GOVERNMENT OF WESTERN AUSTRALIA

Cockburn sound annual environmental monitoring report 2018–19

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 2018 to 30 June 2019.

Environmental Value: Ecosystem Health

Nutrient enrichment and phytoplankton biomass

The relevant Environmental Quality Guidelines (EQG) for nutrient enrichment were met at all of the Cockburn Sound water quality monitoring sites with the exception of three sites in the High Protection Area—South (HPA-S) and the Moderate Protection Area site at Jervoise Bay Northern Harbour. A detailed assessment of the available monitoring data against the ‘Nutrient enrichment’ Environmental Standards (EQS) (i) Chlorophyll α concentration and light attenuation, (ii) Seagrass shoot density and (iii) lower depth limit (LDL) found that these EQS were not exceeded.

The relevant ‘Phytoplankton biomass’ (measured as chlorophyll α) EQG (i) were met at all sites. However, the relevant ‘Phytoplankton biomass’ EQG (ii) was not met at the Mangles Bay site in HPA-S or the Jervoise Bay Northern Harbour site. A more detailed assessment of the chlorophyll α concentrations at the Mangles Bay and Northern Harbour sites found that the Mangles Bay site met the relevant EQS, while the Jervoise Bay Northern Harbour site did not.

With the exception of two Garden Island sites and the Southern Flats site, median seagrass shoot densities at seagrass monitoring sites in Cockburn Sound were higher in 2019 than in 2018. The 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 and at two-thirds of the quadrats at the 3.2 m depth site.

The increase or stability in the distribution of seagrass in the deeper waters of Cockburn Sound suggests that water quality and light availability are adequate for seagrass growth. Since 2017, LDLs have remained stable or become deeper and above the established baseline values (Fraser *et al*. 2019). The stability of the LDLs suggest that factors other than light availability are driving the continued seagrass declines across Cockburn Sound, Warnbro Sound, and Owen Anchorage (Fraser *et al*. 2019).

Other physical and chemical stressors

The relevant EQG for dissolved oxygen concentration was met at one of 10 water monitoring sites in the High Protection Areas and five of eight water monitoring sites in the Moderate Protection Areas. The water monitoring sites that exceeded the relevant

‘Dissolved oxygen concentration’ EQG, were found to have met the relevant ‘Dissolved oxygen concentration’ EQS.

Dissolved oxygen concentrations were also measured by the Water Corporation in the bottom waters at three monitoring sites in Cockburn Sound in July 2018, October 2018, January 2019 and June 2019. The ‘Dissolved oxygen concentration’ EQG was met at all three Water Corporation monitoring sites.

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 31 January 2019. The relevant ‘Dissolved oxygen concentration’ EQG was met at all sites with the exception of the KBJ3 site, where it was not met between the depths of 13.3 m and 14.2 m.

The relevant ‘Salinity’ EQG were met at all sites with the exception of the surface and bottom waters at the Mangles Bay site in HPA-S and the bottom waters at the CS9 and CS12 sites in the Moderate Protection Area – Eastern Sound (MPA-ES). A more detailed assessment of these three sites found that they met ‘Salinity’ EQS. There were no known reported deaths of marine organisms attributed to anthropogenically sourced salinity stress on the 2018–19 sampling days.

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

The concentrations of ammonium measured in the depth-integrated water samples collected from the 18 Cockburn Sound water monitoring sites were below the relevant EQG values. Discrete surface and bottom water samples were also taken at site CS13 in HPA-S and Warnbro Sound reference site WS4. At site CS13, the median ammonium concentration of the discrete bottom water samples was significantly higher than that of the discrete surface and integrated water samples for the same site. For the reference site WS4, there was no significant difference between the discrete bottom and integrated water samples; however, the discrete bottom water had significantly more ammonium than that of the discrete surface water sample.

Water samples from the marine waters around the KBT and KBJ were analysed for a range of toxicants, including ammonia, filtered copper, total recoverable hydrocarbons (TRHs) and benzene, toluene, ethylbenzene and xylene (BTEX). The KBT samples were also analysed for lithium and filtered manganese. 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 during the 2018–19 monitoring period. The exceptions were an elevated lead concentration in one sediment sample collected at the KBT3 site and elevated copper and cadmium concentrations in sediment samples at KBJ. A slightly elevated concentration of mercury was recorded in one KBJ sediment sample.

Lead testing was subsequently performed on nine additional samples collected alongside the KBT3 sample location. The lead concentrations in the nine additional samples ranged from 4.1 mg/kg to 6.7 mg/kg, which were below the EQG value for lead. The copper and cadmium concentrations were above the relevant EQG values, but below the re-sampling trigger value.

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 the TBT concentrations to be above the EQG value and re-sampling trigger value. 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 2018–19 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). There were no exceedances of the ‘Faecal pathogens in water’ and ‘Algal biotoxins’ EQG and ‘*E. coli* in shellfish flesh’ EQS in the Kwinana Grain Terminal and Southern Flats shellfish harvesting areas. All of Cockburn Sound shellfish samples taken as part of the WASQAP monthly screening program were found to be negative for biotoxins. The EQC for chemical concentration in seafood flesh were also met in those areas where sampling and analysis were undertaken.

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 generally met at these sites. Very low dissolved oxygen concentrations, below the EQG, were observed in depth waters at two water monitoring sites adjacent to the shellfish harvesting areas – sites CS11 (one instance) and CS13 (two instances).

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

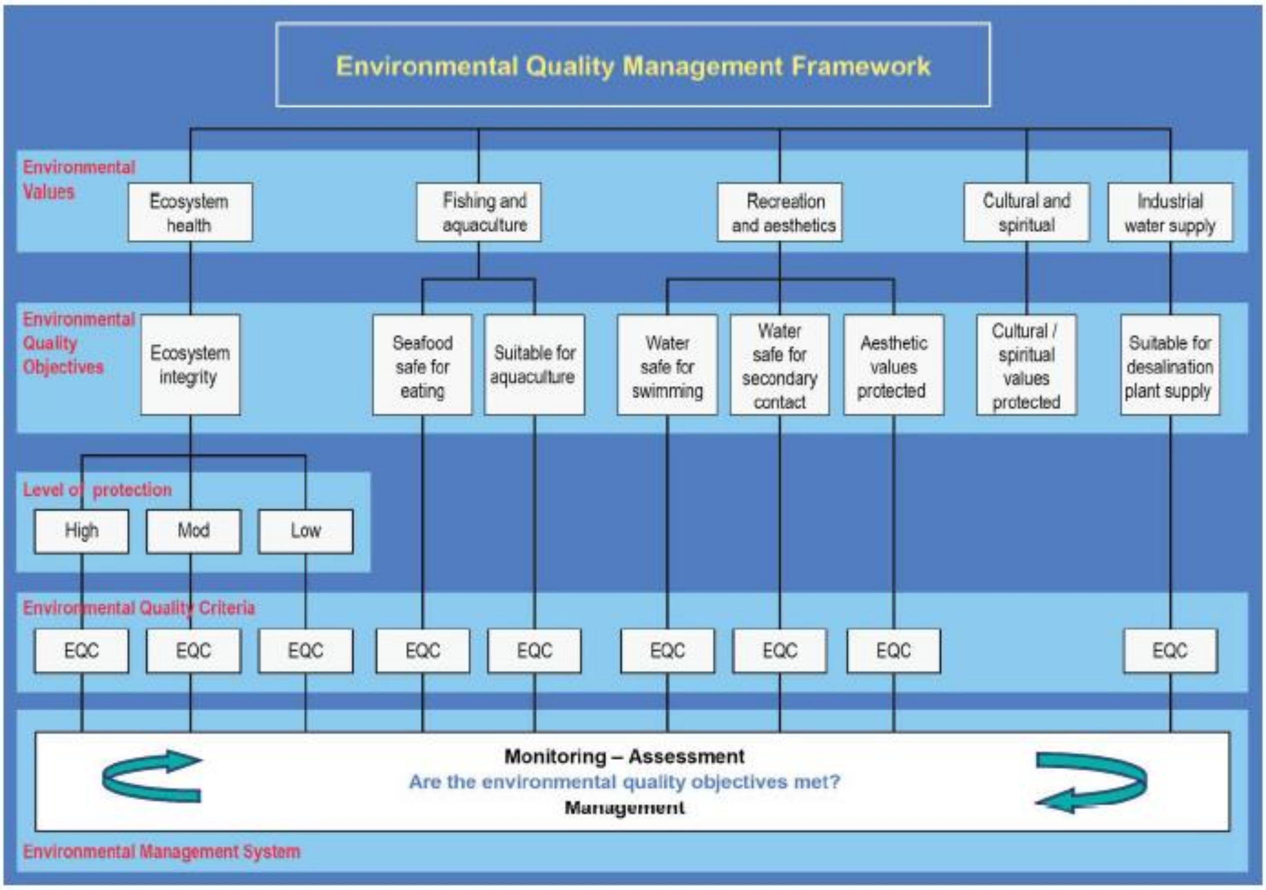
The results from the 2018–19 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant indicated there were minor exceedances of the EQG for Total Suspended Solids (TSS). The suitability of the quality of the intake seawater for the desalination process was not considered to have been compromised. 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 2018–19 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 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)
- 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 in 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 2018–19.

Environmental Quality Objective	Environmental Quality Criteria		Indicator	Data Source
Maintenance of ecosystem integrity	Physical and chemical stressors	Nutrients	*Nutrient enrichment* • Chlorophyll *a* concentration • Light attenuation coefficient • Seagrass shoot density • Seagrass lower depth limit *Phytoplankton biomass*	Department of Water and Environmental Regulation (DWER)
		Other physical and chemical stressors	Dissolved oxygen concentration Water temperature Salinity pH	DWER, Water Corporation, Fremantle Ports, Department of Primary Industries and Regional Development (DPIRD)
	Toxicants (marine waters)	Metals and metalloids	Copper, lithium, manganese	DWER, Fremantle Ports
		Non-metallic inorganics	Ammonia	
		Organics	Benzene, toluene, ethylbenzene, xylene (BTEX)	
		Oils and petroleum hydrocarbons	Total recoverable hydrocarbons (TRHs)	
	Toxicants (sediments)	Metals and metalloids	Arsenic, cadmium, chromium, copper, lead, lithium, manganese, mercury, selenium zinc	Fremantle Ports
		Organometallics	Tributyltin (TBT), dibutyltin (DBT), monobutyltin (MBT)	
		Organics	Polycyclic aromatic hydrocarbons (PAHs)	
		Oils and petroleum hydrocarbons	TRHs	
		PFAS	PFOA, PFOS, PFHxS	

Table 1b. Environmental quality indicators and data sources reported in 2018–19.

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 (e.g. the biodiversity, biomass and abundance of biota) and function (e.g. 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 1% 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 (e.g. 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).

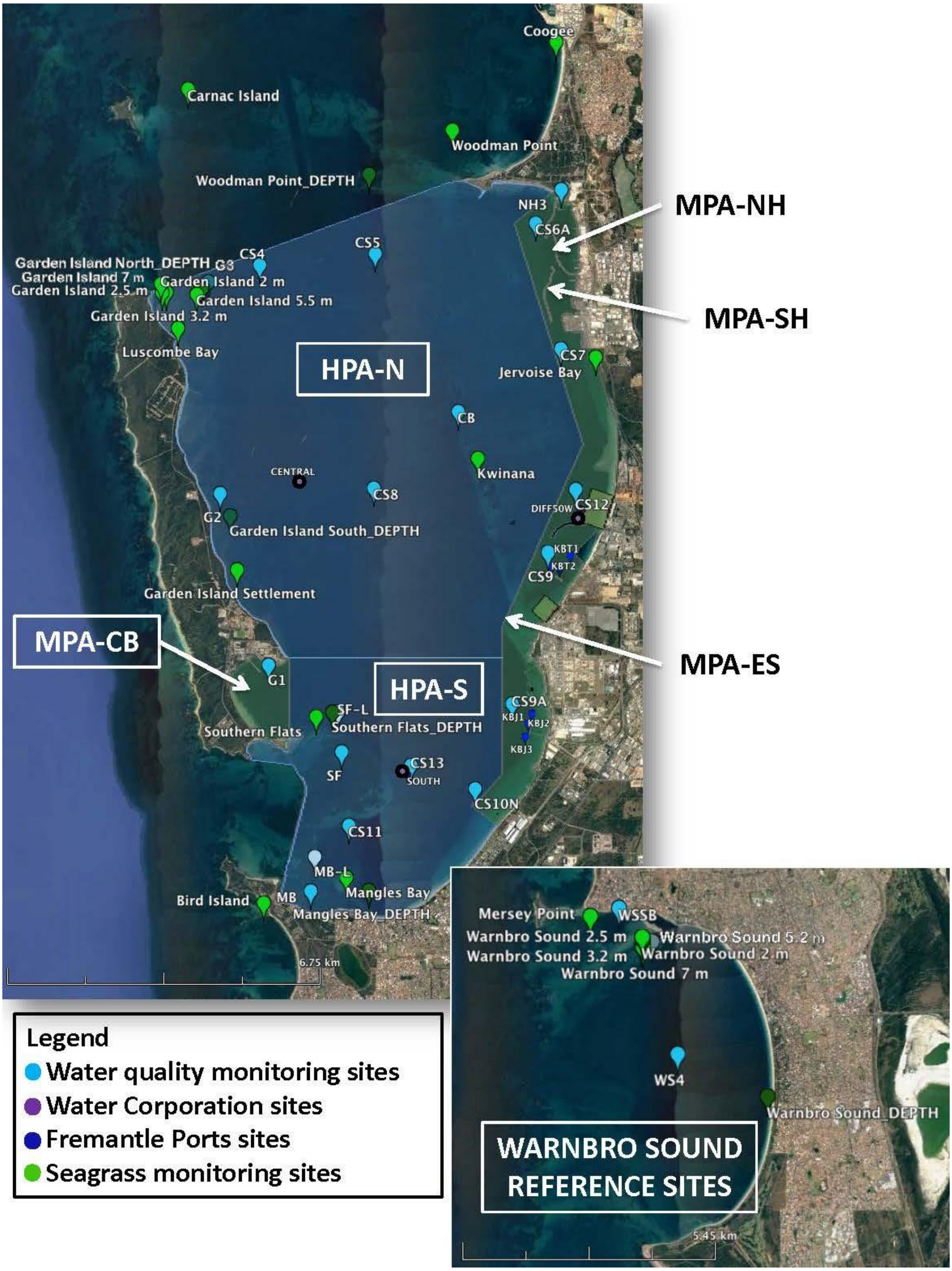


Figure 2. The ecological protection areas in Cockburn Sound and the location of water quality, sediment quality and seagrass monitoring sites in Cockburn Sound and reference sites in Warnbro Sound.

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	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 3 December 2018 and 25 March 2019 (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 and 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 before 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 PAR quantum light sensors (Model LI-192 Licor Inc.) to correct for changes in ambient conditions, with sensors positioned one metre (m) and 7 m below the surface. The light attenuation coefficient was calculated as:

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

The Water Corporation undertook quarterly measurements (19 July 2018, 2 October 2018, 14 January 2019 and 28 June 2019) 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 31 January 2019 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 about 0.5 m below the surface and

[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.

about 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 13 March 2019 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 2 cm 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 (UWA) 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 2019.

The numbers of *Posidonia sinuosa*[4] and *Posidonia australis* shoots were recorded in each of 24 fixed 20 cm by 20 cm quadrats along four[5] 10 m transects at each 'potential impact' and reference site. Shoot density data are normalised to 1 m^2. The height of the tallest shoot (maximum shoot height) and mean shoot height were measured in each quadrat. At each site, 10 1 m x 1 m photographic quadrats were taken at a standard height (1 m) and at about 1 m 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 every 2 m 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.

[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.

Monitoring was undertaken in accordance with Lavery and Gartner (2008) and the 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.
- Minimisation of the occurrence and extent of phytoplankton blooms in Cockburn Sound (EPA 2017).

2.5.1 Re-calculation of the 2018–19 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 2018–19 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 2018–19 monitoring period, the chlorophyll *a* and light attenuation coefficient annual medians at WS4 were within their respective historical ranges (Table 3) and the 2018–19 data were therefore included in the re-calculation of the EQG (Table 4).

Table 3. Assessment of the 2018–19 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	0.067
Historical dataset 80th percentile	0.90	0.091
2018–19 median	0.80	0.085
Assessment	Met criteria specified in the Reference Document	Met criteria specified in the Reference Document
	2018–19 data included in the 2018–19 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 2018–19 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)	1.00	1.80
LAC ($\log_{10}$ m^{-1})	0.099	0.115

Median chlorophyll *a* concentrations at the Warnbro Sound reference site WS4 were about 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 2018–19, the highest recorded chlorophyll *a* concentration at WS4 was 1.5 µg/L. Before 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
- 1.1 µg/L in 2016–17 and 2017–18.

The 2018–19 high protection EQG for chlorophyll *a* was 1.0 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
- 1.8 µg/L in 2016–17, 2017–18 and 2018–19.

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

Table 5. The 2018–19 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	1.00
Conversion factor[7]	x 3	x 3
EQG	2.10	3.00

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 continued to exhibit significant declines in shoot density (Mohring and Rule 2014; Rule 2015; Fraser *et al*. 2016a, 2017, 2018, 2019).

Mean and median shoot densities at Warnbro Sound (WS) 2.0 m and 3.2 m showed statistically significant declines (α=0.05) and at WS 5.2 m, and the downward trend approached significance (α=0.2) (Fraser *et al*. 2019). No significant trends in mean or median shoot densities were observed at WS 2.5 or 7.0 m. There was complete loss of shoot density in and around WS 2.0 m and in two-thirds of the quadrats at WS 3.2 m.

The re-calculated EQS for each depth are presented in Table 6. Percentiles were calculated using data from 2016–19. As the 5th percentile values at WS 2.0 m and 5.2 m and the 20th percentile values at WS 2.5 m, 3.2 m and 7.0 m were below the Absolute Minimum Criteria (AMC) values, the AMC values were used as the EQS for these depths as recommended in the Reference Document.

Table 6. The 2019 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	485	170	53
Warnbro Sound 2.5 m	515	280	48
Warnbro Sound 3.2 m	300	75	25
Warnbro Sound 5.2 m	375	250	195
Warnbro Sound 7.0 m	175	75	25

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 23 quadrats, which is

[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.

considerably less than that recommended in the Reference Document.

The ‘rolling’ four-year percentiles of seagrass shoot density showed significant downward trends in 20th, 5th and 1st percentiles for reference sites WS 2.0 m, 2.5 m and 3.2 m (Table 7). A potential downward trend was observed for WS 7.0 m for all percentiles ($\alpha = 0.2$). No significant trends were observed for WS 5.2 m. The percentiles calculated for WS 2.0 m and 3.2 m reflect the complete loss of shoot density in and around 2.0 m depth and in two-thirds of the quadrats at 3.2 m depth.

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	-0.66	**<0.01**	-0.74	**<0.001**	-0.82	**<0.0001**
Warnbro Sound 2.5 m	-0.42	**0.047**	-0.70	**<0.0001**	-0.92	**<0.0001**
Warnbro Sound 3.2 m	-0.44	**0.036**	-0.41	*0.052*	-0.79	**<0.0001**
Warnbro Sound 5.2 m	-0.22	0.31	-0.11	0.62	-0.22	0.32
Warnbro Sound 7.0 m	-0.31	*0.19*	-0.38	*0.083*	-0.31	*0.19*

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 and 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 2018–19 non river-flow period:

High protection: *The median chlorophyll a concentration/light attenuation coefficient in HPA-N and HPA-S during the 2018–19 non river-flow period is not to exceed a chlorophyll a concentration of 1.00 µg/L or a light attenuation coefficient of 0.099 $\log_{10}$ m^{-1}.*

Moderate protection: *The median chlorophyll a concentration/light attenuation*

> *coefficient in MPA-ES and MPA-CB during the 2018–19 non river-flow period is not to exceed a chlorophyll a concentration of 1.80 µg/L or a light attenuation coefficient of 0.115 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, MPA-CB, and MPA-ES, but not in HPA-S. The elevated chlorophyll *a* concentrations and light attenuation coefficients are indicative of nutrient enrichment in HPA-S. The highest chlorophyll *a* concentrations and light attenuation coefficients were recorded at Jervoise Bay Northern Harbour (NH3) in MPA-NH. The 'Nutrient enrichment' EQG were not applied to MPA-NH because of the absence of macro-benthic primary producers, such as seagrass, within the harbour.

Table 8. Assessment of the 2018–19 individual site and ecological protection area chlorophyll *a* concentrations and light attenuation coefficients (LAC) against the 'Nutrient enrichment' EQG.

Ecological Protection Area	Site	Chlorophyll *a* (µg/L)			LAC (log_{10} m^{-1})			Assessment
		2018–19 EQG	2018–19 Site median	2018–19 Ecological Protection Area median	2018–19 EQG	2018–19 Site median	2018–19 Ecological Protection Area median	
HPA-N	CS4	1.0	0.75	0.5	0.099	0.085	0.085	EQG met
	CS5		0.55			0.088		
	CS8		0.6			0.084		
	CB		0.5			**0.101**		
	G2		0.5			0.084		
	G3		0.5			0.0825		
HPA-S	CS11	1.0	**1.45**	**1.3**	0.099	**0.104**	**0.1015**	EQG not met
	CS13		**1.5**			**0.101**		
	SF		0.55			0.095		
	MB/MB-L		**1.6**			**0.109**		
MPA-CB	G1	1.8	0.85	0.85	0.115	0.084	0.084	EQG met
MPA-ES	CS10N	1.8	1.3	0.9	0.115	0.107	0.109	EQG met
	CS12		0.9			0.107		
	CS6A		0.8			**0.118**		
	CS7		0.75			0.114		
	CS9		1.25			0.109		
	CS9A		1.25			0.1075		
MPA-NH	NH3	-	3.65	3.65	-	0.146	0.146	-

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

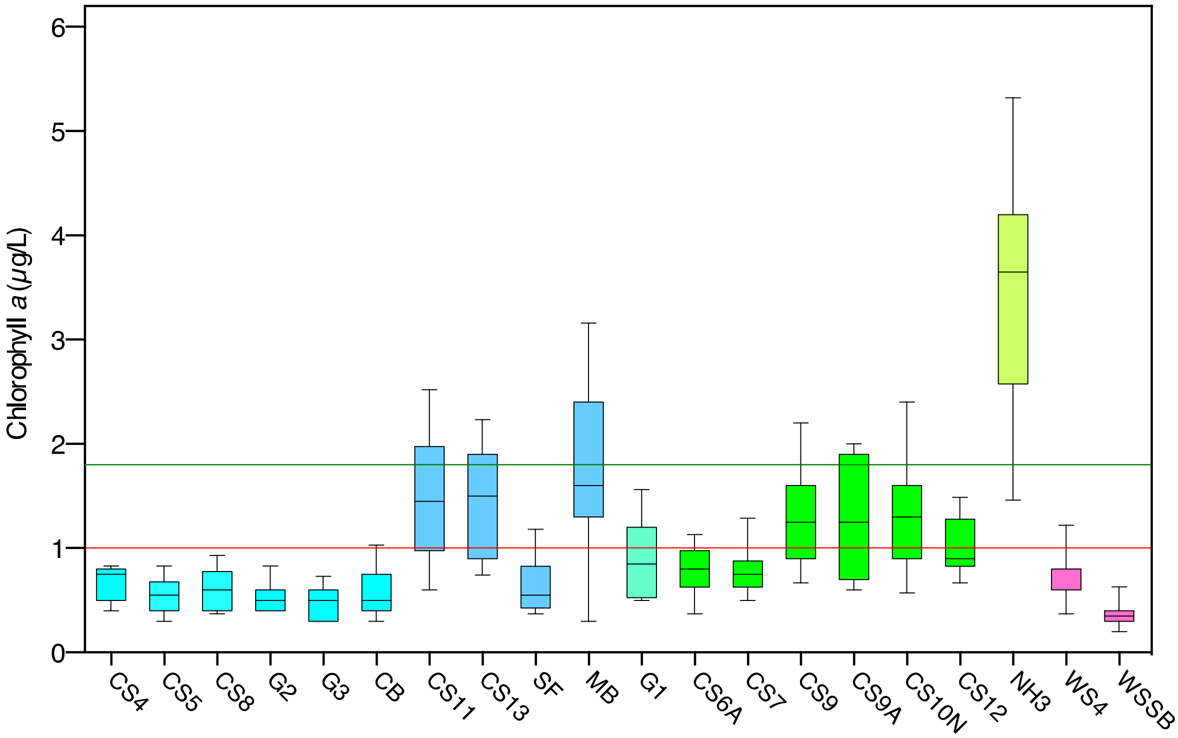


Figure 3. Median chlorophyll *a* concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2018 to March 2019.

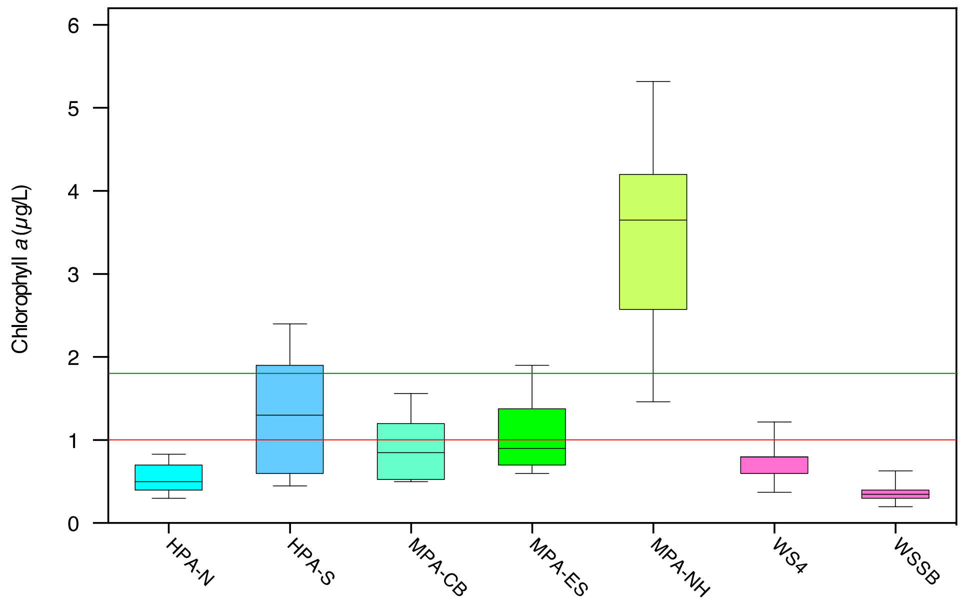


Figure 4. Median chlorophyll *a* concentration for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2018 to March 2019.

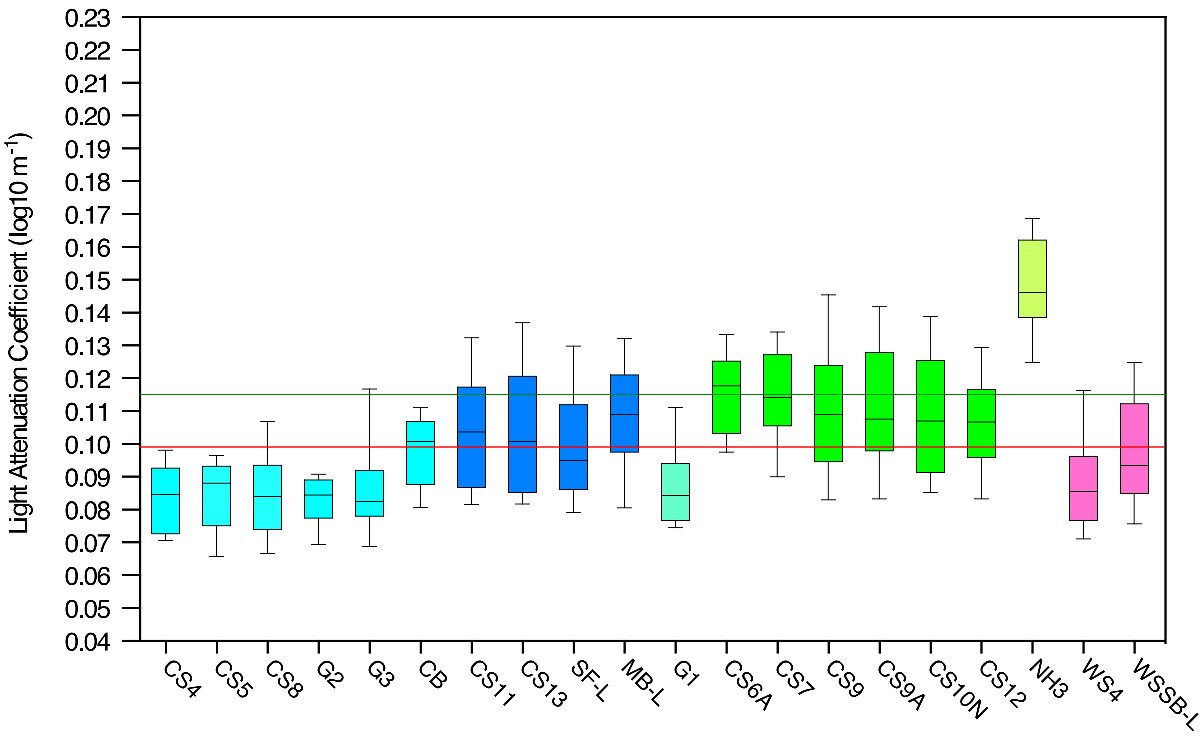


Figure 5. Median light attenuation coefficient at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2018 to March 2019.

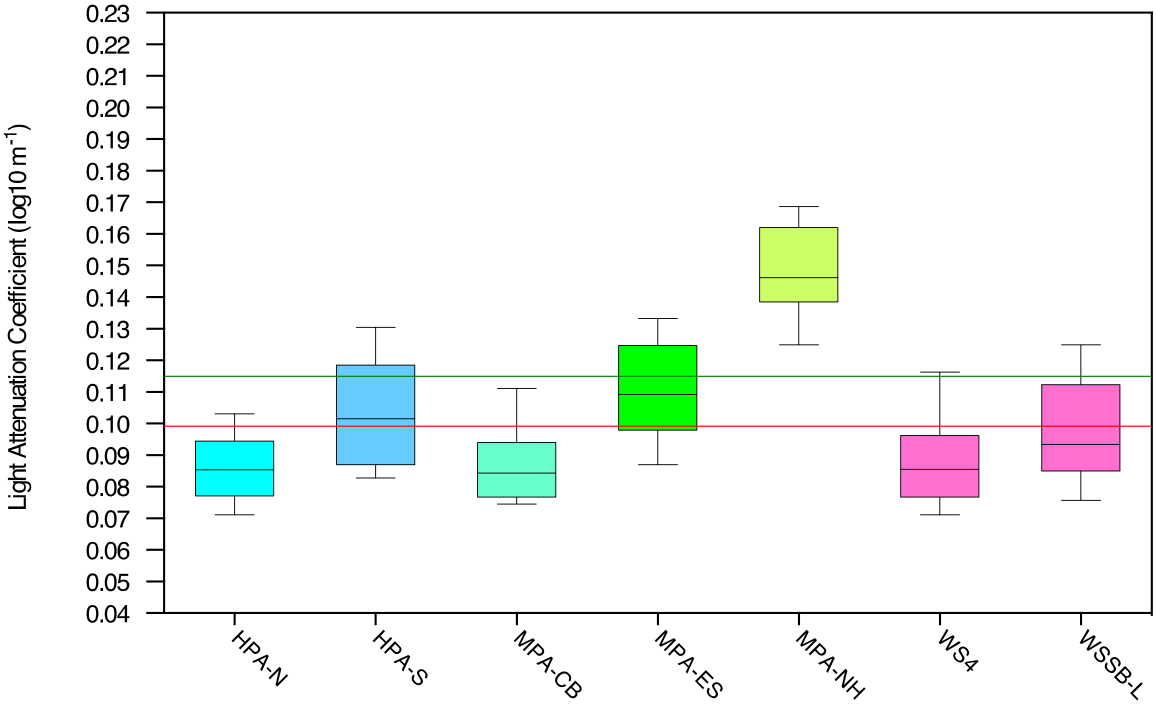


Figure 6. Median light attenuation coefficient for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2018 to March 2019.

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 2018–19 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

The ‘Nutrient enrichment’ EQG were not met in HPA-S, which triggered a more detailed assessment against the ‘Nutrient enrichment’ EQS (EQS A, Table 1a, Reference Document):[8]

High Protection:

i. *The ‘Nutrient enrichment’ EQG is not to be exceeded in a second consecutive year*

unless

Median Posidonia sinuosa meadow shoot density measured at a site in HPA-S during January and in any one of the two consecutive years is:

- *Greater than the ‘absolute minimum’ (5th percentile) seagrass shoot density:*

2.0–3.0 m depth: 500 shoots/m^2

[8] Note that where there are more than one EQC for an indicator designated by i, ii, iii, etc., each one is to be considered individually. If any one of the multiple EQC are exceeded then the guideline or standard for that indicator has not been met.

3.0–4.0 m depth: 171 shoots/m²

and

- *Greater than the annually updated rolling 20th percentile of the Warnbro Sound reference site shoot density:*

2.0–3.0 m depth: 2018: 475 shoots/m²

2019: 515 shoots/m²

3.0–4.0 m depth: 2018: 260 shoots/m²

2019: 300 shoots/m²

ii. The 'Nutrient enrichment' EQG is not to be exceeded in any year

unless

Median Posidonia sinuosa meadow shoot density measured at a site in HPA-S in the same year is greater than the rolling 5th percentile of the Warnbro Sound reference site shoot density updated to incorporate 2019 data:

2.0–3.0 m depth: 280 shoots/m²

3.0–4.0 m depth: 75 shoots/m²

iii. The 'Nutrient enrichment' EQG is not to be exceeded in any year

unless

The lower depth limit of seagrass meadows does not show a statistically significant retreat relative to the baseline depths:

Garden Island North: 9.8 m (95% confidence interval ±0.20)

Garden Island South: 7.6 m (95% confidence interval ±0.35)

Woodman Point: 8.4 m (95% confidence interval ±0.51)

Warnbro Sound: 8.7 m (95% confidence interval ±0.82).

EQS(i) Chlorophyll a concentration and light attenuation

Assessment of chlorophyll *a* concentrations and light attenuation coefficients for two consecutive years indicates that the 'Nutrient enrichment' EQG were met in 2017–18 but not met in 2018–19 in HPA-S (Table 9). The 'Nutrient enrichment' EQS(i) was therefore met for 2018–19.

Table 9. Assessment of chlorophyll *a* concentrations and light attenuation coefficients (LAC) in HPA-S and MPA-ES for 2017–18 and 2018–19 against the 'Nutrient enrichment' EQG.

Ecological Protection Area	2017–18				2018–19				Assessment
	Chl *a* (µg/L)		LAC ($\log_{10}$ m^{-1})		Chl *a* (µg/L)		LAC ($\log_{10}$ m^{-1})		
	EQG	Annual median	EQG	Annual median	EQG	Annual median	EQG	Annual median	
HPA-S	1.1	0.7	0.096	0.077	1.10	**1.2**	0.096	**0.105**	EQG met in 2017–18 but not 2018–19

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

EQS(ii) Seagrass shoot density

For assessment against the 'Nutrient enrichment' EQS(ii), the 2019 median seagrass shoot densities at the Southern Flats, Mangles Bay and Jervoise Bay monitoring sites were compared against the 'rolling' four-year 5th (high protection) at the relevant Warnbro Sound reference sites (Table 10). The EQS(ii) was met at both sites.

Table 10. Assessment of median seagrass shoot density at Southern Flats, Mangles Bay and Jervoise Bay seagrass monitoring sites against the 'rolling' four-year 5th percentile (high protection).

Ecological Protection Area	Year	Seagrass Monitoring Site	Reference Site	Rolling 4-year 5th percentile (shoots/m^2)	Median shoot density (shoots/m^2)	Assessment
HPA-S	2019	Southern Flats	WS 2.5 m	280	838	EQS(ii) met
	2019	Mangles Bay	WS 3.2 m	75	325	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. There are four long-term depth transect sites established in 2001 – Garden Island North, Garden Island South, Woodman Point, and Warnbro Sound. Two additional depth transect sites were established in 2017 – one at Mangles Bay and one at Southern Flats.

Since 2017, the mean LDL increased marginally (i.e. became deeper) from 9.0 m to 9.2 m at the Mangles Bay depth transect site and decreased (i.e. became shallower) from 11.5 m to 8.0 m at the Southern Flats depth transect site. The mean LDL of seagrass at the Garden Island South, Woodman Point and Warnbro Sound 'depth limit' sites were significantly deeper in 2019 compared with the baseline LDL for each site (Table 11). The EQS(iii) was met at all the 'depth limit' sites. There are no 'depth limit' sites in MPA-ES.

Discussion

Although the 'Nutrient enrichment' EQG were exceeded in HPA-ES, the EQS were found to have not been exceeded based on the available information. The increase or stability in the distribution of seagrass in deeper waters suggests that water quality and light availability are adequate for seagrass growth.

Since 2017, LDLs have remained stable or become deeper and above the established baseline values (Fraser *et al*. 2019). The stability of the LDLs suggest that factors other than light availability are driving the continued seagrass declines across Cockburn Sound, Warnbro Sound, and Owen Anchorage (Fraser *et al*. 2019).

Table 11. Mean baseline and 2019 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 2019 Lower depth limit (m)	*P* (one-tail)	Assessment
HPA-N	Garden Island North	9.8	9.9	0.42	EQS(iii) met
	Garden Island South	7.6	11.3	**<0.001**	EQS(iii) met
Outside Cockburn Sound	Woodman Point	8.4	11.0	**<0.001**	EQS(iii) met
Reference Site	Warnbro Sound	8.7	10.0	**<0.001**	EQS(iii) met

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

Seagrass shoot density at other sites within and outside Cockburn Sound

With the exception of Garden Island 3.2 m and 7.0 m and Southern Flats, median seagrass shoot densities at the monitoring sites in Cockburn Sound were higher in 2019 than 2018 (Table 12). Median shoot densities were lower in 2019 than 2018 at Carnac Island and Woodman Point. At the reference sites in Warnbro Sound, there was a complete loss of seagrass at the Warnbro Sound 2.0 m and in two-thirds of the quadrats at Warnbro Sound 3.2 m.

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

Ecological Protection Area	Site	2018 median shoot density (shoots/m^2)	2019 median shoot density (shoots/m^2)
HPA-N	Garden Island Settlement	750	913
	Kwinana	700	813
	Garden Island 2.0 m	738	1300
	Garden Island 2.5 m	688	775
	Garden Island 3.2 m	688	**613**
	Garden Island 5.5 m	550	700
	Garden Island 7.0 m	550	**375**
	Luscombe Bay	1000	1275
HPA-S	Southern Flats	900	**838**
	Mangles Bay	150	325
MPA-ES	Jervoise Bay	175	500
Sites outside Cockburn Sound	Coogee	425	675
	Bird Island	325	675
	Mersey Point	563	1100
	Carnac Island	838	**650**
	Woodman Point	175	**113**
Warnbro Sound Reference Sites	Warnbro Sound 2.0 m	0	0
	Warnbro Sound 2.5 m	725	1050
	Warnbro Sound 3.2 m	425	**375**

Ecological Protection Area	Site	2018 median shoot density (shoots/m^2)	2019 median shoot density (shoots/m^2)
	Warnbro Sound 5.2 m	525	613
	Warnbro Sound 7.0 m	225	788

Note: Text in bold indicates a shoot density less than the 2018 median shoot density.

Table 13. 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)	2019 median shoot density (shoots/m^2)
HPA-N	Garden Island Settlement	WS 2.0 m	666	485	913
	Kwinana	WS 5.2 m	419	375	813
	Garden Island 2.0 m	WS 2.0 m	666	485	1300
	Garden Island 2.5 m	WS 2.5 m	500	515	775
	Garden Island 3.2 m	WS 3.2 m	300	300	613
	Garden Island 5.5 m	WS 5.2 m	419	375	700
	Garden Island 7.0 m	WS 7.0 m	175	175	375
	Luscombe Bay	WS 2.0 m	666	485	1275
Sites outside Cockburn Sound	Coogee	WS 5.2 m	419	375	675
	Bird Island	WS 2.0 m	666	485	675
	Mersey Point	WS 3.2 m	500	300	1100
	Carnac Island	WS 5.2 m	300	375	650
	Woodman Point	WS 2.5 m	300	515	**113**

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 13).

With the exception of Woodman Point, median seagrass shoot densities at the sites outside of Cockburn Sound 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 13).

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

Phytoplankton biomass

Phytoplankton biomass (measured as chlorophyll *a*) recorded at the 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.3; Figure 2) over the 2018–19 non river-flow period was assessed against the 'Phytoplankton biomass' EQG (EQG C, Table 1a, Reference Document):

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 2018–19 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 2018–19 non river-flow period.

Moderate protection: *i. Median phytoplankton biomass in MPA-ES is not to exceed 3.00 µg/L on more than one occasion during the 2018–19 non river-flow period.*

ii. Phytoplankton biomass at any site is not to exceed 3.00 µg/L on 50% or more occasions during the 2018–19 non river-flow period.

The results of the assessment against the EQG are presented in Tables 14 and 15. The 'Phytoplankton biomass' EQG(i) were met at all sites in HPA-N, HPA-S and MPA-ES during the 2018–19 non river-flow period (Table 14). The median chlorophyll *a* concentration in HPA-S reached the EQG(i) on 11 March 2019. 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).

The 'Phytoplankton biomass' EQG(ii) were met at all sites in HPA-N and HPA-S except at Mangles Bay during the 2018–19 non river-flow period (Table 15). 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 14. Assessment of median chlorophyll *a* concentrations in HPA-N, HPA-S and MPA-ES on each sampling occasion during the 2018–19 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: 3.00 µg/L
3/12/2018	0.4	0.5	0.7
10/12/2018	0.4	0.6	0.7
17/12/2018	0.5	1.2	0.9
24/12/2018	0.4	1.1	0.8
7/01/2019	0.5	1.7	1.2
14/01/2019	0.5	1.9	1.2
21/01/2019	0.4	0.8	0.6
29/01/2019	0.5	1.1	0.8
4/02/2019	0.8	1.6	1.5
11/02/2019	0.6	1.8	1.0
18/02/2019	0.9	1.8	1.9
25/02/2019	0.6	1.4	1.1
4/03/2019	0.6	1.4	1.1
11/03/2019	0.7	2.1	1.4
18/03/2019	0.8	1.4	1.5
25/03/2019	0.8	1.8	1.4
Assessment	EQG(i) met in HPA-N, HPA-S and MPA-ES on all sampling occasions during the 2018–19 non river-flow period		

In Cockburn Sound, the chlorophyll *a* concentrations ranged from 0.3 µg/L recorded at various sites in HPA-N, HPA-S and MPA-ES to 6.3 µg/L, which was recorded at site NH3 in MPA-NH on 11 March 2019. The chlorophyll *a* concentrations at the two reference sites in Warnbro Sound ranged from 0.2 µg/L at site WSSB to 1.5 µg/L on 25 March 2019 at site WS4.

The highest chlorophyll *a* concentration recorded in HPA-N was 1.1 µg/L at site CB on 18 February 2019. The highest chlorophyll *a* concentration recorded in HPA-S was 3.3 µg/L at Mangles Bay on 11 March 2019. For MPA-ES, the highest chlorophyll *a* concentration recorded was 2.4 µg/L at site CS10 on 11 March 2019.

The high protection ‘Phytoplankton biomass’ EQG(ii) was exceeded at site MB (Mangles Bay) in HPA-S on six of the 16 sampling occasions. The exceedances ranged from 2.3 µg/L on 7 January 2019 to 3.3 µg/L on 11 March 2019.

The moderate protection ‘Phytoplankton biomass’ EQG(ii) was exceeded at Jervoise Bay Northern Harbour site NH3 in MPA-NH on 11 of the 16 sampling occasions. The exceedances ranged from 3.4 µg/L on 4 February 2019 to 6.3 µg/L on 11 March 2019. 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.

Table 15. Assessment of chlorophyll *a* concentrations at 18 water quality monitoring sites in Cockburn Sound during the 2018–19 non river-flow period against the ‘Phytoplankton biomass’ EQG(ii).

Ecological Protection Areas	Site	2018–19 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	3	19%	EQG(ii) met
	CS13		16	2	13%	EQG(ii) met
	SF		16	0	0%	EQG(ii) met
	MB		16	**6**	**38%**	EQG(ii) not met
MPA-CB	G1	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	16	0	0%	EQG(ii) met
MPA-ES	CS10N	Phytoplankton biomass not to exceed 3.00 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 3.00 µg/L on 50% or more occasions	16	**11**	**69%**	EQG(ii) not met

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

Assessment against the Environmental Quality Standard

EQS(ii) ‘Phytoplankton biomass’ at Mangles Bay (MB)

The ‘Phytoplankton biomass’ EQG(ii) was not met at the Mangles Bay site MB in HPA-S, which triggers more detailed assessment against the high protection ‘Phytoplankton biomass’ EQS(ii) (EQS C(ii), Table 1a, Reference Document):

> *Phytoplankton biomass at any site is not to exceed the EQC as updated annually*

on 25% or more occasions during the non river-flow period and in two consecutive years.

The results are presented in Table 16. Assessment of phytoplankton biomass at MB during the non river-flow period for two consecutive years indicates that phytoplankton biomass exceeded 2.10 µg/L on 25% or more occasions in 2018–19, but not in 2017–18. The 'Phytoplankton biomass' EQS(ii) was therefore met.

Table 16. Assessment of chlorophyll *a* concentrations at Mangles Bay (MB) against the high-protection 'Phytoplankton biomass' EQS(ii) over two consecutive years (2017–18 and 2018–19).

Site	Year	EQS	Number of occasions EQS was exceeded	Per cent (%) of occasions EQS was exceeded	Assessment
MB	2017–18	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	0 (out of 16)	0%	EQS met
	2018–19	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	6 (out of 16)	38%	

EQS(ii) 'Phytoplankton biomass' at 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 any site is not to exceed the EQC as updated annually 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 in 2017–18 and 3.00 µg/L in 2018–19 on 50% or more occasions. The 'Phytoplankton biomass' EQS(ii) was therefore not 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 (2017–18 and 2018–19).

Site	Year	EQS	Number of occasions EQS was exceeded	Per cent (%) of occasions EQS was exceeded	Assessment
NH3	2017–18	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	9 (out of 16)	56%	EQS not met
	2018–19	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	11 (out of 16)	69%	

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) recorded in the bottom waters[9] at the 18 water quality monitoring sites in Cockburn Sound (Section 2.3; Figure 2) over the 2018–19 non river-flow period were assessed against the 'Dissolved oxygen concentration' EQG (EQG D, Table 1a, Reference Document):

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 7. As measurements were made at about weekly intervals during the non river-flow period, the dissolved oxygen concentrations recorded at each site on each sampling occasion, rather than median concentrations, were compared against the EQC.

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 2018–19 non river-flow period against the 'Dissolved oxygen concentration' EQC.

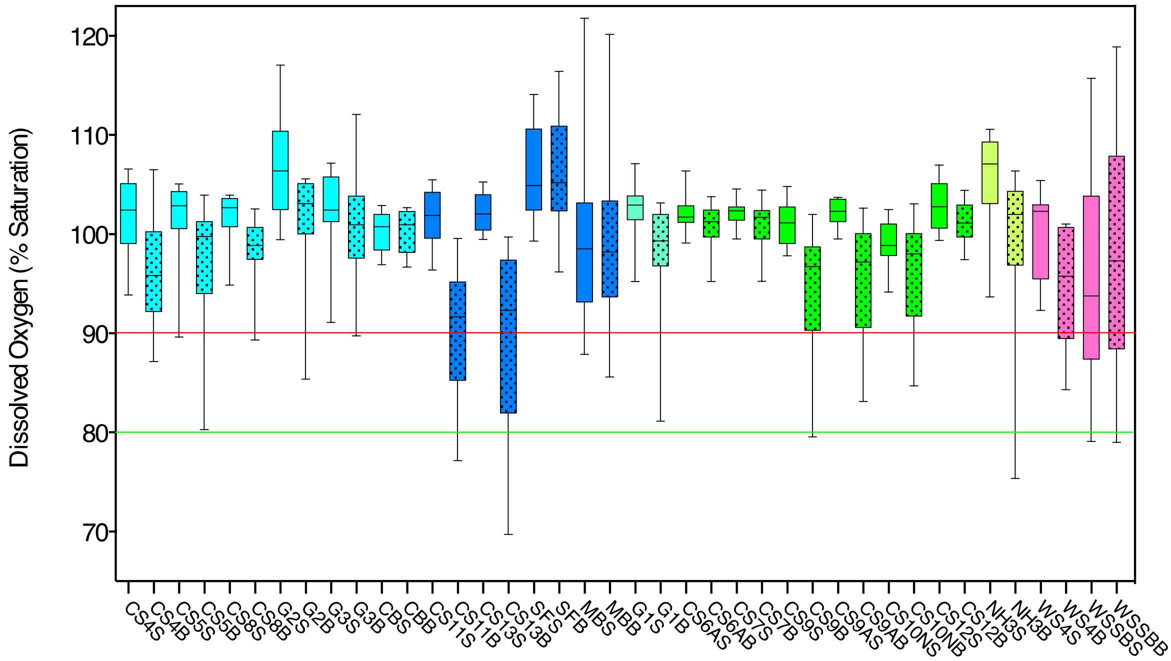
Ecological Protection Area	Site (approximate depth)	Number of sampling occasions	No. of occasions EQG was not met	No. of occasions EQS(i) was not met	Assessment
HPA-N	CS4 (21 m)	16	2	0	EQG not met, EQS(i) met
	CS5 (19 m)	16	3	0	EQG not met, EQS(i) met
	CS8 (20 m)	16	1	0	EQG not met, EQS(i) met
	CB (9.5 m)	16	0	-	EQG met
	G2 (10 m)	16	2	0	EQG not met, EQS(i) met
	G3 (13 m)	16	1	0	EQG not met, EQS(i) 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	1	0	EQG not met, EQS(i) met
	MB (1.5 m)	16	1	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	1	0	EQG not met, EQS(i) met
	CS9A (16.5 m)	16	1	0	EQG not met, EQS(i) met
MPA-NH	NH3 (10 m)	16	2	0	EQG not met, EQS(i) met
Reference Sites	WS4 (17.5 m)	16	4 <90%	0 <60%	N/A
	WSSB (2.5 m)	16	5 <90%	0 <60%	N/A

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

With the exception of the site CB in HPA-N, the dissolved oxygen concentrations in the bottom waters at sites in HPA-N and HPA-S were below the high protection ‘Dissolved oxygen concentration’ EQG (90% saturation) on one or more occasions. The lowest dissolved oxygen concentration recorded in HPA-N was 78% saturation at site CS5 on 11 March 2019 and in HPA-S, 68.5% saturation at site CS11 on 29 January 2019. The lowest dissolved oxygen concentrations recorded at sites SF (Southern Flats) and MB (Mangles Bay) were 85.2% and 72.6%, respectively, which were recorded on 10 December 2018.

The moderate protection ‘Dissolved oxygen concentration’ EQG (80% saturation) was not met at sites CS9 and CS9A in MPA-ES on 11 March 2019. The sites CS9 and CS9A recorded 77.4% saturation and 79.0% saturation, respectively, on this date. The lowest dissolved oxygen concentrations recorded at site NH3 (Northern Harbour) were 76.4% saturation on 10 December 2018 and 73.0% saturation on 11 March 2019.

At the reference sites in Warnbro Sound, the lowest dissolved oxygen concentration recorded was 80.0% saturation at WS4 on 21 January 2019 and 73.5% saturation at WSSB on 29 January 2019.



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 7. 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 2018 to March 2019.

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.

The ‘Dissolved oxygen concentration’ EQG have not been met in Cockburn Sound, except at site CS12, and Warnbro Sound on at least one or more occasions during the non river-flow period in the past decade (Table 19). The number of occurrences of low dissolved oxygen concentration has been greater at the deeper sites in HPA-S (CS11 and CS13) and HPA-N (CS4, CS5 and CS8).

Table 19. Number of occasions during each non river-flow period since 2009–10 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)	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
HPA-N	CS4 (21 m)	1	2	2	1	0	1	3	6	0	2
	CS5 (19 m)	0	2	3	0	1	0	2	3	0	3
	CS8 (20 m)	1	3	3	1	1	0	6	6	0	1
	CB (9.5 m)	0	0	1	0	1	0	0	0	0	0
	G2 (10 m)	0	2	1	0	0	1	0	1	1	2
	G3 (13 m)	0	0	1	1	0	1	2	2	0	1
HPA-S	CS11 (18 m)	5	7	4	5	4	10	8	11	6	6
	CS13 (20.5 m)	9	8	2	6	4	6	9	11	7	7
	SF (3.5 m)	2	1	0	0	1	2	2	0	0	1
	MB (1.5 m)	4	4	3	4	2	6	3	7	8	1
MPA-CB	G1 (15 m)	0	0	0	0	0	0	1	0	0	0
MPA-ES	CS10N (14 m)	1	2	1	0	2	0	3	2	0	0
	CS12 (10 m)	0	0	0	0	0	0	0	0	0	0
	CS6A (10.5 m)	0	0	0	0	0	0	1	1	0	0
	CS7 (10.5 m)	0	1	2	1	0	0	0	1	0	0
	CS9 (13 m)	0	3	1	0	0	0	1	3	0	1
	CS9A (16.5 m)	0	3	0	1	1	0	0	3	0	1
MPA-NH	NH3 (10 m)	1	1	3	1	0	0	0	4	0	2
Reference Sites	WS4 (17.5 m)	5	3	2	5	6	3	6	6	3	4
	WSSB (2.5 m)	3	2	0	1	0	1	4	2	2	5

The results of the assessment of the dissolved oxygen concentrations in bottom waters measured quarterly over the 2018–19 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 met in the bottom waters at the sites in HPA-N and HPA-S. The moderate protection ‘Dissolved oxygen concentration’ EQG was met in the bottom waters at site DIFF50W.

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 2018	October 2018	January 2019	June 2019
HPA-N	Central (21 m)	EQG met	EQG met	EQG met	EQG met
HPA-S	South (20 m)	EQG met	EQG met	EQG 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[10] and at two of the three sites around the Kwinana Bulk Jetty[11] surveyed by Fremantle Ports on 31 January 2019. The moderate protection 'Dissolved oxygen concentration' EQG was not met between the depths of 13.3 m and 14.2 m at the Kwinana Bulk Jetty 3 (KBJ3) site. The lowest dissolved oxygen concentration recorded at the KBJ3 site was 77.5% saturation at the depth of 14.2 m, which was the lowest depth recorded for this site.

Assessment against the Environmental Quality Standard

The 'Dissolved oxygen concentration' EQG were not met at 12 of the 18 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*

[10] Depths varied between about 10.5 m and 11.5 m.
[11] Depths varied between about 12 m and 16.5 m.

deoxygenation.

The dissolved oxygen concentrations in the bottom waters at 12 of the 18 water quality monitoring sites were below the 'Dissolved oxygen concentration' EQG (Table 18). In HPA-N, the lowest dissolved oxygen concentration recorded was 78% saturation (CS5 on 11 March 2019). The lowest dissolved oxygen concentration recorded in HPA-S was 68.5% saturation (CS11 on 29 January 2019).

The lowest dissolved oxygen concentrations recorded in MPA-ES were 77.4% and 79.0% saturation at CS9 and CS9A, respectively, on 11 March 2019. Similarly, the lowest dissolved oxygen concentrations recorded at site NH3 in MPA-NH was 73.0% saturation on 11 March 2019.

As the lowest dissolved oxygen concentrations at the 12 sites were greater than 60% saturation, 'Dissolved oxygen concentration' EQS(i) was considered to have been met at the 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 on the days that Cockburn Sound water quality sampling was undertaken during the 2018–19 non river-flow period ('Dissolved oxygen concentration' EQS(iii)).

2.6.2 Water temperature

Measurements of surface[12] and bottom[13] water temperatures recorded at the 18 water quality monitoring sites[14] (Section 2.3; Figure 2) over the 2018–19 non river-flow period were assessed against the 'Water temperature' EQG (EQG E, Table 1a, Reference Document):

High protection: *Median temperature at an individual site over the 2018–19 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 2018–19 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 8. At all sites, the median

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

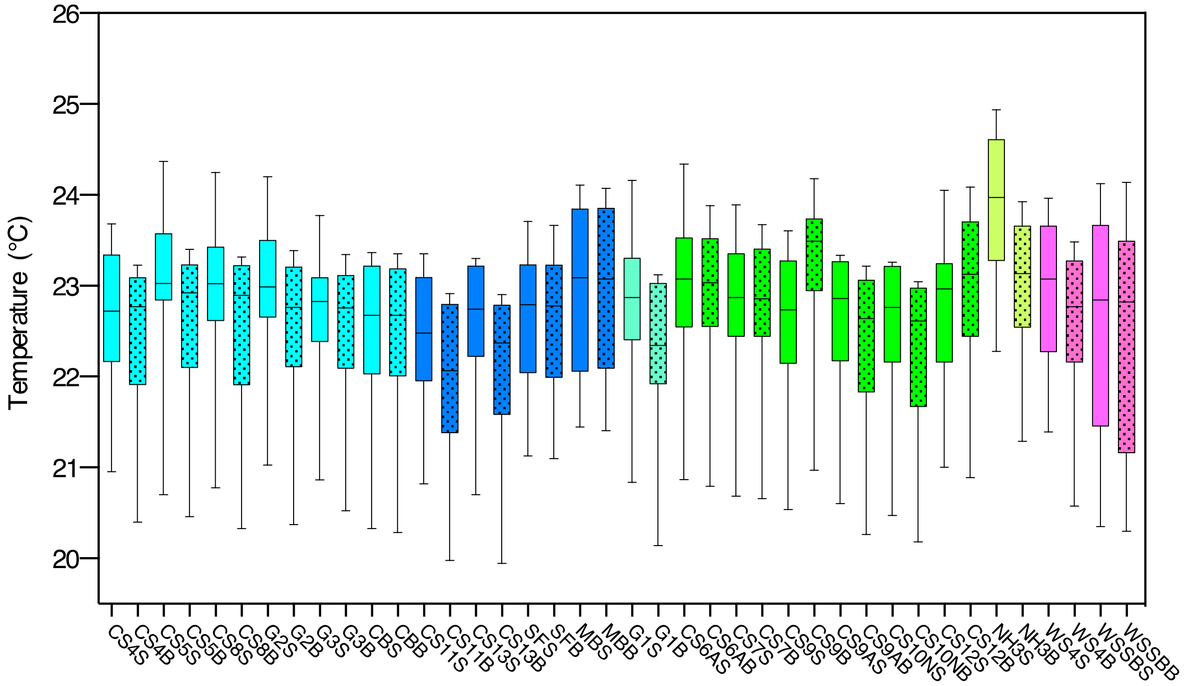
surface and bottom water temperatures recorded over the 2018–19 non river-flow period met the ‘Temperature’ EQG.

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

Table 21. Assessment of median surface and bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound over the 2018–19 non river-flow period against the ‘Temperature’ EQG.

Ecological Protection Area	Site	Temperature (° C)				Assessment
		2018–19 EQG (Surface)	2018–19 median (Surface)	2018–19 EQG (Bottom)	2018–19 median (Bottom)	
HPA-N	CS4	≤23.7	22.7	≤23.3	22.8	EQG met
	CS5		23.0		22.9	EQG met
	CS8		23.0		22.9	EQG met
	CB		22.7		22.7	EQG met
	G2		23.0		22.8	EQG met
	G3		22.8		22.8	EQG met
HPA-S	CS11	≤23.7	22.5	≤23.3	22.1	EQG met
	CS13		22.7		22.4	EQG met
	SF	≤23.7	22.8	≤23.5	22.8	EQG met
	MB		23.1		23.1	EQG met
MPA-CB	G1	≤24.0	22.9	≤23.5	22.3	EQG met
MPA-ES	CS10N	≤24.0	22.8	≤23.5	22.6	EQG met
	CS12		23.0		23.1	EQG met
	CS6A		23.1		23.0	EQG met
	CS7		22.9		22.7	EQG met
	CS9		22.7		23.5	EQG met
	CS9A		22.9		22.6	EQG met
MPA-NH	NH3	≤24.0	24.0	≤23.5	23.1	EQG met

Note: Sites MB (about 1.3 m depth) and SF (about 3.5 m depth) were assessed against the reference site WSSB (about 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 8. 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 2018 to March 2019.

2.6.3 Salinity

Measurements of surface[15] and bottom[16] water salinities recorded at the 18 water quality monitoring sites[17] (Section 2.3; Figure 2) over the 2018–19 non river-flow period were assessed against the 'Salinity' EQG (EQG F, Table 1a, Reference Document):

High protection: *Median salinity at an individual site over the 2018–19 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 2018–19 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 the Warnbro Sound reference sites WS4 or WSSB for the same period.*

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

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

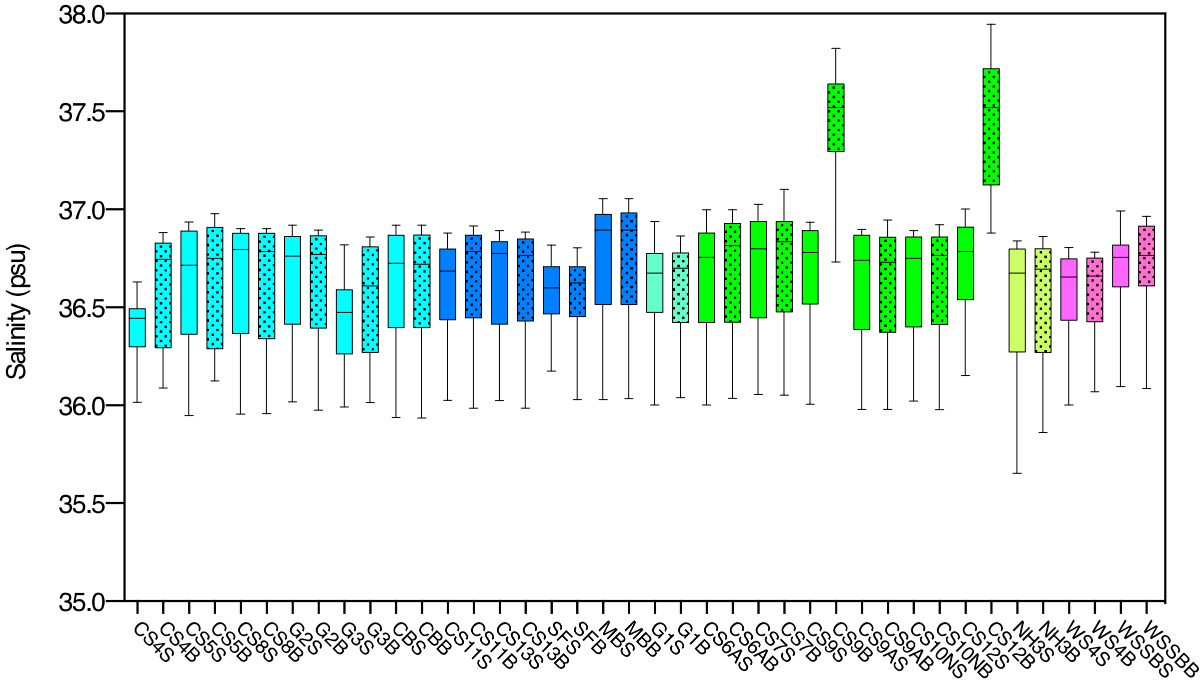
[17] Note that this indicator has been developed for use at the local scale (e.g. around an outfall) rather than broader scales (EPA 2017).

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 9. The median surface and bottom water salinities recorded over the 2018–19 non river-flow period met the ‘Salinity’ EQG at all sites with the exception of sites MB, CS9 and CS12. The median surface and bottom water salinities at site MB in HPA-S were above the ‘Salinity’ EQG. Elevated median salinities were recorded in the bottom waters at CS9 and CS12 in MPA-ES.

Table 22. Assessment of median surface and bottom salinities at 18 water quality monitoring sites in Cockburn Sound over the 2018–19 non river-flow period against the ‘Salinity’ EQG.

Ecological Protection Area	Site	Salinity (practical salinity units [psu])				Assessment
		2018–19 EQG (Surface)	2018–19 median (Surface)	2018–19 EQG (Bottom)	2018–19 median (Bottom)	
HPA-N	CS4	36.4 ≤ x ≤ 36.8	36.4	36.4 ≤ x ≤ 36.8	36.7	EQG met
	CS5		36.7		36.8	EQG met
	CS8		36.8		36.8	EQG met
	CB		36.7		36.7	EQG met
	G2		36.8		36.8	EQG met
	G3		36.5		36.6	EQG met
HPA-S	CS11	36.4 ≤ x ≤ 36.8	36.7	36.4 ≤ x ≤ 36.8	36.8	EQG met
	CS13		36.8		36.8	EQG met
	SF	36.6 ≤ x ≤ 36.8	36.6	36.6 ≤ x ≤ 36.9	36.6	EQG met
	MB		**36.9**		**36.9**	EQG not met
MPA-CB	G1	36.0 ≤ x ≤ 36.8	36.7	36.0 ≤ x ≤ 36.8	36.7	EQG met
MPA-ES	CS10N	36.0 ≤ x ≤ 36.8	36.7	36.0 ≤ x ≤ 36.8	36.8	EQG met
	CS12		36.8		**37.5**	EQG not met in bottom waters
	CS6A		36.8		36.8	EQG met
	CS7		36.8		36.8	EQG met
	CS9		36.8		**37.5**	EQG not met in bottom waters
	CS9A		36.7		36.7	EQG met
MPA-NH	NH3	36.0 ≤ x ≤ 36.8	36.7	36.0 ≤ x ≤ 36.8	36.7	EQG met

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



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 salinities at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2018 to March 2019.

The results of the assessment of salinity in bottom waters measured quarterly over the 2018–19 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 m west of the Perth Seawater Desalination Plant diffuser, in July 2018, January 2019 and June 2019 compared with 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 2018	October 2018	January 2019	June 2019
HPA-N	Central	35.2	34.9	36.6	35.5
HPA-S	South	35.2	34.8	36.6	35.5
MPA-ES	DIFF50W	35.8	34.8	37.4	35.8
Sites outside Cockburn Sound	Parmelia Bank	35.3	34.9	36.2	35.5
	Owen Anchorage	35.2	35.0	36.5	35.5

Assessment against the Environmental Quality Standard

The ‘Salinity’ EQG were not met in the surface waters at MB and bottom waters at MB, CS9 and CS12 which triggers more detailed assessment against the high protection and 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 surface water salinity at MB and bottom water salinities at MB, 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[18] 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 because of 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 2018–19 non river-flow period that may have been attributable to anthropogenically sourced salinity stress ('Salinity' EQS(ii)).

2.6.4 pH

Measurements of surface[19] and bottom[20] water pH recorded at the 18 water quality monitoring sites[21] (Section 2.3; Figure 2) over the 2018–19 non river-flow period were assessed against the 'pH' EQG (EQG G, Table 1a, Reference Document):

High protection: *Median pH at an individual site over the 2018–19 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 2018–19 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.*

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 2018–19 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

[18] Moderate protection bottom waters = 38.1 practical salinity units (the median of suitable reference site data ± 1.4; 36.7 + 1.4); high protection bottom waters = 38.0 practical salinity units (the median of suitable reference site data ± 1.3; 36.7 + 1.3)
[19] Measured at 50 cm below the water surface.
[20] Measured at 50 cm above the sediment surface.
[21] Note that this indicator has been developed for use at the local scale (e.g. around an outfall) rather than broader scales (EPA 2017).

Wienczugow 2019).

Table 24. Assessment of median surface and bottom pH at 18 water quality monitoring sites in Cockburn Sound over the 2018–19 non river-flow period against the 'pH' EQG.

Ecological Protection Area	Site	pH (pH units)				Assessment
		2018–19 EQG (Surface)	2018–19 median (Surface)	2018–19 EQG (Bottom)	2018–19 median (Bottom)	
HPA-N	CS4	8.1 ≤ x ≤ 8.2	8.1	8.1 ≤ x ≤ 8.2	8.1	EQG met
	CS5		8.1		8.1	EQG met
	CS8		8.1		8.1	EQG met
	CB		8.1		8.1	EQG met
	G2		8.2		8.1	EQG met
	G3		8.1		8.1	EQG met
HPA-S	CS11	8.1 ≤ x ≤ 8.2	8.1	8.1 ≤ x ≤ 8.2	8.1	EQG met
	CS13		8.1		8.1	EQG met
	SF	8.1 ≤ x ≤ 8.2	8.1	8.1 ≤ x ≤ 8.2	8.2	EQG met
	MB		8.1		8.1	EQG met
MPA-CB	G1	8.1 ≤ x ≤ 8.2	8.1	8.1 ≤ x ≤ 8.2	8.2	EQG met
MPA-ES	CS10N	8.1 ≤ x ≤ 8.2	8.1	8.1 ≤ x ≤ 8.2	8.1	EQG met
	CS12		8.1		8.1	EQG met
	CS6A		8.1		8.1	EQG met
	CS7		8.1		8.1	EQG met
	CS9		8.1		8.1	EQG met
	CS9A		8.1		8.1	EQG met
MPA-NH	NH3	8.1 ≤ x ≤ 8.2	8.1	8.1 ≤ x ≤ 8.2	8.1	EQG met

Note: Sites MB (about 1.3 m depth) and SF (about 3.5 m depth) assessed against the reference site WSSB (about 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 2018–19 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 16 µg N/L at CS10 in MPA-ES on 11 March 2019. The highest ammonium concentration of the discrete bottom water samples was 31 µg N/L at CS13 in HPA-S on 11 March 2019.

The median ammonium concentration of the discrete bottom water samples at site C13 in HPA-S was significantly higher than for the surface and integrated water samples for the same site (Cossington and Wienczugow 2019). For the reference site WS4, there was no significant difference between the bottom and integrated water samples; however, the bottom water had significantly more ammonium than that of the surface water (Cossington and Wienczugow 2019).

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 and HPA-S were below the high protection EQG value for toxic effects of 500 µg/L for ammonia. At sites in HPA-N, the 95th percentile of the ammonium concentrations varied between 0.7 µg N/L and 2.1 µg N/L and at sites in HPA-S, between 1.0 µg N/L and 3.5 µg N/L.

The 95th percentile of the ammonium concentrations at sites in MPA-CB and MPA-ES were below the moderate protection EQG value for toxic effects of 1,200 µg/L for ammonia. At site G1 in MPA-CB, the 95th percentile of the ammonium concentrations was 1.2 µg N/L and at sites in MPA-ES, between 1.6 µg N/L and 10.3 µg N/L. The 95th percentile of the ammonium concentrations at Jervoise Bay Northern Harbour (NH3) in MPA-NH was 4.9 µg N/L.

2.7.2 Toxicants in marine waters around the Kwinana Bulk Terminal and Kwinana Bulk Jetty

Surface marine water samples were collected in February 2019 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.

At all sites, the Total Toxicity of the Mixture (TTM)[22], 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.

[22] TTM = Σ (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.

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	<3	<3	<3	<3	<3	<3
Copper (filtered)	EQG: 3.0	0.3	0.2	0.4	0.3	0.3	0.3
Manganese (filtered)	LRV: 80[1]	1.1	0.9	1.0	Not measured		
Lithium	-	200	190	190	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]	<1	<1	<1	<1	<1	<1
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.

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 2019 (Section 2.3; Figure 2). The samples were analysed for total organic carbon, metals (arsenic, cadmium, chromium, copper, lead, lithium[23], 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.*

There are no EQG values for lithium, manganese and selenium.

The median concentrations of arsenic, chromium, copper, lead, mercury and zinc in

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

both sampling areas, the Kwinana Bulk Terminal and Kwinana Bulk Jetty, were below the relevant EQG values (Table 26). In the Kwinana Bulk Terminal sampling area, the lead concentration at site KBT3 exceeded the re-sampling trigger value. Lead testing was subsequently performed on nine additional samples collected alongside the KBT3 sample location, immediately adjacent to KBT3, over an area of 150 m^2. The lead concentrations in the nine additional samples ranged from 4.1 mg/kg to 6.7 mg/kg, which were below the EQG value for lead.

In the Kwinana Bulk Jetty sampling area, the copper concentration at site KBJ 2 was above the EQG value, but below the re-sampling trigger value. Elevated cadmium concentrations were reported in the sediment at sites KBJ 1 and 2, with the median concentration of cadmium in the sampling area above the EQG, but below the re-sampling trigger value. A slightly elevated concentration of mercury was recorded in one of the Kwinana Bulk Jetty samples (KBJ1).

After normalisation to 1% Total organic carbon[24], median concentrations of TBT in the Kwinana Bulk Terminal samples were below the EQG value (Table 26). Elevated concentrations of TBT were recorded in two Kwinana Bulk Jetty samples (KBJ 1 and 2). The concentrations of TBT at KBJ2 were above the EQG re-sampling trigger value. As the TBT concentration at KBJ2 was above the EQG re-sampling trigger value, an elutriate analysis was conducted to determine the bioavailability of the toxicant, the results of which were above the EQG value and re-sampling trigger value. It is likely that the elevated TBT concentrations were a result of historical contaminants in the sediments.

There are no ECG values for the TBT break-down products DBT or MBT (Table 26). Two of the three Kwinana Bulk Terminal samples had a Butylin Degradation Index (BDI) 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 reported for all KBT and KBJ sites were below the relevant EQG values (Table 27). The concentrations of PAHs in the majority of samples were below the analytical limit of reporting, with the exception of KBJ 1. The PAH concentrations reported for KBJ 1 exceeded the relevant EQG values, with the exception of acenaphthelene which was below the analytical limit of reporting.

There are no EQG values for TRHs. The concentrations of TRHs were below the analytical limit of reporting for all of the sites except KBJ 1 and KBJ 2. The concentrations of PFOS and PFOA were below the analytical limit of reporting at all sites.

[24] 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.

Table 26. Assessment of toxicants (metals and organotins) 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	5.4	6.0	8.3	6.0	5.4	5.7	3.3	5.7
Cadmium	1.5	10	0.1	0.1	0.3	0.1	**2.5**	**6.8**	0.3	**2.5**
Chromium	80	370	23	25	16	23	31	35	14	31
Copper	65	270	19	37	22	22	24	**90**	10	24
Lead	50	220	9.9	10.0	**280**	10.0	9.3	9.9	2.8	9.3
Lithium	-	-	9.9	11	4.2	9.9	Not measured			
Manganese	-	-	30	31	460	31	Not measured			
Mercury	0.15	1	0.10	0.09	0.04	0.09	**0.17**	0.14	0.04	0.14
Selenium	-	-	0.40	0.46	0.17	0.40	0.72	0.78	0.43	0.72
Zinc	200	410	39	36	58	39	75	150	12	75
Organotins (µg Sn/kg normalised to 1% TOC)										
Tributyltin	5	70	1.6	1.4	0.5	1.4	**37.4**	**557.1**	3.5	**37.4**
Dibutyltin	-	-	1.0	0.9	0.1	0.9	5.8	11.4	1.5	5.8
Monobutyltin	-	-	0.9	0.7	0.1	0.7	0.9	1.4	0.5	0.9
Butylin Degradation Index (BDI)	-	-	1.2	1.1	0.4	-	0.2	0.02	0.6	-

Table 27. Assessment of toxicants (organics) 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
Organics (mg/kg normalised to 1% TOC)										
Acenaphthene	0.016	0.5	<0.1	<0.1	<0.1	<0.1	**0.2**	<0.1	<0.1	<0.1
Acenaphthelene	0.044	0.64	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Anthracene	0.085	1.1	<0.1	<0.1	<0.1	<0.1	**0.1**	<0.1	<0.1	<0.1
Benzo(a)anthracene	0.261	1.6	0.1	<0.1	<0.1	<0.1	**0.8**	<0.1	<0.1	<0.1
Benzo(a)pyrene	0.43	1.6	0.1	<0.1	<0.1	<0.1	**0.7**	<0.1	<0.1	<0.1
Chrysene	0.384	2.8	0.1	<0.1	<0.1	<0.1	**0.7**	<0.1	<0.1	<0.1
Dibenzo(a,h)anthracene	0.063	0.26	<0.1	<0.1	<0.1	<0.1	**0.2**	<0.1	<0.1	<0.1
Fluoranthene	0.6	5.1	0.1	<0.1	<0.1	<0.1	**2.4**	<0.1	<0.1	<0.1
Fluorene	0.019	0.54	<0.1	<0.1	<0.1	<0.1	**0.2**	<0.1	<0.1	<0.1
Naphthalene	0.16	2.1	<0.1	<0.1	<0.1	<0.1	**0.08**	<0.1	<0.1	<0.1
Phenathrene	0.24	1.5	0.1	<0.1	<0.1	<0.1	**2.6**	<0.1	<0.1	<0.1
Pyrene	0.665	2.6	0.1	<0.1	<0.1	<0.1	**2.1**	0.1	<0.1	<0.1
Total Recoverable Hydrocarbons (C10–C36)	-	-	<250	<250	<250	<250	280	660	<250	<250
Total Perfluorooctane sulfonate	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
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 results from the 2018–19 monitoring programs in Cockburn Sound indicate that there was a low risk that the Environmental Quality Objective 'Maintenance of ecosystem integrity' is not being achieved in most of Cockburn Sound.

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 UWA 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 at 12 of the 18 water quality monitoring sites in Cockburn Sound on one or more occasions over the 2018–19 non river-flow period. There were no reports of deaths of marine organisms on the water quality sampling days during the 2018–19 period. Mass fish deaths around Palm Beach and the Rockingham Yacht Club jetties occurred on 5 February 2019. Subsequently, mass starfish deaths on Challenger Beach in Kwinana occurred on 8 February 2019. The mass fish deaths on 5 February 2019 were limited to Scaly Mackerel. DPIRD (Fisheries) Aquatic Diagnostics conducted tests on fish tissue samples from these sites, the results of which were inconclusive. DWER's Phytoplankton Ecology Unit analysed water samples from these areas. No potentially harmful phytoplankton species in bloom densities were found in the water samples.

In 2017, an Expert Advisory Panel was convened to review the Cockburn Sound water quality monitoring programs in terms of effectiveness and efficiency in delivering the data and information required for assessment against the Environmental Quality Criteria. A key recommendation in the Expert Advisory Panel's *Review of the Cockburn Sound Water Quality Monitoring Programs* was the deployment of telemetered water quality monitoring instruments that could be attached to infrastructure in Cockburn Sound (e.g. piles, channel markers) to provide real-time, continuous monitoring of Cockburn Sound.

DWER is in the process of purchasing telemetered water quality monitoring instruments and accessories for deployment at four water quality monitoring sites in Cockburn Sound. Continuous water quality monitoring using telemetry will allow for the more timely detection of environmental changes, such as those associated with algal bloom or pollution events that may result in mass fish deaths.

Cockburn Sound is likely to experience further pressures in the future, particularly from urbanisation and industrial and infrastructure development along the coast (BMT Western Australia 2018). There is a limited understanding of the ecological resilience of Cockburn Sound's marine ecosystem to these pressures.

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 because of its relatively undisturbed state compared with the Sound. Over the years, Warnbro Sound has become increasingly impacted by 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 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 that 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 our 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). Sampling over the 2018–19 monitoring period was undertaken by Blue Lagoon Mussels as part of the WASQAP and was administered by the Department of Health.

Between July 2018 and June 2019, water samples for bacteriological monitoring were collected on six occasions from five sites (SF6, SF8, SF9, SF10, SF11) in the Southern Flats harvesting area[25] and 11 occasions from five sites (KGT1, KGT2, KGT3, KGT4, KGT5) in the Kwinana Grain Terminal harvesting area.[26] Shellfish samples were also collected for bacteriological testing on 11 occasions from two Kwinana Grain Terminal sites (North and South) and on six occasions from one Southern Flats site. Samples were analysed by PathWest Laboratory.

Depth-integrated water samples for phytoplankton identification and enumeration were collected about 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 were taken. The samples were analysed by Dalcon Environmental 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

[25] Harvesting area classified as ‘approved’ under the wasqap operations manual.
[26] Harvesting area classified as ‘conditionally approved’ under the wasqap operations manual.

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). Five shellfish flesh samples were collected between October 2018 and February 2019 at Kwinana Grain Terminal harvesting area. Twelve shellfish flesh samples were collected between July 2018 and June 2019 at the Southern Flats harvesting area.

Source: Department of Health (2017)

Note: Mussel Aquaculture Closed Safety Zones are designated areas around recognised contamination points that should not be considered as potential sites for shellfish aquaculture.

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

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). Fifteen mussels of uniform size (about 55–90 mm shell length) were collected from the nearest suitable infrastructure (e.g. wharf pylons, ladders) on 27 March 2019. 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). Analyses for metals, organotins and PAHs were undertaken by ChemCentre.

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]) recorded at five sites in each of the harvesting areas in Cockburn Sound over the 2018–19 monitoring period 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.*

The results of the assessment against the EQG are presented in Table 28. Over the 2018–19 monitoring period both components of the 'Faecal pathogens in water' EQG were met at all sites in the Kwinana Grains Terminal and Southern Flats harvesting areas.

Table 28. 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 2018 and June 2019 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	3.0	EQG met
KGT2	1.0	2.0	EQG met
KGT3	1.0	2.0	EQG met
KGT4	1.0	1.0	EQG met
KGT5	1.0	1.0	EQG met
SF6	1.0	3.4	EQG met
SF8	1.0	1.0	EQG met
SF9	1.0	1.0	EQG met
SF10	1.0	1.0	EQG met
SF11	1.0	1.0	EQG met

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 2018–19 monitoring period were assessed against the 'Algal biotoxins' EQG (Table 29). 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).

Table 29. 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 results of the assessment against the EQG are presented in Table 30. The ‘Algal biotoxins’ EQG was met in the Kwinana Grain Terminal and Southern Flats shellfish harvesting areas between July 2018 and June 2019.

Table 30. Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2018 and June 2019 against the 'Algal biotoxins' EQG.

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	Toxic algae recorded	Cell density (cells/L)	Cell density (cells/L)
09/07/2018	No toxic algae detected	-	-
23/07/2018	No toxic algae detected	-	-
6/08/2018	*Dinophysis caudata* var pendiculata	130	110
27/08/2018	*Pseudo-nitzschia* delicatissima group	1,110	1,240
10/09/2018	*Pseudo-nitzschia* delicatissima group	4,360	3,840
	Pseudo-nitzschia seriata group	880	1,110
25/09/2018	*Dinophysis acuminata*	60	50
8/10/2018	*Dinophysis acuminata*	10	10
	Pseudo-nitzschia delicatissima group	12,500	9,800
	Pseudo-nitzschia seriata group	250	120
22/10/2018	No toxic algae detected	-	-
12/11/2018	No toxic algae detected	-	-
26/11/2018	*Pseudo-nitzschia* delicatissima group	2,520	3,930
3/12/2018	*Pseudo-nitzschia* delicatissima group	5,880	6,220
17/12/2018	*Pseudo-nitzschia* delicatissima group	14,680	16,220
	Pseudo-nitzschia seriata group	5,120	4,250
14/01/2019	*Pseudo-nitzschia* delicatissima group	8,950	10,280
	Pseudo-nitzschia seriata group	4,380	5,120
29/01/2019	*Pseudo-nitzschia* delicatissima group	4,420	3,880
12/02/2019	*Pseudo-nitzschia* delicatissima group	1,010	1,010
26/02/2019	*Pseudo-nitzschia* delicatissima group	503	407
	Pseudo-nitzschia seriata group	4,109	1,103
13/03/2019	*Pseudo-nitzschia* delicatissima group	70	60
25/03/2019	*Pseudo-nitzschia* delicatissima group	210	60
8/04/2019	*Pseudo-nitzschia* delicatissima group	330	120
23/04/2019	*Pseudo-nitzschia* delicatissima group	440	480
	Pseudo-nitzschia seriata group	60	80
13/05/2019	*Prorocentrum rhathymum*	10	Not detected
3/06/2019	*Prorocentrum rhathymum*	30	50
12/06/2019	*Pseudo-nitzschia* delicatissima group	4,800	4,100
	Prorocentrum rhathymum	30	20
24/06/2019	*Pseudo-nitzschia* delicatissima group	6,230	5,320
Assessment	EQG was met at Kwinana Grain Terminal and Southern Flats shellfish harvesting areas.		

Under WASQAP, routine monthly biotoxin screening was introduced in 2015 for all harvesting areas. All the samples for Cockburn Sound in the 2018–19 reporting period were negative for PSP, DSP and ASP biotoxins (Table 31).

Table 31. Results of monthly biotoxin screening in the 2018–19 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
9/07/2018	-	Negative	-	Negative	-	Negative
23/07/2018	-	Negative	-	-	-	-
06/08/2018	-	Negative	-	Negative	-	Negative
10/09/2018	-	Negative	-	Negative	-	Negative
8/10/2018	Negative	Negative	Negative	Negative	Negative	Negative
12/11/2018	Negative	Negative	Negative	Negative	Negative	Negative
3/12/2018	Negative	Negative	Negative	Negative	Negative	Negative
29/01/2019	Negative	Negative	Negative	Negative	Negative	Negative
12/02/2019	Negative	Negative	Negative	Negative	Negative	Negative
13/03/2019	-	Negative	-	Negative	-	Negative
23/04/2019	-	Negative	-	Negative	-	Negative
14/05/2019	-	Negative	-	Negative	-	Negative

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 2018–19 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 32. Both components of the EQS were met in both harvesting areas over the 2018–19 monitoring period.

Table 32. Assessment of *E. coli* counts in mussel flesh collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2018 and June 2019 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			
9/07/2018	1.8	1.8	1.8	EQS met
06/08/2018	4.0	1.8	-	EQS met
11/09/2018	1.8	1.8	1.8	EQS met
8/10/2018	1.8	1.8	-	EQS met
12/11/2018	1.8	1.8	1.8	EQS met
3/12/2018	1.8	1.8	-	EQS met
30/01/2019	1.8	1.8	1.8	EQS met
25/03/2019	1.8	1.8	-	EQS met
13/05/2019	2.0	1.8	-	EQS met
12/06/2019	1.8	2.0	-	EQS met
24/06/2019	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.*[27]

The results of the assessment against the EQC are presented in Table 33. Where there are EQC, the concentrations of metals in mussel flesh at sites in Cockburn Sound were below the relevant EQG or EQS, except for selenium which exceeded the the EQG at the KBT and KBJ sites. The concentrations of PAHs in mussel flesh sampled from mussels at the KBT and KBJ sites were all below the analytical limits of reporting.

[27] 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 33. 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)	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (inorganic)[1]	-	1.0	0.09	0.09	0.2	0.09	< 0.06	< 0.08	< 0.08	0.08	<0.025	<0.025
Cadmium	-	2.0	0.97	0.96	0.74	0.96	0.68	0.81	0.85	0.81	0.8	1.0
Chromium	-	-	0.86	0.88	1.1	0.86	0.57	0.78	0.61	0.61	Not measured	
Copper	30	-	4.1	5.6	5.1	5.1	3.3	5.0	3.9	3.9	3.9	4.2
Lead	-	2.0	0.83	0.63	0.72	0.72	0.42	0.53	0.42	0.42	0.4	0.4
Mercury	-	0.5 (mean level)	0.06	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.03	0.02
Selenium	1.0	-	**2.6**	**2.7**	**2.8**	**2.7**	**1.9**	**3.2**	**2.3**	**2.3**	Not measured	
Zinc (EQG for oysters)	290	-	120	140	150	140	95	160	110	110	140	130
Tributyltin	-	-	0.003	0.004	0.003	0.003	0.002	0.001	0.002	0.002	Not measured	
Organics												
Polychlorinated Biphenyls (PCBs) (fish)	-	0.5	Not measured				Not measured				Not measured	
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				Not measured	Not measured
BHC (sum of isomers of 1,2,3,4,5,6-hexachloro-cyclohexane, excluding gamma-isomer Lindane)	-	0.01[2]	Not measured				Not measured				Not measured	Not measured
Chlordane (sum of cis- and trans-chlordane)	-	0.05[2]	Not measured				Not measured				Not measured	Not measured
DDT (sum of p,p'-DDT, o,p'-DDT, p,p'-DDE and p,p'-DDD)	-	1.0[2]	Not measured				Not measured				Not measured	Not measured
Heptachlor (sum of heptachlor and heptachlor epoxide)	-	0.05[2]	Not measured				Not measured				Not measured	Not measured
Hexachlorobenzene (HCB)	-	0.1[2]	Not measured				Not measured				Not measured	Not measured
Lindane (BHC-gamma)	-	1.0[2]	Not measured				Not measured				Not measured	Not measured

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 2018–19 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 Tables 34 and 35. 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 2018–19 non river-flow period. Very low dissolved oxygen concentrations (below the EQG) were recorded in the depth waters at sites CS11 on 29 January 2019 (4.9 mg/L) and CS13 on 21 January 2019 (4.7 mg/L) and 11 March 2019 (4.9 mg/L).

Table 34. Assessment of dissolved oxygen concentrations in surface waters and at depth, measured at four sites adjacent to the shellfish harvesting areas in Cockburn Sound over the 2018–19 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])	3/12/2018	7.6	7.6	7.7	7.7	7.7	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	10/12/2018	7.5	7.4	7.6	7.5	7.5		
	17/12/2018	7.3	7.2	7.3	7.3	7.3		
	24/12/2018	7.2	7.0	7.5	7.4	7.3		
	7/01/2019	7.2	6.9	7.3	7.2	7.2		
	14/01/2019	7.1	7.0	7.1	7.1	7.1		
	21/01/2019	7.1	7.0	7.2	7.2	7.2		
	29/01/2019	7.3	6.9	7.1	7.3	7.2		
	4/02/2019	7.1	6.9	7.2	7.0	7.1		
	11/02/2019	7.1	7.0	7.0	7.1	7.1		
	18/02/2019	7.2	6.9	7.1	7.0	7.1		
	25/02/2019	7.2	7.0	6.9	7.2	7.1		
	4/03/2019	7.0	6.8	7.1	6.9	7.0		
	11/03/2019	6.8	6.0	6.5	6.9	6.7		
	18/03/2019	6.9	6.8	6.8	7.0	6.9		
	25/03/2019	6.9	6.7	6.8	6.9	6.9		
Depth waters dissolved oxygen (mg/L)	3/12/2018	7.7	7.7	7.5	7.3	7.6	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	10/12/2018	7.3	7.5	7.3	7.3	7.3		
	17/12/2018	6.9	7.2	7.0	7.2	7.1		
	24/12/2018	6.8	6.1	6.5	6.6	6.6		
	7/01/2019	6.9	6.3	6.7	6.1	6.5		
	14/01/2019	6.9	6.9	6.5	6.5	6.7		
	21/01/2019	6.2	6.1	5.6	**4.7**	5.9		
	29/01/2019	7.2	6.9	**4.9**	5.7	6.3		
	4/02/2019	7.0	6.9	6.8	6.5	6.9		
	11/02/2019	7.0	7.0	6.6	6.8	6.9		
	18/02/2019	7.1	7.0	6.5	6.8	6.9		
	25/02/2019	6.7	7.1	6.0	6.0	6.4		
	4/03/2019	5.9	6.8	6.2	5.7	6.2		
	11/03/2019	5.5	5.8	5.7	**4.9**	5.6		
	18/03/2019	6.1	6.8	5.9	5.8	6.0		
	25/03/2019	6.7	6.8	6.5	6.7	6.7		

Table 35. Assessment of pH in surface waters and at depth, measured at four sites adjacent to the shellfish harvesting areas in Cockburn Sound over the 2018–19 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 pH	3/12/2018	8.2	8.2	8.2	8.2	8.2	6–9	EQG met on all sampling occasions and at all sites
	10/12/2018	8.2	8.2	8.2	8.2	8.2		
	17/12/2018	8.2	8.2	8.2	8.2	8.2		
	24/12/2018	8.2	8.2	8.3	8.3	8.3		
	7/01/2019	8.2	8.2	8.2	8.2	8.2		
	14/01/2019	8.2	8.2	8.2	8.2	8.2		
	21/01/2019	8.1	8.0	8.2	8.1	8.1		
	29/01/2019	8.1	8.1	8.1	8.1	8.1		
	4/02/2019	8.1	8.1	8.2	8.1	8.1		
	11/02/2019	8.1	8.1	8.1	8.1	8.1		
	18/02/2019	8.1	8.1	8.1	8.1	8.1		
	25/02/2019	8.2	8.2	8.1	8.2	8.2		
	4/03/2019	8.1	8.1	8.1	8.1	8.1		
	11/03/2019	8.1	8.1	8.1	8.1	8.1		
	18/03/2019	8.1	8.1	8.1	8.1	8.1		
	25/03/2019	8.1	8.1	8.1	8.1	8.1		
Depth waters pH	3/12/2018	8.2	8.2	8.2	8.2	8.2	6–9	EQG met on all sampling occasions and at all sites
	10/12/2018	8.2	8.2	8.2	8.2	8.2		
	17/12/2018	8.2	8.2	8.2	8.2	8.2		
	24/12/2018	8.2	8.2	8.2	8.2	8.2		
	7/01/2019	8.2	8.2	8.2	8.2	8.2		
	14/01/2019	8.2	8.2	8.2	8.2	8.2		
	21/01/2019	8.0	8.0	8.1	8.0	8.0		
	29/01/2019	8.1	8.1	8.0	8.0	8.1		
	4/02/2019	8.1	8.2	8.1	8.1	8.1		
	11/02/2019	8.1	8.1	8.1	8.1	8.1		
	18/02/2019	8.1	8.1	8.1	8.1	8.1		
	25/02/2019	8.1	8.2	8.1	8.1	8.1		
	4/03/2019	8.1	8.1	8.1	8.1	8.1		
	11/03/2019	8.1	8.1	8.1	8.1	8.1		
	18/03/2019	8.0	8.1	8.0	8.0	8.0		
	25/03/2019	8.1	8.1	8.1	8.1	8.1		

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 2018–19 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). The concentrations of selected toxicants (ammonia, nitrate–nitrite, copper and manganese) in surface water samples collected at sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) on one occasion on 1 February 2019 (Section 2.3; Figure 2) 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 36. The toxicant concentrations recorded at all the sites were below the relevant EQG values.

3.5 Conclusions

Based on the results from the 2018–19 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 (e.g. swimming) is safe to undertake.
- 'Maintenance of secondary contact recreation values' – secondary contact recreation (e.g. 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
- 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 2018–19 monitoring period (Figure 12). The sampling program was administered by the Department of Health. 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 about 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.[28]

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

Samples were analysed for enterococci by PathWest Laboratory. Enterococci are the bacterial indicator recommended by the National Health and Medical Research

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

Council (2008).

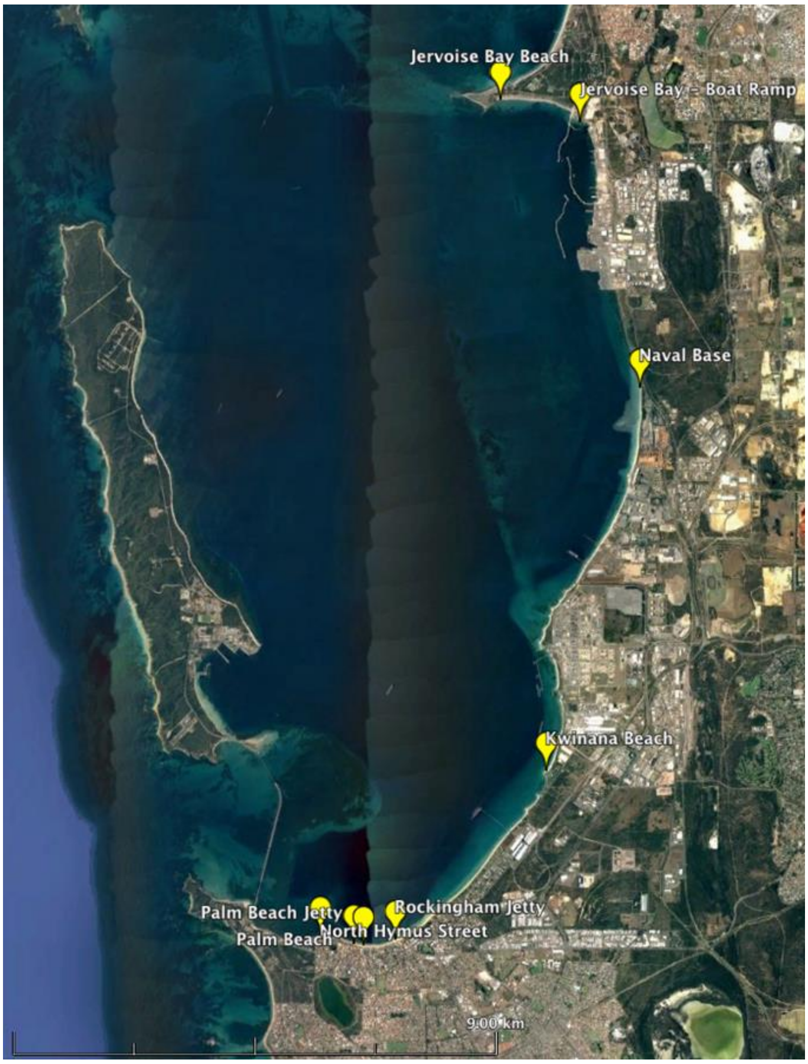


Figure 12. Sampling locations associated with recreational beaches in Cockburn Sound.

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 2018–19 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 37. The 'Faecal pathogens' EQG for both primary and secondary contact recreation were met at all of the sites monitored over the 2018–19 monitoring period.

Table 37. Assessment of the 95th percentile of enterococci counts (samples collected between 2014–15 and 2018–19) 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	56	200	2,000	110
Jervoise Bay Beach[1]	Program	64			36
Rockingham Beach + Jetty[1]	Program	49			125
Palm Beach Jetty[1]	Program	58			45
Naval Base[1]	Program	24			2
Kwinana Beach[1]	Program	24			80
Jervoise Bay Boat Ramp[1]	Non-core	64			12
Palm Beach[1]	Non-core	32			130
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 2018–19 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.*[29]

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 38. Water clarity and pH met the relevant 'Physical' EQC for primary and secondary contact recreation at all the sites.

[29] 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 38. Assessment of pH and water clarity (Secchi disc) at 18 water quality monitoring sites in Cockburn Sound over the 2018–19 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	8.1	8.1	>1.6 m	6.2 – 12.1	EQC met at all sites
CS5		8.1	8.1		5.4 – 12.4	
CS6A		8.1	8.1		3.8 – 8.3	
CS7		8.1	8.1		4.2 – 8.1	
CS8		8.1	8.1		4.8 – 10.8	
CS9		8.1	8.1		4.0 – 9.4	
CS10N		8.1	8.1		4.1 – 10.5	
CS11		8.1	8.1		4.1 – 9.9	
CS12		8.1	8.1		4.2 – 9.2	
CS13		8.1	8.1		4.0 – 10.8	
CS9A		8.1	8.1		3.9 – 11.2	
CB		8.1	8.1		4.8 – 8.6	
G1		8.1	8.2		4.2 – 9.8	
G2		8.2	8.1		4.9 – 10.6	
G3		8.1	8.1		5.1 – 9.9	
SF		8.2	8.2		3.4 – 8.8	
MB		8.1	8.1		4.2 – 7.2	
NH3		8.1	8.1		3.1 – 4.8	

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 2018 to March 2019 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)
- odours.

The results are summarised in Tables 39 (a) and (b).

Grain was observed on the water surface at CS10N adjacent to the Kwinana Grain Jetty on four occasions (3 December 2018, 7 January 2019, 29 January 2019 and 18 March 2019), with a large quantity of grain dust present in both water and air on the last occasion (18 March 2019). Grain was also observed on the water surface at CS13 on one occasion (24 December 2018).

Odours were reported at sites adjacent to the industrial area on the eastern shore of Cockburn Sound (CS6A, CS7, CS8, CS9A and CS12) on eight occasions.

Algal blooms were observed on 14 of the 16 water quality sampling days, with phytoplankton scum being noted throughout the monitoring period from December 2018 to March 2019. Algal blooms were observed at Jervoise Bay Northern Harbour (NH3) in MPA-NH on 12 days The frequency and size of the algal blooms did not reach the magnitude of those observed in 2017, when there was an increase in the concentrations of chlorophyll *a* and a reduction in the Secchi depths measured (Cossington and Wienczugow 2019).

Although no large-scale fish kills were observed on the water quality sampling days during the 2018–19 monitoring season, a decomposed Globefish (Diodon nicthemerus) was found near site CS9 on 18 March 2019 (Cossington and Wienczugow 2019). The observation coincided with a large algal bloom that extended to the south along the eastern portion of the Cockburn Sound. Phytoplankton samples were collected at the 18 Cockburn Sound and two Warnbro Sound water quality monitoring sites on 11 February 2019, after a reported fish kill, and within observed algal blooms on 18 March 2019 (Cossington and Wienczugow 2019). No toxic phytoplankton species were identified in the analyses by the Phytoplankton Ecology Unit at the Department of Water and Environmental Regulation (personal communication, 2019).

Table 39(a). 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 2018–19 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
3/12/2018	CB, CS12, CS10N, CS11, MB (surface phytoplankton scum)	-	-	-	MB (seagrass blooms)	CS11	CB, CS12, CS11, MB, WSSB, G1 (algae, seagrass); CS10N (grain)	CS12 (industrial odours)
10/12/2018	CS6A, CS7, CB, CS10N, MB, NH3 (surface phytoplankton scum; well-defined algal bloom south end of Cockburn Sound)	MB, NH3	-	MB (algal blooms)	MB, NH3 (very green)	CS9A	CB, MB,G1 (algae; seagrass)	WSSB (dredging at boat ramp)
17/12/2018	MB, NH3 (algae)	NH3	-	CS7 (plume from nearby ship); MB (algal mat)	CS7 (plume from nearby ship), NH3 (algae)	-	CS7 (plume); MB, G1, G2, G3 (algae, seagrass)	CS7 (industrial odours)
24/12/2018	CS7, CS10N, MB, NH3 (surface phytoplankton scum)	NH3	-	MB (algae), NH3 (algal blooms)	CS10N (green); MB, NH3 (algal blooms)	-	CS13 (grain); MB (algae); G3 (seagrass)	-
7/01/2019	CS6A,CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, NH3 (surface phytoplankton scum)	NH3	-	NH3 (algal blooms)	NH3 (algal blooms)	-	CS10N (grain, phytoplankton); WSSB, WS4 (seagrass); CS5 (macrophytes)	-
14/01/2019	CS6A, CS7, CS9A, MB, SF,G1, CS8, NH3, WSSB,WS4 (large algal bloom); CB, CS12, CS9, CS10N, CS13, CS11 (surface phytoplankton scum)	CS6A, CS7, CS9A, MB, SF,G1, CS8, NH3, WSSB,WS4	-	CS7, CS9A, MB, SF,G1, CS8, NH3, WSSB,WS4 (algal blooms)	CS9A, MB, SF,G1, CS8, NH3, WSSB,WS4 (algal blooms)	-	-	-
21/01/2019	CS6A, CS7, CB, CS12,CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, NH3 (surface phytoplankton scum)	MB, SF, G1, NH3	-	MB, SF, G1, NH3 (algal blooms)	MB, SF, G1, NH3 (algal blooms)	-	MB, G1, NH3 (phytoplankton, algal blooms); WSSB, WS4 (seagrass)	G1, NH3, WSSB, WS4 (decomposing seagrass)
29/01/2019	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF (surface phytoplankton scum,seagrass); CS5 (seagrass)	-	-	CS10N (grain)	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11 (green)	-	CS10N (grain); CB, MB, SF, CS5 (seagrass)	CS6A (industrial odours)

Table 39(b). 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 2018–19 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
4/02/2019	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, CS8, G2, G3, CS4, NH3 (surface phytoplankton scum, algal bloom)	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, CS8, G2, G3, CS4, NH3	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, CS8, G2, G3, CS4, NH3	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, CS8, G2, G3, CS4, NH3 (green; algal blooms)	-	MB, SF, CS8, G2,G3 (seagrass)	-
11/02/2019	NH3 (algal bloom)	MB, NH3	-	CS10N,CS13, CS11, MB, NH3	CS10N,CS13, CS11 (milky appearance); MB, NH3 (algal blooms)	-	WS4 (seagrass)	-
18/02/2019	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11 (surface phytoplankton scum, algal bloom)	CS6A, CS7, CB, CS12, CS9, CS9A	-	CS9 (vessel movement)	CS6A (very green); CS7, CB, CS12, CS9, CS9A, CS10N (green)	-	MB, SF, G2 (algae)	CS6A, CS12 (industrial odours)
25/02/2019	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N (surface phytoplankton scum, algal bloom)	CS7, CB, CS12, CS9, CS9A, CS10N	-	CS7	CS7, CB, CS12, CS9, CS9A, CS10N (green)	-	CS13, MB, SF, CS8, G2, G3, CS4, CS5, WSSB (seagrass)	CS12, CS9A (industrial odours)
4/03/2019	CS7, CB, CS12, CS9, CS9A, CS13, NH3 (surface phytoplankton scum, algal bloom)	CS7, CB, CS12, CS9, CS9A, CS13, NH3	-	-	CS7, CB, CS12, CS9, CS9A, CS13, NH3 (green)	-	MB, SF, G1, CS8, G2, G3, CS4, WSSB (seagrass)	CS12 (industrial odours)
11/03/2019	CS7, CB, CS9A, CS10N, SF, NH3, WS4 (surface phytoplankton scum, algal bloom)	CS7, CB, CS9A, CS10N, SF, NH3, WS4	-	CS7, CB, CS9A, CS10N, SF, NH3, WS4 (algal blooms); CS9 (tug wash)	CS7, CB (green); CS10N, NH3 (very green)	-	SF, G1 CS8, G2, CS5 (seagrass)	-
18/03/2019	CS7, CB, CS12, CS11, MB, WS4 (surface phytoplankton scum, algal bloom)	CS9 (very large algal bloom); CS9A, CS10N, CS11, MB, NH3, WS4	CS9 (dead puffer fish)	CS7, CB, CS12, CS9, CS9A, CS10N, CS11, MB, NH3, WS4	CS7, CB, CS12, NH3 (green); CS9, CS9A (very green)	CS10N (large quantity of grain on water surface and in air)	CS10N (large quantity of grain on water surface); MB, SF, G1, CS8, G2, G3, CS4, CS5, WSSB, WS4 (seagrass)	CS12 (industrial odours)
25/03/2019	CS6A, CS7, CB, CS12, CS9, CS9A, CS13, CS11, MB, SF,G1, NH3 (surface phytoplankton scum, algal bloom)	CS7, CB, CS12, CS9, CS9A, CS13, CS11, MB, SF,G1, NH3, WS4	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, G2, NH3, WS4	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, G2, NH3, WS4	-	SF, CS8, WSSB (seagrass)	CS8 (industrial odours)

4.5 Conclusions

Based on the results from the 2018–19 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.

Table 36. 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.

Site	Ammonia (µg N/L)			Nitrate–Nitrite (µg N/L)			Copper (µg/L)		Manganese (µg/L)	
	EQG	Surface	Bottom	EQG	Surface	Bottom	EQG	Surface	EQG	Surface
KBT1		< 3	16		< 2	3		0.3		1.1
KBT2		< 3	3		< 2	< 2		0.2		0.9
KBT3		< 3	7		< 2	9		0.4		1.0
KBJ1		< 3	< 3		< 2	< 2		0.3		Not measured
KBJ2		< 3	< 3		< 2	2		0.3		Not measured
KBJ3	≤1,000	< 3	20	Nitrite-N ≤100 Nitrate-N ≤100,000	< 2	8	≤5	0.3	≤10	Not measured
CS13		1.1	19.7		1	1		Not measured		Not measured
CS9A		95th percentile = 4.6			95th percentile = 1			Not measured		Not measured
CS10N		95th percentile = 10.2			95th percentile = 1			Not measured		Not measured
CS11		95th percentile = 3.5			95th percentile = 1			Not measured		Not measured
Assessment				EQG met at all sites						

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), 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 about 18% 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. All equipment at the Desalination Plant is routinely recalibrated to ensure accuracy and reliability.

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 three times in the reporting period. 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

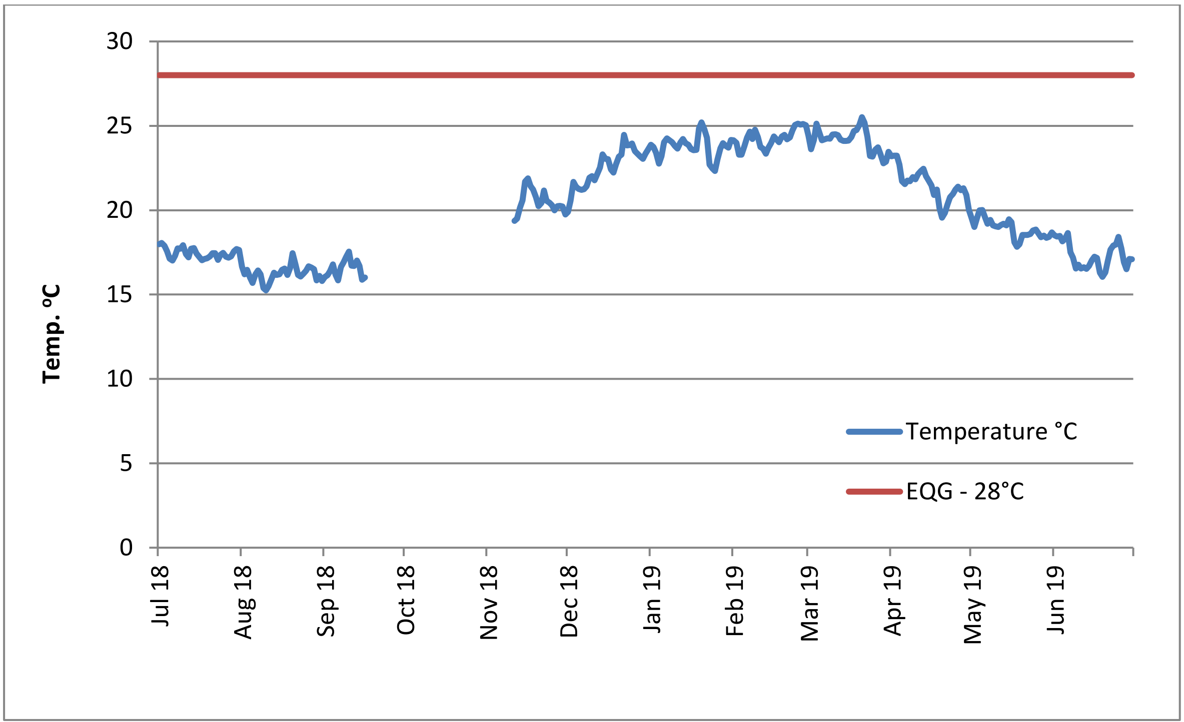
5.3.1 Biological Indicators

Enterococci did not exceed the EQG of 32 Colony Forming Units per 100 millilitres (CFU/100 mL) on any sampling occasion over the July 2018 to June 2019 monitoring period. *Enterococci* was generally under the Limit of Reporting (LOR) of <

10 MPN/100mL. The highest recording during the reporting period was 10 MPN/100mL which was recorded on three occasions.

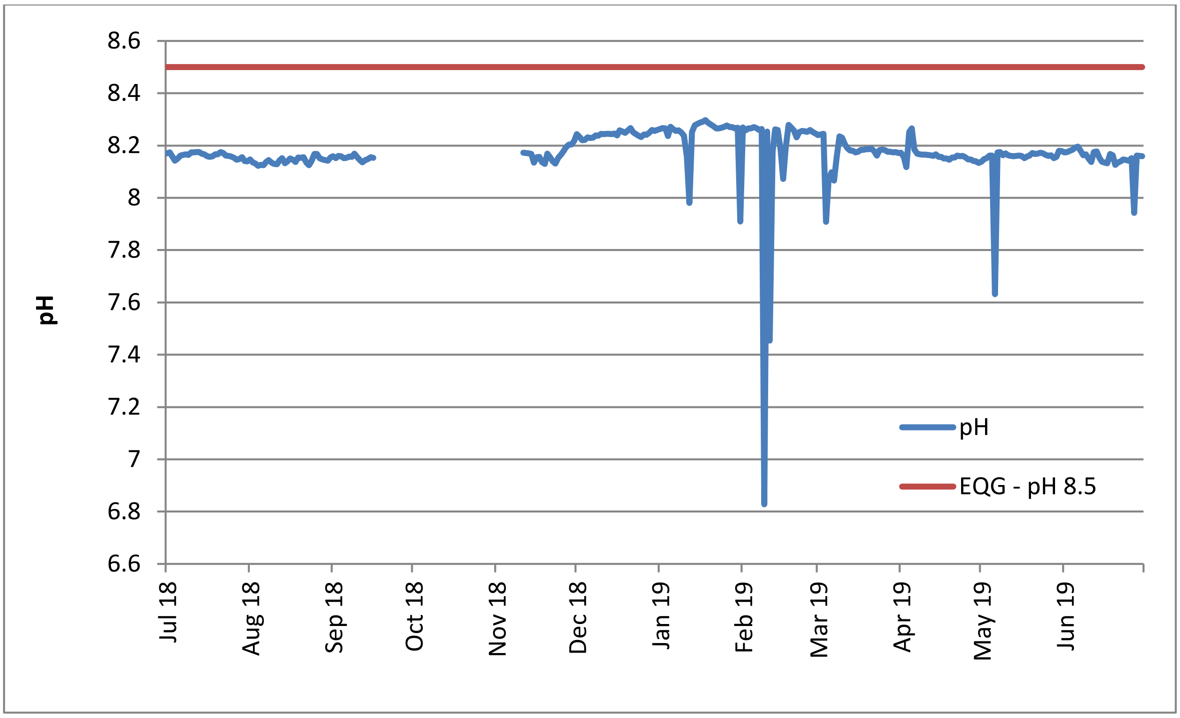
5.3.2 Physical and Chemical Indicators

Over the 2018–19 monitoring period, the temperature of the intake seawater was below the EQG of 28°C (Figure 22) and pH was below the EQG of 8.5 (Figure 23). Dissolved oxygen concentrations were above the EQG of 2 milligrams per litre (mg/L) over the monitoring period (Figure 24).



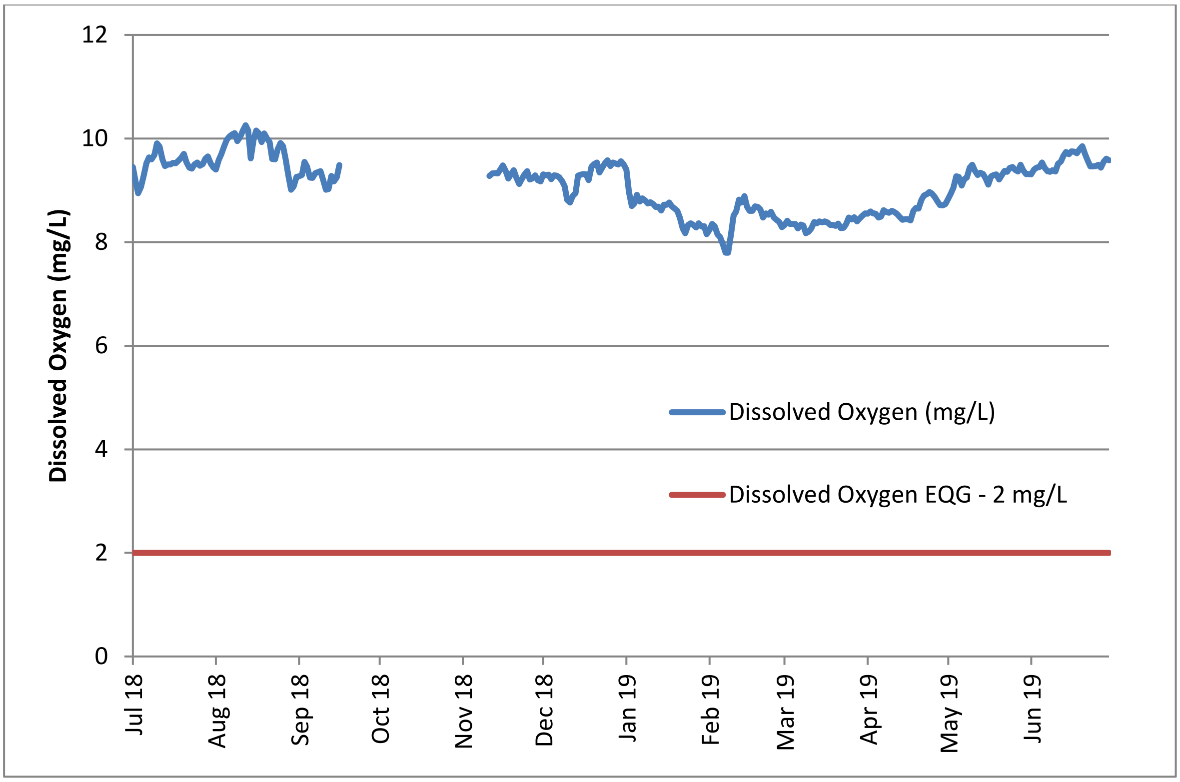
Note: Data recorded during the scheduled plant shutdown have been removed, as the data are not representative of seawater quality (data removed from 17/09/18 – 11/11/18).

Figure 22. Daily average temperature of the intake seawater over the 2018–19 monitoring period.



Note: Data recorded during the scheduled plant shutdown have been removed, as the data are not representative of seawater quality (data removed from 17/09/18 – 11/11/18). Single point decreases in pH such as those that occurred on 09/02/19, are also associated with short-term plant shutdowns and the data are not representative of seawater quality.

Figure 23. Daily average pH of the intake seawater over the 2018–19 monitoring period.



Note: Data recorded during the scheduled plant shutdown have been removed, as the data are not representative of seawater quality (data removed from 17/09/18 – 11/11/18).

Figure 24. Daily average dissolved oxygen concentration of the intake seawater over the 2018–19 monitoring period.

The ‘rolling’ four-week median concentration of TSS exceeded the EQG of 4.5 mg/L from late July 2018 to late December 2018, and again in February 2019 (Figure 25). There was one individual exceedance of the EQG of 9 mg/L in August 2018. The one exceedance 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.

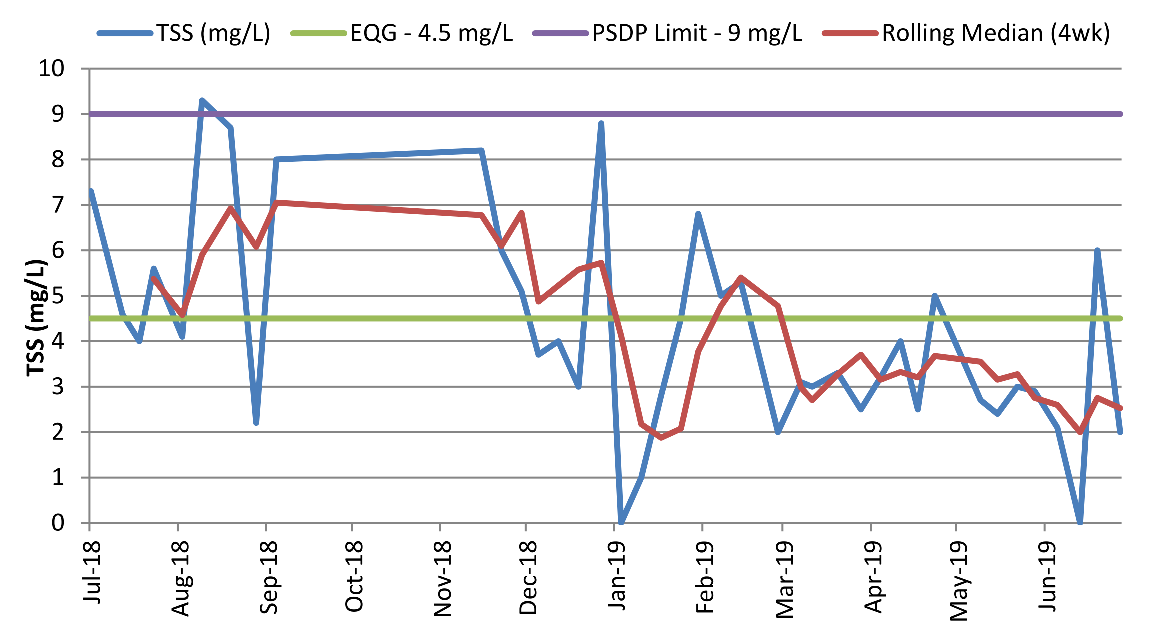


Figure 25. Weekly and 'rolling' four-weekly median total suspended solids (TSS) concentration in the intake seawater over the 2018–19 monitoring period.

Over the 2018–19 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 44). The Water Corporation advised that boron is removed by the reverse osmosis process.

Table 44. Quarterly concentrations of boron and bromide in the intake seawater over the 2018–19 monitoring period.

Sampling Occasion	Boron (mg/L)		Bromide (mg/L)	
	EQG	Concentration	EQG	Concentration
July 2018	5.2	4.4	77	52
December 2018		4.6		68
April 2019		5		66

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 2018–19 monitoring period. Natural variation in the quality of the intake seawater was observed by the Water Corporation over the 2018–19 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 2018–19 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 2000–02 (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 (e.g. cadmium 0.7 µg/L) or narrative statements (e.g. 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 because of 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 nearby 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 an LRV it does not necessarily mean an impact is likely. Exceedance of an 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 1 m 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 with 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 firefighting 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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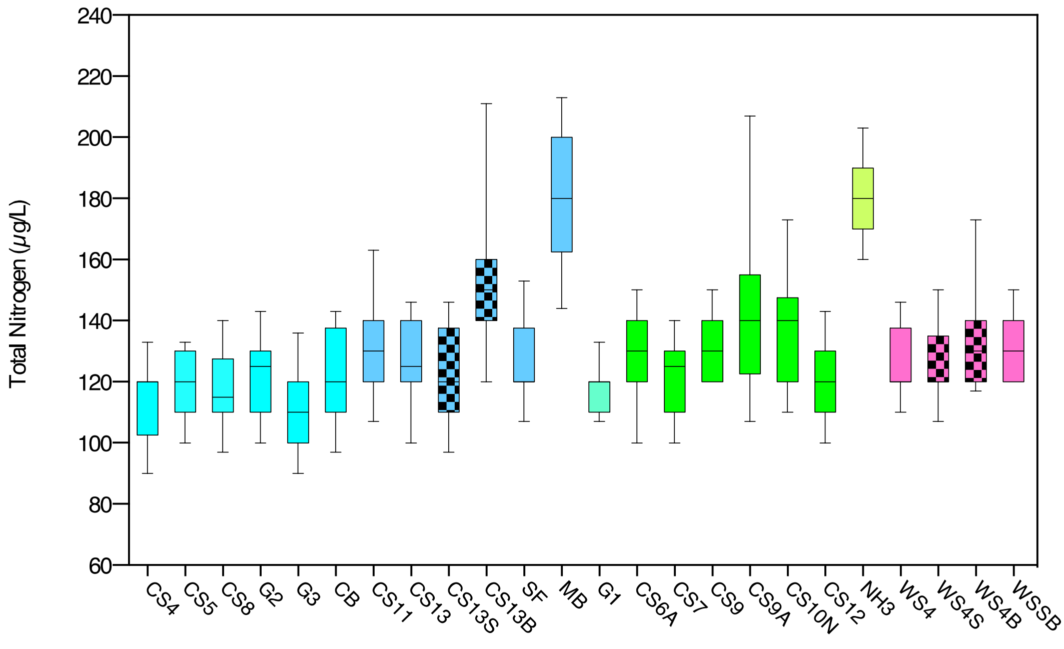
Appendix A: 2018–19 Nutrient Concentrations

Total nitrogen

Total nitrogen concentrations over the 2018–19 non river-flow period ranged from 90 micrograms per litre (µg/L) recorded at four sites in Cockburn Sound (CS4, CS8, G3 and CB) in HPA-N to 270 µg/L recorded at site CS9A in the eastern Sound on 25 February 2019 (Cossington and Wienczugow 2019).

The median total nitrogen concentrations at the Mangles Bay site MB and Northern Harbour site NH3 were 180 µg/L were significantly higher than most of the other sites with the exception of sites CS9, CS9A, CS10N, NH3 and WSSB (Figure A.1; Cossington and Wienczugow 2019).

The total nitrogen at site CS13 showed median total nitrogen concentrations in the bottom water that were significantly higher than those in the integrated water samples and surface water samples (Cossington and Wienczugow 2019). There was no significant difference between the surface water and integrated sample medians. At the Warnbro Sound site WS4, there were no significant differences between the total nitrogen medians in the surface, integrated and bottom water samples.



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 2018 to March 2019.

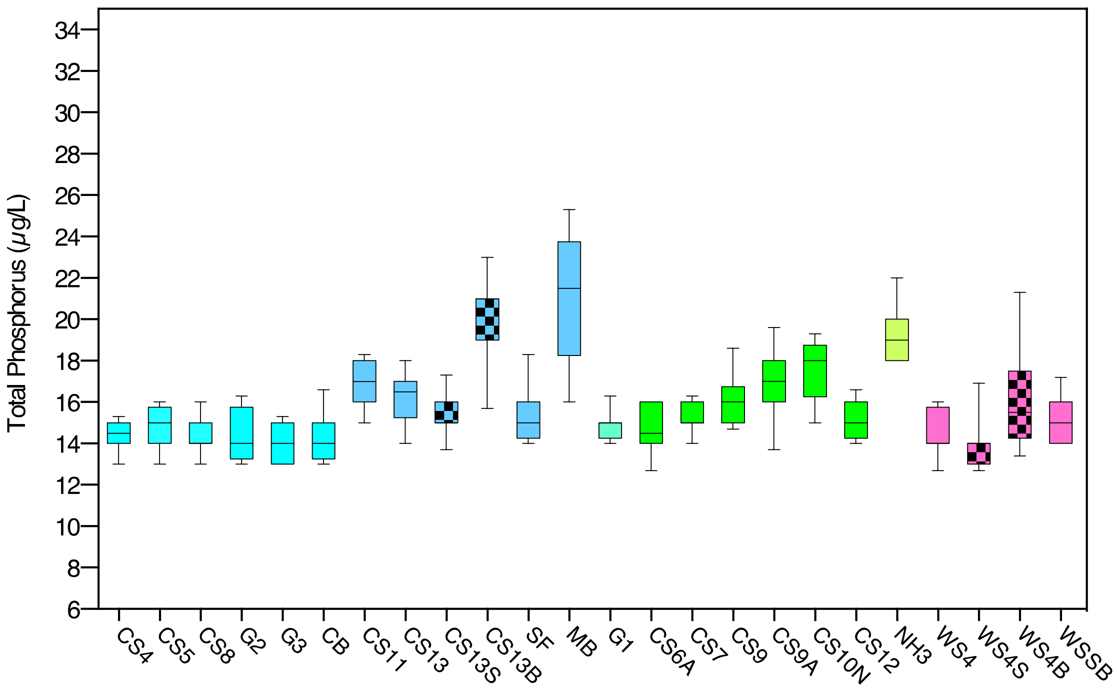
Comparisons of median total nitrogen concentrations between ecological protection areas showed that MPA-NH was significantly higher that all other areas in Cockburn and Warnbro Sound (Cossington and Wienczugow 2019).

Total phosphorus

Total phosphorus concentrations ranged from 12 µg/L at Warnbro Sound reference site WS4 and site CS6A in MPA-ES to 26 µg/L at the Mangles Bay site MB in HPA-S, which was recorded on 18 February 2019 (Cossington and Wienczugow 2019).

The highest median total phosphorus concentrations were recorded at the Mangles Bay site MB (Figure A.2; Cossington and Wienczugow 2018). The median total phosphorus concentration at site MB and Northern Harbour site NH3 were significantly higher than the other sites with the exception of sites CS9, CS9A, CS10N, CS11 and CS13.

The median total phosphorus concentration was significantly higher in the bottom waters sampled at Warnbro Sound reference site WS4 and site CS13 in HPA-S when compared with that of the surface waters sampled at these sites (Cossington and Wienczugow 2019). The bottom water at site CS13 also had a significantly higher median total phosphorus concentration than the integrated water median at the same site.



Notes:

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(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.

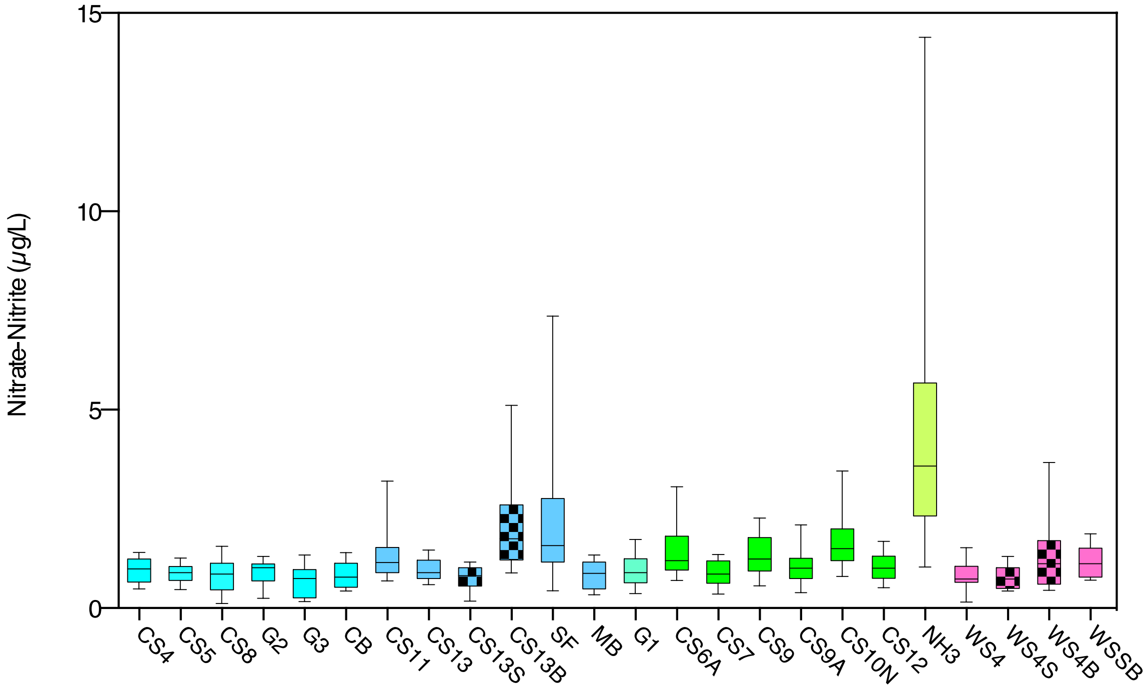
Figure A.2. Median total phosphorus concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2018 to March 2019.

Comparisons of the median total phosphorus concentrations between ecological protection areas showed that the Northern Harbour in MPA-NH and the southern HPA-S had the highest total phosphorus concentrations during 2019 (Cossington and Wienczugow 2019).

Nitrate-nitrite

Nitrate–nitrite concentrations ranged from less than the analytical reporting limit (< 2 µg/L) which was recorded at all sites on numerous occasions, to 8 µg/L at the Northern Harbour site NH3 in MPA-NH on 25 February 2019. Median nitrate–nitrite concentrations were below the analytical reporting limit at all sites with the exception of site NH3 (Figure A.3; Cossington and Wienczugow 2019).

Median nitrate–nitrite concentrations in surface water samples at site CS13 were significantly lower than the medians in bottom waters or integrated sample (Cossington and Wienczugow 2019). There were no significant differences between median nitrate–nitrite in surface, bottom and integrated water samples at the Warnbro Sound reference site WS4 (Figure A.3).



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 2018 to March 2019.

Comparisons of the median nitrate–nitrite concentrations between ecological protection areas showed that MPA-NH was significantly higher than all other ecological protection areas with the exception of MPA-ES (Cossington and Wienczugow 2019). The median nitrate–nitrite concentrations were also found to be significantly higher in the southern end of the Sound than the northern end

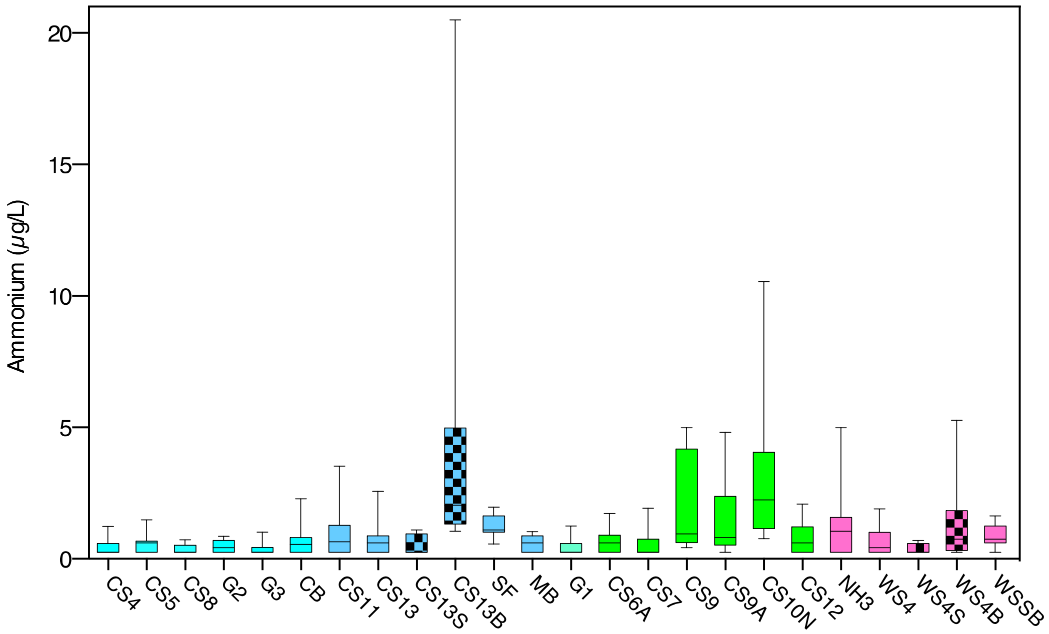
(Cossington and Wienczugow 2019).

Ammonium

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 16 µg/L recorded at site CS10N on 11 March 2019 (Cossington and Wienczugow 2019).

The highest median ammonium concentration was 2.25 µg/L at site CS10N in MPA-ES (Figure A.4; Cossington and Wienczugow 2019). The median ammonium concentration at CS10N was significantly higher than for all of the sites in HPA-N, sites CS6A and CS7 in MPA-ES, site G1 in MPA-CB, site MB in HPA-S and Warnbro Sound reference site WS4.

The median ammonium concentration of the discrete bottom water samples at site CS13 was elevated and significantly higher than the medians of the surface and integrated water samples at the same site (Cossington and Wienczugow 2019). There was no significant difference between the bottom and integrated water samples found at Warnbro Sound reference site WS4, however there was a significant difference between the median ammonium concentrations of the bottom and surface water samples (Cossington and Wienczugow 2019).



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 2018 to March 2019.

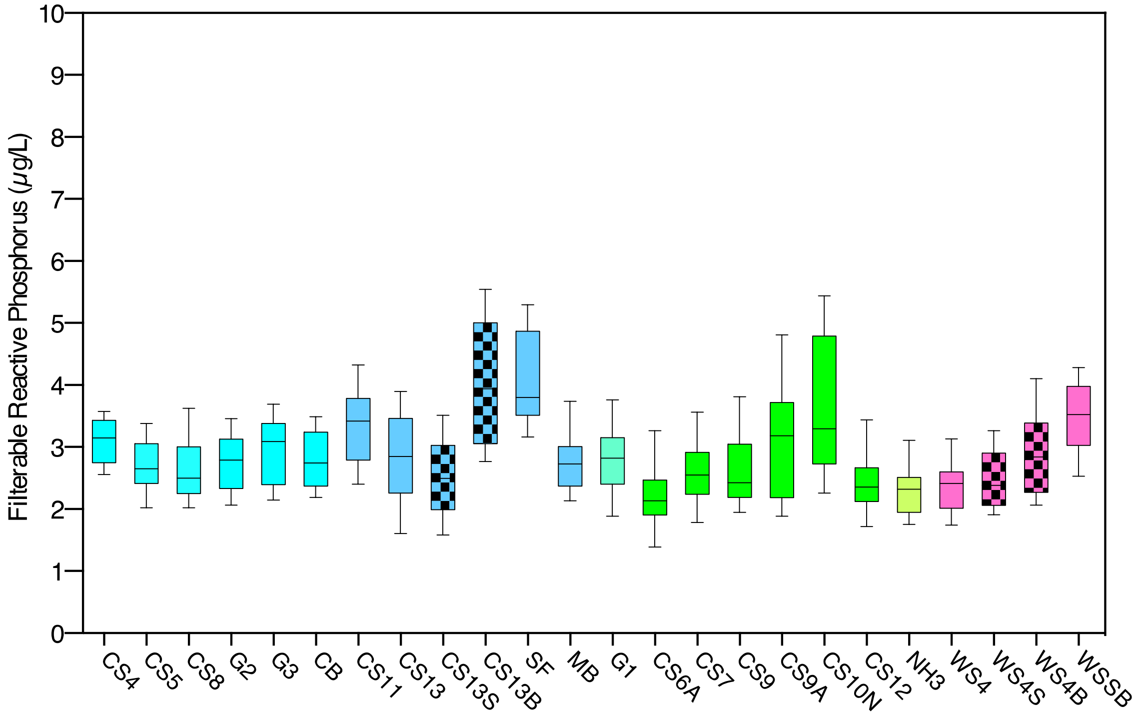
Comparisons of the median ammonium concentrations between ecological protection areas showed that HPA-N had significantly lower median ammonium concentrations than HPA-S, MPA-ES, MPA-NH and Warnbro Sound reference site WSSB (Cossington and Wienczugow 2019). MPA-ES was also found to be significantly higher than MPA-CB.

Filterable reactive phosphorus

Filterable reactive phosphorus (FRP) concentrations ranged from less than the analytical reporting limit (< 2 µg/L) which was recorded at most sites to 6 µg/L at sites CS10N and CS9A recorded on 24 December 2018 and 25 March 2019, respectively (Cossington and Wienczugow 2019).

The highest median FRP concentration was 3.8 µg/L at site CSSF in HPA-S (Figure A.5; Cossington and Wienczugow 2019). Sites CS10N and CSSF had significantly higher median FRP concentrations than sites CS6A and CS7 in MPA-ES, NH3 in MPA-NH, CS5 in HPA-N and Warnbro Sound reference site WS4.

The median FRP concentration in the bottom water samples at site CS13 were significantly higher than those in the surface and integrated water samples at the same site (Cossington and Wienczugow 2019). There were no significant differences between the median FRP concentrations of the surface, bottom and integrated water samples at Warnbro Sound reference site WS4.



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 sites; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Hatched bars = concentrations in discrete surface (S) and bottom (B) waters.

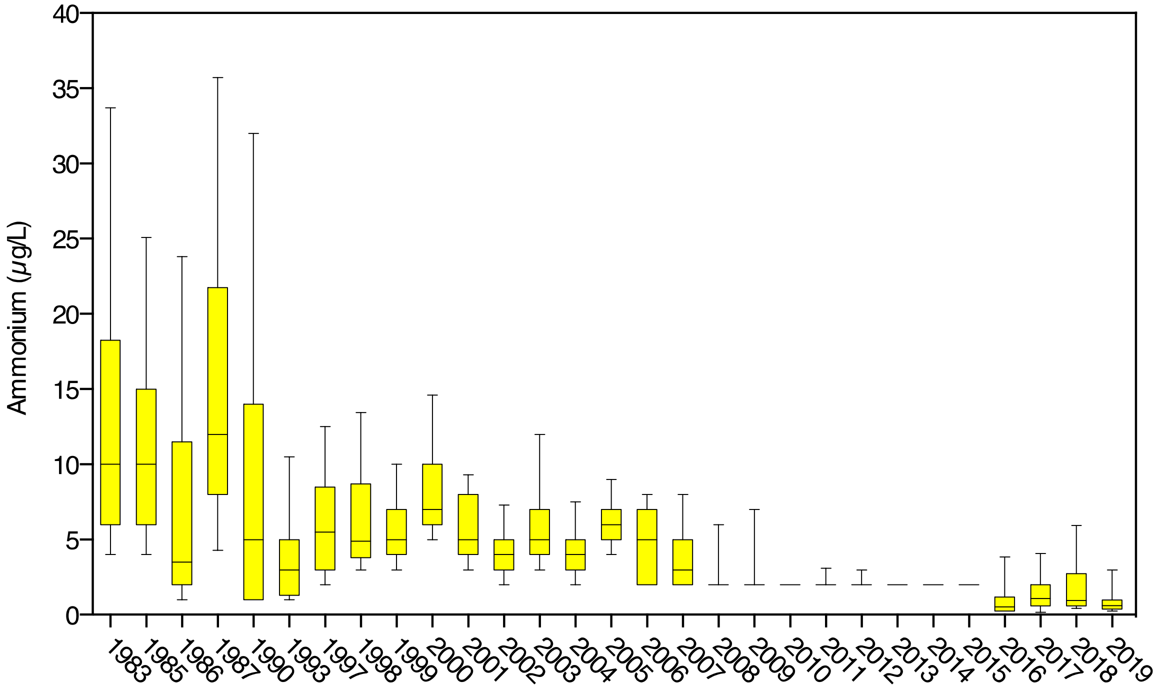
Figure A.5. Median filterable reactive phosphorus concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2018 to March 2019.

The highest median FRP concentrations of all of the ecological protection areas were at the HPA-S sites and Warnbro Sound reference site WSSB (Cossington and Wienczugow 2019). The median FRP concentrations at HPA-S sites and WSSB were significantly higher than the median FRP concentrations at site WS4, sites in HPA-N, sites in eastern Sound MPA-ES and site NH3 in MPA-NH.

Appendix B: Variations and trends over time in nutrient concentrations

Ammonium

Median non river-flow period ammonium concentrations in Cockburn Sound have declined from the 1980s to the 1990s and 2000s, and again from around 2008 onwards (Figure B1; Cossington and Wienczugow 2019). The variability between sites within years has also decreased over that time. The median ammonium concentrations at historical Cockburn Sound sites (i.e. CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11) in 2019 were not significantly different from the median concentrations recorded in the previous three years from 2016–18, but were significantly lower than earlier years.



Notes:

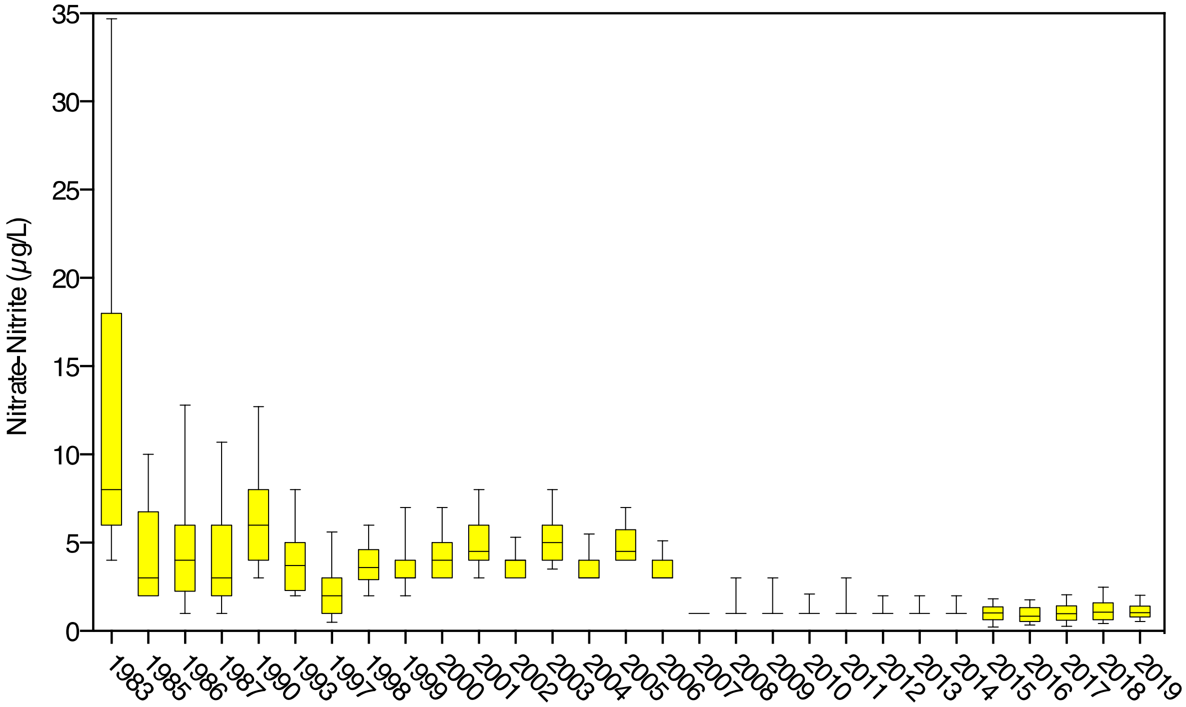
(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(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 2019.

Nitrate–nitrite

The median nitrate–nitrite concentrations at the historical Cockburn Sound sites in the 2018–19 non river-flow season were not significantly different from the concentrations recorded from seasons 2006–07 to 2017–18, but were significantly lower than nitrate–nitrite concentrations recorded before 2006–07 (Figure B2; Cossington and Wienczugow 2019). The median nitrate–nitrite concentrations for the historical Cockburn Sound have fluctuated very little since 2007, while the site NH3 has experienced more fluctuations during the same period (Cossington and Wienczugow 2019).

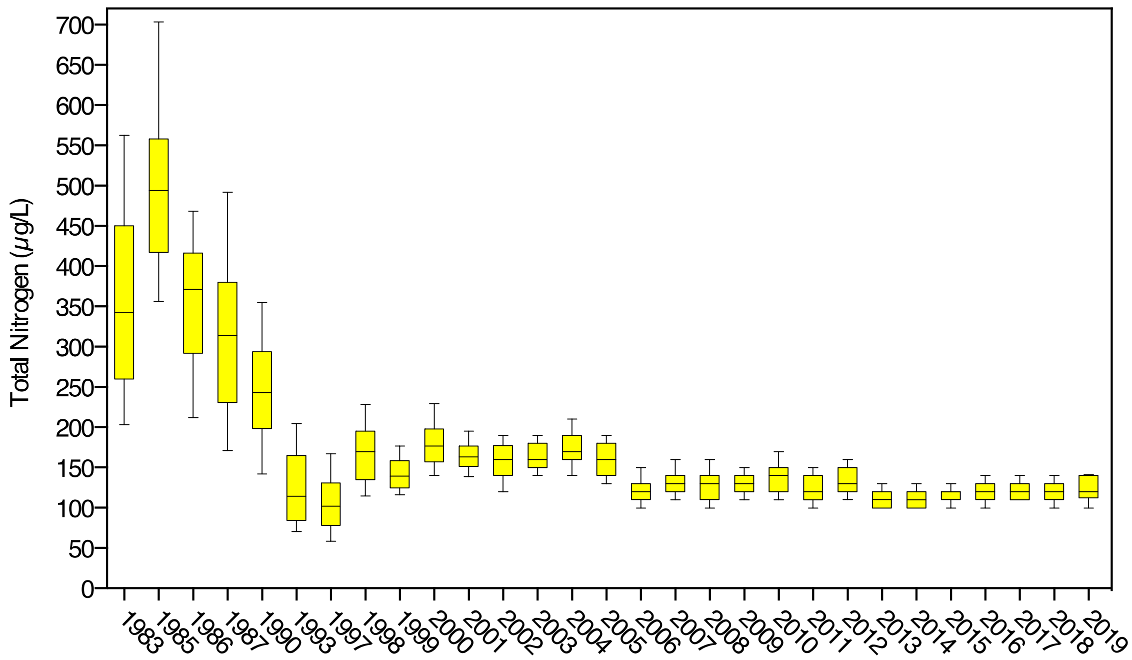


Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure B.2. Median nitrate–nitrite concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2019.

Total nitrogen

The median total nitrogen concentrations at the Cockburn Sound historical sites in 2018–19 were not significantly different to the median total nitrogen concentrations for seasons 1992–93, 1996–97 and from 2005–06 to 2017–18 (Figure B3; Cossington and Wienczugow 2019).



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

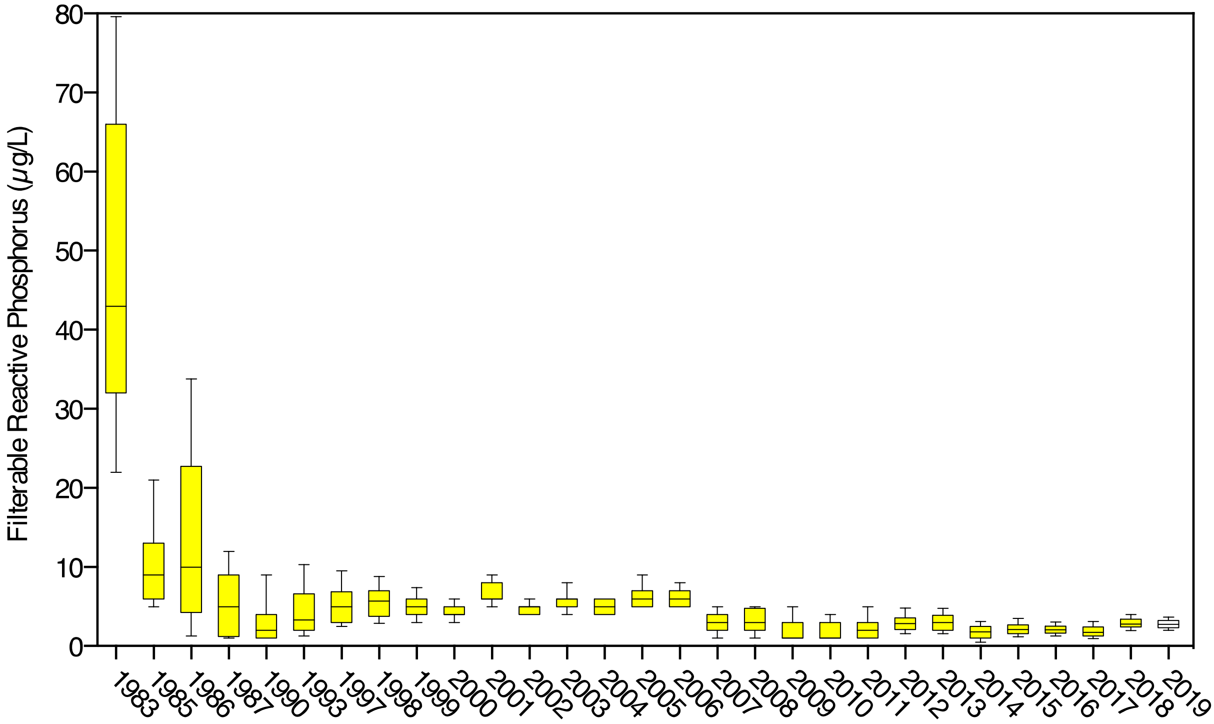
Figure B.3. Median total nitrogen concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2019.

Median concentrations in 2018–19 were significantly lower than all other years when total nitrogen was measured.

Filterable reactive phosphorus

Median non river-flow period filterable reactive phosphorus (FRP) concentrations at historical Cockburn Sound sites have decreased over the past 35 years, although concentrations have generally remained unchanged over the past 12 years (Figure B.4; Cossington and Wienczugow 2019).

The median FRP concentrations at these sites were significantly higher in 2018–19 than in 2013–14 and 2016–17 (Cossington and Wienczugow 2019). There were no significant differences for the periods from 2006–07 to 2012–13, 2014–15 to 2015–16 and 2017–18. The median filterable reactive phosphorus concentrations in 2018–19 were significantly lower than in all years before 2006–07, with the exception of 1990 and 1993, where there were no significant differences.

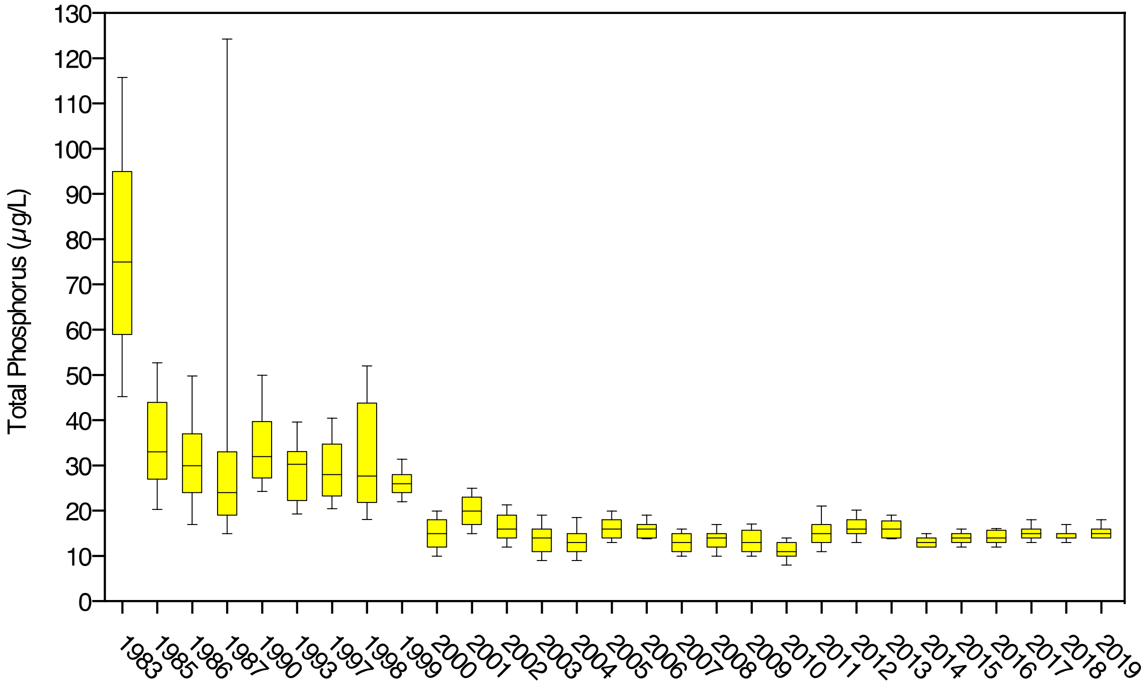


Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure B.4. Median filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2019.

Total phosphorus

Median total phosphorus concentrations at the historical Cockburn Sound sites have slowly decreased over the years (Figure B.6; Cossington and Wienczugow 2019). The median total phosphorus concentrations at the historical Cockburn Sound sites in 2018–19 were significantly lower than in the 1980s and 1990s when total phosphorus was measured. Plots of median total phosphorus concentrations at each site over time are presented in Figure B.5.

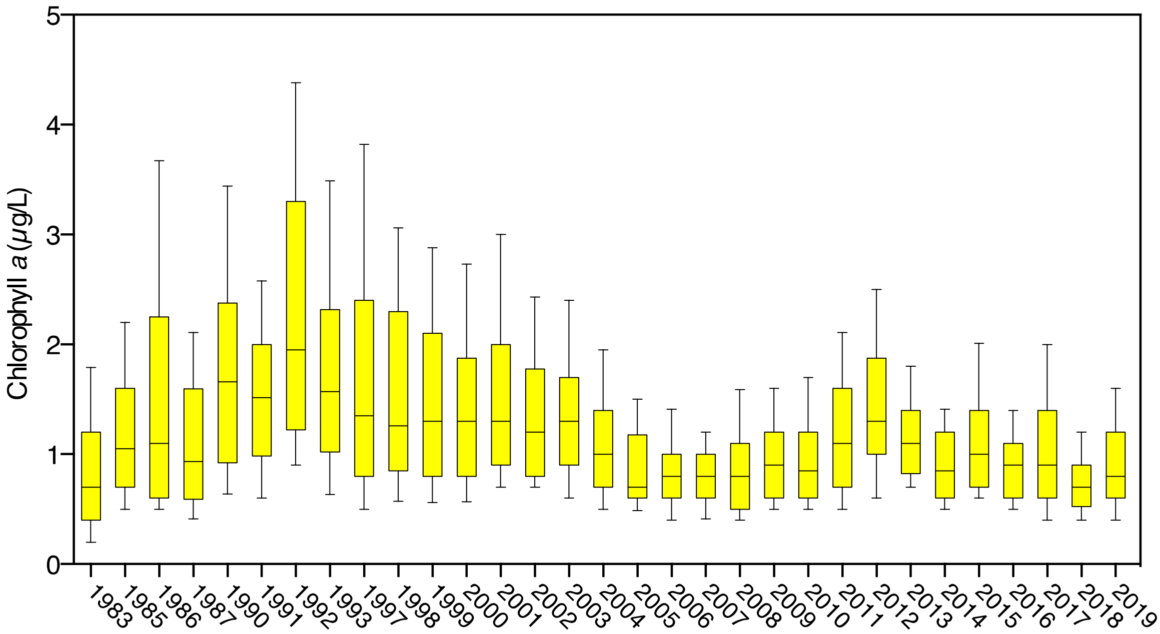


Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure B.5. Median total phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2019.

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 early 1980s to mid-1990s, remained high in the early 2000s, and then decreased in the mid-2000s (Figure C.1; Cossington and Wienczugow 2019). There was an increase over the years from 2011–13.

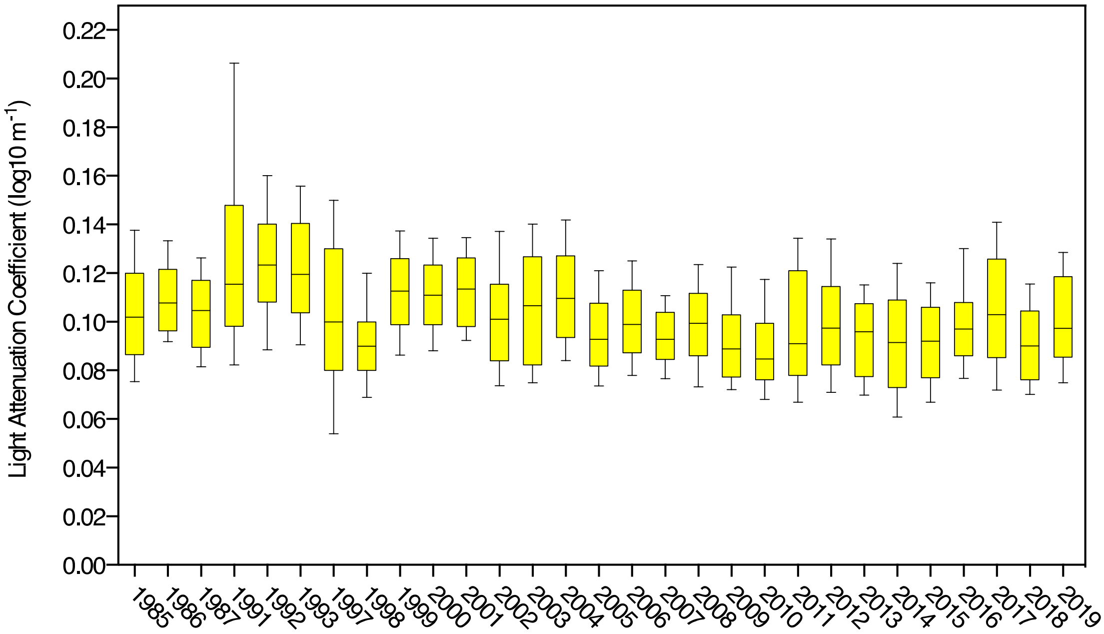


Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure C.1. Median chlorophyll *a* concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2019.

The median chlorophyll *a* concentration at the historical Cockburn Sound sites in the season 2018–19 was not significantly different to the concentrations reported in 1983–87, 2004–11 and 2014–18 (Cossington and Wienczugow 2019). The median chlorophyll *a* concentration in 2018–19 at these sites were significantly lower than in 1990 to 2003, 2012 and 2013.

Median light attenuation coefficients (LAC) at the historical Cockburn Sound sites in 2018–19 (2019) were significantly lower than in seasons 1990–91 (1991) to 1992–93 (1993) or 1998–99 (1999) to 2000–01 (2001), but significantly higher than in 2009–10 (2010) (Figure C.2; Cossington and Wienczugow 2019). There was no significant difference with all 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 2019.

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 (Fraser et al. 2019). Plots of mean and median shoot density at each site over time are presented in Figure D.1 (Fraser et al. 2019).

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	0.02	0.96	0.02	0.96
	Garden Island 2.5 m	0.07	0.71	0.09	0.64
	Garden Island 3.2 m	-0.29	*0.12*	-0.31	*0.09*
	Garden Island 5.5 m	-0.53	**0.003**	-0.50	**0.006**
	Garden Island 7.0 m	-0.27	*0.15*	-0.30	0.11
	Luscombe Bay	0.12	0.58	0.04	0.87
	Garden Island Settlement	-0.28	*0.19*	-0.19	0.38
	Kwinana	-0.20	0.32	-0.31	*0.12*
HPA-S	Southern Flats	-0.25	*0.17*	-0.22	0.23
	Mangles Bay	-0.28	*0.17*	-0.20	0.34
MPA-ES	Jervoise Bay	-0.41	**0.04**	-0.44	**0.03**
Sites Outside Cockburn Sound	Carnac Island	-0.03	0.91	-0.01	0.99
	Coogee	-0.26	0.25	-0.25	0.29
	Woodman Point	-0.45	**0.03**	-0.24	0.25
	Bird Island	-0.14	0.51	-0.21	0.32
	Mersey Point	-0.05	0.83	0.01	0.50
Reference Sites	Warnbro Sound 2.0 m	-0.54	**0.006**	-0.50	**0.01**
	Warnbro Sound 2.5 m	-0.18	0.34	-0.15	0.43
	Warnbro Sound 3.2 m	-0.51	**0.004**	-0.52	**0.004**
	Warnbro Sound 5.2 m	-0.32	*0.08*	-0.29	*0.12*
	Warnbro Sound 7.0 m	0.01	0.99	-0.06	0.80

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

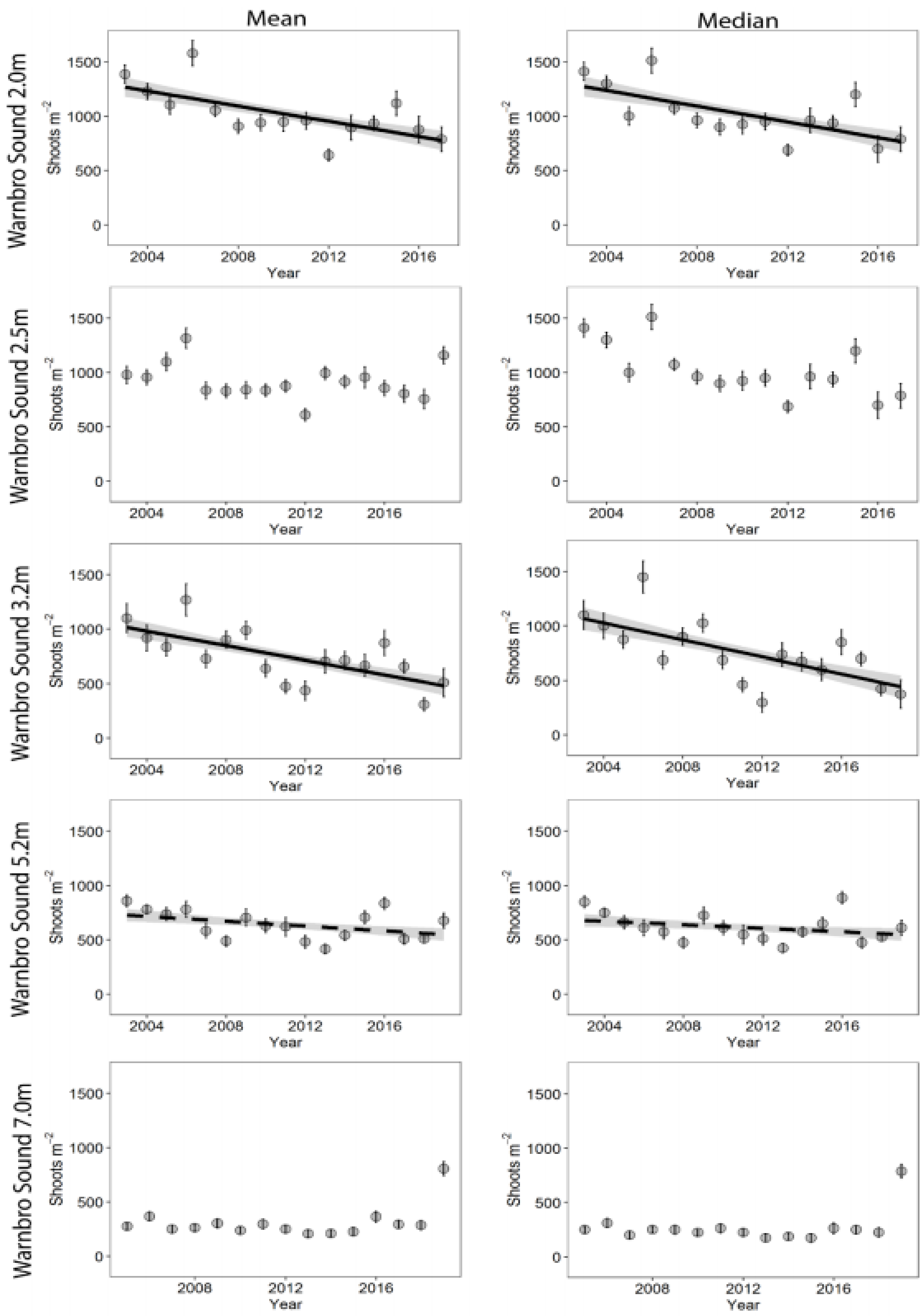
There were significant (α = 0.05) downward trends in mean and median shoot densities at Garden Island 5.5 m and Jervoise Bay. There were potential[30] downward trends (α = 0.2) in mean and median shoot densities at Garden Island 3.2 m; in mean shoot density at Mangles Bay, Southern Flats, Garden Island Settlement and Garden Island 7.0 m; and in median shoot density at Kwinana. There were no significant increases in shoot density reported at any site.

There was a significant (α = 0.05) downward trend in mean shoot density at Woodman Point. There were no significant trends in mean or median shoot densities at any of

[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.

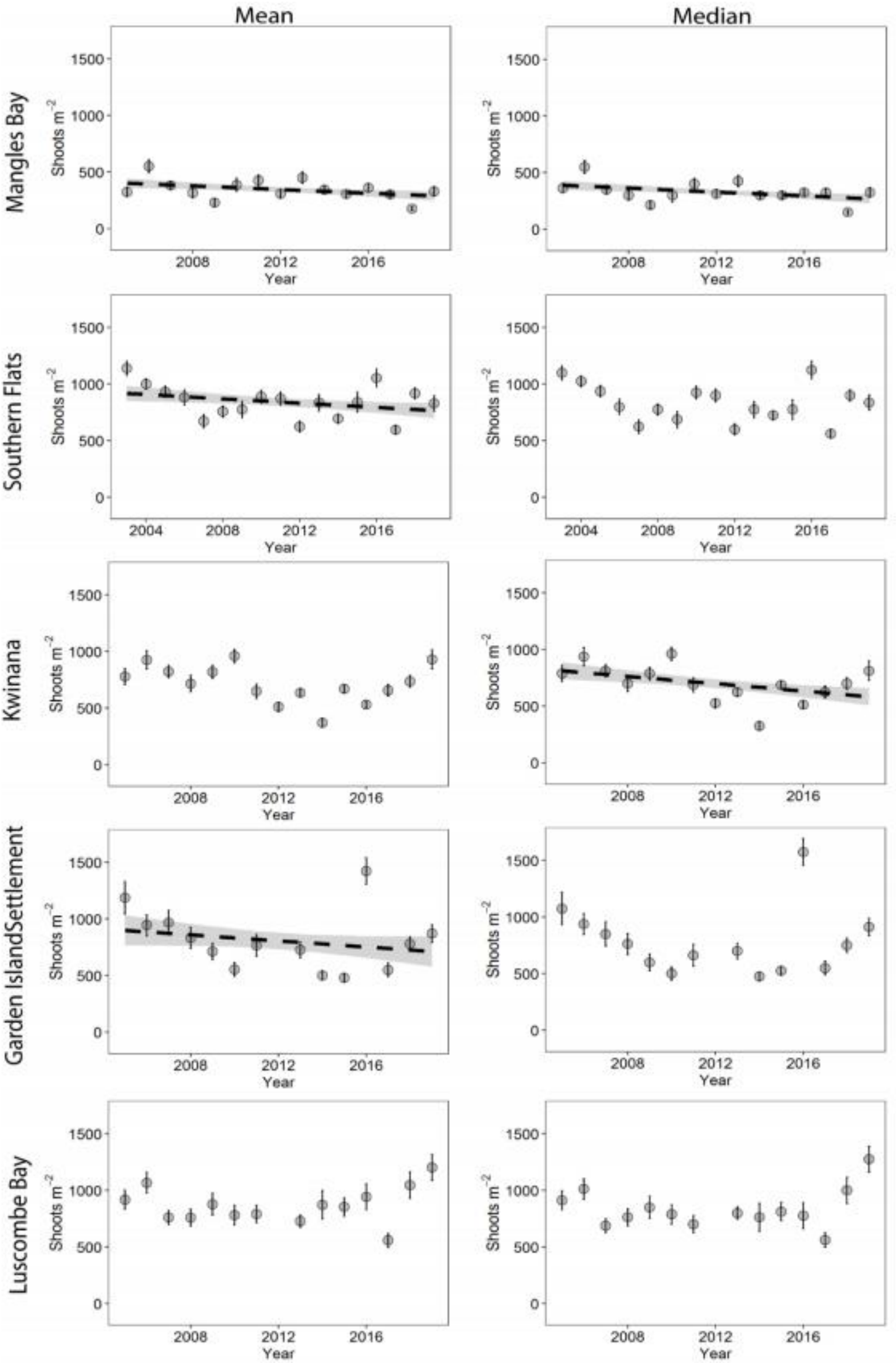
the other monitoring sites outside Cockburn Sound (Coogee, Carnac Island, Mersey Point, and Bird Island).

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). There were potential downward trends in mean and median shoot densities recorded at Warnbro Sound 5.2 m.



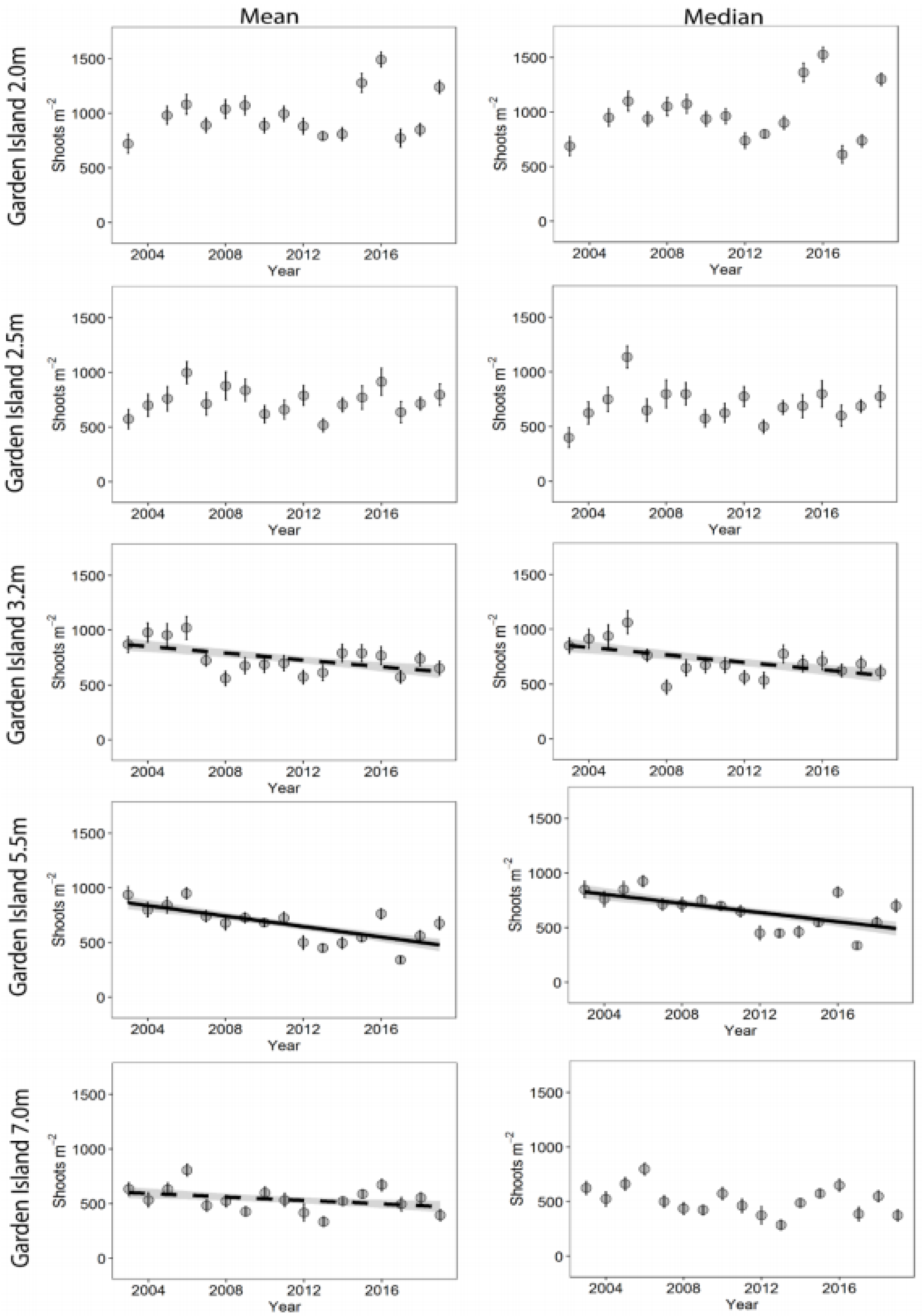
Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.

Figure D.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.



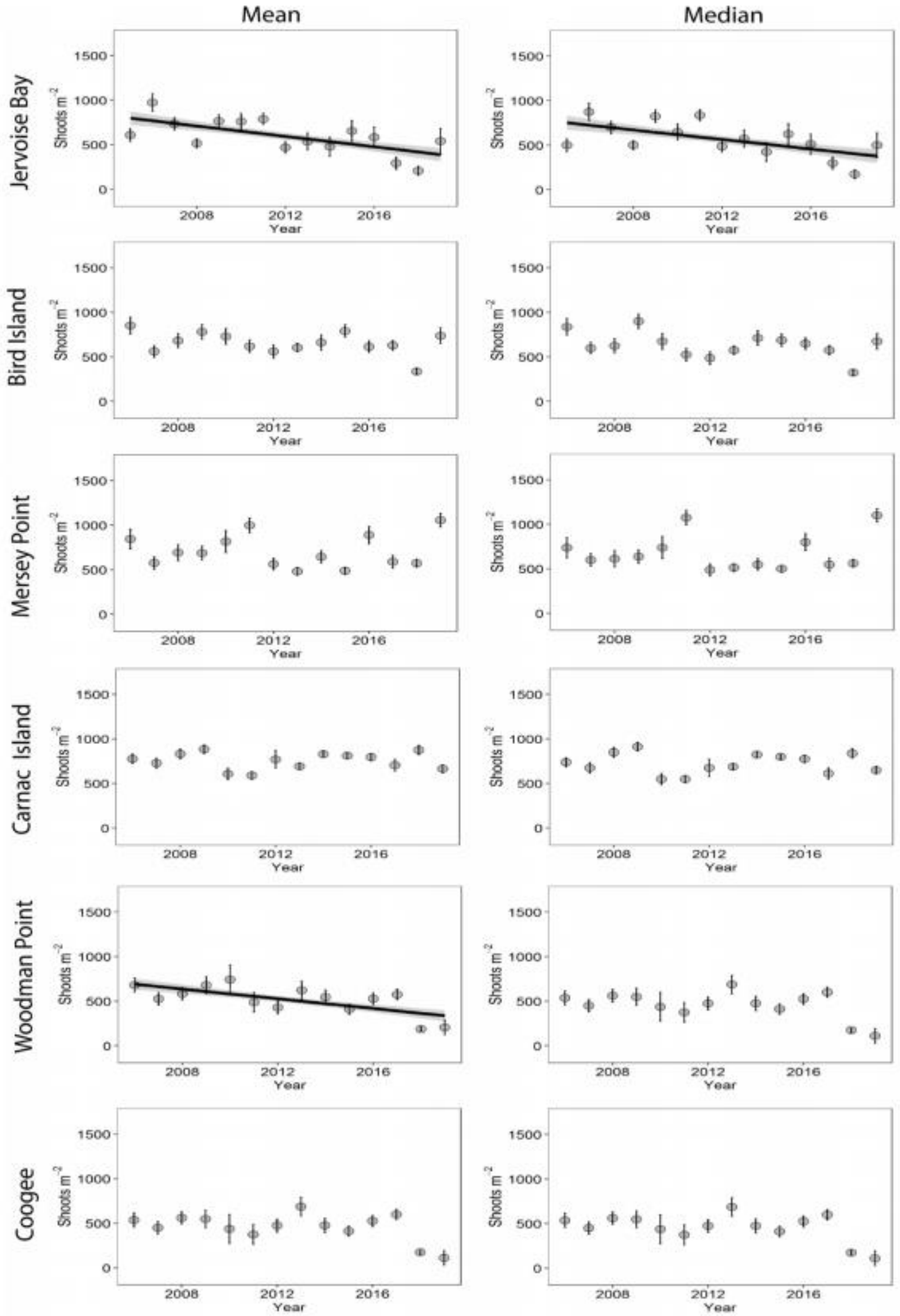
Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.

Figure D.2. Trends in mean (± standard error) and median shoot densities at five potential impact sites 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.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.

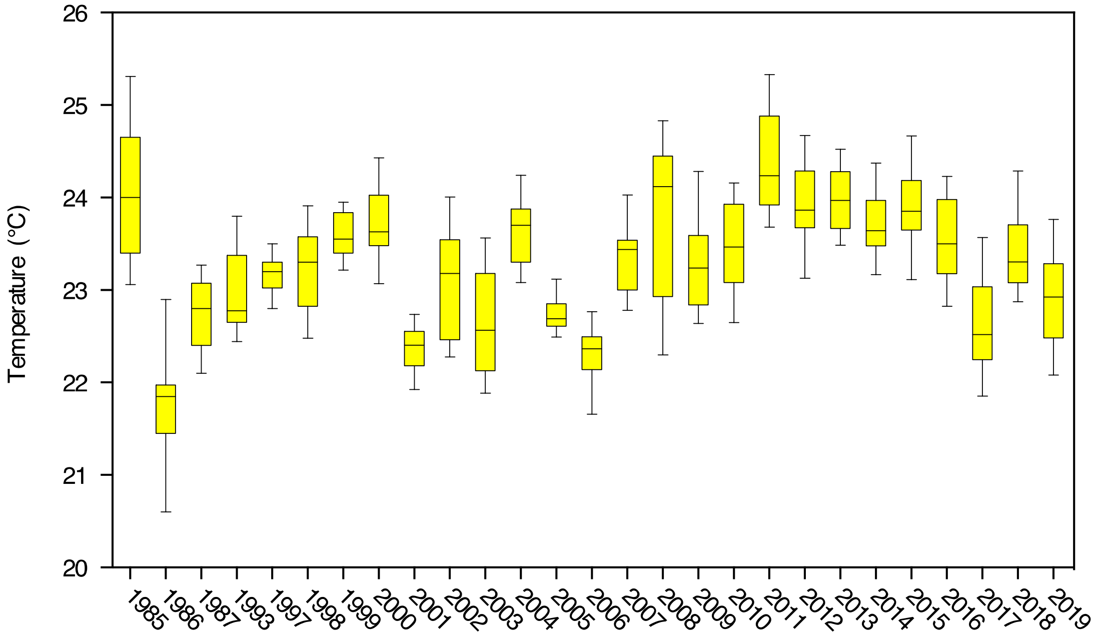
The results of the Mann-Kendall trend analyses of the mean lower depth limit (LDL) at the four 'depth limit' sites are presented in Table D.2 (Fraser et al. 2019). There were no significant trends in LDL over time for any of the sites. However, these data should be treated with caution because of the absence of data for the period from 2009–12. The depth transects sites at Southern Flats and Mangles Bay were excluded from the trend analyses as these sites were recently established.

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	0.40	0.46
Garden Island South	0.47	0.26
Woodman Point	0.20	0.81
Warnbro Sound	0.40	0.46

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 (Cossington and Wienczugow 2019). February temperatures have been used as historically it has been the warmest month for water temperatures and provides more reliable comparisons of near maximum temperatures.



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 1985 to 2019.

The trends in water temperature in Cockburn Sound are similar to those reported elsewhere off the Western Australian coastline and are attributed to global climate change (Keesing *et al*. 2016).

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.

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

[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).

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).