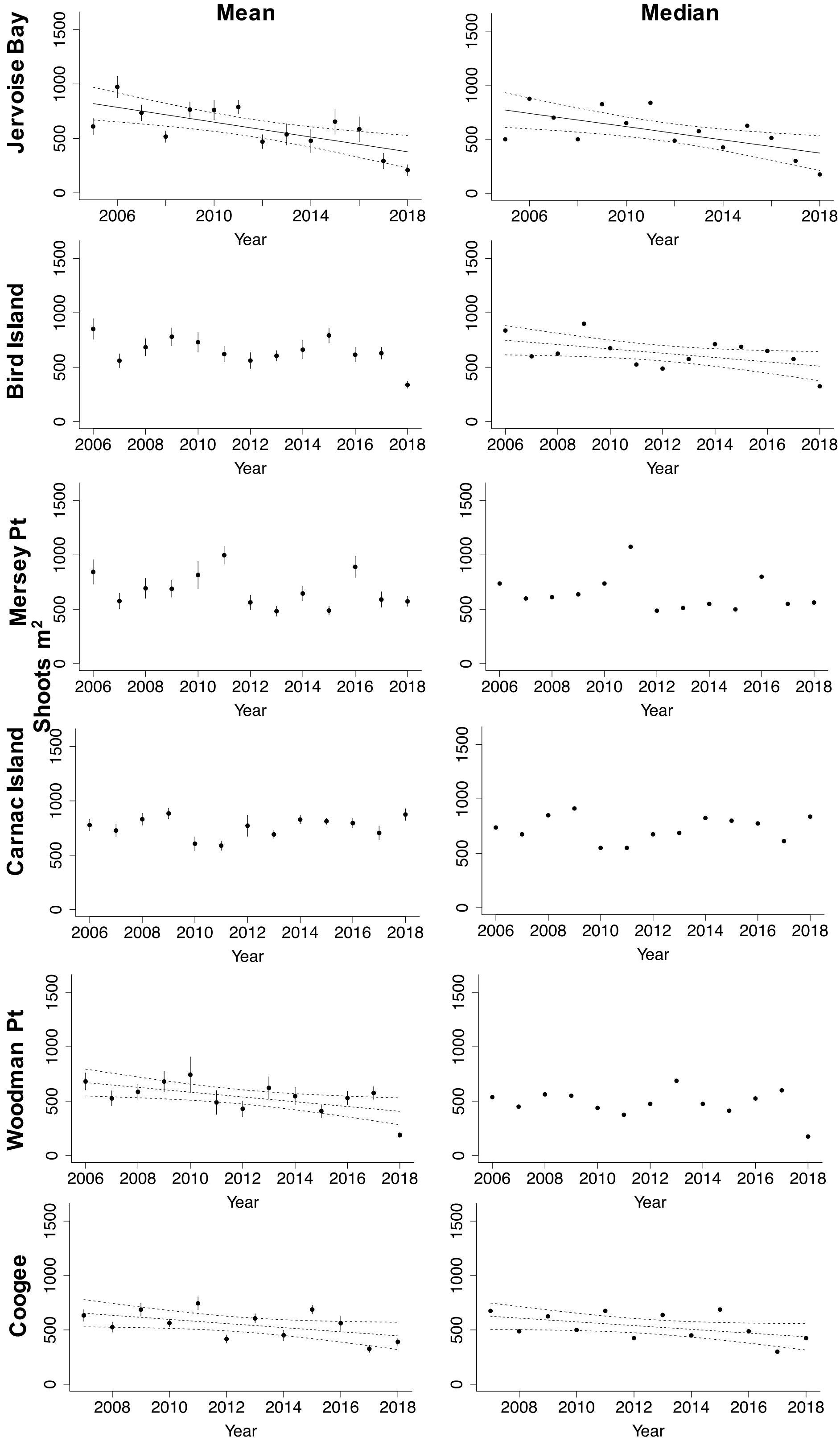


Figure D.2. Trends in mean (± standard error) and median shoot densities at five potential impact sites in the Cockburn Sound High Ecological Protection Area. Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.



Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.

Figure D.3. Trends in mean (± standard error) and median shoot densities at five potential impact sites on the eastern shore of Garden Island in the Cockburn Sound High Ecological Protection Area.



Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.

Figure D.4. Trends in mean (± standard error) and median shoot densities at one potential impact in the Cockburn Sound Moderate Ecological Protection Area Eastern Sound (Jervoise Bay) and five potential impact sites outside Cockburn Sound

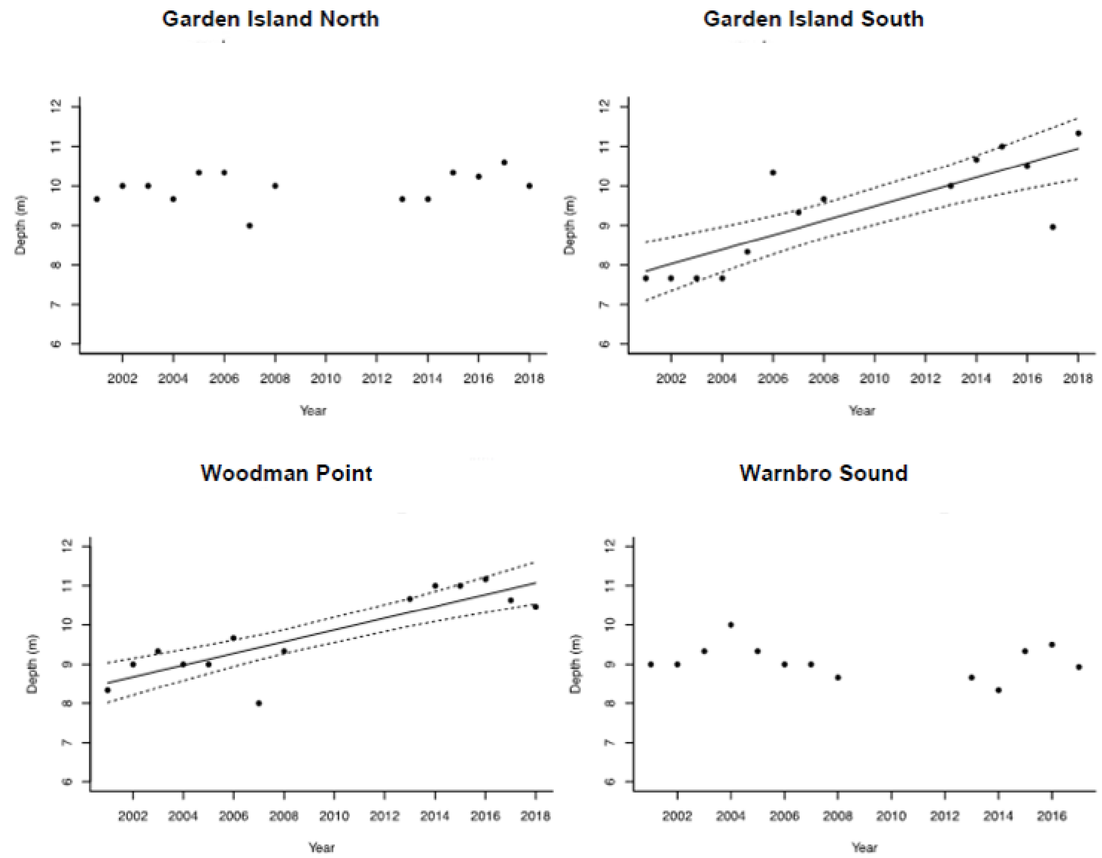
The results of the Mann-Kendall trend analyses of the mean Lower Depth Limit (LDL) at the four ‘depth limit’ sites are presented in Table D.2. Plots of the mean LDL at each site over time are presented in Figure D.5. Shoot density data were collected at the Warnbro Sound ‘depth limit’ site, but the lower depth limit was not recorded. The trend analysis for the Warnbro Sound ‘depth limit’ site was based on available data recorded from 2001 to 2017.

The mean LDLs have increased significantly at Garden Island South and Woodman Point over the 18 years that the sites have been monitored. There were no significant trends in the mean LDLs at the Garden Island North or Warnbro Sound ‘depth limit’ sites based on the available data.

Table D.2. Results of Mann-Kendall trend analyses of the mean Lower Depth Limit at the three ‘depth limit’ sites in and around Cockburn Sound and one ‘depth limit’ reference site in Warnbro Sound.

Site	Mann-Kendall Statistic	*p*-value
Garden Island North	0.24	0.28
Garden Island South	0.69	**0.0009**
Woodman Point	0.57	**0.007**
Warnbro Sound	-0.19	0.42

Note: *p*-values < 0.05 are shown in bold.



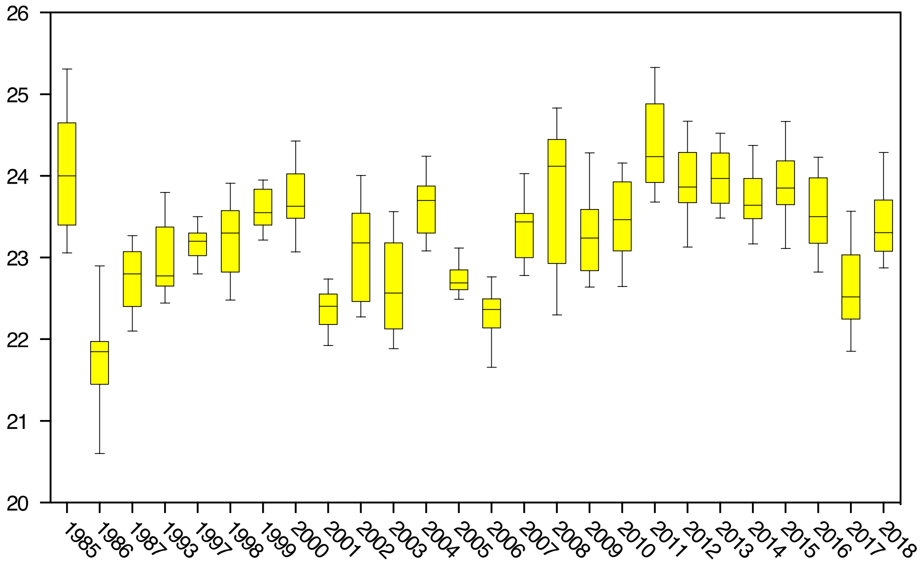
Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands. Note the missing data between 2009 and 2012.

Figure D.5. Trends in mean Lower Depth Limit (LDL) of seagrass meadows at the ‘depth limit’ sites in and around Cockburn Sound and the reference ‘depth limit’ site in Warnbro Sound.

Seagrass LDLs decreased (were shallower) at the Garden Island North and Woodman Point and Warnbro Sound ‘depth limit’ sites in 2018 compared to 2017 but increased (were deeper) at Garden Island South. The LDL increased from 5.2 m to 9.2 m at Mangles Bay and decreased from 7.9 m to 7.5 m at the Southern Flats between 2017 and 2018.

Appendix E: Variations and Trends over Time in Water Temperature in Cockburn Sound

The trends in median February bottom water temperatures measured at the eight Cockburn Sound sites for which there are long-term data available (CS4, CS5, CS8, CS6/CS6A, CS7, CS9, CS10/10N and CS11) can be seen in Figure E.1.



Notes:

(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) Medians calculated for the eight sites in Cockburn Sound (CS4, CS5, CS8, CS6/CS6A, CS7, CS9, CS10/CS10N and CS11) for which there are long-term data available.

Figure E.1. Median February bottom water temperatures in Cockburn Sound over the period 1983 to 2018.

Keesing *et al*. (2016) reported a significant increase in both surface and bottom water temperatures in Cockburn Sound between 1985 and 2014,[31] with an increase in surface water temperature of 0.0325 ± 95% Confidence Interval 0.016°C and in bottom water temperature of 0.0295 ± 95% Confidence Interval 0.014°C per year. These rates of changes are similar to those reported elsewhere off the Western Australian coastline and are attributed to global climate change (Keesing *et al*. 2016). The 2010–11 mean surface water temperature of 24°C was significantly ($p < 0.0001$) warmer than other years between 2008 and 2014 (consistent with the marine heat wave which occurred in early 2011), while 2008–09 was significantly cooler (mean 22.7°C) than other years between 2008 and 2014 (Keesing *et al*. 2016). There were similar patterns in water temperatures at the seabed, with 2010–11 being the warmest and 2008–09 the coolest between 2008 and 2014 (Keesing *et al*. 2016).

[31] Based on analysis of the data for CS4 and CS5 – the sites closest to the open ocean – for which there are long-term data available. Only March data were analysed as the effect of climate change in south-western Australia involves a lengthening of the warm season and this is when the climate change signal is most pronounced (Keesing *et al.* 2016).

The Department of Primary Industries and Regional Development maintains Onset Tidbit temperature loggers at three sites (Navy Ammunition Jetty [depth 9.5 m]; Alcoa Jetty [depth 5 m]; and Mangles Bay South [depth 1 m]) in Cockburn Sound to support ongoing fisheries management.

The monthly average temperatures at each site for October to March from 2008-09 to 2017-18 are presented in Figures E.2 to E.4. No temperature data were available for the Navy Ammunition Jetty for October 2011 to March 2012, 2016-17 and 2017-18. No temperature data were available for the Alcoa Jetty for October 2014 to March 2015.

In 2018, the average temperatures for January, February and March at the Alcoa Jetty and for January and February at Mangles Bay South were the second lowest recorded monthly averages for these months. At Mangles Bay South, March 2018 was the lowest monthly average for March to date.

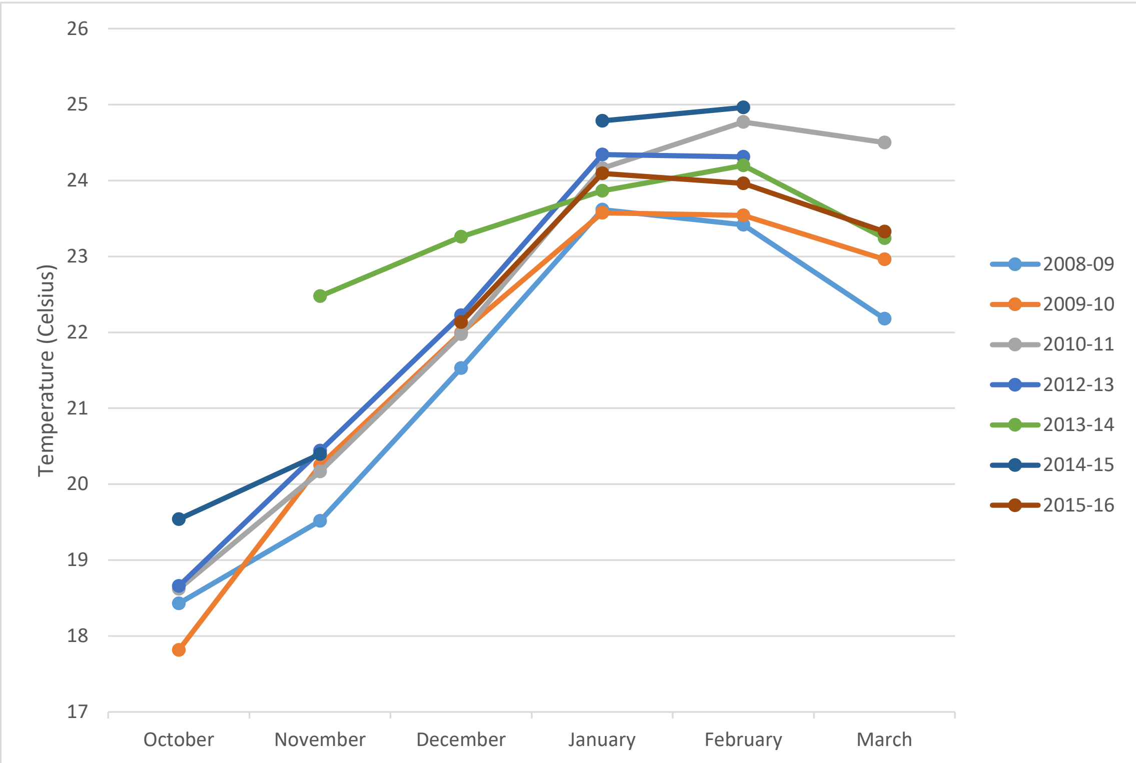


Figure E.2. Monthly average temperatures at the Navy Ammunition Jetty for October to March from 2008-09 to 2016-17. No data were available for October 2011 to March 2012, 2016-17 and 2017-18.

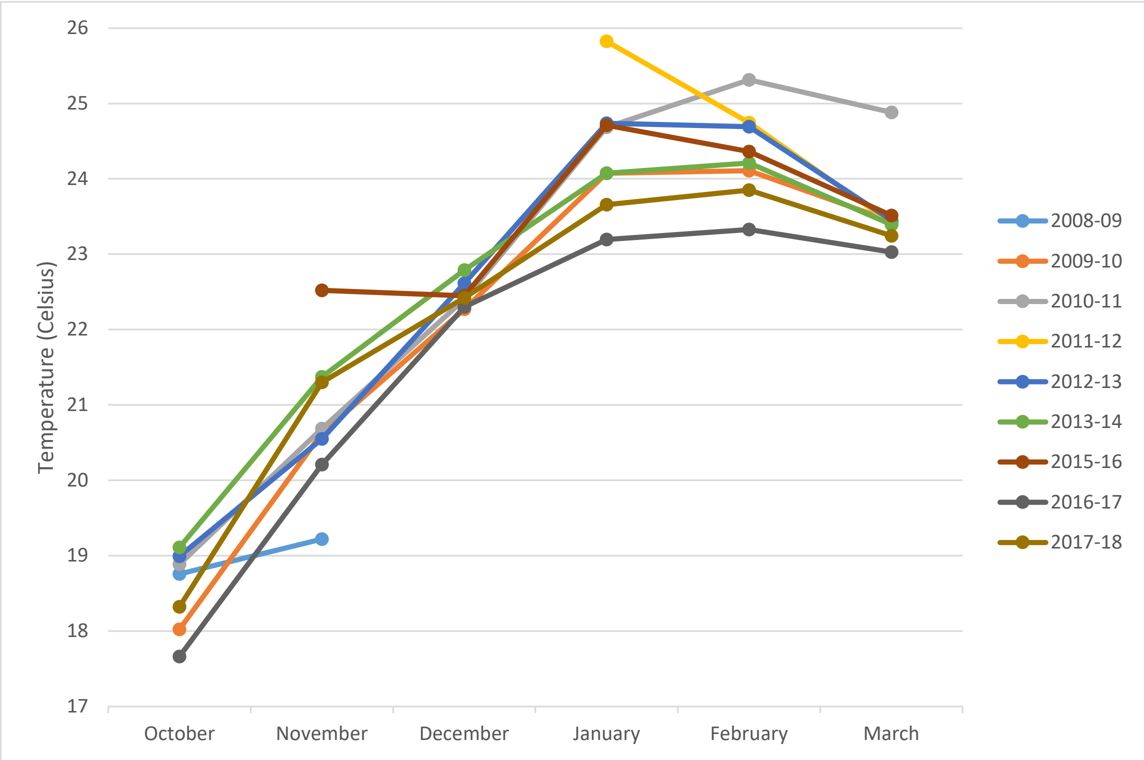


Figure E.3. Monthly average temperatures at the Alcoa Jetty for October to March from 2008-09 to 2017-18. No data were available for October 2014 to March 2015.

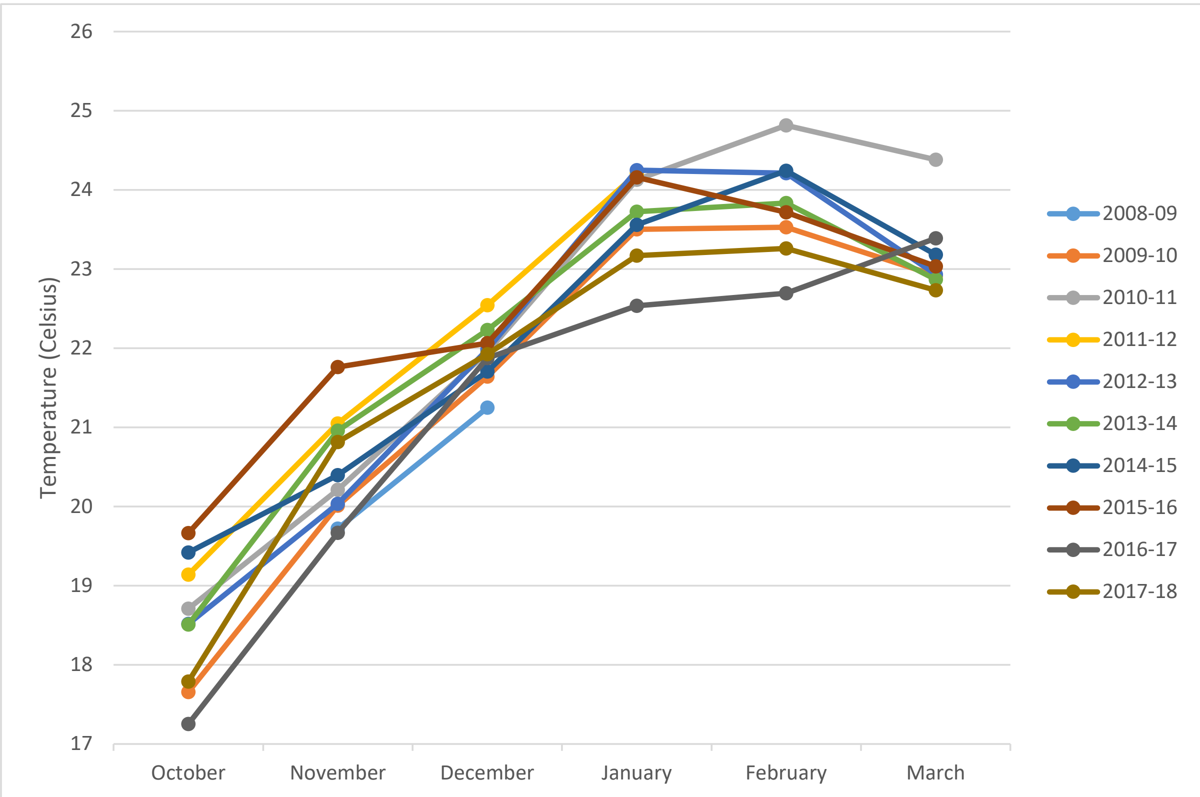


Figure E.4. Monthly average temperatures at Mangles Bay South between for October to March from 2008-09 to 2017-18.