GOVERNMENT OF
WESTERN AUSTRALIA

Cockburn Sound Annual Environmental Monitoring Report 2016–2017

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

Cockburn Sound Management Council

Produced and published by
Cockburn Sound Management Council
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7000
Facsimile +61 8 6364 7001
National Relay Service 13 36 77

October 2017

Acknowledgements

The Cockburn Sound Management Council would like to thank the public authorities who have provided environmental monitoring data and information for inclusion in this report.

The Council would in particular like to thank Mr John Polglaze (community representative on the Council), Mr Kevin McAlpine (EPA Services, Department of Water and Environmental Regulation) and Dr Peter Musk (Strategic Policy and Programs (Environment), Department of Water and Environmental Regulation) for reviewing a draft of this report. The Council would also like to thank Mr Denis Doak and Mr Gino Valenti (Fremantle Ports), Mr Gordon Groth and Ms Caroline Harris (Water Corporation), Dr Dave Abdo (Department of Primary Industries and Regional Development), Ms Tracey Stamp, Mr Jared Koutsoukos and Dr Richard Lugg (Environmental Health Directorate, Department of Health) and Dr Bill Richmond (Contaminated Sites, Department of Water and Environmental Regulation) for reviewing sections of a draft of this report.

The Department of Water and Environmental Regulation was established by the Government of Western Australia on 1 July 2017. It is a result of the amalgamation of the Department of Environment Regulation, Department of Water and the Office of the Environmental Protection Authority. This publication may contain references to previous government departments and programs. Please contact CSMC@DWER.wa.gov.au to clarify any specific information.

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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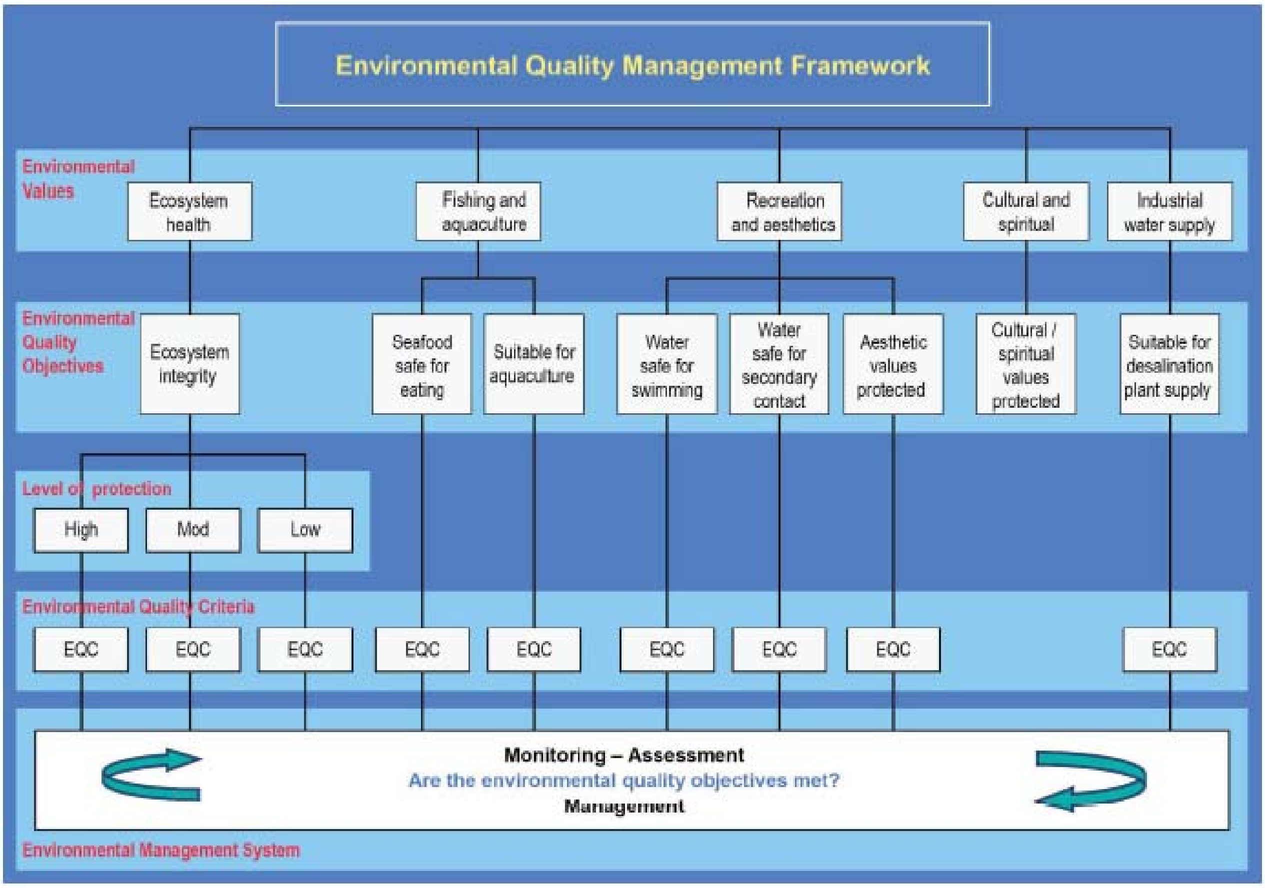
1. Introduction

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 2016–17 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 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 Table 1.

Table 1. Environmental quality indicators and data sources reported on in 2016–17.

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) (formerly the Department of Environment Regulation)
		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) (formerly the Department of Fisheries)
	Toxicants (marine waters)	Metals and metalloids	Aluminium, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Lithium, Manganese, Mercury, Silver, Zinc	DWER Fremantle Ports
		Non-metallic inorganics	Ammonia	
		Organics	Benzene, toluene, ethylbenzene, xylene (BTEX) Naphthalene (polycyclic aromatic hydrocarbon)	
		Oils and petroleum hydrocarbons	Total recoverable hydrocarbons (TRHs)	
		Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)	21 substances	
	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)	

Environmental Quality Objective	Environmental Quality Criteria		Indicator	Data Source
		Oils and petroleum hydrocarbons	TRHs	
Maintenance of seafood safe for human consumption	Biological contaminants		Faecal pathogens in water *Escherichia coli* (*E. coli*) in shellfish flesh Algal biotoxins	Blue Lagoon Mussels DPIRD
	Chemicals	Metals	Inorganic arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Selenium, Zinc	Blue Lagoon Mussels Fremantle Ports
		Organometallics	TBT, DBT, MBT	
		Organic chemicals	Polychlorinated biphenyls (PCBs) PAHs	
		Pesticides	Organochlorine pesticides (Aldrin and Dieldrin, Benzene hexachloride [BHC], Lindane, Chlordane, Dichlorodiphenyltrichloro-ethane (DDT), Dichloro-diphenyldichloroethylene (DDE), Dichlorodiphenyl-dichloroethane [DDD], Heptachlor, Hexachlorobenzene [HCB]) Organophosphate pesticides	
Maintenance of aquaculture	Physico-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	City of Cockburn, City of Kwinana, City of Rockingham
	Physical		pH Water clarity	DWER
	Toxic chemicals	Inorganic chemicals	Copper, Manganese Nitrate–Nitrite	DWER Fremantle Ports
		Organic chemicals	BTEX	
		PFAS	21 substances	
Maintenance of secondary contact recreation values	Biological		Faecal pathogens	City of Cockburn, City of Kwinana, City of Rockingham
	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	

Environmental Quality Objective	Environmental Quality Criteria	Indicator	Data Source
		Boron Bromide	

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

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

With respect to the Environmental Value 'Cultural and Spiritual', 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 (EPA 2017). It is more difficult to define spiritual values in terms of environmental quality requirements.

2. Environmental Value: Ecosystem Health

2.1 Environmental Quality Objective

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

2.2 Levels of Protection

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

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

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

A few small areas around outfalls in Cockburn Sound (less than one per cent of the protected area) have been designated as having a low level of ecological protection, where 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 other societal benefits also need to be considered (for example use of marine waters for receiving waste and the economic benefits of industrial development) when managing environmental quality and these 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.

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[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).

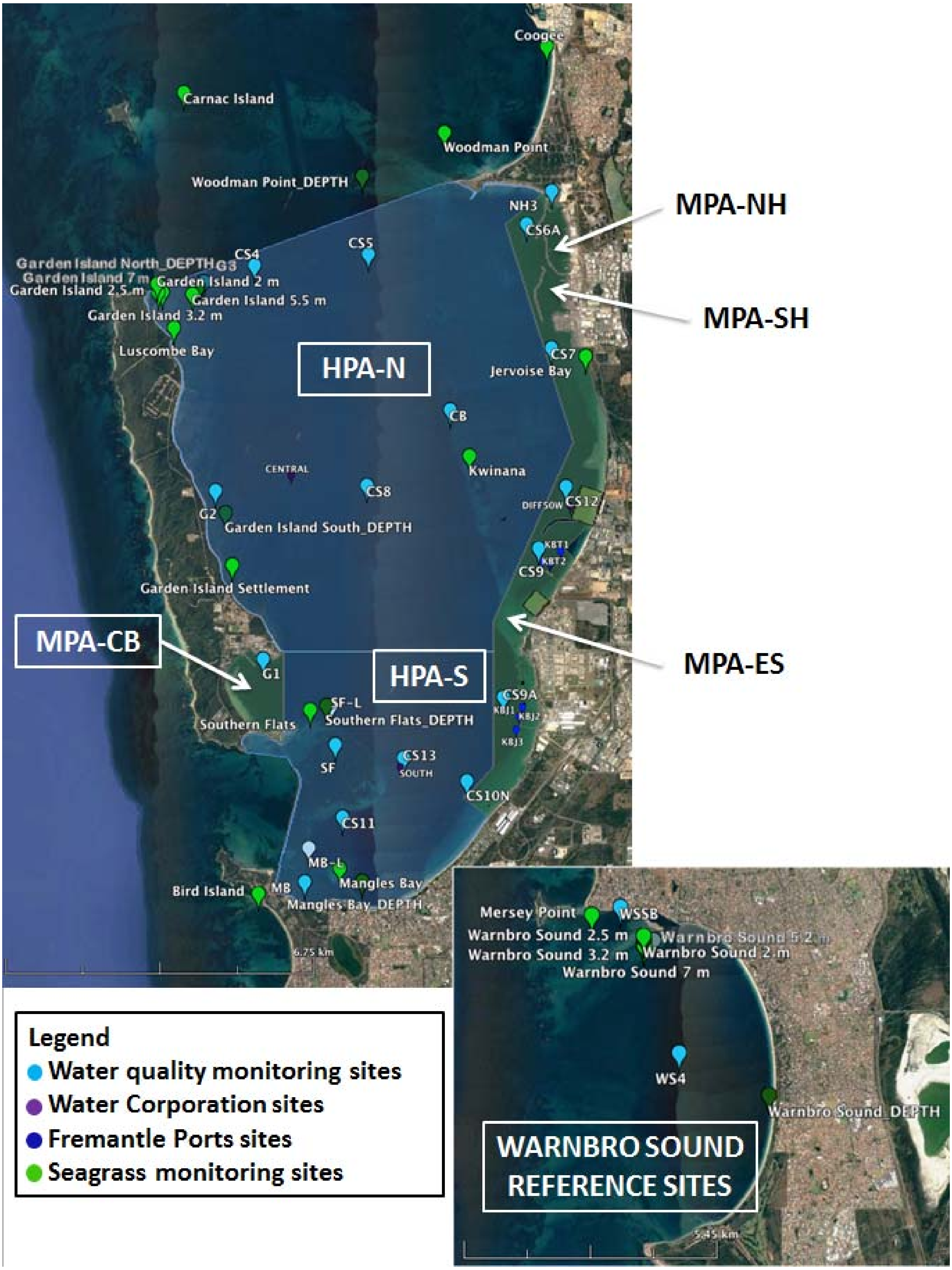

Figure 2. The ecological protection areas in Cockburn Sound and the location of water quality, sediment quality and seagrass monitoring sites in Cockburn Sound and reference sites in Warnbro Sound.

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

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	**CS4, CS5, CS8, G2, G3 and CB sampled for perfluoroalkyl and polyfluoroalkyl substances (PFAS)**
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 **Southern Flats_DEPTH, Mangles Bay_DEPTH**	**CS11, CS13, Southern Flats (SF) and Mangles Bay (MB) sampled for PFAS** **Six sites in Mangles Bay sampled for metals in water**
Moderate Protection Area Careening Bay (MPA-CB)	G1		**G1 sampled for PFAS**
Moderate Protection Area Eastern Sound (MPA-ES)	CS6A, CS7, CS9, CS9A, CS10N and CS12; DIFF50W	Jervoise Bay	**CS6A, CS7, CS9, CS9A, CS10N and CS12 sampled for PFAS** 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)		**Jervoise Bay Northern Harbour (NH3) sampled for PFAS**
Moderate Protection Area Southern Harbour (MPA-SH)	Not currently monitored		
Reference sites	WS4, WSSB/WSSB-L Light attenuation measured at WSSB-L located close to the shallow site WSSB since December 2015	Warnbro Sound (WS) 2.0 m, 2.5 m, 3.2 m, 5.2 m, 7.0 m Warnbro Sound_DEPTH Other seagrass sites outside Cockburn Sound which are also monitored: Coogee, Woodman Point, Carnac Island, Bird Island, Mersey Point, Woodman Point_DEPTH	**WS4 and WSSB sampled for PFAS**

Note: Text in bold indicates new or additional monitoring undertaken in the 2016–17 monitoring period.

2.3 Water Quality and Sediment Quality Monitoring

Water quality was monitored on 16 occasions, generally at weekly intervals, between 1 December 2016 and 27 March 2017 (the summer non river-flow period) at 18 sites in Cockburn Sound and two reference sites in Warnbro Sound (Figure 2; Table 2). Sampling and analysis were undertaken by Murdoch University's Marine and Freshwater Research Laboratory (MAFRL).

On each sampling occasion:

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

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

The Water Corporation undertook quarterly (26 July 2016, 11 October 2016, 20 January 2017 and 4 April 2017) measurements of the physical-chemical parameters dissolved oxygen, salinity and temperature as depth profiles through the water column 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 1 March 2017. Measurements of the physical-chemical parameters dissolved oxygen, salinity and temperature as depth profiles through the water column were also collected at each site on 1 March 2017.

[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.

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

Sediment samples were collected on 17 March 2017 at all the sites except KBJ2, which was sampled on 20 March 2017. Five 100 millimetre (mm) diameter sediment cores were collected within one square metre (m^2) at each site using polycarbonate corers. The top two centimetres of each core was separated and homogenised into one composite sample from each site. The sediment samples were stored on ice for transport to the laboratory. The samples were analysed by Eurofins 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

Seagrass monitoring was undertaken 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 2017.

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

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

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

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

Monitoring was undertaken by the University of Western Australia and the Department of Parks and Wildlife (now the Department of Biodiversity, Conservation and Attractions) 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; and
- minimisation of the occurrence and extent of phytoplankton blooms in Cockburn Sound (EPA 2017).

2.5.1 Re-calculation of the 2016–17 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 2016–17 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 2016–17 monitoring period, the chlorophyll *a* and light attenuation coefficient annual medians at WS4 were within their respective historical ranges (Table 3) and the 2016–17 data were therefore included in the re-calculation of the EQG (Table 4).

Table 3. Assessment of the 2016–17 chlorophyll *a* concentration and light attenuation coefficient (LAC) medians against the 20th and 80th percentiles of the WS4 historical dataset.

	Chlorophyll *a* (micrograms per litre [μg/L])	LAC (log_{10} m^{-1})
Historical dataset 20th percentile	0.40	0.066
Historical dataset 80th percentile	0.81	0.090
2016–17 median	0.60	0.069
Assessment	Met criteria specified in the Reference Document	Met criteria specified in the Reference Document
	2016–17 data included in the 2016–17 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 2016–17 high protection and moderate protection EQG for chlorophyll *a* concentration and light attenuation coefficient (LAC).

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

Median chlorophyll *a* concentrations at the Warnbro Sound reference site WS4 were around 0.7 micrograms per litre (µg/L) in the late 1970s/early 1980s and 1990s, decreased to 0.4 µg/L in the mid-2000s, increased to 0.8 µg/L in 2010–11 and 2011–12, and have varied between 0.6 µg/L and 0.85 µg/L since that time (Figure 3). 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 1.6 µg/L in 2010–11, 1.5 µg/L in 2011–12, 2.2 µg/L in 2012–13, 1.7 µg/L in 2013-14, 1.8 µg/L in 2014–15, 1.4 µg/L in 2015–16 and 3.1 µg/L in 2016–17. Prior to 2010–11 a chlorophyll *a* concentration greater than 1.4 µg/L had been recorded on only one occasion (1.8 µg/L in 2002–03) since chlorophyll *a* concentrations were first measured at WS4.

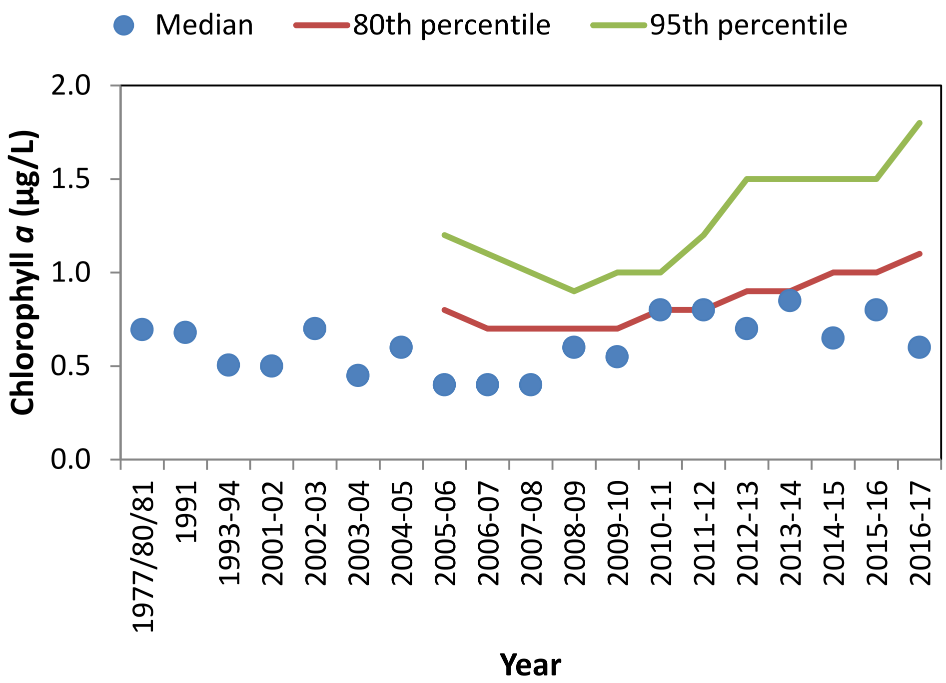


Figure 3. Median chlorophyll *a* concentrations at the Warnbro Sound reference site WS4 and the rolling 6-year 80th and 95th percentiles of chlorophyll *a* concentrations.

There has been a corresponding increase in the EQG for chlorophyll *a* in recent years (Figure 3). The high protection EQG was:

- 0.7 µg/L in 2009–10;
- 0.9 µg/L in 2012–13 and 2013–14; and

- 1.0 µg/L in 2014–15 and 2015–16.

The moderate protection EQG was:

- 1.0 µg/L in 2009–10;
- 1.2 µg/L in 2011–12; and
- 1.5 µg/L in 2014–15 and 2015–16.

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

Table 5. The 2016–17 high protection and moderate protection EQG for phytoplankton biomass.

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

Seagrass shoot density

The EQS for *Posidonia sinuosa* shoot densities are based on 'rolling' four-year percentiles and, consistent with Section 3.1.2 in the Reference Document, are re-calculated and updated each year using the monitoring results for each monitored depth at the Warnbro Sound reference site. Seagrass shoot densities at the reference sites in Warnbro Sound have continued to exhibit significant declines in shoot density (Mohring and Rule 2014; Rule 2015; Fraser *et al*. 2016a 2017). Compared to the shoot densities recorded in 2016, mean and median shoot densities decreased at all the Warnbro Sound reference sites with the exception of median shoot densities at Warnbro Sound 2.0 m (Fraser *et al*. 2017).

In 2017 only two of the original 24 quadrats remained at the Warnbro Sound 2.0 m reference site (Fraser *et al.* 2017) and the calculation of the 'rolling' four-year percentiles was therefore based on 62 shoot density counts. 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 increase in median shoot densities observed at Warnbro Sound 2.0 m is likely to reflect that the median was derived from density counts in the two quadrats remaining at this site.

The re-calculated EQS for each depth are presented in Table 6. Because of the low number of data points at the Warnbro Sound 3.2 m reference site, the shoot densities recorded in the six quadrats along a fifth transect established in 2014 were included in the calculation of the 'rolling' four-year percentiles.

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

Table 6. The 2017 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	650	301	25
Warnbro Sound 2.5 m	615	296	48
Warnbro Sound 3.2 m	325	101	45
Warnbro Sound 5.2 m	400	244	145
Warnbro Sound 7.0 m	125	50	25

The results of Mann-Kendall trend analyses of the EQS for seagrass shoot density are presented in Table 7. Significant (α = 0.05) downward trends in the 'rolling' four-year 20th percentiles of seagrass shoot densities were reported at Warnbro Sound 2.0 m, Warnbro Sound 3.2 m and Warnbro Sound 7.0 m; the 'rolling' four-year 5th percentiles at Warnbro Sound 2.0 m, Warnbro Sound 2.5 m and Warnbro Sound 7.0 m; and the 'rolling' four-year 1st percentiles at Warnbro Sound 2.0 m, Warnbro Sound 2.5 m, Warnbro Sound 3.2 m and Warnbro Sound 5.2 m.

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

Reference Site	Rolling 4-year 20th percentiles of seagrass shoot density (shoots per square metre [shoots/m^2])		Rolling 4-year 5th percentiles of seagrass shoot density (shoots/m^2)		Rolling 4-year 1st percentiles of seagrass shoot density (shoots/m^2)	
	Mann-Kendall Statistic	*p*-value (two-tailed test)	Mann-Kendall Statistic	*p*-value (two-tailed test)	Mann-Kendall Statistic	*p*-value (two-tailed test)
Warnbro Sound 2.0 m	-0.75	**0.001**	-0.88	**< 0.0001**	-0.89	**0.00015**
Warnbro Sound 2.5 m	-0.25	0.298	-0.68	**0.003**	-0.89	**0.00012**
Warnbro Sound 3.2 m	-0.48	**0.038**	-0.31	*0.191*	-0.71	**0.003**
Warnbro Sound 5.2 m	-0.40	*0.093*	-0.42	*0.072*	-0.60	**0.011**
Warnbro Sound 7.0 m	-0.76	**0.001**	-0.57	**0.015**	-0.27	0.317

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' has been identified as a potential cause of the decline in shoot densities at the Warnbro Sound reference sites, with some sites (e.g. Warnbro Sound 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 Warnbro Sound 2.0 m (Lavery and Westera 2005). Significant decreases in shoot densities at Warnbro Sound 3.2 m were also reported in 2005. Relatively high levels of intrusion of potentially toxic sediment sulfides into seagrass tissues have been reported at the reference sites which may also be contributing to the declines observed at these sites (Fraser *et al.* 2016b).

2.5.2 Assessment of Compliance with the 'Nutrient enrichment' EQC

Chlorophyll *a* and Light Attenuation

Chlorophyll *a* concentrations and light attenuation coefficients recorded at the 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.3; Figure 2) over the 2016–17 non river-flow period were assessed against the 'Nutrient enrichment' EQG (EQG A, Table 1a, Reference Document):

High protection: *The median chlorophyll a concentration/light attenuation coefficient in HPA-N and HPA-S during the 2016–17 non river-flow period is not to exceed a chlorophyll a concentration of 1.10 µg/L or a light attenuation coefficient of 0.096 log_{10} m^{-1}.*

Moderate protection: *The median chlorophyll a concentration/light attenuation coefficient in MPA-ES and MPA-CB during the 2016–17 non river-flow period is not to exceed a chlorophyll a concentration of 1.80 µg/L or a light attenuation coefficient of 0.114 log_{10} m^{-1}.*

The results are presented in Table 8 and Figures 4, 5, 6 and 7. The 'Nutrient enrichment' EQG for chlorophyll *a* were met in HPA-N, MPA-CB and MPA-ES, but not in HPA-S. The 'Nutrient enrichment' EQG for light attenuation were met in HPA-N and MPA-CB, but not in HPA-S and MPA-ES. The elevated chlorophyll *a* concentrations and light attenuation coefficients are indicative of nutrient enrichment in parts of Cockburn Sound.

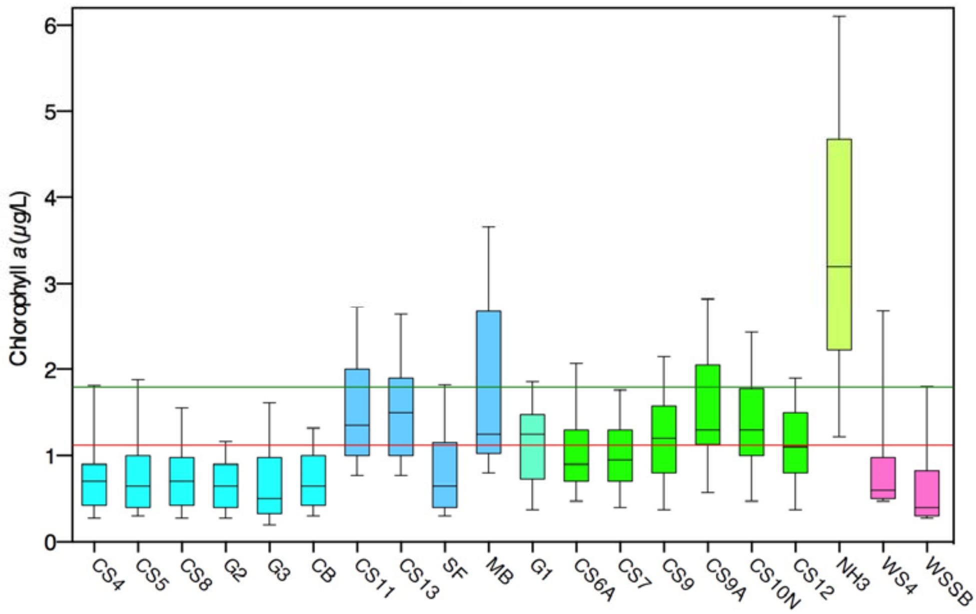
The highest chlorophyll *a* concentrations and light attenuation coefficients were recorded at Jervoise Bay Northern Harbour (NH3) in MPA-NH; however, due to the absence of macro-benthic primary producers (for example seagrass) within the harbour, the 'Nutrient enrichment' EQG were not applied in this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

Table 8. Assessment of the 2016–17 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
		2016–17 EQG	2016–17 Site median	2016–17 Ecological Protection Area median	2016–17 EQG	2016–17 Site median	2016–17 Ecological Protection Area median	
HPA-N	CS4	1.1	0.7	0.6	0.096	0.085	0.093	EQG met
	CS5		0.7			0.094		
	CS8		0.7			0.089		
	CB		0.7			**0.113**		
	G2		0.7			0.092		
	G3		0.5			0.087		
HPA-S	CS11	1.1	**1.4**	**1.2**	0.096	**0.103**	**0.105**	Chlorophyll *a*

Ecological Protection Area	Site	Chlorophyll *a* (µg/L) 2016–17 EQG	Chlorophyll *a* (µg/L) 2016–17 Site median	Chlorophyll *a* (µg/L) 2016–17 Ecological Protection Area median	LAC (log_{10} m^{-1}) 2016–17 EQG	LAC (log_{10} m^{-1}) 2016–17 Site median	LAC (log_{10} m^{-1}) 2016–17 Ecological Protection Area median	Assessment
	CS13		**1.5**			**0.111**		and LAC EQG not met
	SF		0.7			**0.097**		
	MB/MB-L		**1.3**			**0.113**		
MPA-CB	G1	1.8	1.3	1.3	0.114	0.106	0.106	EQG met
MPA-ES	CS10N	1.8	1.3	1.2	0.114	0.104	**0.115**	Chlorophyll *a* EQG met LAC EQG not met
	CS12		1.1			**0.115**		
	CS6A		0.9			**0.117**		
	CS7		1.0			**0.122**		
	CS9		1.2			0.108		
	CS9A		1.3			0.113		
MPA-NH	NH3	N/A	3.2	3.2	N/A	0.151	0.151	N/A

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



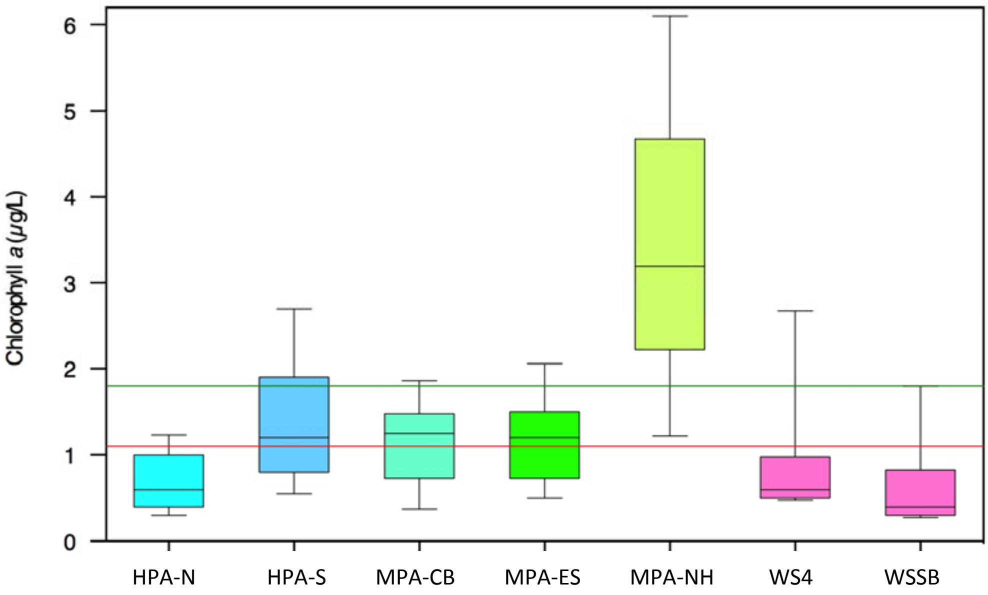
Notes:

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

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

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

Figure 4. Median chlorophyll *a* concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2016 to March 2017.

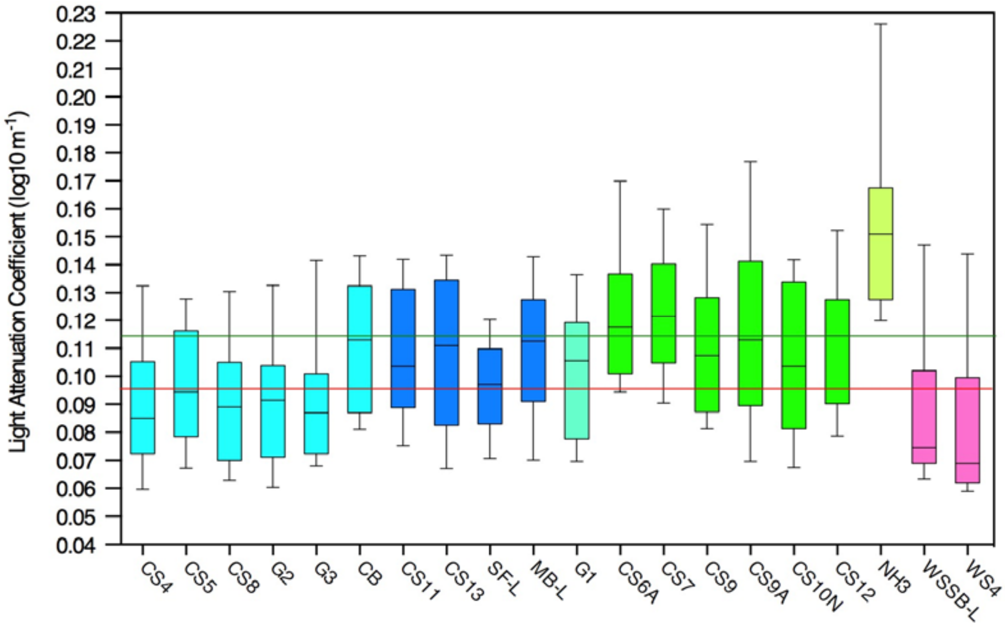


Notes:

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

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

Figure 5. 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 2016 to March 2017.



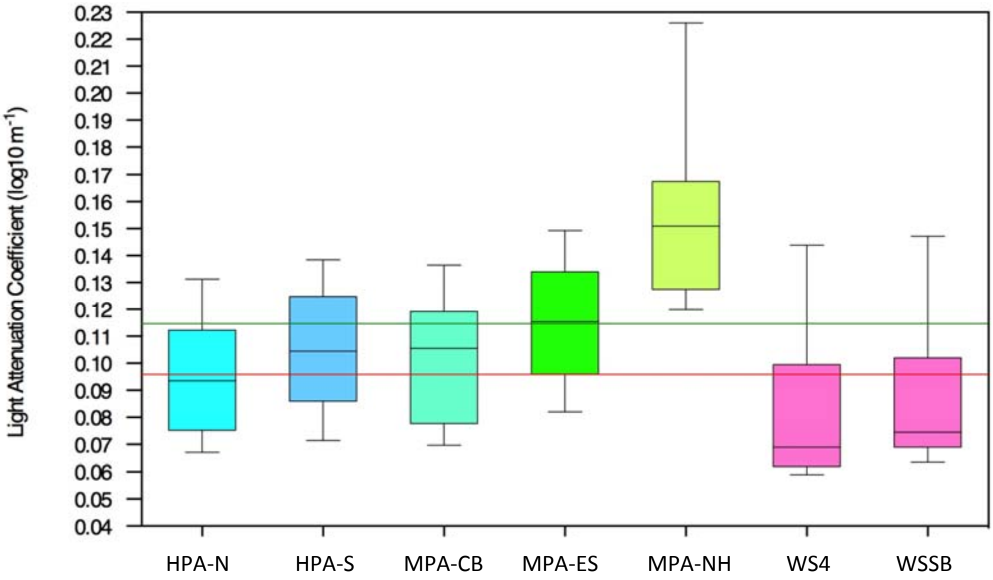
Notes:

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

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

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

Figure 6. Median light attenuation coefficient at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2016 to March 2017.



Notes:

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

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

Figure 7. 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 2016 to March 2017.

There have been improvements in water quality in Cockburn Sound over the last 30 years, with a significant reduction in dissolved inorganic nutrient concentrations since around 2006–07 (Keesing *et al.* 2016; Cossington and Wienczugow 2017; Appendix B). This is attributed to a reduction in nutrient inputs from external sources, including the diversion of industrial wastewater and the discharge from wastewater treatment plants into the Sepia Depression Ocean Outlet Landline (SDOOL) in 2005; improvements in groundwater through remediation; and a reduction in groundwater recharge due to less than average long-term rainfall.

Information on nutrient concentrations (total nitrogen, nitrate–nitrite, ammonium, total phosphorus and filterable reactive phosphorus) at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound over the 2016–17 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 and MPA-ES which triggers 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*

[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.

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/m²*
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:	*2016: 690 shoots/m²*
	2017: 615 shoots/m²
3.0–4.0 m depth:	*2016: 280 shoots/m²*
	2017: 325 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 2017 data:

2.0–3.0 m depth:	*296 shoots/m²*
3.0–4.0 m depth:	*101 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).*

Moderate 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 MPA-ES during January and in any one of the two consecutive years is:

- *Greater than the 'absolute minimum' (1st percentile) seagrass shoot density:*

2.0–3.0 m depth:	*275 shoots/m²*

and

- *Greater than the annually updated rolling 5th percentile of* the *Warnbro Sound reference site shoot density:*

  2.0–3.0 m depth: 2016: 358 shoots/m²

  2017: 296 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 MPA-ES in the same year is greater than the rolling 1st percentile of the Warnbro Sound reference site shoot density updated to incorporate 2017 data:

2.0–3.0 m depth: 48 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).

<u>*EQS(i) Chlorophyll a concentration and light attenuation*</u>

Assessment of chlorophyll *a* concentrations and light attenuation coefficients for two consecutive years indicates that the 'Nutrient enrichment' EQG were met in 2015–16 but not met in 2016–17 in HPA-S and MPA-ES (Table 9). The 'Nutrient enrichment' EQG were therefore not exceeded in a second consecutive year.

Table 9. Assessment of chlorophyll *a* concentrations and light attenuation coefficients (LAC) in HPA-S and MPA-ES for 2015–16 and 2016–17 against the 'Nutrient enrichment' EQG.

Ecological Protection Area	2015–16				2016–17				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	1.00	0.9	0.097	0.096	1.10	**1.2**	0.096	**0.105**	EQG met in 2015–16 but not 2016–17
MPA-ES	1.53	1.1	0.113	0.106	1.80	1.2	0.114	**0.115**	EQG met in 2015–16 but not 2016–17

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

<u>*EQS(i) Seagrass shoot density*</u>

While the 'Nutrient enrichment' EQG were not exceeded in a second consecutive

year, the 2016 and 2017 median seagrass shoot densities at the Southern Flats (approximately 2.5 m depth) and Mangles Bay (approximately 3.2 m depth) monitoring sites located in HPA-S and the Jervoise Bay (approximately 2.5 m depth) monitoring site located in MPA-ES, were compared against the 'absolute minimum' seagrass shoot densities (Table 10) and the 'rolling' four-year 20th (high protection) or 5th (moderate protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites (Table 11).

At all three sites, the median shoot densities recorded in 2016 and 2017 were higher than the 'absolute minimum' seagrass shoot densities recorded at the relevant reference site (Table 10).

Table 10. Assessment of median seagrass shoot density at Southern Flats, Mangles Bay and Jervoise Bay seagrass monitoring sites for two consecutive years against the 'absolute minimum' seagrass shoot densities.

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

At Southern Flats the median shoot density recorded in 2016 was higher than the 'rolling' four-year 20th percentile, but the median shoot density recorded in 2017 was lower than the 'rolling' four-year 20th percentile (Table 11). At Mangles Bay, the median shoot density recorded in 2016 was higher than the 'rolling' four-year 20th percentile and the median shoot density recorded in 2017 was equal to the 'rolling' four-year 20th percentile (Table 11). At Jervoise Bay, the median shoot densities recorded in 2016 and 2017 were higher than the 'rolling' four-year 5th percentiles of shoot densities measured at the relevant Warnbro Sound reference site (Table 11).

Table 11. Assessment of median seagrass shoot density at Southern Flats, Mangles Bay and Jervoise Bay seagrass monitoring sites for two consecutive years against the 'rolling' four-year 20th (high protection) or 5th (moderate protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites.

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

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

EQS(ii) Seagrass shoot density

For assessment against the 'Nutrient enrichment' EQS(ii), the 2017 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) or 1st (moderate protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites (Table 12). The EQS(ii) was met at all three sites.

Table 12. Assessment of median seagrass shoot density at Southern Flats, Mangles Bay and Jervoise Bay seagrass monitoring sites against the 'rolling' four-year 5th (high protection) or 1st (low protection) percentiles of seagrass shoot densities measured at the relevant Warnbro Sound reference sites.

Ecological Protection Area	Year	Seagrass Monitoring Site	Reference Site	Rolling 4-year 5th or 1st percentile (shoots/m^2)	Median shoot density (shoots/m^2)	Assessment
HPA-S	2017	Southern Flats	WS 2.5 m	296	563	EQS(ii) met
	2017	Mangles Bay	WS 3.2 m	101	325	EQS(ii) met
MPA-ES	2017	Jervoise Bay	WS 2.5 m	48	300	EQS(ii) met

EQS(iii) Lower Depth Limit

The assessment against the 'Nutrient enrichment' EQS(iii) involves analysis of the Lower Depth Limit (LDL) of seagrass meadows at a 'depth limit' site relative to the baseline depth. The mean LDL of seagrass at the Garden Island North, Garden Island South and Woodman Point 'depth limit' sites were significantly deeper in 2017 compared to the baseline LDL for each site (Table 13). The EQS(iii) was met at all the 'depth limit' sites. Note there are no 'depth limit' sites in MPA-ES and the two 'depth limit' sites in HPA-S were only established in 2017. The increase or stability in the distribution of seagrass in deeper waters suggests that water quality and light availability in HPA-N are generally adequate for seagrass growth given that seagrass is growing near its depth limit in Cockburn Sound.

Table 13. Mean baseline and 2017 Lower Depth Limit (LDL) at the Garden Island North, Garden Island South, Woodman Point and Warnbro Sound '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 2017 Lower Depth Limit (m)	*P* (one-tail)	Assessment
HPA-N	Garden Island North	9.8	10.6	**0.049**	EQS(ii) met
	Garden Island South	7.6	9.0	**< 0.001**	EQS(ii) met
Outside Cockburn Sound	Woodman Point	8.4	10.6	**0.042**	EQS(ii) met
Reference Site	Warnbro Sound	8.7	8.9	0.271	N/A

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

Discussion

On the basis of the information available, it is considered that while the 'Nutrient enrichment' EQG were exceeded in HPA-S and MPA-ES, the EQS were met, indicating that nutrient enrichment-related reduction in light availability at the seafloor is unlikely to be driving changes in seagrass shoot density at these sites. There have been decreases in median shoot densities recorded at the sites in HPA-S (Southern

Flats and Mangles Bay) and in MPA-ES (Jervoise Bay), however the trends were not significant ($\alpha = 0.05$) (Appendix D).

The seagrass declines and lack of recovery in Cockburn Sound, Owen Anchorage and Warnbro Sound are possibly being driven by environmental factors other than water quality and light availability, with factors such as sediment stressors, hydrodynamics or temperature changes suggested as potential causes (Mohring and Rule 2013; Fraser *et al.* 2016b). Fraser *et al.* (2016b) considered the fact that there has been an improvement in water quality at the same time as a decline in seagrass shoot density suggests that the current pressure-response pathway needs to be modified to account for other drivers of seagrass declines and lack of recovery.

Seagrass Shoot Density at other Sites within and outside Cockburn Sound

With the exception of two sites (Mangles Bay and Kwinana), median seagrass shoot densities at the monitoring sites in Cockburn Sound were lower in 2017 than in 2016 (Table 14). In particular, median shoot densities were lower at the Garden Island sites, with the median shoot densities recorded in 2017 at Garden Island Settlement, Garden Island 2.0 m and Garden Island 5.5 m less than half the densities recorded in 2016. Median shoot densities were also lower in 2017 than in 2016 at four of the sites outside Cockburn Sound (Coogee, Bird Island, Mersey Point, and Carnac Island) and at four of the reference sites in Warnbro Sound.

Table 14. Median seagrass shoot densities at seagrass monitoring sites inside and outside Cockburn Sound and at the Warnbro Sound reference sites.

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

The ‘Nutrient enrichment’ EQG were met in HPA-N. 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 15). 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 15. 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)	2017 median shoot density (shoots/m^2)
HPA-N	Garden Island Settlement	WS 2.0 m	666	650	**550**
	Kwinana	WS 5.2 m	419	400	625
	Garden Island 2.0 m	WS 2.0 m	666	650	**613**
	Garden Island 2.5 m	WS 2.5 m	500	615	**600**
	Garden Island 3.2 m	WS 3.2 m	171	325	625
	Garden Island 5.5 m	WS 5.2 m	419	400	**338**
	Garden Island 7.0 m	WS 7.0 m	59	125	388
	Luscombe Bay	WS 2.0 m	666	650	**563**
Sites outside Cockburn Sound	Coogee	WS 5.2 m	419	400	**300**
	Bird Island	WS 2.0 m	666	650	**575**
	Mersey Point	WS 3.2 m	500	325	550
	Carnac Island	WS 5.2 m	419	400	613
	Woodman Point	WS 2.5 m	500	615	**600**

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 Garden Island 3.2 m, Garden Island 7.0 m and Kwinana monitoring sites 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 15). At the Garden Island Settlement, Garden Island 2.0 m, Garden Island 5.5 m and Luscombe Bay monitoring sites, median shoot densities were below both the ‘absolute minimum’ shoot density and the ‘rolling’ four-year 20th percentile of shoot density at the relevant Warnbro Sound reference sites. Median seagrass shoot density at Garden Island 2.5 m was below the ‘rolling’ four-year 20th percentile of shoot density, but above the ‘absolute minimum’ shoot density.

Median seagrass shoot densities at Mersey Point and Carnac Island 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 15). Median seagrass shoot density at Woodman Point was above the ‘absolute minimum’ shoot density, but below the ‘rolling’ four-year 20th percentile of shoot density.

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 2016–17 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 2016–17 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 2016–17 non river-flow period.*

Moderate protection:

i. *Median phytoplankton biomass in MPA-ES is not to exceed 3.30 µg/L on more than one occasion during the 2016–17 non river-flow period.*

ii. *Phytoplankton biomass at any site is not to exceed 3.30 µg/L on 50% or more occasions during the 2016–17 non river-flow period.*

The results of the assessment against the EQG are presented in Table 16 and Table 17. The high protection 'Phytoplankton biomass' EQG(i) was not met in HPA-S and the high protection 'Phytoplankton biomass' EQG(ii) was not met at Mangles Bay (MB) over the 2016–17 non river-flow period. This was the first monitoring period since 2012–13 in HPA-S and 2011–12 at MB that phytoplankton biomass did not meet the 'Phytoplankton biomass' EQG. The 'Phytoplankton biomass' EQG(i) has not been met six times since 2005–06 in HPA-S. The median chlorophyll *a* concentrations in HPA-S and at MB are presented in Figure 8.

Table 16. Assessment of median chlorophyll *a* concentrations in HPA-N, HPA-S and MPA-ES on each sampling occasion during the 2016–17 non river-flow period against the 'Phytoplankton biomass' EQG(i).

Sampling date	HPA-N Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	HPA-S Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	MPA-ES Chlorophyll *a* concentration (µg/L) EQG: 3.30 µg/L
1/12/2016	0.3	0.9	0.5
9/12/2016	0.3	0.8	0.5
16/12/2016	0.3	1.0	0.6
23/12/2016	0.4	1.2	0.8
9/01/2017	0.6	1.1	1.1
16/01/2017	0.8	**2.3**	1.2
23/01/2017	0.8	1.4	1.3
30/01/2017	0.9	1.6	1.7
6/02/2017	0.5	1.1	0.9
13/02/2017	0.9	0.9	1.1
20/02/2017	1.5	1.2	1.5
27/02/2017	0.9	1.8	1.6
6/03/2017	0.6	1.3	1.1
13/03/2017	1.0	**3.1**	1.4
20/03/2017	1.6	**2.2**	2.2

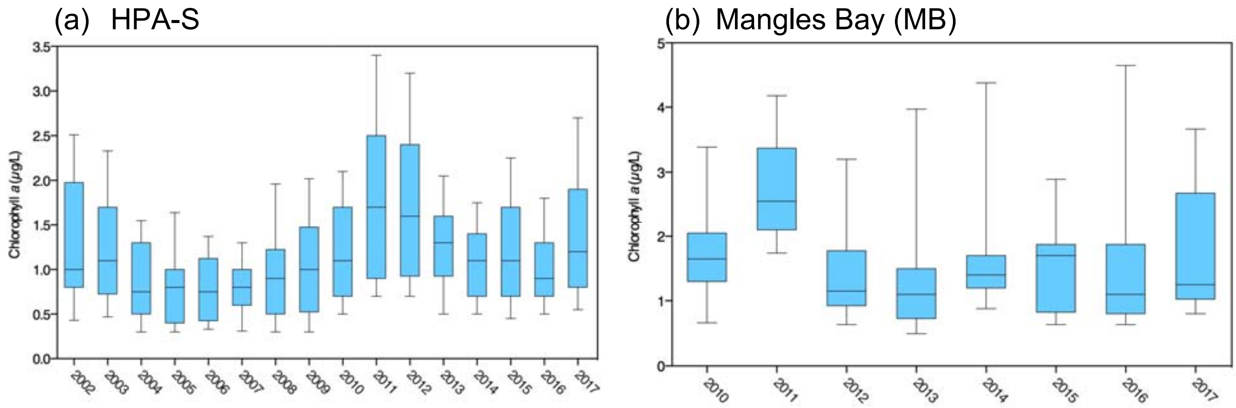
Sampling date	HPA-N Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	HPA-S Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	MPA-ES Chlorophyll *a* concentration (µg/L) EQG: 3.30 µg/L
27/03/2017	1.2	1.8	1.9
Assessment	EQG(i) met in HPA-N and MPA-ES on all sampling occasions EQG(i) not met in HPA-S on three sampling occasions during the 2016–17 non river-flow period		

Note: text in bold indicates an exceedance of the EQ**G.**

Table 17. Assessment of chlorophyll *a* concentrations at 18 water quality monitoring sites in Cockburn Sound during the 2016–17 non river-flow period against the 'Phytoplankton biomass' EQG(ii).

Ecological Protection Areas	Site	2016–17 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	1	6.25%	EQG(ii) met
	CS5		16	1	6.25%	EQG(ii) met
	CS8		16	1	6.25%	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	2	12.5%	EQG(ii) met
	CS13		16	2	12.5%	EQG(ii) met
	SF		16	0	0%	EQG(ii) met
	MB		**16**	**5**	**31.25%**	EQG(ii) exceeded
MPA-CB	G1	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	16	0	0%	EQG(ii) met
MPA-ES	CS10N	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	16	0	0%	EQG(ii) met
	CS12		16	0	0%	EQG(ii) met
	CS6A		16	1	6.25%	EQG(ii) met
	CS7		16	0	0%	EQG(ii) met
	CS9		16	0	0%	EQG(ii) met
	CS9A		16	1	6.25%	EQG(ii) met
MPA-NH	NH3	Phytoplankton biomass not to exceed 3.30 µg/L on 50% or more occasions	16	7	43.75%	EQG(ii) met

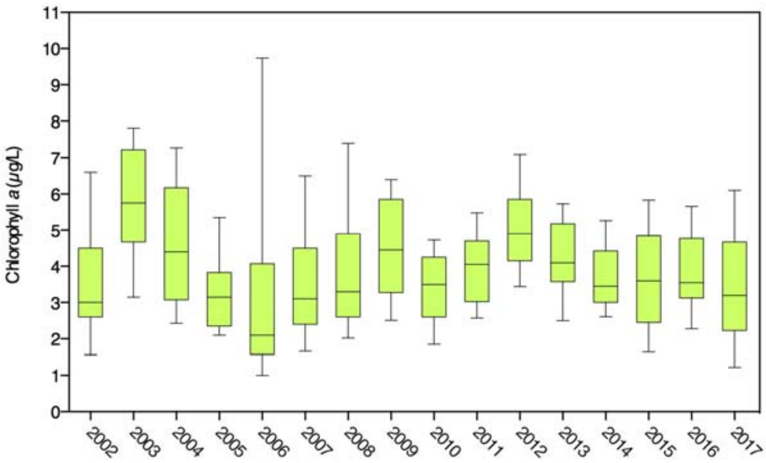
Note: text in bold indicates an exceedance of the EQG.



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

Figure 8. Median chlorophyll *a* concentrations in the High Protection Area South (HPA-S) and Mangles Bay (MB) since the commencement of water quality monitoring.

The moderate protection 'Phytoplankton biomass' EQG(ii) was met in Jervoise Bay Northern Harbour (NH3). This is significant because the moderate protection 'Phytoplankton biomass' EQC have consistently not been met since 2003 when reporting began. Elevated chlorophyll *a* concentrations and decreased light attenuation have also been consistently reported at NH3. The median chlorophyll *a* concentrations at NH3 since 2002 are presented in Figure 9.



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

Figure 9. Median chlorophyll *a* concentrations at the Jervoise Bay Northern Harbour site (NH3).

Assessment against the Environmental Quality Standard

<u>EQS(i) 'Phytoplankton biomass' in HPA-S</u>

The 'Phytoplankton biomass' EQG(i) was not met in HPA-S which triggers more detailed assessment against the high protection 'Phytoplankton biomass' EQS(i) (EQS C(i), Table 1a, Reference Document):

> *Median phytoplankton biomass is not to exceed 2.10 µg/L on more than one occasion during the non river-flow period and in two consecutive years.*

The results are presented in Table 18. Assessment of phytoplankton biomass in HPA-S during the non river-flow period for two consecutive years indicates that the median

phytoplankton biomass exceeded 2.10 µg/L on more than one occasion in 2016–17, but not in 2015–16. The 'Phytoplankton biomass' EQS(i) was therefore met.

Table 18. Assessment of median chlorophyll *a* concentrations in High Protection Area South (HPA-S) against the high protection '*Phytoplankton biomass*' EQS(i) over two consecutive years (2015–16 and 2016–17).

Ecological Protection Area	Year	EQS	Number of occasions EQS was exceeded	Assessment
HPA-S	2015–16	Phytoplankton biomass not to exceed 2.10 µg/L on more than one occasion	0 (out of 16)	EQS met
	2016–17	Phytoplankton biomass not to exceed 2.10 µg/L on more than one occasion	3 (out of 16)	

EQS(ii) 'Phytoplankton biomass' at Mangles Bay

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

> *Phytoplankton biomass at MB is not to exceed 2.10 µg/L on 25% or more occasions during the non river-flow period and in two consecutive years.*

The results are presented in Table 19. 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 per cent or more occasions in 2016–17, but not in 2015–16. The 'Phytoplankton biomass' EQS(ii) was therefore met.

Table 19. Assessment of chlorophyll *a* concentrations at Mangles Bay (MB) against the high protection '*Phytoplankton biomass*' EQS(ii) over two consecutive years (2015–16 and 2016–17).

Site	Year	EQS	Number of occasions EQS was exceeded	Per cent (%) of occasions EQS was exceeded	Assessment
MB	2015–16	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	3 (out of 16)	18.75%	EQS met
	2016–17	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	5 (out of 16)	31.25%	

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

2.6.1 Dissolved Oxygen Concentration

Measurements of dissolved oxygen concentrations (% saturation) recorded in the bottom waters[9] at the 18 water quality monitoring sites in Cockburn Sound (Section 2.3; Figure 2) over the 2016–17 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 20 and Figure 10. As measurements were made at approximately 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.

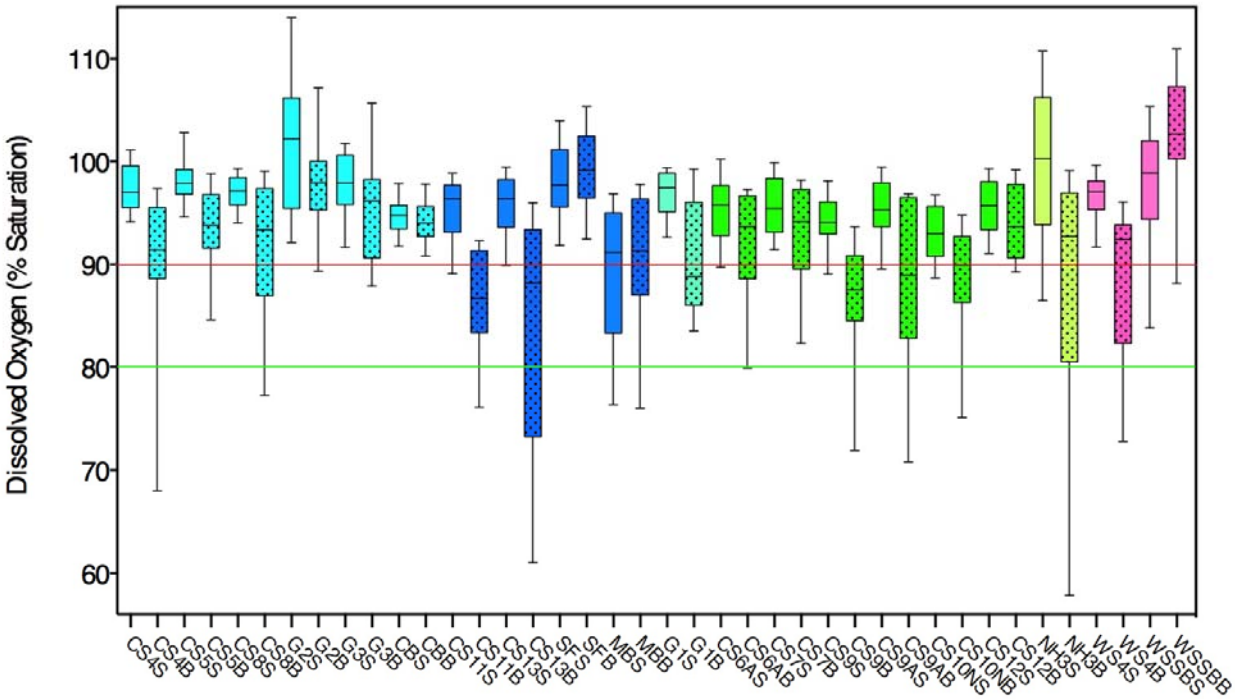
Table 20. Assessment of dissolved oxygen concentrations (% saturation) in the bottom waters at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the 2016–17 non river-flow period against the 'Dissolved Oxygen concentration' EQC.

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	6	1	EQG not met, EQS(i) not met
	CS5 (19 m)	16	3	0	EQG not met, EQS(i) met
	CS8 (20 m)	16	6	0	EQG not met, EQS(i) met
	CB (9.5 m)	16	0	-	EQG met
	G2 (10 m)	16	1	0	EQG not met; EQS(i) met
	G3 (13 m)	16	2	0	EQG not met, EQS(i) met
HPA-S	CS11 (18 m)	16	11	0	EQG not met, EQS(i) met
	CS13 (20.5 m)	16	11	1	EQG not met, EQS(i) not met
	SF (3.5 m)	16	0	-	EQG met
	MB (1.5 m)	16	7	0	EQG not met, EQS(i) met
MPA-CB	G1 (15 m)	16	0	-	EQG met
MPA-ES	CS10N (14 m)	16	2	0	EQG not met, EQS(i) met
	CS12 (10 m)	16	0	-	EQG met
	CS6A (10.5 m)	16	1	0	EQG not met, EQS(i) met
	CS7 (10.5 m)	16	1	0	EQG not met; EQS(i) met
	CS9 (13 m)	16	3	1	EQG not met, EQS(i) not met
	CS9A (16.5 m)	16	3	0	EQG not met; EQS(i) met
MPA-NH	NH3 (10 m)	16	4	2	EQG not met, EQS(i) not met
Reference	WS4 (17.5 m)	16	6 < 90%	0 < 60%	N/A

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

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
Sites	WSSB (2.5 m)	16	2 < 90%	0 < 60%	N/A

Dissolved oxygen concentrations in the bottom waters at 14 of the 18 monitoring sites in Cockburn Sound were below the high (90% saturation) and moderate (80% saturation) protection ‘Dissolved Oxygen concentration’ EQG on between one and 11 occasions during the 2016–17 non river-flow period. The greatest incidences of low dissolved oxygen concentrations were recorded between late January and late March 2017.



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 10. 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 2016 to March 2017.

Low dissolved oxygen concentrations were also recorded at both reference sites in Warnbro Sound on occasions between the end of January to mid-March 2017. The lowest dissolved oxygen concentrations were recorded on 30 January 2017 at WSSB (86% saturation) and 6 March 2017 at WS4 (71% saturation). Concentrations of below 90% saturation were recorded over five consecutive sampling occasions at WS4.

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.

Low dissolved oxygen concentrations (below 90% saturation) were recorded over six consecutive sampling occasions at CS8 (19.9 m depth) and CS11 (18 m), and over nine consecutive sampling occasions at CS13 (20.4 m). On one of the occasions at CS13 a dissolved oxygen concentration less than 60% was recorded. At Jervoise Bay Northern Harbour (NH3) dissolved oxygen concentrations below 80% saturation were recorded over four consecutive sampling occasions, and on two of these occasions concentrations less than 60% saturation were recorded.

Review of the incidence of low dissolved oxygen concentrations in bottom waters at the 18 water quality monitoring sites in Cockburn Sound indicates that, over the past nine non river-flow periods (2008–09 onwards), the ‘Dissolved Oxygen concentration’ EQG have not been met at all of the sites (with the exception of CS12) on one or more occasions during each non river-flow period (Table 21). The high protection ‘Dissolved Oxygen concentration’ EQG has not been met in the non river-flow period on between one and 11 occasions at sites in HPA-S, with the greatest number of occurrences at the two deeper sites CS11 and CS13; and on between one and six occasions at sites in HPA-N, with the greatest number of occurrences at the three deeper sites, CS4, CS5 and CS8.

The moderate protection ‘Dissolved Oxygen concentration’ EQG has not been met in the non river-flow period on between one and four occasions (Table 21). The greatest number of occurrences was recorded at CS9 and CS9A in 2010–11 and 2016–17, CS10N in 2015–16 and at Jervoise Bay Northern Harbour (NH3) in 2011–12 and 2016–17.

Since 2008–09, dissolved oxygen concentrations less than 90% saturation have been recorded on between one and six occasions at the two reference sites in Warnbro Sound, with the greatest number of occurrences at the deeper site WS4 (Table 21).

Table 21. Number of occasions during each non river-flow period since 2008–09 when dissolved oxygen concentrations (% saturation) in the bottom waters at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound did not meet the ‘Dissolved Oxygen concentration’ EQG.

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

Ecological Protection Area	Site (approximate depth)	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17
	CS7 (10.5 m)	0	0	1	2	1	0	0	0	1
	CS9 (13 m)	0	0	3	1	0	0	0	1	3
	CS9A (16.5 m)	0	0	3	0	1	1	0	0	3
MPA-NH	NH3 (10 m)	0	1	1	3	1	0	0	0	4
Reference Sites	WS4 (17.5 m)	2	5	3	2	5	6	3	6	6
	WSSB (2.5 m)	5	3	2	0	1	0	1	4	2

The results of the assessment of the dissolved oxygen concentrations in bottom waters measured quarterly over the 2016–17 monitoring period at the three Water Corporation sites in Cockburn Sound, and two sites located outside Cockburn Sound, are presented in Table 22. The high protection 'Dissolved Oxygen concentration' EQG was not met on one occasion at the site Central; the high protection 'Dissolved Oxygen concentration' EQS(i) was met.

Table 22. 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 2016	October 2016	January 2017	April 2017
HPA-N	Central (21 m)	EQG not met; EQS(i) 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 high protection 'Dissolved Oxygen concentration' EQG was met in the bottom waters at all the sites sampled in south-western Mangles Bay on 11 October 2016.[10] On 20 January 2017, the concentration of dissolved oxygen in the bottom waters at one of the sites sampled met the high protection EQG.[11] Dissolved oxygen concentrations in the bottom waters at four of the sites were below the high protection EQG; the high protection 'Dissolved Oxygen concentration' EQS(i) was met.

The moderate protection 'Dissolved Oxygen concentration' EQG was met in the bottom waters at the three sites around the Kwinana Bulk Terminal[12] surveyed by Fremantle Ports on 1 March 2017. The moderate protection 'Dissolved Oxygen concentration' EQG was not met at the two deepest sites around the Kwinana Bulk Jetty[13]. The moderate protection 'Dissolved Oxygen concentration' EQS(i) was met at both sites.

Assessment against the Environmental Quality Standard

The 'Dissolved Oxygen concentration' EQG were not met at 14 of the water quality monitoring sites which triggers more detailed assessment against the high protection

[10] Depths varied between approximately 2.5 metres and 14.5 metres.
[11] Depths varied between approximately 11.5 metres and 14 metres.
[12] Depths varied between approximately 10.5 metres to 11.5 metres.
[13] Depths varied between approximately 12 metres and 16.5 metres.

and moderate protection 'Dissolved Oxygen concentration' EQS (EQS D, Table 1a, Reference Document):

High protection:

i. *The median dissolved oxygen concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 60% saturation.*

ii. *No significant change beyond natural variation in any ecological or biological indicators that are affected by poorly oxygenated water unless that change can be demonstrably linked to a factor other than oxygen concentration.*

iii. *No deaths of marine organisms resulting from deoxygenation.*

Moderate protection:

i. *The median dissolved oxygen concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than 60% saturation.*

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

iii. *No deaths of marine organisms resulting from deoxygenation.*

The dissolved oxygen concentrations in the bottom waters at four of the 18 water quality monitoring sites were below the 'Dissolved Oxygen concentration' EQS(i) (Table 20). The dissolved oxygen concentrations recorded at CS4 in HPA-N (54% saturation), CS13 in HPA-S (49% saturation) and CS9 in MPA-ES (59% saturation) were below the 'Dissolved Oxygen concentration' EQS(i) on 6 March 2017. The dissolved oxygen concentration recorded in Jervoise Bay Northern Harbour (NH3) was below the moderate protection 'Dissolved Oxygen concentration' EQS(i) on 27 February (55% saturation) and 6 March 2017 (59% saturation).

The 'Dissolved Oxygen concentration' EQG have not been met at CS4, CS13, CS9 and NH3 on one or more occasions over the past nine non river-flow periods (Table 21); however, 2016–17 was the first time that the 'Dissolved Oxygen concentration' EQS(i) has not been met at these sites. Since the 2008–09 non river-flow period, there have been three other occasions when the 'Dissolved Oxygen concentration' EQS(i) has not been met:

- 47% saturation recorded at CS11 on 28 February 2011;
- 57% saturation recorded at CS7 on 28 March 2011; and
- 45% saturation at CS10N on 29 February 2016.

The 2016–17 non river-flow period is also the first time since the 2008–09 that the 'Dissolved Oxygen concentration' EQS(i) was not met on two consecutive sampling occasions at any site (NH3).

CS4 and CS13 are deep sites (>20 m) located within the deeper central basin (17–22 m) and would therefore be expected to be subject to significant stratification, which

is usually a prerequisite for low dissolved oxygen concentrations. The waters of Cockburn Sound are generally well mixed and well oxygenated, and meet the 'Dissolved Oxygen concentration' EQC for high ecological protection during winter and spring (Department of Environmental Protection 1996; D.A. Lord & Associates Pty Ltd 2001; Hart and Church 2006). There are periods, mostly during late summer and autumn, when low dissolved oxygen concentrations may be experienced for short periods of time, in particular in the deeper waters at the southern end of Cockburn Sound.

There were no reports to the Cockburn Sound Management Council of deaths of marine organisms during the periods when low dissolved oxygen concentrations were recorded over the 2016–17 non river-flow period that may have been attributable to deoxygenation ('Dissolved Oxygen concentration' EQS(iii)).

The 'Dissolved Oxygen concentration' EQS(i) was not met at: CS4 in HPA-N; CS13 in HPA-S; CS9 in MPA-ES; and Jervoise Bay Northern Harbour (NH3) in MPA-NH, which triggers the requirement to initiate a management response. This would normally focus on identifying the cause or source of the exceedance and then implementing appropriate source control. Noting that the 'Dissolved Oxygen concentration' EQS(i) was not met at sites throughout Cockburn Sound rather than in any one specific area, the dissolved oxygen concentrations recorded over the past nine non river-flow periods (Table 21), and that the waters of Cockburn Sound are generally well mixed and well oxygenated, the Cockburn Sound Management Council does not consider that a management response is required at this time. The Council will continue to monitor dissolved oxygen concentrations and report against the 'Dissolved Oxygen concentration' EQC. The Council will also continue to review the results from each monitoring period in the context of previous year's data to assess whether there is evidence of a decline in the oxygen status of Cockburn Sound.

2.6.2 Water Temperature

Measurements of surface[14] and bottom[15] water temperatures recorded at the 18 water quality monitoring sites[16] (Section 2.3; Figure 2) over the 2016–17 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 2016–17 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 2016–17 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.*

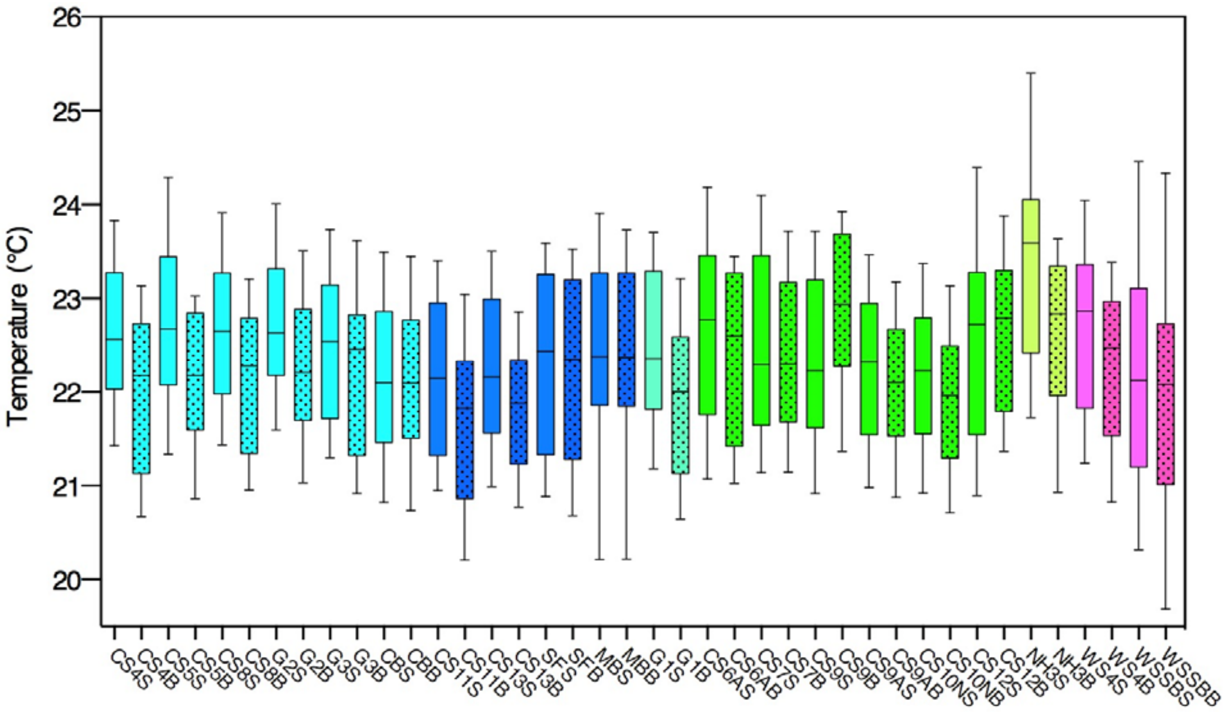
[14] Measured at 50 cm below the water surface.
[15] Measured at 50 cm above the sediment surface.
[16] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2017).

The results of the assessment against the EQG are presented in Table 23. Median surface and bottom water temperatures at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound are shown in Figure 11. At all sites, the median surface and bottom water temperatures recorded over the 2016–17 non river-flow period met the ‘Temperature’ EQG.

Table 23. Assessment of median surface and bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound over the 2016–17 non river-flow period against the ‘Temperature’ EQG.

Ecological Protection Area	Site	Temperature (° C)				Assessment
		2016–17 EQG (Surface)	2016–17 median (Surface)	2016–17 EQG (Bottom)	2016–17 median (Bottom)	
HPA-N	CS4	≤ 23.40	22.56	≤ 22.99	22.18	EQG met
	CS5		22.67		22.18	EQG met
	CS8		22.65		22.28	EQG met
	CB		22.10		22.09	EQG met
	G2		22.64		22.21	EQG met
	G3		22.55		22.46	EQG met
HPA-S	CS11	≤ 23.40	22.15	≤ 22.99	21.82	EQG met
	CS13		22.16		21.88	EQG met
	SF	≤ 23.11	22.43	≤ 22.75	22.35	EQG met
	MB		22.38		22.37	EQG met
MPA-CB	G1	≤ 23.97	22.35	≤ 23.38	22.00	EQG met
MPA-ES	CS10N	≤ 23.97	22.23	≤ 23.38	21.96	EQG met
	CS12		22.72		22.79	EQG met
	CS6A		22.78		22.60	EQG met
	CS7		22.29		22.30	EQG met
	CS9		22.23		22.93	EQG met
	CS9A		22.32		22.11	EQG met
MPA-NH	NH3	≤ 23.97	23.60	≤ 23.38	22.84	EQG met

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



Notes:

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

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

Figure 11. 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 2016 to March 2017.

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

2.6.3 Salinity

Measurements of surface[17] and bottom[18] water salinities recorded at the 18 water quality monitoring sites[19] (Section 2.3; Figure 2) over the 2016–17 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 2016–17 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 2016–17 non river-flow period, measured according to the Standard Operating Procedures, is not to deviate beyond the 5th and*

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

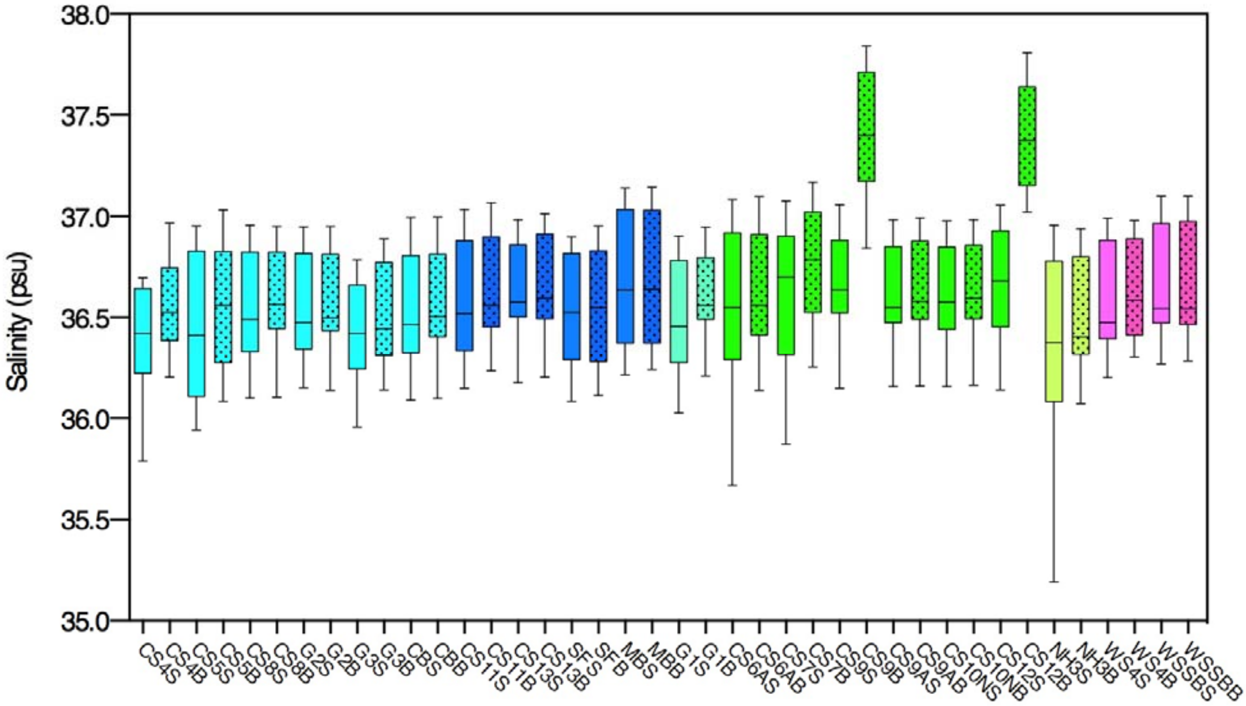
95th percentiles of the natural salinity range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period.

The results of the assessment against the EQG are presented in Table 24. Median surface and bottom water salinities at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound are shown in Figure 12. The median surface and bottom water salinities recorded over the 2016–17 non river-flow period met the 'Salinity' EQG at all sites with the exception of the bottom waters at CS9 and CS12 in MPA-ES. Elevated median salinities were recorded in the bottom waters at CS9 and CS12.

Table 24. Assessment of median surface and bottom salinities at 18 water quality monitoring sites in Cockburn Sound over the 2016–17 non river-flow period against the 'Salinity' EQG.

Ecological Protection Area	Site	Salinity (practical salinity units [psu])				Assessment
		2016–17 EQG (Surface)	2016–17 median (Surface)	2016–17 EQG (Bottom)	2016–17 median (Bottom)	
HPA-N	CS4	36.39 ≤ x ≤ 36.90	36.42	36.41 ≤ x ≤ 36.90	36.52	EQG met
	CS5		36.41		36.56	EQG met
	CS8		36.49		36.57	EQG met
	CB		36.47		36.50	EQG met
	G2		36.47		36.50	EQG met
	G3		36.42		36.44	EQG met
HPA-S	CS11	36.39 ≤ x ≤ 36.90	36.52	36.41 ≤ x ≤ 36.90	36.56	EQG met
	CS13		36.58		36.59	EQG met
	SF	36.47 ≤ x ≤ 36.98	36.53	36.45 ≤ x ≤ 36.99	36.55	EQG met
	MB		36.64		36.64	EQG met
MPA-CB	G1	36.22 ≤ x ≤ 36.99	36.45	36.32 ≤ x ≤ 36.98	36.56	EQG met
MPA-ES	CS10N	36.22 ≤ x ≤ 36.99	36.57	36.32 ≤ x ≤ 36.98	36.60	EQG met
	CS12		36.68		**37.37**	EQG not met in bottom waters
	CS6A		36.55		36.56	EQG met
	CS7		36.70		36.78	EQG met
	CS9		36.63		**37.40**	EQG not met in bottom waters
	CS9A		36.55		36.58	EQG met
MPA-NH	NH3	36.22 ≤ x ≤ 36.99	36.38	36.32 ≤ x ≤ 36.98	36.41	EQG met

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



Notes:

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

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

Figure 12. 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 2016 to March 2017.

The results of the assessment of salinity in bottom waters measured quarterly over the 2016–17 monitoring period at the three Water Corporation sites in Cockburn Sound, and two sites located outside Cockburn Sound, are presented in Table 25. Slightly elevated salinities were recorded in bottom waters at DIFF50W, located 50 metres west of the Perth Seawater Desalination Plant diffuser, in July 2016, January 2017 and April 2017 compared to Central and South in Cockburn Sound, and Parmelia Bank and Owen Anchorage located outside Cockburn Sound.

Table 25. 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 2016	October 2016	January 2017	April 2017
HPA-N	Central	35.44	35.47	36.90	36.57
HPA-S	South	35.41	35.51	37.03	36.56
MPA-ES	DIFF50W	36.17	35.45	37.35	37.19
Sites outside Cockburn Sound	Parmelia Bank Owen Anchorage	35.41 35.46	35.60 35.48	36.43 36.95	36.34 36.29

Assessment against the Environmental Quality Standard

The moderate protection 'Salinity' EQG was not met in the bottom waters at CS9 and CS12 which triggers more detailed assessment against the moderate protection

'Salinity' EQS (EQS F, Table 1a, Reference Document):

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

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

Median bottom water salinities at CS9 and CS12 were higher than the 'Salinity' EQG by less than one practical salinity unit (psu) and were below the default moderate protection salinity trigger value[20] in the Reference Document. The risk of a persistent and significant change beyond natural variation in any ecological or biological indicators as a result of elevated salinity is therefore considered to be low ('Salinity' EQS(i)).

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

There were no known reports of deaths of marine organisms over the 2016–17 non river-flow period that may have been attributable to anthropogenically-sourced salinity stress ('Salinity' EQS(ii)).

2.6.4 pH

Measurements of surface[21] and bottom[22] water pH recorded at the 18 water quality monitoring sites[23] (Section 2.3; Figure 2) over the 2016–17 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 2016–17 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 2016–17 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 26. At all sites, the median surface and bottom water pH recorded over the 2016–17 non river-flow period met the 'pH' EQG.

[20] Moderate protection bottom waters = 37.98 practical salinity units (the median of suitable reference site data ± 1.4; 36.58 + 1.4).
[21] Measured at 50 cm below the water surface.
[22] Measured at 50 cm above the sediment surface.
[23] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2017).

Table 26. Assessment of median surface and bottom pH at 18 water quality monitoring sites in Cockburn Sound over the 2016–17 non river-flow period against the 'pH' EQG.

Ecological Protection Area	Site	pH (pH units)				Assessment
		2016–17 EQG (Surface)	2016–17 median (Surface)	2016–17 EQG (Bottom)	2016–17 median (Bottom)	
HPA-N	CS4	8.2 ≤ x ≤ 8.3	8.3	8.2 ≤ x ≤ 8.3	8.3	EQG met
	CS5		8.3		8.2	EQG met
	CS8		8.3		8.3	EQG met
	CB		8.2		8.2	EQG met
	G2		8.3		8.3	EQG met
	G3		8.3		8.3	EQG met
HPA-S	CS11	8.2 ≤ x ≤ 8.3	8.2	8.2 ≤ x ≤ 8.3	8.2	EQG met
	CS13		8.3		8.2	EQG met
	SF	8.1 ≤ x ≤ 8.2	8.2	8.1 ≤ x ≤ 8.3	8.3	EQG met
	MB		8.2		8.2	EQG met
MPA-CB	G1	8.1 ≤ x ≤ 8.4	8.3	8.1 ≤ x ≤ 8.3	8.2	EQG met
MPA-ES	CS10N	8.1 ≤ x ≤ 8.4	8.2	8.1 ≤ x ≤ 8.3	8.2	EQG met
	CS12		8.2		8.2	EQG met
	CS6A		8.2		8.2	EQG met
	CS7		8.2		8.2	EQG met
	CS9		8.2		8.2	EQG met
	CS9A		8.2		8.2	EQG met
MPA-NH	NH3	8.1 ≤ x ≤ 8.4	8.3	8.1 ≤ x ≤ 8.3	8.3	EQG met

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

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

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

Over the 2016–17 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 13 µg N/L and 15 µg N/L at Jervoise Bay Northern Harbour (NH3) on 13 February 2017 and 13 March 2017, respectively. The highest concentrations (53 µg N/L on 13 February 2017 and 69 µg N/L on 6 March 2017) were recorded in bottom waters at CS13 in HPA-S.

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

The 95th percentile of the ammonium concentrations at sites in HPA-N varied between 1.9 µg N/L and 3.3 µg N/L and between 2.4 µg N/L and 5.2 µg N/L at sites in HPA-S, all below the high protection EQG value for toxic effects of 500 µg/L for ammonia. The 95th percentile of the ammonium concentrations at sites in MPA-ES varied between 2.9 µg N/L and 8.4 µg N/L, below the moderate protection EQG value for toxic effects of 1,200 µg/L for ammonia. Similarly, at G1 in MPA-CB and Jervoise Bay Northern Harbour (NH3) in MPA-NH, where the 95th percentiles of the ammonium

concentrations were 2.2 µg N/L and 13.5 µg N/L, respectively.

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

Surface marine water samples were collected in March 2017at 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) and the polycyclic aromatic hydrocarbon naphthalene. 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 27). 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. Concentrations of naphthalene were below the analytical limits of reporting and below the EQG.

Table 27. 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	280	29	11
Copper (filtered)	EQG: 3.0	0.3	0.3	0.3	0.3	0.4	2.1
Manganese (filtered)	LRV: 80[1]	2.0	1.9	2.1	Not measured		
Lithium	-	200	210	210	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]	< 2	< 2	< 2	< 2	< 2	< 2
	o-xylene LRV: 350[1]	< 1	< 1	< 1	< 1	< 1	< 1
Total Xylenes	-	< 3	< 3	< 3	< 3	< 3	< 3
Total Recoverable Hydrocarbons (C10–C36)	LRV: 7[1, 2]	< 100	< 100	< 100	< 100	< 100	< 100
Naphthalene	EQG: 90	< 10	< 10	< 10	< 10	< 10	< 10

Toxicant (µg/L)	EQG/LRV (µg/L)	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Total Toxicity of Mixtures (TTM)	If TTM > 1, mixture exceeded water quality guideline	< 1	< 1	< 1	< 1	< 1	< 1

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

(1) High protection LRV (there is no moderate protection LRV).

(2) LRV for Total Petroleum Hydrocarbons.

At all sites, the Total Toxicity of the Mixture (TTM), based on the effects of ammonia, copper, benzene and naphthalene, was below one (Table 27). The combined additive effect of these contaminants was therefore not expected to result in adverse effects on marine flora or fauna in the vicinity of the sampling sites.

2.7.3 Investigation into Toxicants in Marine Waters of Mangles Bay

As part of the investigation into the slightly elevated concentrations of dissolved cadmium and zinc recorded in a single water sample collected in Mangles Bay in HPA-S in December 2015 (Cockburn Sound Management Council 2016), additional sampling and analyses were undertaken in Mangles Bay on 11 October 2016 and 20 January 2017. On each sampling occasion, depth-integrated water samples were collected from five sites in south-western Mangles Bay in the vicinity of the site sampled in December 2015. The samples were analysed for ultra-trace concentrations of dissolved metals (aluminium, arsenic, cadmium, chromium, cobalt, copper, lead, mercury, silver and zinc). Sample analysis was undertaken by MAFRL.

The concentrations of dissolved aluminium, cadmium, chromium, cobalt, lead, mercury, silver and zinc were below or equal to the analytical limits of reporting in the samples collected in Mangles Bay on both sampling occasions (Table 28). The concentrations of cadmium, cobalt, lead, mercury, silver and zinc were also below or equal to the relevant high protection EQG. The concentrations of dissolved arsenic were below the high protection LRV for arsenic (III) and arsenic (V) at all sites on both sampling occasions.

With one exception, the concentrations of dissolved copper were below or equal to the high protection EQG at all the sites on both sampling occasions (Table 28). In October 2016 the concentration of dissolved copper reported in one sample (Site 5) slightly exceeded the high protection EQG, but was below the moderate protection EQG (3 µg/L). The analytical laboratory confirmed that all the quality assurance/quality control checks were passed and advised that the sample was run twice to confirm the result and that a separate field sample was also analysed.

Site 5 is located in shallow water (approximately 2.5 m depth) in south-western Mangles Bay and the elevated concentration of copper recorded at this site is possibly due to antifouling or corrosion inhibiting products on vessels anchored in proximity to the site. A previous study by the Department of Environment (2004) reported slightly higher concentrations of copper in Cockburn Sound than in Warnbro Sound, offshore or northern metropolitan waters. The slightly higher concentrations were identified as possibly due to industrial inputs and/or antifouling or corrosion inhibiting products used on vessels and infrastructure on the eastern side of the Sound.

Table 28. Assessment of dissolved metals in water samples collected in Mangles Bay in October 2016 and January 2017 against the high protection EQG or LRV for 'Toxicants in marine waters'.

Metals (µg/L)	EQG/LRV	October 2016						January 2017					
		Site 1	Site 2	Site 3	Site 4	Site 5	95th Percentile	Site 1	Site 2	Site 3	Site 4	Site 6	95th Percentile
Aluminium	LRV: 0.5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Arsenic[1]	As III LRV: 2.3 As V LRV: 4.5	1.7	1.6	1.6	1.5	1.7	1.7	2.0	2.1	2.0	2.0	2.1	2.1
Cadmium	EQG: 0.7	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Chromium[2]	Cr III EQG: 7.7 Cr VI EQG: 0.14	< 0.2	< 0.2	< 0.2	< 0.2	0.2	0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Cobalt	EQG: 1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Copper	EQG: 0.3	0.3	0.2	0.2	0.2	**0.4**	**0.38**	0.2	0.3	0.3	0.3	0.3	0.3
Lead	EQG: 2.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Mercury	EQG: 0.1	< 0. 1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Silver	EQG: 0.8	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Zinc	EQG: 7	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Notes:

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

1. The analytical results did not differentiate between arsenic species; total dissolved arsenic was measured.
2. The analytical results did not differentiate between chromium species; total dissolved chromium was measured.

2.7.4 Investigation into PFAS in Marine Waters of Cockburn Sound

The preliminary sampling program for perfluoroalkyl and polyfluoroalkyl substances (commonly referred to as PFAS) at *HMAS Stirling* (Garden Island) by the Department of Defence identified concentrations of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in groundwater on the island that exceeded the screening levels for groundwater (drinking water) and surface water (recreational use) (GHD 2016). In January 2017 the Cockburn Sound Management Council collected water samples to measure the concentrations of PFAS in the marine waters of Cockburn Sound.

On 9 January 2017, depth-integrated water samples were collected from each of the monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound (Section 2.3; Figure 2). Sampling was undertaken in accordance with the sample collection methods identified in Appendix 1 of the *Interim Guideline on the Assessment and Management of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)* (Department of Environment Regulation 2017). The samples were analysed for 21 perfluoroalkyl and polyfluoroalkyl substances.[24] Sample analysis was undertaken by Eurofins, which is NATA-accredited for the analyses, using a Liquid Chromatography/Tandem Mass Spectrometry (LC-MS/MS) methodology approved by the United States Environmental Protection Agency.

Concentrations of the 21 PFAS analytes were equal to or below the analytical limits of reporting (between 0.005 µg/L or 0.05 µg/L) at all the sites sampled in Cockburn Sound and Warnbro Sound. The results from the Cockburn Sound sampling for PFOS, PFOA, 1H.1H.2H.2H-perfluorooctanesulfonic acid (6:2 FTS) and 1H.1H.2H.2H-perfluorodecanesulfonic acid (8:2 FTS), the four PFAS analytes reported on in groundwater bores on Garden Island (GHD 2016), are provided in Table 29.

Table 29. Concentrations of perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), 1H.1H.2H.2H-perfluorooctanesulfonic acid (6:2 FTS) and 1H.1H.2H.2H-perfluorodecanesulfonic acid (8:2 FTS) (µg/L)

Ecological Protection Area	Site	PFOS	PFOA	6:2 FTS	8:2 FTS
HPA-N	CS4	< 0.005	< 0.005	< 0.01	< 0.01
	CS5	0.005	< 0.005	< 0.01	< 0.01
	CS8	< 0.005	< 0.005	< 0.01	< 0.01
	CB	< 0.005	< 0.005	< 0.01	< 0.01
	G2	< 0.005	< 0.005	< 0.01	< 0.01
	G3	< 0.005	< 0.005	< 0.01	< 0.01
HPA-S	CS11	< 0.005	< 0.005	< 0.01	< 0.01
	CS13	< 0.005	< 0.005	< 0.01	< 0.01

[24] The following PFAS were analysed for: perfluorobutanesulfonic acid (PFBS), perfluorobutanoic acid (PFBA), perfluorohexanesulfonic acid (PFHxS), perfluorooctanesulfonic acid (PFOS), perfluorodecanesulfonic acid (PFDS), perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), perfluorododecanoic acid (PFDoA), perfluorotridecanoic acid (PFTrDA), perfluorotetradecanoic acid (PFTeDA), perfluorooctanesulfonamide (PFOSA), N-ethyl-perfluoroocatanesulfonamidoacetic acid (NEtFOSAA), N-methyl-perfluorooctanesulfonamidoacetic acid (NMeFOSAA), 1H.1H.2H.2H-perfluorohexanesulfonic acid (4:2 FTS), 1H.1H.2H.2H-perfluorooctanesulfonic acid (6:2 FTS), 1H.1H.2H.2H-perfluorodecanesulfonic acid (8:2 FTS).

Ecological Protection Area	Site	PFOS	PFOA	6:2 FTS	8:2 FTS
	SF	< 0.005	< 0.005	< 0.01	< 0.01
	MB	< 0.005	< 0.005	< 0.01	< 0.01
MPA-CB	G1	< 0.005	< 0.005	< 0.01	< 0.01
MPA-ES	CS10N	< 0.005	< 0.005	< 0.01	< 0.01
	CS12	< 0.005	< 0.005	< 0.01	< 0.01
	CS6A	< 0.005	< 0.005	< 0.01	< 0.01
	CS7	< 0.005	< 0.005	< 0.01	< 0.01
	CS9	< 0.005	< 0.005	< 0.01	< 0.01
	CS9A	< 0.005	< 0.005	< 0.01	< 0.01
MPA-NH	NH3	< 0.005	< 0.005	< 0.01	< 0.01
Reference Sites	WS4	< 0.005	< 0.005	< 0.01	< 0.01
	WSSB	< 0.005	< 0.005	< 0.01	< 0.01

There are no EQC for protecting the marine ecosystem from the effects of PFAS in marine waters in the Reference Document. The Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE 2017) has developed draft and interim ecological screening levels (ESLs) for PFOS and PFOA in marine waters (Table 30). Exceedance of the ESLs does not necessarily imply that the contamination poses an unacceptable risk; the ESLs should be considered as generic screening levels which, if exceeded, indicate further more detailed investigation is required. These values provide a collective view of the available science and application of Australian approaches on the development of ecological based screening levels (CRC CARE 2017). The ESLs are subject to ongoing revision and may be revised downwards in the future.

Table 30. Marine ecosystem, Ecological Screening Levels for perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) (µg/L)

% Species Protection	PFOS (µg/L)	PFOA (µg/L)
99% species protection	0.29	3,000
95% species protection	7.8	8,500
90% species protection	32	14,000
80% species protection	130	22,000

Source: CRC CARE (2017)

The analytical limits of reporting are below the 99% species protection (which apply in the high protection areas; Reference Document) and 90% species protection (which apply in the moderate protection areas; Reference Document) ESLs derived for PFOS and PFOA in marine environments.

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 2017 (Section 2.3; Figure 2). The samples were analysed for Total Organic Carbon, metals (arsenic, cadmium, chromium, copper,

lead, lithium[25], manganese, mercury, selenium and zinc), organotins (tributyltin [TBT], dibutyltin [DBT] and monobutyltin [MBT]), polycyclic aromatic hydrocarbons (PAHs) and total recoverable hydrocarbons (TRHs).

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

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

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

The median concentrations of arsenic, chromium, copper, lead and zinc in both sampling areas were below the relevant EQG values (Table 31). Elevated concentrations of cadmium and mercury were recorded in one of the Kwinana Bulk Jetty samples (KBJ1). The median concentrations of cadmium and mercury in sediments at the Kwinana Bulk Jetty were below the EQG value and the concentrations of both toxicants at KBJ1 were below the EQG re-sampling trigger. There are no EQG values for lithium, manganese and selenium.

After normalisation to 1% Total Organic Carbon[26], median concentrations of TBT were below the EQG value (Table 31). An elevated concentrations of TBT was recorded in one of the Kwinana Bulk Jetty samples (KBJ2), the concentration was below the re-sampling trigger. There are no EQG values for the break-down products DBT or MBT.

There were significant concentrations of MBT (the final TBT break-down product) in the Kwinana Bulk Jetty and Kwinana Bulk Terminal samples, suggesting that substantial TBT degradation has occurred. Five of the six samples had a Butyltin Degradation Index (BDI) equal to or greater than one (Table 31), indicating that over half of the TBT originally deposited had been degraded into DBT and MBT. These levels of degradation are as expected noting that the half-life of TBT in sediments is at least two to five years (Batley *et al*. 1992), but may be in the order of tens of years in anaerobic sediments (Dowson *et al*. 1996), and international treaties banning the use of TBT antifouling products on commercial vessels only came into force between 2003 and 2008. The TBT concentration in the KBJ2 sample was higher than in the other samples and the sample had a BDI of less than one, indicating that TBT had not yet reached its half-life at this site. Concentrations of DBT and MBT were nevertheless also high, indicating that there has been significant degradation. The high TBT concentration in this sample could indicate the presence of paint flakes in the sediment that are not randomly distributed, leading to variable TBT concentrations.

The median concentrations of PAHs were below the relevant EQG values (Table 31). The concentrations of PAHs in all the samples from both sampling areas were below the EQG values. There are no EQG values for TRHs, however, the concentrations of TRHs at all the sites were below the analytical limit of reporting.

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

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

Chemical (milligrams per kilogram [mg/kg])	Environmental Quality Criteria		Kwinana Bulk Terminal				Kwinana Bulk Jetty			
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median
Metals										
Arsenic	20	70	2.5	2	4	2.5	< 2	< 2	< 2	< 2
Cadmium	1.5	10	< 0.4	< 0.4	< 0.4	< 0.4	**3.3**	0. 6	< 0.4	0.6
Chromium	80	370	29	25	8.4	25	23	17	8.4	17
Copper	65	270	19	20	< 5	19	9.3	11	< 5	9.3
Lead	50	220	15	10	< 5	10	6.7	5.2	< 5	5.2
Lithium	-	-	16	14	< 5	14	Not measured			
Manganese	-	-	46	37	45	45	Not measured			
Mercury	0.15	1	< 0.1	< 0.1	< 0.1	0.1	**0.2**	< 0.1	< 0.1	0.1
Selenium	-	-	< 2	< 2	< 2	< 2	6.1	< 2	< 2	2
Zinc	200	410	79	28	< 5	28	49	41	13	41
Organotins (µg Sn/kg normalised to 1% TOC)										
Tributyltin	5	70	0.7	1.2	0.9	0.9	3.5	**44.4**	2.9	3.5
Dibutyltin	-	-	0.8	0.9	0.4	0.8	2.7	15.6	1.5	2.7
Monobutyltin	-	-	1.2	0.9	0.7	0.9	1.8	7.8	1.5	1.8
Butyltin Degradation Index (BDI)	-	-	2.9	1.4	1.2	-	1.3	**0.5**	1.0	-
Organics (mg/kg normalised to 1% TOC)										
Acenaphthene	0.016	0.5	0.001	< 0.001	< 0.001	0.001	0.003	< 0.001	< 0.001	0.001
Acenaphthelene	0.044	0.64	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Anthracene	0.085	1.1	0.003	0.0005	0.0004	0.0005	0.003	< 0.001	< 0.001	0.001
Benzo(a)anthracene	0.261	1.6	0.014	0.003	0.002	0.003	0.018	0.007	< 0.001	0.007
Benzo(a)pyrene	0.43	1.6	0.018	0.003	0.002	0.003	0.012	0.005	< 0.001	0.005
Chrysene	0.384	2.8	0.015	0.003	0.002	0.003	0.019	0.007	< 0.001	0.007
Dibenzo(a,h)anthracene	0.063	0.26	0.006	0.001	0.0004	0.001	0.003	0.001	< 0.001	0.001
Fluoranthene	0.6	5.1	0.033	0.007	0.003	0.007	0.058	0.016	< 0.001	0.016
Fluorene	0.019	0.54	< 0.001	< 0.001	< 0.001	< 0.001	0.003	< 0.001	< 0.001	0.001
Naphthalene	0.16	2.1	0.001	< 0.001	< 0.001	0.001	0.003	0.001	< 0.001	0.001
Phenathrene	0.24	1.5	0.012	0.002	0.001	0.002	0.023	0.006	< 0.001	0.006
Pyrene	0.665	2.6	0.030	0.007	0.002	0.007	0.048	0.016	< 0.001	0.016
Total PAH	4	45	0.201	0.037	0.017	0.037	0.234	0.077	< 0.001	0.077
Total Recoverable Hydrocarbons (C10–C36)	-	-	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50

2.9 Conclusion

Based on the results from the 2016–17 monitoring programs it can be concluded that with respect to nutrient enrichment, there is a high degree of certainty that the Environmental Quality Objective 'Maintenance of ecosystem integrity' is being achieved in the northern part of the Sound. The 'Nutrient enrichment' EQG were met in the High Protection Area North (HPA-N) and the Moderate Protection Area Careening Bay (MPA-CB). The 'Nutrient enrichment' EQG for chlorophyll *a*, but not the EQG for light attenuation, was also met in the Moderate Protection Area Eastern Sound (MPA-ES). The 'Phytoplankton biomass' EQG were met in HPA-N and MPA-ES, as well as at all sites in these areas, at G1 in MPA-CB and Jervoise Bay Northern Harbour (NH3) in the Moderate Protection Area Northern Harbour (MPA-NH).

The 'Nutrient enrichment' EQG were not met in the High Protection Area South (HPA-S) and the 'Phytoplankton biomass' EQG were not met in HPA-S and at the Mangles Bay site (MB) in HPA-S indicating that there is uncertainty as to whether the Environmental Quality Objective has been achieved and triggering a more detailed assessment against the EQS. The 'Nutrient enrichment' EQS and the 'Phytoplankton biomass' EQS were met in HPA-S, indicating that there is a low risk that the Environmental Quality Objective has not been achieved. However, elevated chlorophyll *a* concentrations and phytoplankton biomass, as well as higher light attenuation coefficients, which are indicative of elevated dissolved inorganic nutrient concentrations, are ongoing concerns in the southern part of Cockburn Sound. Dissolved inorganic nutrient concentrations (in particular ammonium and filterable reactive phosphorus) are still relatively high in HPA-S and the south-eastern part of MPA-ES compared to HPA-N and the Warnbro Sound reference sites (Cossington and Wienczugow 2017; Appendix A). Higher nutrient concentrations in the south-eastern part of the Sound are consistent with predicted concentrations of submarine groundwater nutrient inputs in the region south of James Point and may also be related to poor circulation compared to other parts of the Sound (Keesing *et al.* 2016).

While there have been improvements in water quality in Cockburn Sound, analysis of trends in seagrass shoot densities (Appendix D) indicates that there have been significant declines over the past 11–15 years at some sites in Cockburn Sound. This suggests that environmental factors other than a nutrient enrichment-related reduction in light availability at the seafloor may also be playing an important role in seagrass decline or lack of recovery in Cockburn Sound. Seagrass at sites on the east coast of Garden Island where the largest declines were recorded (Fraser *et al.* 2017) have some of the most depleted ratios of the two most common stable isotopes of sulfur ($\delta^{34}S$) in their tissues, indicating this area is being impacted by intrusion of sedimentary sulfides (Fraser *et al*. 2016b). Research currently being undertaken by the University of Western Australia is investigating whether low nocturnal dissolved oxygen concentrations at the Garden Island sites are making the seagrass more vulnerable to sulfide intrusion (Fraser *et al*. 2017).

The 'Dissolved Oxygen concentration' EQG were not met in the bottom waters at 14 of the 18 water quality monitoring sites in Cockburn Sound on one or more occasions over the 2016–17 non river-flow period. The 'Dissolved Oxygen concentration' EQS(i) was not met on one occasion at three sites (CS4 in HPA-N, CS13 in HPA-S and CS9 in MPA-ES) and on two occasions at one site (NH3 in MPA-NH). There were no reports of deaths of marine organisms during the periods when low dissolved oxygen concentrations were recorded over the 2016–17 non river-flow period that may have

been attributable to deoxygenation.

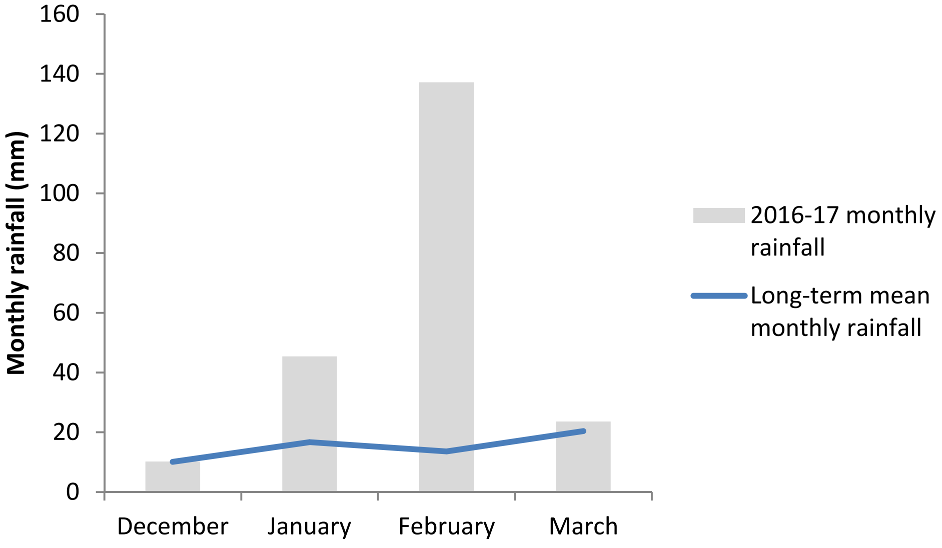
With the exception of localised elevated salinities in bottom waters at two sites (CS9 and CS12, possibly reflecting localised effects due to the proximity of the sites to saline water discharge from the Perth Seawater Desalination Plant) in MPA-ES, the EQC for protecting the marine ecosystem from the effects of the other physical and chemical stressors were met. The EQC for toxicants in sediments and marine waters were generally met in those areas where sampling and analysis were undertaken over the 2016–17 monitoring period. The exception was the slightly elevated concentration of copper recorded in a water sample collected in shallow depths in Mangles Bay, which is possibly attributable to antifouling or corrosion inhibiting products on anchored vessels. There were no known reports of deaths of marine organisms over the 2016–17 reporting period that may have been attributable to anthropogenically-sourced stress.

The results from the 2016–17 monitoring programs in Cockburn Sound indicate that there is a low risk that the Environmental Quality Objective 'Maintenance of ecosystem integrity' is not being achieved in most of Cockburn Sound.

2.9.1 Unusual Summer Weather

The 2016–17 summer, in particular February 2017, was one of the wettest summers on record for southwest Western Australia, including the Perth area (Figure 13; Bureau of Meteorology 2017a, b). Atmospheric moisture from tropical lows in the north of the State produced a number of significant cloudbands, resulting in persistent rainfall to the South West Land Division in late January and early February 2017 (Bureau of Meteorology 2017a).

Rainfall in January 2017 was above average (Bureau of Meteorology 2017c). The monthly rainfall total recorded at Perth Metro (45.4 mm) was the sixth wettest on record; and RAAF Pearce and Perth Airport both recorded monthly rainfall totals at least three times the January average. February 2017 monthly rainfall totals were in the 80–140 mm range across Perth and were more than five times higher than normal (Bureau of Meteorology 2017b). Several sites recorded the highest total February rainfall on record, and many sites reported the wettest February for at least two decades. The monthly rainfall total of 137.2 mm recorded at Perth Metro was the second-highest February rainfall total on record at the site and the wettest for 62 years since the record high of 166.3 mm in February 1955. Record high daily rainfalls were recorded on 10 February 2017, with 114.4 mm recorded at Perth Metro, the second highest daily rainfall for any month. Rainfall across the Perth area in March 2017 was also above average (in the 20 to 40 mm range) (Bureau of Meteorology 2017d).



Source: Perth Metro weather station [009225], Bureau of Meteorology (www.bom.gov.au)

Figure 13. Monthly rainfall over the period December 2016 to March 2017 and long-term (1993–2017) mean monthly rainfall.

The combination of high rainfall totals in late January and early February 2017 resulted in flooding to large parts of southwest Western Australia, with major flooding reported in the Avon catchment and minor flooding in the Swan downstream from the Avon (Bureau of Meteorology 2017a). High rainfall in the Avon catchment caused the Swan River water level to rise and flush nutrients and increased sediment loads down the river (www.swanregionstrategy.com.au [accessed 3 July 2017]), resulting in a large plume of turbid fresh water from the Swan River estuary flowing into the coastal waters and extending into Cockburn Sound (Figure 14).

Fresh water flows during floods can affect a range of water quality properties in near-shore coastal environments, including temperature, salinity, turbidity, total and dissolved nutrients, suspended solids, organic matter content, dissolved oxygen and the presence of chemical pollutants (Commonwealth of Australia 2013). Atypical weather patterns, such as the above average rainfall recorded in late January and early February 2017, have the potential to have an influence on Cockburn Sound water quality and need to be taken into account when evaluating the water quality monitoring results.

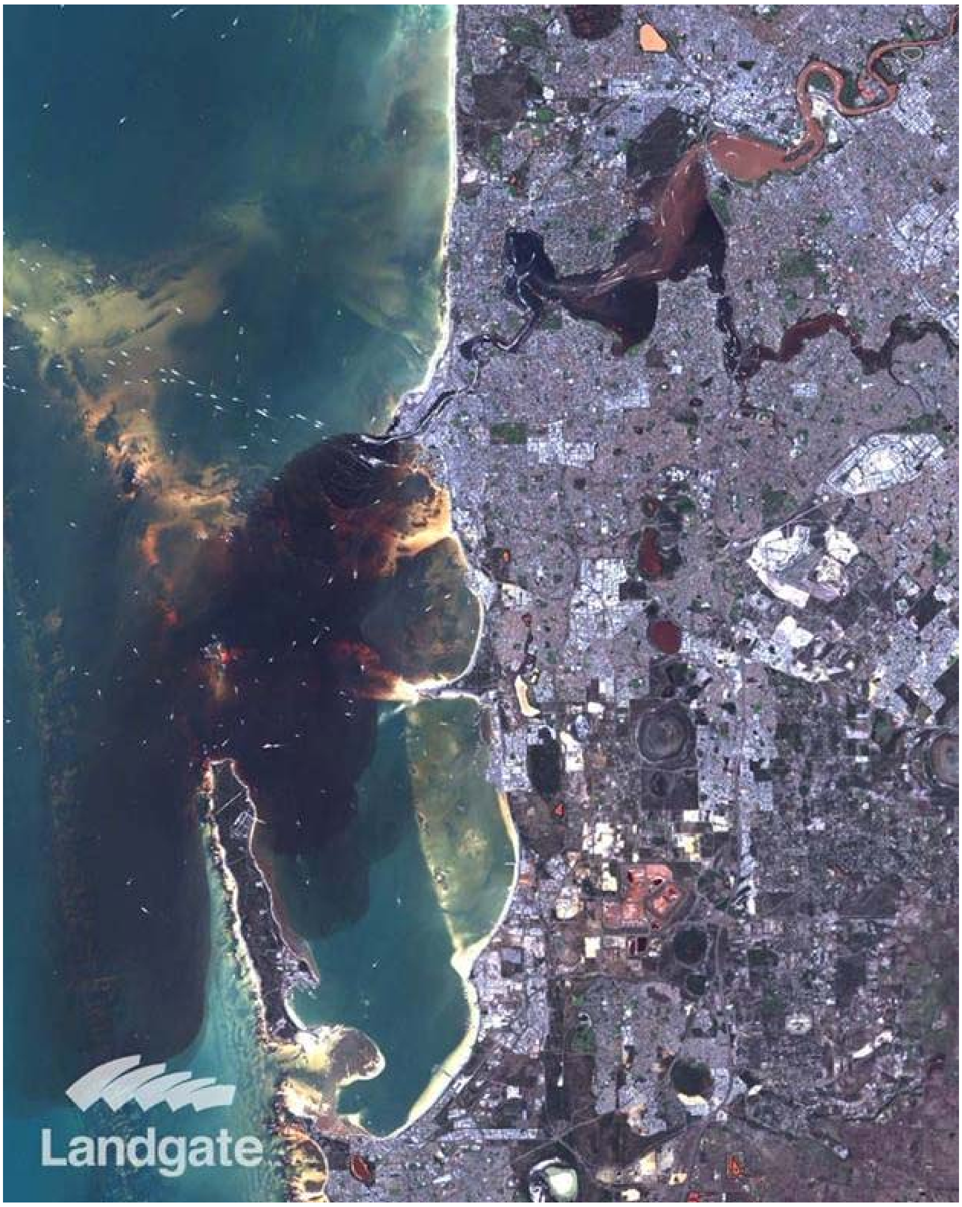


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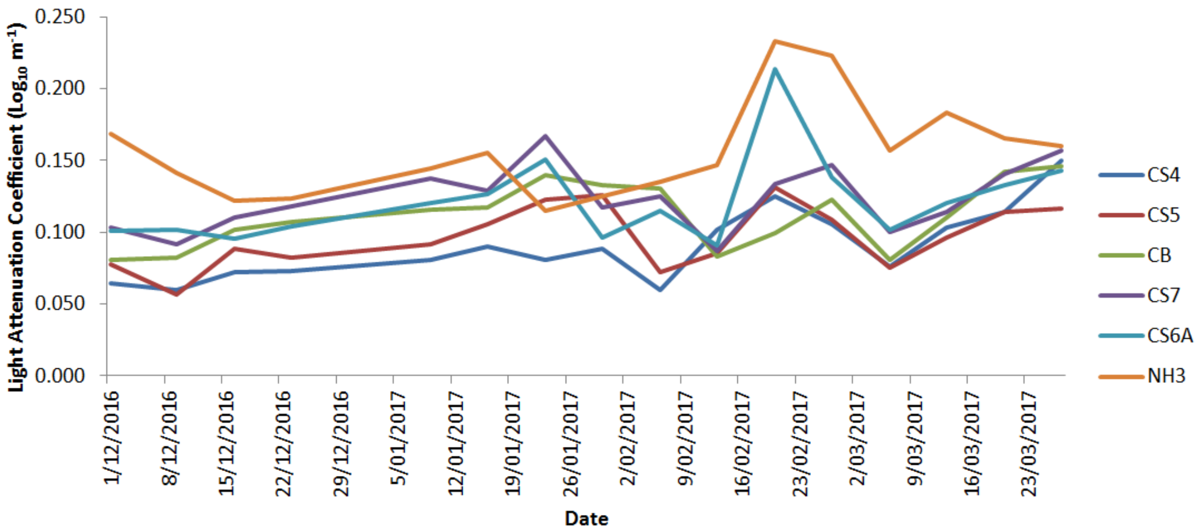
Figure 14. Tannins and sediment from the Avon catchment flowing through the Swan River mouth into Perth's coastal waters and extending into Cockburn Sound in February 2017.

An extensive plume of riverine, tannin-stained water was observed extending from the mouth of the Swan River, west to Carnac Island and south into the northern Cockburn Sound during the latter half of February 2017 (Cossington and Wienczugow 2017). Tannin-stained water was observed by the field team at water quality monitoring sites (CS4, CS5, CB, CS7, CS6A and NH3) in the northern Cockburn Sound on 20 and 27 February 2017. Increased light attenuation coefficients (Figure 15(a)) and reduced Secchi depth readings were also recorded and the riverine water was detectable as a reduction in the salinity of the surface waters at the northern-most sites in Cockburn Sound (Figure 15(b)). There were also an increased number of observations of algal blooms over the January to March 2017 period (Section 4.4).

(a) Light Attenuation Coefficient



(b) Surface Salinity

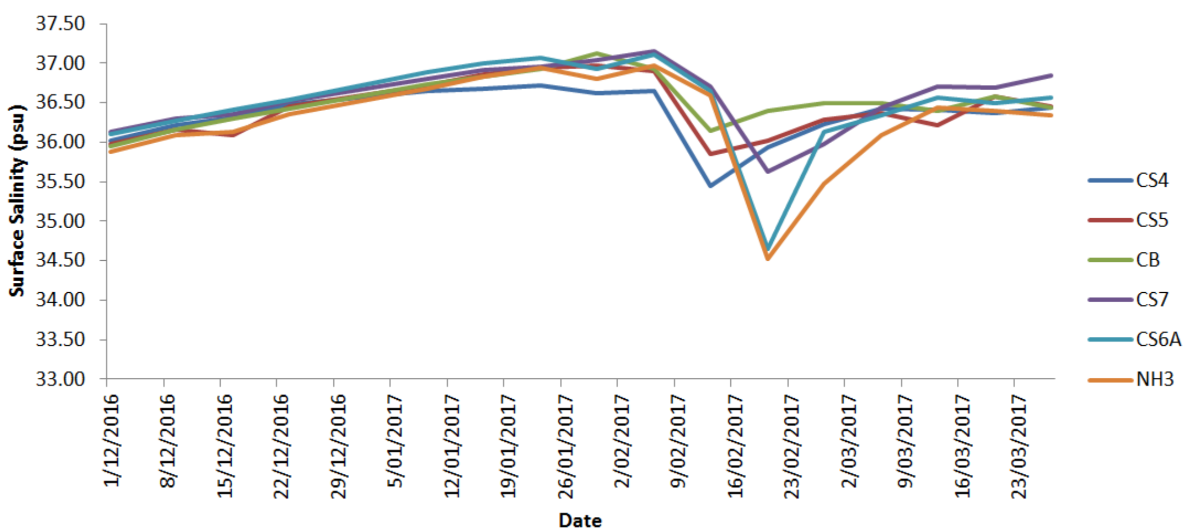
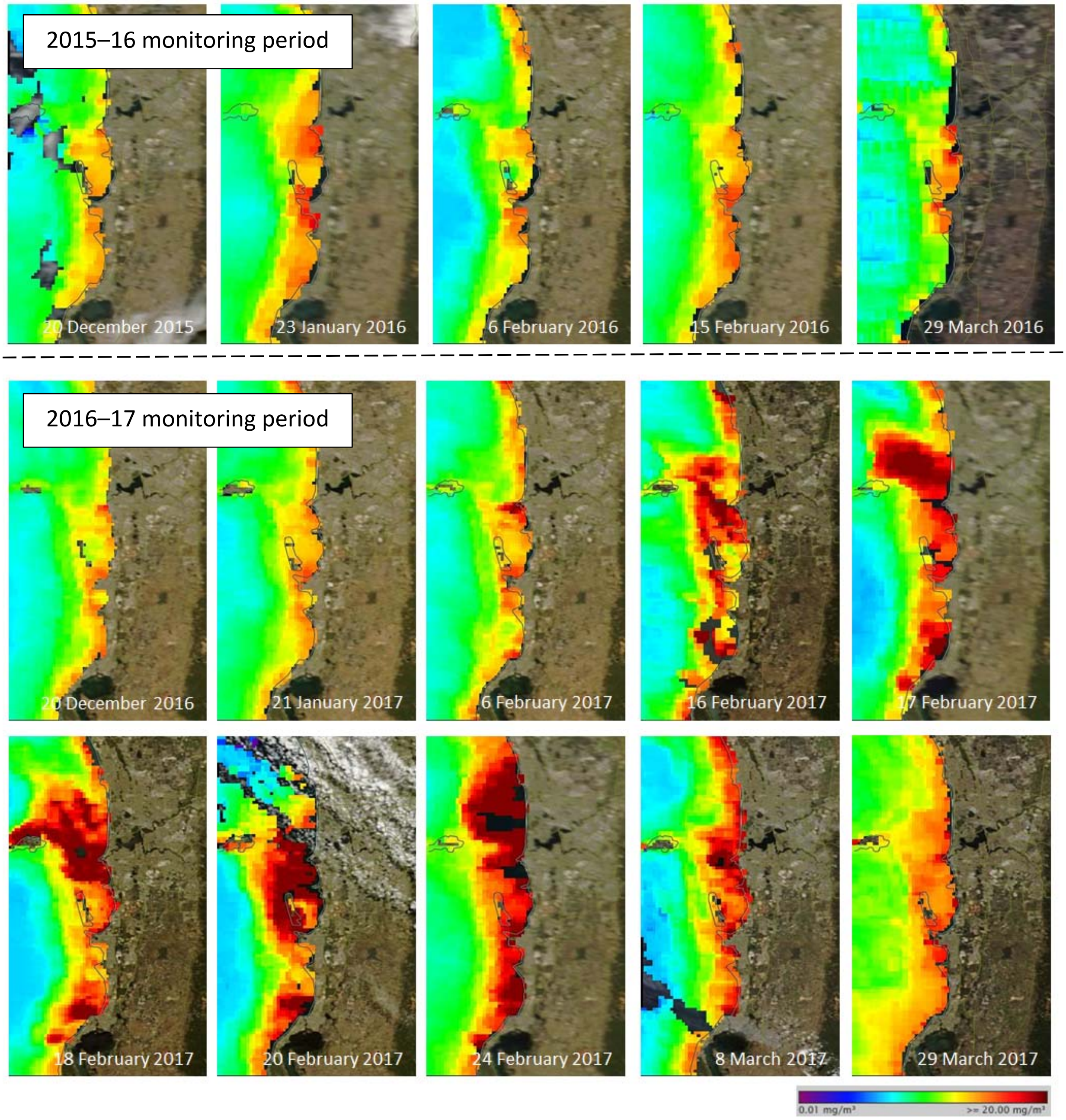


Figure 15. (a) Light attenuation coefficient ($\log_{10}$ m^{-1}) and (b) surface salinity (psu) at sites in northern Cockburn Sound over the 2016–17 non river-flow period.

The unusual rainfall and associated flooding in the Avon and Swan River catchments in late January and early February 2017 may have contributed to increased nutrient and chlorophyll *a* concentrations (Figure 16), increased light attenuation and the declines in seagrass shoot density at sites in Cockburn Sound that were reported over the 2016–17 monitoring period (Cossington and Wienczugow 2017; Fraser *et al*. 2017). While it would normally be expected that a response in healthy *Posidonia sinuosa* to declines in water quality would take a few months to become apparent, if the plants are under pre-existing stress (for example Fraser *et al*. 2016b), the resilience of the plants would be lower and impacts could occur over shorter time periods (Dr Matthew Fraser, School of Biological Sciences and the UWA Oceans

Institute, University of Western Australia, pers. comm.).

Increased nutrient (Appendix A) and chlorophyll *a* concentrations (Figure 16) were also reported in Warnbro Sound, which may also be a reflection of the unusual weather conditions experienced in January and February 2017.

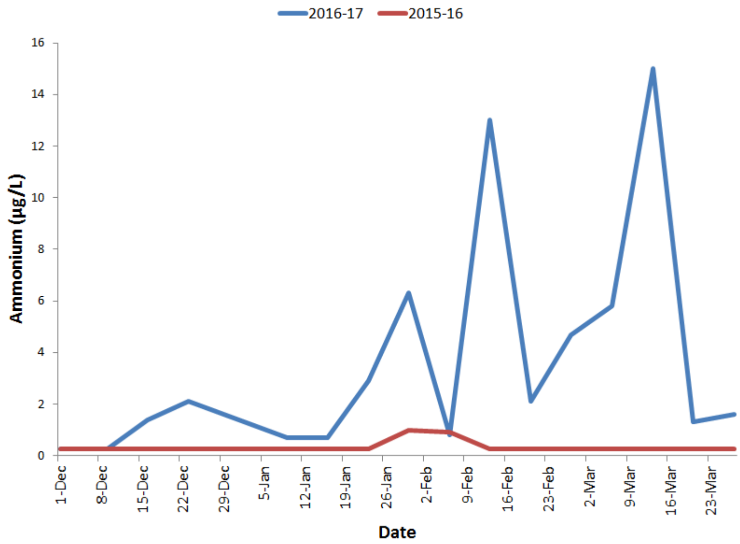


Source: NASA Worldview (http://worldview.earthdata.nasa.gov)

Figure 16. Chlorophyll *a* concentrations (mg/m^3) in Perth's coastal waters, including Cockburn Sound, over the 2015–16 and 2016–17 monitoring periods.

An increase in fresh water input along the eastern and southern shores of Cockburn Sound associated with the rainfall events in January and February 2017 may also have contributed to the increase in dissolved inorganic nutrient concentrations recorded at some sites along the eastern shoreline of Cockburn Sound over the 2016–17 monitoring period (Figure 17).

(a) NH3



(b) CS6A

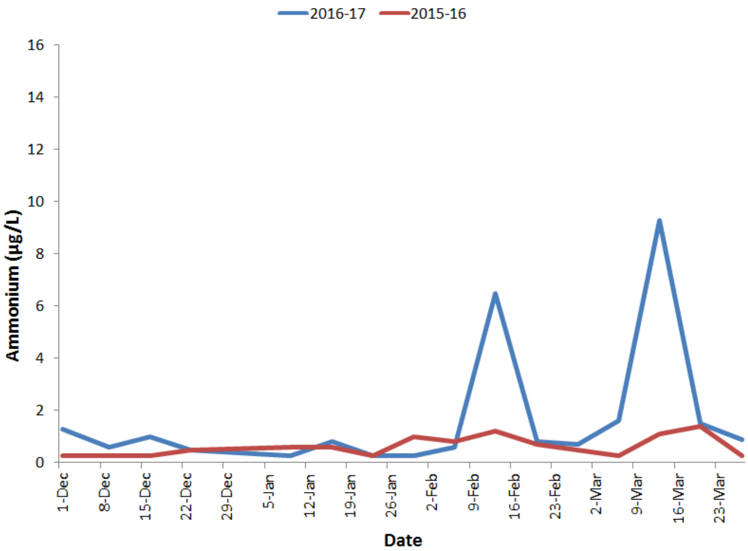


Figure 17. Ammonium concentrations (µg/L) at (a) NH3 and (b) CS6A over the 2015–16 and 2016–17 non river-flow periods.

In Jervoise Bay Northern Harbour (NH3) very low ammonium concentrations have been reported over the past eight years (Figure 18(a)). However, ammonium concentrations exceeding 3 µg/L were recorded on a number of occasions over the 2016–17 monitoring period (Figure 17(a)). Similarly, nitrate–nitrite concentrations at NH3, which have historically been high due to the influence of groundwater inflow but have decreased in recent years, were the highest recorded since 2006 (Figure 18(b)). The increased ammonium and nitrate–nitrite concentrations recorded in the Jervoise Bay Northern Harbour may have been attributable to high levels of rainwater associated runoff, with excess nutrients being retained within the harbour due to low flushing (Cossington and Wienczugow 2017). Elevated concentrations of ammonium (Figure 17(b)) and nitrate-nitrite concentrations were also recorded at CS6A, located at the entrance to Jervoise Bay Northern Harbour.

(a) Ammonium (b) Nitrate–Nitrite

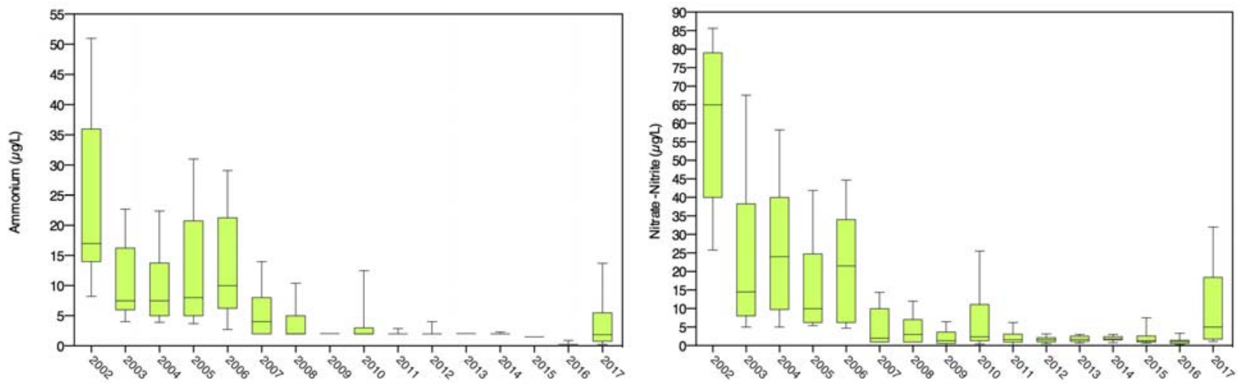


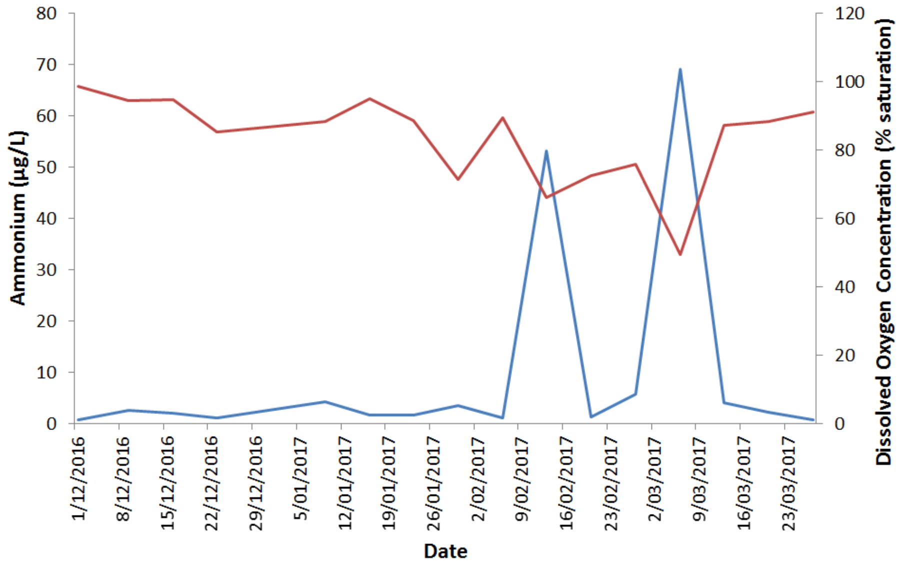
Figure 18. Median (a) ammonium and (b) nitrate–nitrite concentrations (µg/L) at the Jervoise Bay Northern Harbour site (NH3) between 2001–02 and 2016–17.

Low dissolved oxygen concentrations were recorded in the bottom waters at sites across Cockburn Sound between late January and late March 2017. These low concentrations may have been attributable to stratification and reduced mixing in the water column. An increase in biological oxygen demand at the seabed due to the decomposition of particulate organic matter from the catchment and increased algal productivity associated with elevated nutrient inputs with fresh water inflows, may also have contributed to the low dissolved oxygen concentrations.

Low levels of dissolved oxygen concentrations over extended periods of time can result in the release of nutrients from the sediments into the water column. The highest concentrations of ammonium (53 µg/L and 69 µg/L) and filterable reactive phosphorus (11 µg/L and 16 µg/L) in the bottom waters at CS13 were recorded on 13 February 2017 and 6 March 2017, respectively (Figure 19). The elevated nutrient concentrations coincided with a period of low dissolved oxygen concentrations in the bottom waters at this site. A dissolved oxygen concentration of 66% saturation was recorded on 13 February 2017 and 49% saturation on 6 March 2017, which was the seventh consecutive week when dissolved oxygen concentrations below 90% saturation were recorded.[27]

[27] Note field measurements of dissolved oxygen concentrations were made at 50 cm above the sediment surface and dissolved oxygen concentrations may be much lower at the water/sediment surface interface, in particular if there is vertical stratification of the water column.

(a) Ammonium



(b) Filterable Reactive Phosphorus

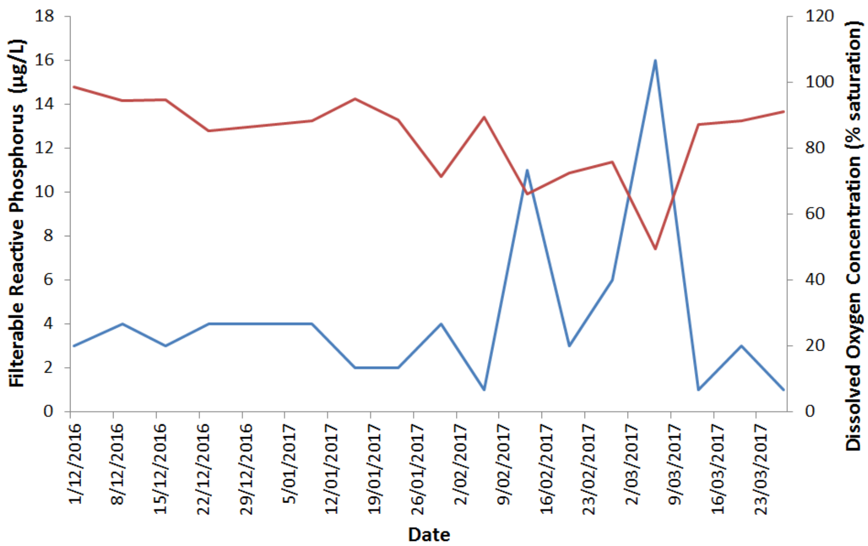


Figure 19. Dissolved oxygen concentrations (red line) and (a) ammonium and (b) filterable reactive phosphorus concentrations (µg/L) (blue line) in the bottom waters at CS13 over the 2016–17 monitoring period.

The Cockburn Sound Management Council will continue to monitor water quality in Cockburn Sound and report against the Environmental Quality Objectives and Criteria. It will also draw attention to unusual weather conditions that may be influencing monitoring results. The Council has initiated an assessment of the current and emerging driving forces and pressures on Cockburn Sound, the Sound's current condition and trends, impacts on the Sound and management responses. This assessment will help the Council and stakeholders to identify, plan for and manage existing and emerging risks so that the environmental values of Cockburn Sound are protected and maintained.

2.9.2 Warnbro Sound Reference Sites

Environmental quality in Warnbro Sound in the Shoalwater Islands Marine Park has historically been relatively high and considered to be practically independent of environmental quality in Cockburn Sound (EPA 2017). Warnbro Sound was originally selected as the most appropriate reference area for Cockburn Sound due to its relatively undisturbed state compared with the Sound as it had not been subject to the same levels of nutrient inputs or anthropogenic pressures. However, with increased population growth and development in the area, pressures on Warnbro Sound have increased in recent years diminishing its value as a reference location.

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 reason(s) for the change in chlorophyll *a* concentrations at the reference site warrants 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*. 2017). In 2017 significant declines in median shoot density were reported at two of the five reference sites, compared to only two of the 11 sites in Cockburn Sound and none of the monitoring sites located outside Cockburn Sound (Appendix D).

The Safety Bay region is one of the most dynamic areas of Warnbro Sound with respect to sediment transport processes and coastline movement (Hollings 2004). This is attributed to the presence of the Tern Island sand bar which has affected the wave field of the area and provides a significant sediment source. The Warnbro Sound reference sites are subject to sediment erosion and the development of 'blow outs' (Mohring and Rule 2014; Rule 2015) which are significantly affecting the integrity of these sites. Relatively high levels of intrusion of potentially toxic sediment sulfides into seagrass tissues have also been reported at the reference sites (Fraser *et al.* 2016b). This is indicative of environmental pressures on the seagrass at these sites which may be contributing to the observed declines in seagrass shoot density. These factors reduce the value of the Warnbro Sound sites as reliable reference sites for comparison with Cockburn Sound.

The Cockburn Sound Management Council convened an Expert Advisory Panel to review the Cockburn Sound water quality monitoring programs and provide advice and recommendations on future monitoring in Cockburn Sound. One of the matters considered by the Panel was whether Warnbro Sound remains a valid reference location for Cockburn Sound. The Council is considering alternatives to monitoring and reporting against water quality and seagrass shoot density at reference sites in Warnbro Sound.

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 2015* (WASQAP Operations Manual; Department of Health 2015). 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 20). Sampling over the 2016–17 monitoring period was undertaken by Blue Lagoon Mussels and administered by the Department of Health. The Department of Primary Industries and Regional Development provided funding for the analysis of phytoplankton community composition (species composition and abundance).

Between July 2016 and June 2017, water samples for bacteriological monitoring were collected on six occasions from five sites (SF6, SF8, SF9, SF10, SF11) in the Southern Flats harvesting area[28] and 14 occasions from five sites (KGT1, KGT2, KGT3, KGT4, KGT5) in the Kwinana Grain Terminal harvesting area.[29] Shellfish samples were also collected for bacteriological testing on 14 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.

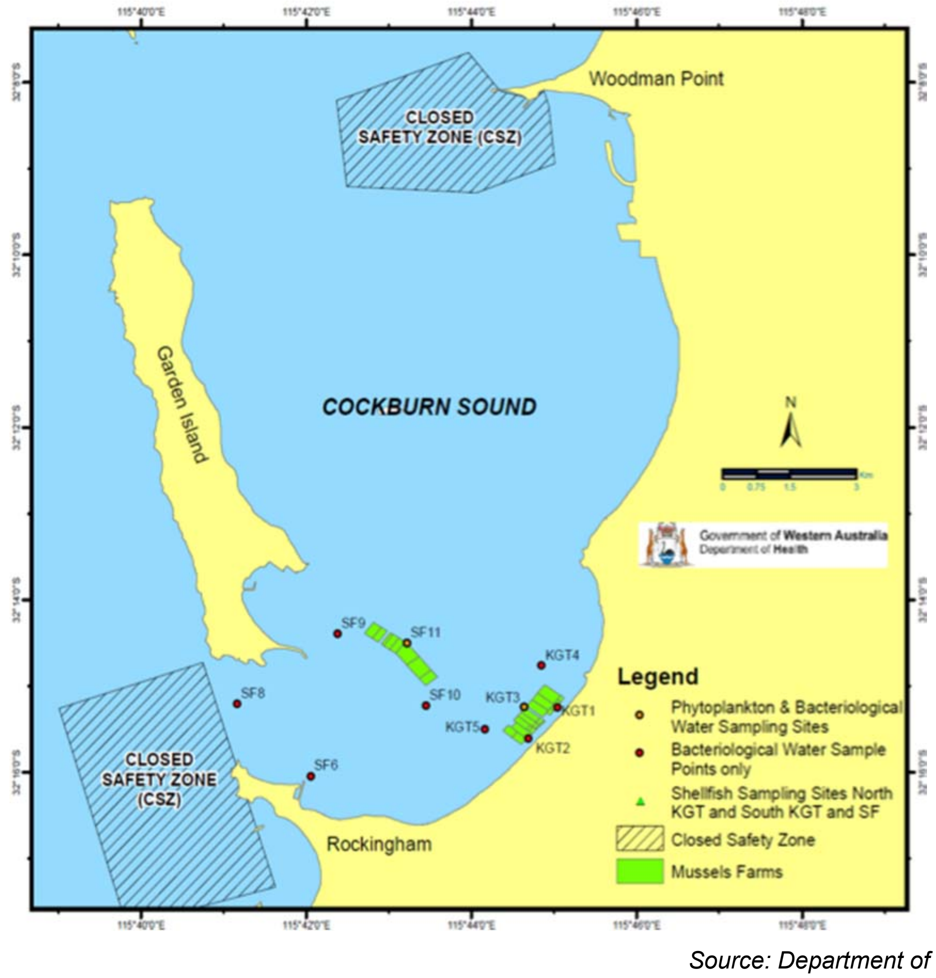
Depth-integrated water samples for phytoplankton identification and enumeration were collected twice monthly on scheduled dates (during periods when shellfish were being harvested) at one of the Kwinana Grain Terminal sites (KGT3) and one of the Southern Flats sites (SF11). Samples were collected from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

[28] Harvesting area classified as ‘approved’ under the WASQAP Operations Manual.
[29] Harvesting area classified as ‘conditionally approved’ under the WASQAP Operations Manual.

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 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 every month 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).

Representative samples of shellfish flesh from the Kwinana Grain Terminal harvesting area and the Southern Flats harvesting area were collected in January 2017 to determine levels of chemical contamination within the harvesting areas. Samples were analysed for metals (inorganic arsenic, cadmium, copper, lead, mercury and zinc), organochlorine and organophosphate pesticides, and polychlorinated biphenyls (PCBs) by Advanced Analytical Australia Pty Ltd.



Source: Department of Health (2015)

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 20. 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). Approximately 30 mussels of

uniform size (approximately 55–90 mm shell length) were collected from the nearest suitable infrastructure (e.g. wharf pylons, ladders) on 7 June 2017. 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 were undertaken by MAFRL and for organotins and PAHs by Advanced Analytical Australia (AAA).

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 2016–17 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 32. Over the 2016–17 monitoring period both components of the ‘Faecal pathogens in water’ EQG were met at all sites in both harvesting areas.

Table 32. 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 2016 and June 2017 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	< 1	EQG met
KGT2	< 1	1.7	EQG met
KGT3	< 1	9.4	EQG met
KGT4	< 1	< 1	EQG met
KGT5	< 1	< 1	EQG met
SF6	< 1	< 1	EQG met
SF8	< 1	< 1	EQG met
SF9	< 1	< 1	EQG met
SF10	< 1	< 1	EQG met
SF11	< 1	< 1	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 2016–17 monitoring period were assessed against the ‘Algal biotoxins’ EQG (Table 33). 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 33. 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 34. On 23 September 2016, 3 October 2016 and 12, 26 and 29 June 2017, the cumulative densities of *Pseudo-nitzschia delicatissima* group and *Pseudo-nitzschia seriata* group exceeded 50,000 cells per litre (cells/L) at the Southern Flats harvesting area. The cumulative densities of *Pseudo-nitzschia delicatissima* group and *Pseudo-nitzschia seriata* group exceeded 50,000 cells/L at the Kwinana Grain Terminal harvesting area on 23 and 27 September 2016, 3 October 2016 and 26 June 2017.

Table 34. Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2016 and June 2017 against the 'Algal biotoxins' EQG.

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	Toxic algae recorded	Cell density (cells/L)	Cell density (cells/L)
5/07/2016	*Dinophysis acuminata*	300	10
	Dinophysis caudata var. *pediculata*	700	40
19/07/2016	*Dinophysis acuminata*	10	20
	Dinophysis caudata var. *pediculata*	20	20
	Pseudo-nitzschia delicatissima group	70	590
9/08/2016	*Dinophysis acuminata*	50	20
	Gymnodinium/Karenia complex	10	-
18/08/2016	*Dinophysis acuminata*	30	210
	Dinophysis caudata var. *pediculata*	10	10
	Pseudo-nitzschia delicatissima group	4,800	2,600
	Pseudo-nitzschia seriata group	200	400
5/09/2016	*Dinophysis acuminata*	10	30
	Dinophysis caudata var. *pediculata*	-	10
	Pseudo-nitzschia delicatissima group	10,800	14,400
	Pseudo-nitzschia seriata group	29,600	22,500
23/09/2016	*Dinophysis acuminata*	30	40

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	Toxic algae recorded	Cell density (cells/L)	Cell density (cells/L)
	Pseudo-nitzschia delicatissima group	**6,400**	**28,000**
	Pseudo-nitzschia seriata group	**64,800**	**66,000**
27/09/2016	*Dinophysis caudata* var. *pediculata*	-	100
	Pseudo-nitzschia delicatissima group	**13,700**	13,500
	Pseudo-nitzschia seriata group	**51,900**	35,600
3/10/2016	*Pseudo-nitzschia delicatissima* group	**38,700**	**39,000**
	Pseudo-nitzschia seriata group	**86,800**	**64,100**
14/10/2016	*Pseudo-nitzschia delicatissima* group	1,720	3,900
	Pseudo-nitzschia seriata group	140	200
31/10/2016	*Dinophysis acuminata*	-	30
	Gymnodinium/Karenia complex	200	100
	Pseudo-nitzschia delicatissima group	-	300
	Pseudo-nitzschia seriata group	-	200
16/11/2016	*Dinophysis acuminata*	-	100
	Pseudo-nitzschia seriata group	100	-
5/12/2016	*Dinophysis acuminata*	150	300
	Pseudo-nitzschia delicatissima group	100	-
19/12/2016	*Dinophysis acuminata*	40	70
	Dinophysis caudata var. *pediculata*	70	-
	Gymnodinium/Karenia complex	100	400
	Pseudo-nitzschia delicatissima group	6,600	18,300
28/12/2016	*Dinophysis acuminata*	10	80
	Dinophysis caudata var. *pediculata*	10	-
	Pseudo-nitzschia delicatissima group	4,700	14,400
9/01/2017	*Pseudo-nitzschia delicatissima* group	13,700	8,100
	Pseudo-nitzschia seriata group	100	100
23/01/2017	*Pseudo-nitzschia delicatissima* group	6,600	8,700
	Pseudo-nitzschia seriata group	200	1,500
6/02/2017	*Dinophysis acuminata*	30	100
	Pseudo-nitzschia delicatissima group	2,500	2,200
	Pseudo-nitzschia seriata group	900	700
20/02/2017	*Pseudo-nitzschia delicatissima* group	21,700	6,600
	Pseudo-nitzschia seriata group	300	-
15/03/2017	*Pseudo-nitzschia delicatissima* group	9,900	7,700
	Pseudo-nitzschia seriata group	4,900	2,400
27/03/2017	*Pseudo-nitzschia delicatissima* group	70	50
10/04/2017	*Pseudo-nitzschia delicatissima* group	1,600	500
24/04/2017	*Pseudo-nitzschia delicatissima* group	-	380
	Pseudo-nitzschia seriata group	190	90
8/05/2017	*Pseudo-nitzschia seriata* group	200	-
22/05/2017	*Dinophysis acuminata*	70	60
	Pseudo-nitzschia delicatissima group	3,300	5,200
	Pseudo-nitzschia seriata group	22,100	35,500
12/06/2017	*Pseudo-nitzschia seriata* group	15,700	**98,400**
26/06/2017	*Dinophysis caudata* var. *pediculata*	90	60
	Pseudo-nitzschia delicatissima group	**26,000**	**20,400**
	Pseudo-nitzschia seriata group	**58,800**	**54,400**
29/06/2017	*Pseudo-nitzschia delicatissima* group	Not sampled	**162,800**
	Pseudo-nitzschia seriata group	Not sampled	**65,200**

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	Toxic algae recorded	Cell density (cells/L)	Cell density (cells/L)
Assessment	Alert level to initiate flesh testing exceeded on 23 and 27 September 2016, 3 October 2016 and 26 June 2017 at the Kwinana Grain Terminal harvesting area Alert level to initiate flesh testing exceeded on 23 September 2016, 3 October 2016, 12, 26 and 29 June 2017 at the Southern Flats harvesting area		

Assessment against the Environmental Quality Standard

The exceedance of the 'Algal biotoxins' EQG on 23 September 2016 and 3 October 2016 at both the Kwinana Grain Terminal harvesting area and the Southern Flats harvesting area, and at the Southern Flats harvesting area on 29 June 2017 triggered shellfish flesh testing for amnesic shellfish poisoning (ASP) biotoxin. The results of the screening for ASP were negative.

Note that:

- as the harvesting area was closed for commercial reasons the exceedance of the 'Algal biotoxins' EQG on 27 September 2016 at the Kwinana Grain Terminal harvesting area did not trigger shellfish flesh testing; and
- the exceedance of the 'Algal biotoxins' EQG at Southern Flats harvesting area on 26 June 2017 did not trigger shellfish flesh testing. Flesh samples collected on 29 June 2017 were tested instead because densities of *Pseudo-nitzschia delicatissima* group and *Pseudo-nitzschia seriata* group had further increased.

Under WASQAP, routine monthly biotoxin screening was introduced in 2015 for all harvesting areas. All the samples for Cockburn Sound in the 2016–17 reporting period were negative for PSP, DSP and ASP biotoxins (Table 35).

Table 35. Results of monthly biotoxin screening in the 2016–17 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 Saxitoxin equivalents/kg	
	Kwinana Grain Terminal	Southern Flats	Kwinana Grain Terminal	Southern Flats	Kwinana Grain Terminal	Southern Flats
5/07/2016	Negative	Negative	Negative	Negative	Negative	Negative
8/08/2016	Negative	Negative	Negative	Negative	Negative	Negative
5/09/2016	Negative	Negative	Negative	Negative	Negative	Negative
31/10/2016	Negative	Negative	Negative	Negative	Negative	Negative
5/12/2016	Negative	Negative	Negative	Negative	Negative	Negative
9/01/2017	Negative	Negative	Negative	Negative	Negative	Negative
6/02/2017	Negative	Negative	Negative	Negative	Negative	Negative
27/03/2017	Negative	Negative	Negative	Negative	Negative	Negative
24/04/2017	Negative	Negative	Negative	Negative	Negative	Negative
8/05/2017	Negative	Negative	Negative	Negative	Negative	Negative
12/06/2017	Negative	Negative	Negative	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 2016–17 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 36. Both components of the EQS were met in both harvesting areas over the 2016–17 monitoring period.

Table 36. Assessment of *E. coli* counts in mussel flesh collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2016 and June 2017 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			
5/07/2016	< 1.8	< 1.8	< 1.8	EQS met
8/08/2016	2	< 1		EQS met
18/08/2016	4.5	4.5		EQS met
5/09/2016	< 1.8	< 1.8	< 1.8	EQS met
3/10/2016	< 1.8	< 1.8		EQS met
31/10/2016	< 1.8	< 1.8	< 1.8	EQS met
5/12/2016	< 1.8	< 1.8		EQS met
23/01/2017	< 1.8	< 1.8	< 1.8	EQS met
6/02/2017	< 1.8	< 1.8		EQS met
20/02/2017	< 1.8	< 1.8		EQS met
27/03/2017	< 1.8	< 1.8	< 1.8	EQS met
24/04/2017	< 1.8	2		EQS met
8/05/2017	< 1.8	< 1.8	< 1.8	EQS met
12/06/2017	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)*
Polychlorinated biphenyls	*0.5 mg/kg*	*(fish).*

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:

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.[30]

The results of the assessment against the EQC are presented in Table 37. Where there are EQC, the concentrations of metals in mussel flesh at sites in Cockburn Sound were all below the relevant EQG or EQS. The concentrations of PCBs, PAHs, organochlorine and organophosphate pesticides in mussel flesh were all below the analytical limits of reporting. In the case of PCBs and the organochlorine pesticides for which there are EQS, the analytical limits of reporting were equivalent to or below the relevant EQS.

[30] Maximum levels of contaminants sourced from Schedule 19, 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 37. 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		Kwinana Bulk Terminal				Kwinana Bulk Jetty				Kwinana Grain Terminal	Southern Flats
	EQG	EQS	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median		
Metals												
Arsenic (Total)	-	-	2.3	2.4	2.6	-	2.3	2.5	2.4	-	18 (dry weight)	17 (dry weight)
Arsenic (inorganic)[1]	-	**1.0**	0.23	0.24	0.26	-	0.23	0.25	0.24	-	0.28[2]	0.36[2]
Cadmium	-	**2.0**	0.08	0.08	0.09	-	0.06	0.11	0.08	-	0.12[2]	0.16[2]
Chromium	-	-	0.12	0.12	0.13	-	0.09	0.11	0.10	-	Not measured	
Copper	**30**	-	0.72	0.68	0.75	0.72	0.50	0.58	0.57	0.57	0.70[2]	0.96[2]
Lead	-	**2.0**	< 0.1	< 0.1	< 0.1	-	< 0.1	< 0.1	< 0.1	-	0.06[2]	0.08[2]
Mercury	-	**0.5 (mean level)**	0.007	0.007	0.009	0.008 (mean)	0.007	0.008	0.008	0.008 (mean)	0.0095[2]	0.0094[2]
Selenium	**1.0**	-	0.6	0.6	0.6	0.6	0.5	0.6	0.5	0.5	Not measured	
Zinc (EQG for oysters)	**290**	-	17	16	21	17	14	21	14	14	15.5[2]	21.4[2]
Tributyltin	-	-	0.0005	0.0009	0.0009	-	0.0006	0.0015	0.0011	-	Not measured	
Organics												
Polychlorinated Biphenyls (PCBs) (fish)	-	**0.5**	Not measured				Not measured				All < 0.01	All < 0.01
Polycyclic aromatic hydrocarbons (PAHs)	-	-	All below limits of reporting				All below limits of reporting				Not measured	
Organochlorine Pesticides												
Aldrin and Dieldrin	-	**0.1**[3]	Not measured				Not measured				Aldrin < 0.01 Dieldrin < 0.1	Aldrin < 0.01 Dieldrin < 0.1
BHC (sum of isomers of 1,2,3,4,5,6-hexachloro-cyclohexane, excluding gamma-isomer Lindane)	-	**0.01**[3]	Not measured				Not measured				BHC-α < 0.01 BHC-β < 0.01 BHC-δ < 0.01	BHC-α < 0.01 BHC-β < 0.01 BHC-δ < 0.01
Chlordane (sum of cis- and trans-chlordane)	-	**0.05**[3]	Not measured				Not measured				cis- < 0.01 trans- < 0.01	cis- < 0.01 trans- < 0.01
DDT (sum of p,p'-DDT, o,p'-DDT, p,p'-DDE and p,p'-DDD)	-	**1.0**[3]	Not measured				Not measured				pp-DDD < 0.01 pp-DDE < 0.01 pp-DDT < 0.01	pp-DDD < 0.01 pp-DDE < 0.01 pp-DDT < 0.01
Heptachlor (sum of heptachlor and heptachlor epoxide)	-	**0.05**[3]	Not measured				Not measured				Heptachlor < 0.01 Heptachlor epoxide < 0.01	Heptachlor < 0.01 Heptachlor epoxide < 0.01
Hexachlorobenzene (HCB)	-	**0.1**[3]	Not measured				Not measured				< 0.01	< 0.01
Lindane (BHC-gamma)	-	**1.0**[3]	Not measured				Not measured				< 0.01	< 0.01

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

1. 10% of total arsenic is assumed to be present as the inorganic form (Stewart and Turnbull 2015).
2. Results reported on a dry weight basis and converted to wet weights: wet weight = dry weight x (1 - %water content/100).
3. 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 2016–17 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 2016–17 non river-flow period should meet the following environmental quality guideline values:

Dissolved oxygen	*≥ 5* mg/L
pH	*6–9.*

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

The results are presented in Table 38. 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 2016–17 non river-flow period.

Table 38. Assessment of dissolved oxygen concentrations and pH in surface waters and at depth, measured at four sites adjacent to the shellfish harvesting areas in Cockburn Sound over the 2016–17 non river-flow period against the 'Physico-chemical stressors' EQG.

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
Surface waters dissolved oxygen (milligrams/litre [mg/L])	1/12/2016	7.1	7.0	7.0	7.1	7.1	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	9/12/2016	7.1	6.9	7.2	7.2	7.2		
	16/12/2016	7.0	6.9	7.0	7.0	7.0		
	23/12/2016	7.1	6.7	7.0	7.0	7.0		
	9/01/2017	6.7	6.7	6.8	6.8	6.7		
	16/01/2017	6.8	6.6	6.6	6.7	6.7		
	23/01/2017	6.8	6.5	6.8	6.7	6.8		
	30/01/2017	6.6	6.3	6.6	6.6	6.6		
	6/02/2017	6.5	6.2	6.4	6.3	6.4		
	13/02/2017	6.4	6.5	6.6	6.5	6.5		
	20/02/2017	6.6	6.6	6.8	6.8	6.7		
	27/02/2017	6.5	6.4	6.2	6.7	6.4		
	6/03/2017	6.5	6.4	6.7	6.7	6.6		
	13/03/2017	6.1	6.1	6.0	6.0	6.1		
	20/03/2017	6.7	6.4	6.9	6.8	6.8		
	27/03/2017	6.8	6.7	6.8	6.7	6.7		

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
Depth waters dissolved oxygen (mg/L)	1/12/2016	7.1	7.0	6.9	7.1	7.0	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	9/12/2016	7.1	6.9	7.1	7.1	7.1		
	16/12/2016	7.0	6.9	7.0	7.0	7.0		
	23/12/2016	7.0	6.5	7.0	7.0	7.0		
	9/01/2017	6.7	6.7	6.5	6.8	6.7		
	16/01/2017	6.8	6.5	6.7	6.7	6.7		
	23/01/2017	6.8	6.6	6.6	6.7	6.6		
	30/01/2017	6.6	6.3	6.5	6.7	6.6		
	6/02/2017	6.4	6.2	6.3	6.3	6.3		
	13/02/2017	6.4	6.5	6.6	6.5	6.5		
	20/02/2017	6.7	6.4	6.7	6.7	6.7		
	27/02/2017	6.5	6.0	6.4	6.5	6.5		
	6/03/2017	6.6	6.3	6.5	6.3	6.4		
	13/03/2017	6.1	6.2	6.0	6.1	6.1		
	20/03/2017	6.7	6.5	6.8	6.8	6.7		
	27/03/2017	6.7	6.6	6.7	6.8	6.7		
Surface waters pH	1/12/2016	8.2	8.2	8.2	8.2	8.2	6–9	EQG met on all sampling occasions and at all sites
	9/12/2016	8.2	8.2	8.2	8.2	8.2		
	16/12/2016	8.0	8.2	8.1	8.2	8.1		
	23/12/2016	8.0	8.0	8.0	8.1	8.0		
	9/01/2017	8.2	8.2	8.1	8.2	8.2		
	16/01/2017	8.2	8.3	8.3	8.3	8.3		
	23/01/2017	8.3	8.3	8.3	8.3	8.3		
	30/01/2017	8.2	8.2	8.2	8.3	8.2		
	6/02/2017	8.3	8.3	8.3	8.3	8.3		
	13/02/2017	8.3	8.2	8.3	8.3	8.3		
	20/02/2017	8.3	8.3	8.3	8.3	8.3		
	27/02/2017	8.3	8.2	8.3	8.3	8.3		
	6/03/2017	8.2	8.2	8.1	8.2	8.2		
	13/03/2017	8.3	8.2	8.3	8.3	8.3		
	20/03/2017	8.2	8.3	8.2	8.3	8.2		
	27/03/2017	8.2	8.2	8.2	8.2	8.2		
Depth waters pH	1/12/2016	8.2	8.2	8.3	8.2	8.2	6–9	EQG met on all sampling occasions and at all sites
	9/12/2016	8.2	8.2	8.2	8.2	8.2		
	16/12/2016	8.2	8.2	8.1	8.2	8.2		
	23/12/2016	8.0	8.0	8.0	8.1	8.0		
	9/01/2017	8.2	8.2	8.2	8.2	8.2		
	16/01/2017	8.2	8.3	8.3	8.3	8.3		
	23/01/2017	8.3	8.3	8.3	8.3	8.3		
	30/01/2017	8.2	8.2	8.2	8.3	8.2		
	6/02/2017	8.3	8.3	8.3	8.3	8.3		
	13/02/2017	8.3	8.2	8.3	8.3	8.3		
	20/02/2017	8.3	8.3	8.3	8.3	8.3		
	27/02/2017	8.3	8.2	8.3	8.3	8.3		
	6/03/2017	8.2	8.2	8.1	8.2	8.2		
	13/03/2017	8.3	8.3	8.3	8.3	8.3		
	20/03/2017	8.2	8.3	8.2	8.3	8.2		
	27/03/2017	8.2	8.2	8.2	8.2	8.2		

3.4.2 Assessment of Compliance with the 'Toxicants' EQG

Concentrations of ammonia and nitrate–nitrite measured at four water quality monitoring sites close to the shellfish harvesting areas in Cockburn Sound (CS9A, CS10N, CS11 and CS13) over the 2016–17 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 in March 2017 (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 39. The toxicant concentrations recorded at all the sites were below the relevant EQG values.

Table 39. 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	< 3		2	< 2		0.3		2.0
KBT2		< 3	< 3		< 2	< 2		0.3		1.9
KBT3		< 3	< 3		< 2	2		0.3		2.1
KBJ1		280	< 3		77	< 2		0.3		Not measured
KBJ2		29	16		10	3		0.4		Not measured
KBJ3	≤1,000	11	37	Nitrite-N ≤100 Nitrate-N ≤100,000	5	10	≤5	2.1	≤10	Not measured
CS13		1.7	57.0		< 2	5		Not measured		Not measured
CS9A		95th percentile = 8.4			95th percentile = < 2			Not measured		Not measured
CS10N		95th percentile = 5.5			95th percentile = < 2			Not measured		Not measured
CS11		95th percentile = 2.4			95th percentile = < 2			Not measured		Not measured
Assessment				EQG met at all sites						

3.5 Conclusions

Based on the results from the 2016–17 monitoring programs in Cockburn Sound, there is a high degree of certainty that the Environmental Quality Objectives 'Maintenance of seafood safe for human consumption' and 'Maintenance of aquaculture' have been achieved in the 'approved' and 'conditionally approved' shellfish harvesting areas in southern Cockburn Sound. There is no information available from other areas in Cockburn Sound or for wild shellfish or fish.

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

4. Environmental Value: Recreation and Aesthetics

4.1 Environmental Quality Objectives

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

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

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

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

4.2 Water Quality Monitoring

The cities of Cockburn, Kwinana, and Rockingham undertook bacterial water sampling at a number of popular recreational beaches (program sites) around Cockburn Sound in the 2016–17 monitoring period (Figure 21). The sampling 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 approximately one sample collected each fortnight). This minimum number of samples is recommended to maintain statistical confidence when assigning a site classification (beach grades) following the National Health and Medical Research Council (2008) guidelines.[31]

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

Samples were analysed for enterococci by PathWest Laboratory. Note that enterococci are the bacterial indicator recommended by the National Health and Medical Research Council (2008).

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

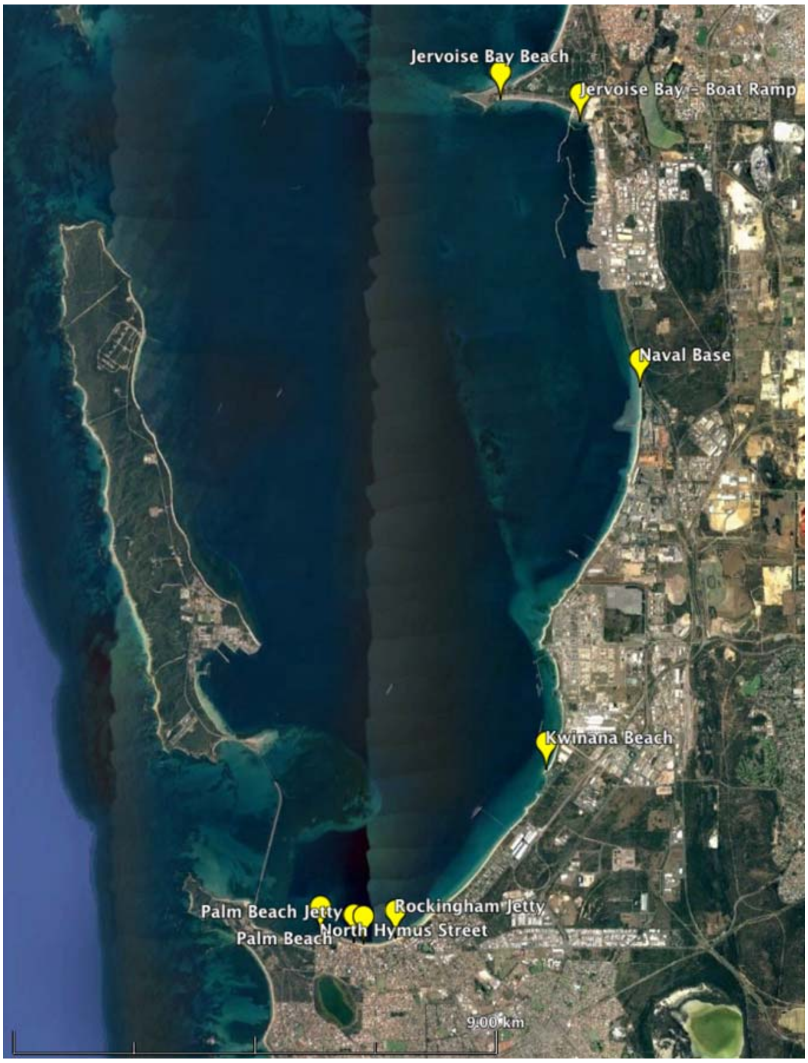


Figure 21. Sampling locations associated with recreational beaches in Cockburn Sound.

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 2016–17 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 40. The 'Faecal pathogens' EQG for both primary and secondary contact recreation were met at all of the sites monitored over the

2016–17 monitoring period. One of the sites (North Hymus Street) met the minimum sample size of 65 samples collected over a five year period.

Table 40. Assessment of the 95th percentile of enterococci counts (samples collected between 2012–13 and 2016–17) 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	Program	66	200	2,000	65
Jervoise Bay Beach	Program	64			65
Rockingham Beach + Jetty	Program	63			195
Palm Beach Jetty	Program	58			26
Naval Base	Program	39			30
Kwinana Beach	Program	37			55
Jervoise Bay Boat Ramp	Reference	54			38
Palm Beach	Reference	23			90
Assessment		Primary contact and secondary contact recreation EQG met at all sites			

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 2016–17 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.*[32]

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

[32] 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 41. Assessment of pH and water clarity (Secchi disc) at 18 water quality monitoring sites in Cockburn Sound over the 2016–17 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	8.3	8.3	>1.6 m	3.3 – 9.5	EQC met at all sites
CS5		8.3	8.2		3.3 – 10.4	
CS6A		8.2	8.2		3.0 – 10.0	
CS7		8.2	8.2		3.5 – 8.6	
CS8		8.3	8.3		3.4 – 11.1	
CS9		8.2	8.2		3.8 – 9.4	
CS10N		8.2	8.2		3.7 – 10.9	
CS11		8.2	8.2		3.5 – 9.7	
CS12		8.2	8.2		3.2 – 9.2	
CS13		8.3	8.2		3.8 – 10.8	
CS9A		8.2	8.2		3.0 – 10.6	
CB		8.2	8.2		3.7 – 9.8	
G1		8.3	8.2		3.1 – 8.1	
G2		8.3	8.3		3.6 – 9.6	
G3		8.3	8.3		3.5 – 9.4	
SF		8.2	8.3		4.0 – 10.8	
MB		8.2	8.2		3.5 – 9.2	
NH3		8.3	8.3		2.2 – 6.0	

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.

4.3.4 Investigation into PFAS in Marine Waters of Cockburn Sound

On 9 January 2017 depth-integrated water samples were collected from each of the water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound and analysed for 21 perfluoroalkyl and polyfluoroalkyl substances (commonly referred to as PFAS) (Sections 2.3 and 2.7.4; Figure 2).

Concentrations of the 21 PFAS substances were equal to or below the analytical limits of reporting (between 0.005 µg/L or 0.05 µg/L) at all the sites sampled in Cockburn Sound and Warnbro Sound (Section 2.7.4). There are no EQC for PFAS for the maintenance of primary or secondary contact recreation values in the Reference Document. The Australian Government (2017) has prepared health-based guidance values for PFAS in recreational waters for use in site investigations and human health risk assessments in Australia (Table 42). The analytical limits of reporting are well below the health-based guidance values for recreational waters.

Table 42. Health-based guidance values for recreational waters

Exposure scenario	PFOS (µg/L)	PFOA (µg/L)
Recreational water quality value	0.7	5.6

Source: Table 1, Australian Government (2017)

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 2016 to March 2017 non river-flow period (Section 2.3; Figure 2), MAFRL undertook qualitative observations of the following indicators of aesthetic quality:

- nuisance organisms;
- algal blooms;
- faunal deaths;
- water clarity;
- colour variation;
- surface films (for example oil and petrochemical films on the water);
- surface or submerged debris (for example grain and litter); and
- odours.

The results are summarised in Table 43.

Grain was observed on the water surface at CS10N adjacent to the Kwinana Grain Jetty on seven occasions over the 2016–17 non river-flow period. Odours were reported at sites adjacent to the industrial area on the eastern shore of Cockburn Sound (CB, CS9, CS9A and CS12) on eight occasions.

Associated with the high rainfall events in January and February 2017 (Section 2.9), a plume of riverine, tannin-stained water was observed extending west to Carnac Island and south into Cockburn Sound. Tannin-stained water was noted on 20 and 27 February 2017 at sites in the northern part of the Sound (CS4, CS5, CB, CS7, CS6A and Jervoise Bay Northern Harbour [NH3]). Algal blooms were also observed at the majority of sites in Cockburn Sound on most sampling occasions from late December 2016, with impacts on water clarity and water colour also reported on these occasions. Algal blooms were observed at the Warnbro Sound reference sites on 9 January 2017, 30 January 2017, 20 March 2017 and 27 March 2017.

Observations of aesthetic quality will be undertaken over the 2017–18 monitoring period.

Table 43. 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 2016–17 non river-flow period.

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour	Surface films	Surface or submerged debris	Odours
1/12/2016	-	-	-	NH3 (turbid)	NH3 (water green colour)	-	Dead pigeon observed between CS9A and CS10N	-
9/12/2016	CS12 and CS9A (surface phytoplankton scum)	-	-	-	-	-	CS10N (grain)	CS9 and CS12 (industrial odours)
16/12/2016	-	-	-	-	-	-	-	CS9A (oil odour)
23/12/2016	CS6A, CS7, CS12, CS9, CS9A, CS10N, CS13, CS11, CB, (phytoplankton with mucus)	MB, SF, G1, G2, CS8, CS5, NH3	-	CS6A, CS7, CS12, CS9, CS9A, CS10N, CS13, CS11, SF, G1, G2, CS8, CB, CS5, NH3	CS6A, CS7, CS12, CS9, CS9A, CS10N, CS13, CS11, SF, G1, G2, CS8, CB, CS5	CS9 (brown surface film)	CS10N (grain)	CS9
9/1/2017	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 Large visible bloom at MB light site	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, G3, CS8, CS4, CS5, NH3; WS4	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, G3, CS8, CS4, CS5, NH3; WS4	-	CS10N and CS13 (grain)	CS10N and CS13 (grain odour)
16/1/2017	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS5, NH3	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS5, NH3	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS5, NH3	-	-	-
23/1/2017	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3	-	-	-
30/1/2017	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB CS7 (transient event associated with ship movements)	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	-	-	-
6/2/2017	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, CS8 and at SF light site	CS10N (dead mussels on surface)	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, CS8 CS7 (transient event	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB (very green in Mangles Bay, clear at light site), G1, G2,	CS5 (surface slick)	-	CS6A, CS9A (industrial odour) CS5 (odour associated with sheep export vessel)

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour	Surface films	Surface or submerged debris	Odours
				associated with ship movements)	CS8			
13/2/2017	-	NH3	-	NH3	NH3	CS5 (oil-like film)	-	CS12 (industrial odour)
20/2/2017	-	CS6A. CS7, CB, CS12	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N (phytoplankton and tannins) CS9A (transient event associated with ship movements) G3, CS4, CS5, NH3 (tannins)	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N (phytoplankton and tannins) CS9A (transient event associated with ship movements) G3, CS4, CS5, NH3 (tannins)	-	-	-
27/2/2017	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, NH3	-	CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, CS6A, CS7, CB, NH3 (phytoplankton and tannins)	CS12, CS9, CS9A, CS10N, CS13, CS11, MB, G1, G2, CS6A, CS7, CB, NH3 (phytoplankton and tannins)	-	CS10N (grain)	-
6/3/2017	CS9A (surface phytoplankton scum)	NH3	-	NH3	NH3	-	CS10N (grain) CS9 (aluminium can)	-
13/3/2017	CS6A (filamentous algae on filter)	CS9A, CS10N, CS13, CS11, MB, G1, G2, G3, NH3	-	CS9A, CS10N, CS13, CS11, MB, G1, G2, G3, NH3	CS9A, CS10N, CS13, CS11, MB, G1, G2, G3, NH3	-	-	-
20/3/2017	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	-	CS10N (grain)	CB, CS12, CS9 (industrial odour)
27/3/2017	CS6A, CS7, CB, CS12, CS9 (phytoplankton scum and mucus)	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	-	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, G2, G3, CS8, CS4, CS5, NH3; WS4 and WSSB	-	CS10N (grain)	CS6A (fish/bait) CS12 (industrial odour)

4.5 Conclusions

Based on the results from the 2016–17 monitoring programs in Cockburn Sound, there were no recorded exceedances of the EQC for the Environmental Quality Objectives ‘Maintenance of primary contact recreation values’ and ‘Maintenance of secondary contact recreation values’. There is, therefore, a high degree of certainty that the Environmental Quality Objectives have been achieved and the waters are safe for recreational activities.

5. Environmental Value: Industrial Water Supply

5.1 Environmental Quality Objective

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

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

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

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

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

5.2 Perth Seawater Desalination Plant Intake Water Quality Monitoring

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

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

5.3.1 Biological Indicators

E.coli did not exceed the EQG of 32 Colony Forming Units per 100 millilitres (CFU/100 mL) on any sampling occasion over the July 2016 to May 2017 monitoring period. The Water Corporation advised there were no *E. coli* results in excess of 32 CFU/100 mL since the Desalination Plant commenced operation in 2006.

Enterococci sampling commenced in May 2017. The EQG of 32 CFU/mL was met on all sampling occasions, with results not exceeding 10 CFU/100mL in the sampling period.

5.3.2 Physical and Chemical Indicators

Over the 2016–17 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). All equipment at the Desalination Plant is routinely recalibrated to ensure accuracy and reliability.

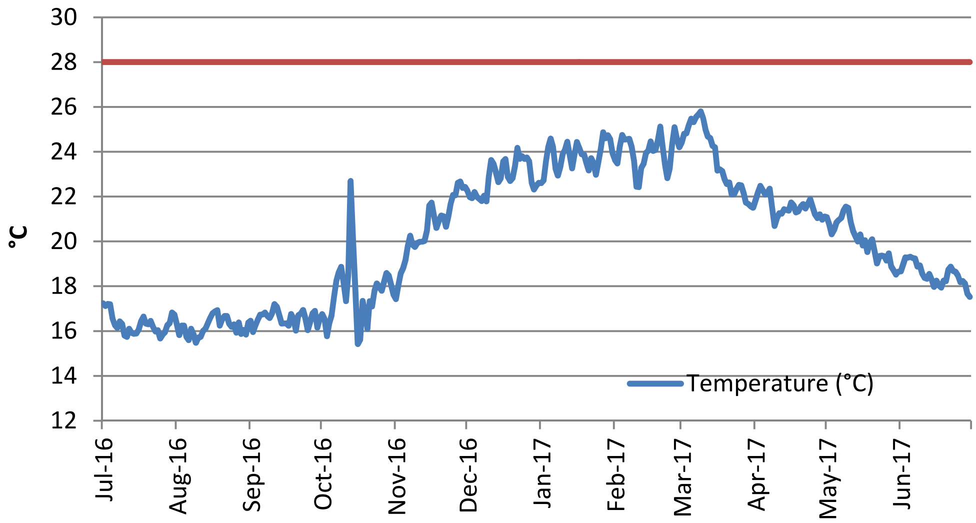


Figure 22. Daily average temperature of the intake seawater over the 2016–17 monitoring period.

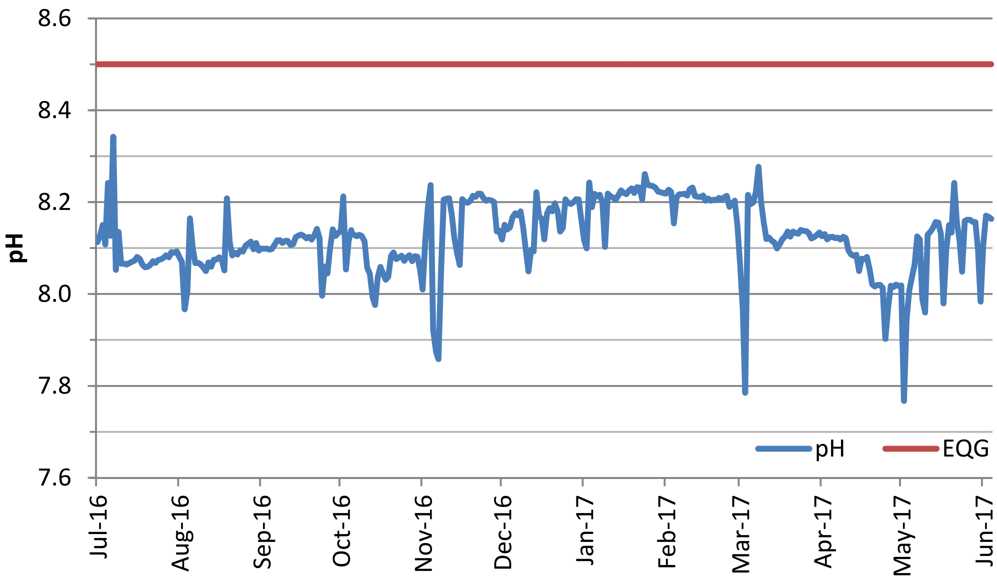


Figure 23. Daily average pH of the intake seawater over the 2016–17 monitoring period.

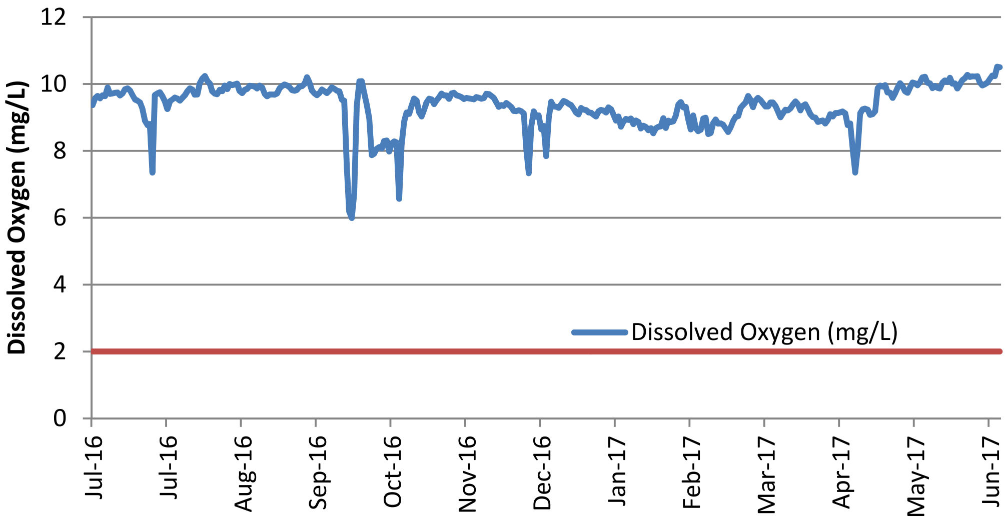


Figure 24. Daily average dissolved oxygen concentration of the intake seawater over the 2016–17 monitoring period.

The 'rolling' four-week median concentration of TSS exceeded the EQG of 4.5 mg/L from early October to late November (Figure 25). No individual TSS concentrations exceeded the EQG of 9 mg/L. 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.

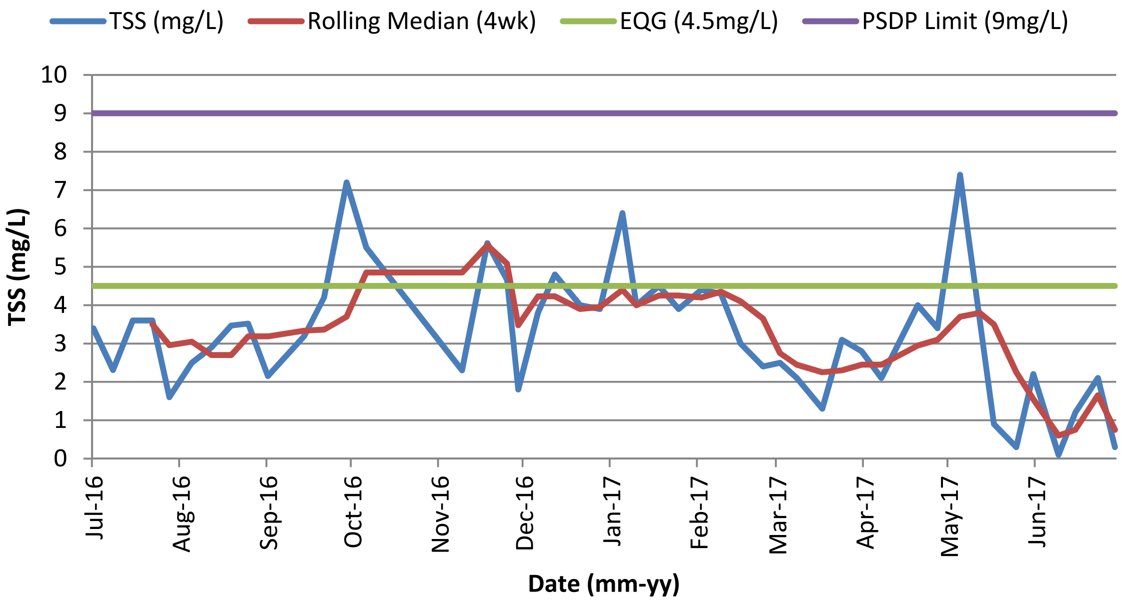


Figure 25. Weekly and 'rolling' four-weekly median total suspended solids (TSS) concentration in the intake seawater over the 2016–17 monitoring period.

Over the 2016–17 monitoring period, hydrocarbon concentrations in the intake seawater did not exceed the Water Corporation's limit, nor did bromide concentrations exceed the EQG of 77 mg/L (Table 44). On three occasions the concentration of boron exceeded the EQG of 5.2 mg/L – twice the recorded concentration was 5.7 mg/L; once the recorded concentration was 5.8 mg/L. 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 2016–17 monitoring period.

Sampling Occasion	Boron (mg/L)		Bromide (mg/L)	
	EQG	Concentration	EQG	Concentration
July 2016	5.2	4.2	77	57
October 2016		**5.8**		65
January 2017		**5.7**		58
April 2017		**5.7**		53

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 2016–17 monitoring period. Natural variation in the quality of the intake seawater was observed by the Water Corporation over the 2016–17 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 2016–17 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant indicated there were minor exceedances in two parameters. 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.

Glossary

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

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

	species and biological communities, rates of ecosystem processes and abundance/biomass of marine life, but which do not result in bioaccumulation/biomagnification in near-by high ecological protection areas).
Low reliability value (LRV)	For a number of toxicants where there are insufficient toxicological data to develop reliable guideline trigger levels, low reliability values have been derived to give guidance in the absence of any higher reliability guidelines being available. LRVs should not be used as default guideline trigger values. However, it is assumed that if ambient concentrations fall below the LRV then there is low risk of ecological impact. If concentrations are above a LRV it does not necessarily mean an impact is likely. Exceedance of a LRV does not trigger mandatory assessment against the Environmental Quality Standards, but does signal that the possibility of ecological impact should be considered, particularly if further increases beyond the LRV are likely.
Lower Depth Limit (LDL)	The maximum depth and distance at which seagrass shoots are observed within a one metre belt either side of the transect line. The objective of this measure is to identify the position of the boundary of a seagrass bed, and, by reference to the baseline and/or reference conditions, to establish the magnitude and direction of change (in other words, gain or loss) of seagrass meadow.
Mann-Kendall trend analysis	The Mann-Kendall trend analysis is a non-parametric statistical test to detect a monotonic upward or downward trend in the variable of interest over time.
Marine biotoxins	Toxic compounds produced by some species of phytoplankton.
Maximum residue limit	The highest concentration of a chemical residue that is legally permitted or accepted in a food.
Mean shoot height	The 80^{th} percentile of shoot heights within quadrats. The tallest 20% of shoots inside a quadrat were excluded and the height of the tallest remaining shoots measured. Mean shoot height is measured as long leaves are often necrotic for much of their length and maximum height may not be an accurate measure of canopy height within each quadrat.
Median	A measure used in statistics representing the ‘middle’ number in a sequence of numbers that has been arranged from the smallest value to the largest value. The main advantage of the median compared to the average or mean of a data set, is that is it not influenced so much by very large or very small values and is therefore considered to be more representative of the majority of values in a data set.
Moderate level of ecological protection	Allows for moderate changes in the quality of water, sediment or biota (such as moderate changes in contaminant concentrations that could cause small changes beyond natural variation in ecosystem processes and abundance/biomass of marine life, but no detectable changes from the natural diversity of species and biological

	communities).
Non river-flow period	The main period for nutrient-related monitoring in Cockburn Sound. This is over summer when river flow is minimal and nutrient concentrations are most stable.
Normalisation	A procedure to adjust concentrations of contaminants in sediments for the influence of natural variability in sediment composition, in particular for grain size, organic matter content and mineralogy.
Nutrients	Elements or compounds, such as nitrogen and phosphorus, that are essential for organic growth and development.
Percentile	A measure used in statistics whereby the p^{th} percentile of a distribution of data is the value that is greater than or equal to *p*% of all the values in the distribution. For example the 80^{th} percentile is greater than or equal to 80% of all values; conversely, 80% of all values are less than or equal to the 80^{th} percentile.
Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)	A group of synthetic fluorine-containing chemicals used in heat, stain and water resistant products (such as non-stick cookware, specialised textiles, Scotchgard™) and were used in fire-fighting foams. PFAS are highly persistent in the environment, moderately soluble, can be transported long distances and transfer between soil, sediment, surface water and groundwater. They have been shown to be toxic to some animals and, because they break down very slowly, can bioaccumulate and biomagnify in some wildlife, including fish. This means that fish and animals higher in the food chain may accumulate higher concentrations of PFAS in their bodies. Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are two of the best-known PFAS and are contaminants of emerging concern in Australia and internationally. They have been identified in the environment at a number of known and suspected contaminated sites in Western Australia.
Phytoplankton	Single-celled plants and other photosynthetic organisms (including cyanobacteria, diatoms and dinoflagellates) that live in the water column.
Public Authority	A Minister of the Crown acting in their official capacity, department of the Government, state agency or instrumentality, local government or other person, whether corporate or not, who or which under the authority of a written law administers or carries on for the benefit of the State, or any district or other part thereof, a social service or public utility.
Re-sampling trigger	Where the total concentration of a contaminant in individual sediment sample sites exceeds the environmental quality guideline re-sampling trigger, additional sampling of that potentially contaminated site will generally be required to better define the area of high concentration.
Seagrass	Submerged flowering plants that mainly occur in shallow marine areas and estuaries.

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

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Appendix A: 2016–17 Nutrient Concentrations

Total nitrogen concentrations over the 2016–17 non river-flow period varied between 80 micrograms per litre (µg/L) at CB in central Cockburn Sound and G3 in north-western Cockburn Sound on 1 December 2016 and 250 and 230 µg/L at Jervoise Bay Northern Harbour (NH3) on 20 and 27 February 2016 respectively (Cossington and Wienczugow 2017). Total phosphorus concentrations varied between 11 µg/L at Southern Flats (SF) on 23 January 2017, CB on 20 February 2017 and G3 on 6 March 2017 and 23 µg/L at the eastern Cockburn Sound site CS9A on 20 March 2017.

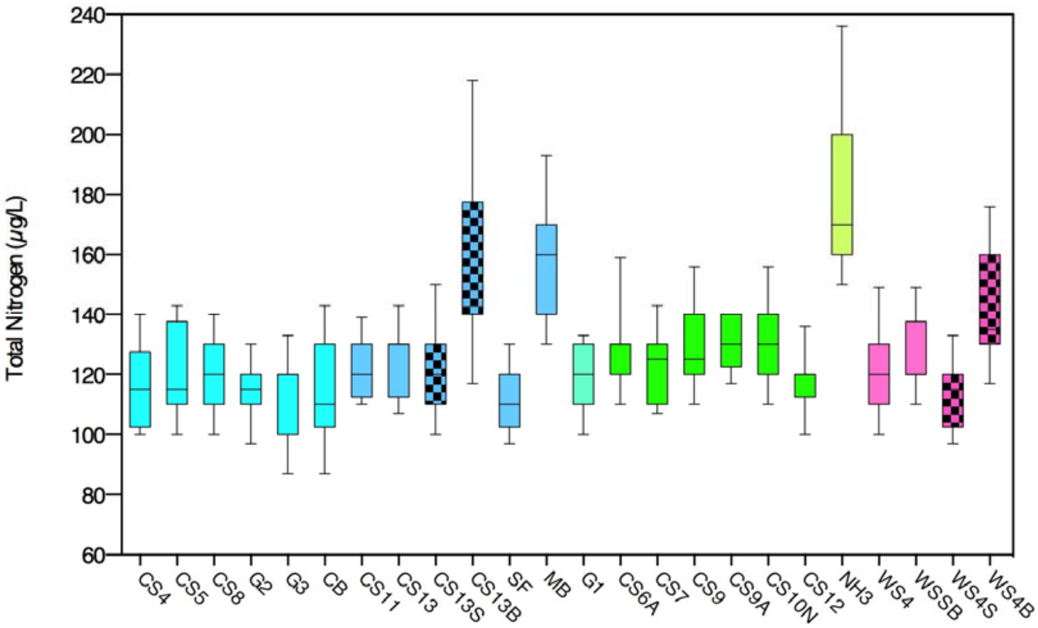
The highest median total nitrogen concentrations were recorded at NH3 (170 µg/L) in MPA-NH and Mangles Bay (MB; 160 µg/L) in HPA-S (Figure A.1; Cossington and Wienczugow 2017), where elevated median chlorophyll *a* concentrations were also reported. Median total nitrogen concentrations at NH3 and MB were significantly[33] higher than recorded at most of the other sites in Cockburn Sound and Warnbro Sound. Other sites with elevated median total nitrogen concentrations included CS13 (130 µg/L) in HPA-S, CS6A (130 µg/L), CS9A (130 µg/L) and CS10N (130 µg/L) in MPA-ES.

The highest median total phosphorus concentrations were recorded at NH3 (18 µg/L), MB (17 µg/L), CS9A (17 µg/L) and CS10N (17 µg/L) (Figure A.2; Cossington and Wienczugow 2017). Other sites with elevated median total phosphorus concentrations included CS9 (16 µg/L) in MPA-ES and CS11 (16 µg/L) and CS13 (16 µg/L) in HPA-S.

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

Significantly higher median total nitrogen and total phosphorus concentrations were recorded in bottom waters than in surface waters at CS13 (surface waters: median total nitrogen: 120 µg/L, median total phosphorus: 16 µg/L; bottom waters: median total nitrogen: 140 µg/L, median total phosphorus: 20 µg/L) and the Warnbro Sound reference site WS4 (surface waters: median total nitrogen: 115 µg/L, median total phosphorus: 12 µg/L; bottom waters: median total nitrogen: 135 µg/L, median total phosphorus: 18 µg/L) (Figure A1 and Figure A2).

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

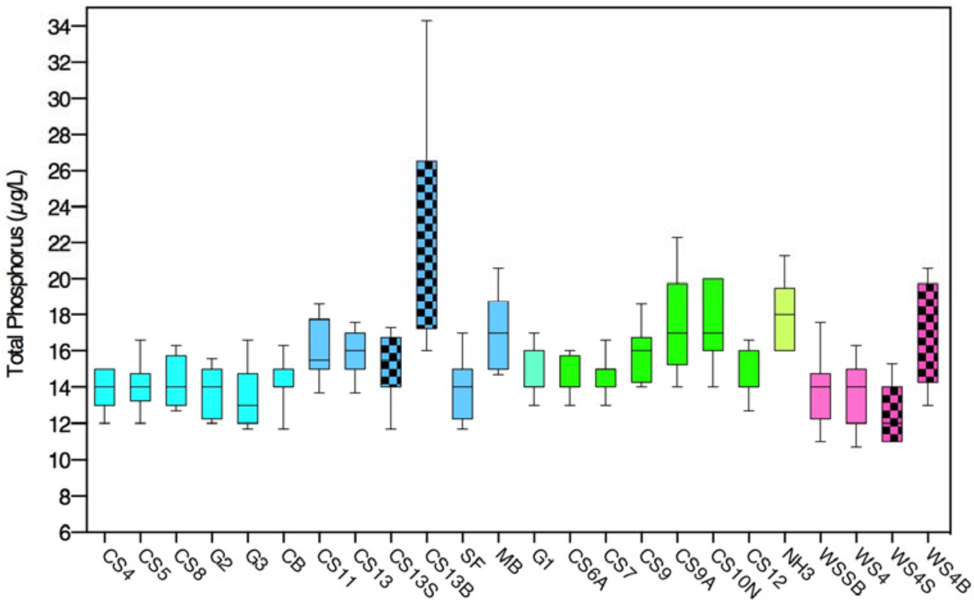


Notes:

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

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

Figure A.1. Median total nitrogen concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2016 to March 2017.



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.

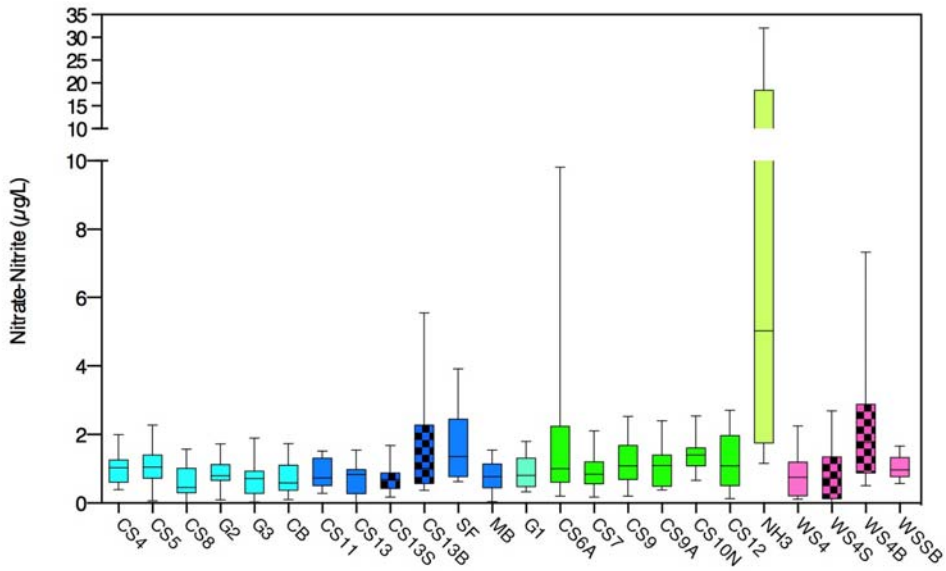
Figure A.2. Median total phosphorus concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2016 to March 2017.

Nitrate–nitrite concentrations ranged from less than the analytical reporting limit (< 2 µg/L) which was recorded at all sites on numerous occasions, to 40 µg/L at NH3 in MPA-NH on 13 March 2017. Median nitrate–nitrite concentrations were below the analytical reporting limit at all sites with the exception of NH3 (5 µg/L) where nitrate–nitrite concentrations were significantly higher that at most of the other sites (Figure A.3; Cossington and Wienczugow 2017).

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 14 µg/L and 16 µg/L at NH3 on 13 February 2017 and 13 March 2017, respectively. The highest median ammonium concentrations were recorded at NH3 (1.9 µg/L), and at CS9 (1.4 µg/L), CS9A (1.5 µg/L) and CS10N (3.5 µg/L) in MPA-ES (Figure A.4; Cossington and Wienczugow 2017). Median ammonium concentrations at CS10N and NH3 were significantly higher than at a number of the Cockburn Sound sites, including CS4 and CS8 in HPA-N and CS7 in MPA-ES.

Filterable reactive phosphorus concentrations ranged from less than the analytical reporting limit (< 2 µg/L) which was recorded at all the sites on numerous occasions and 7 µg/L at CS9A on 23 December 2016 and 13 March 2017. The highest median filterable reactive phosphorus concentration (2.5 µg/L) was recorded at CS10N (Figure A.5; Cossington and Wienczugow 2017).

Median nitrate–nitrite concentrations were significantly lower in surface waters than bottom waters at the reference site WS4, but there was no significant difference between the bottom and surface waters at CS13 (Figure A3). Median ammonium and filterable reactive phosphorus concentrations were significantly higher in bottom waters than in surface waters at both CS13 and the reference site WS4 (Figure A4 and Figure A5).

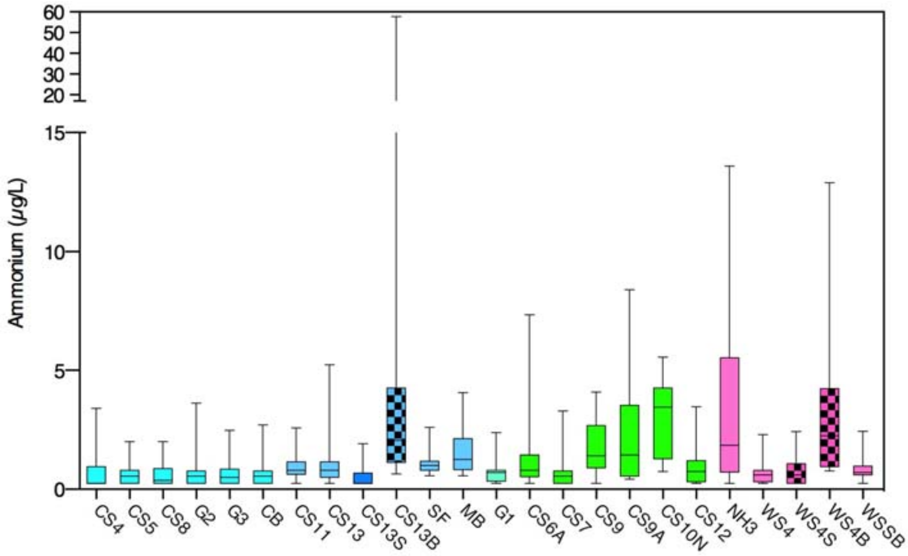


Notes:

(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 2016 to March 2017.

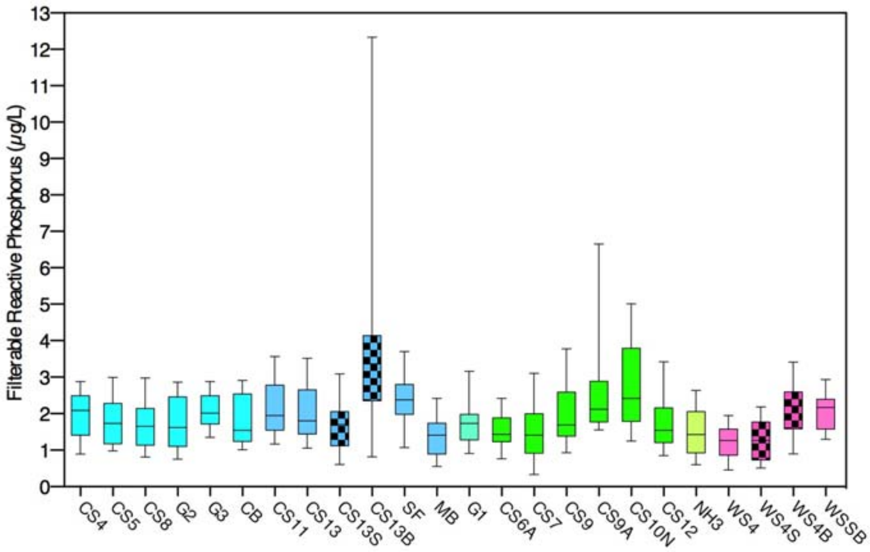


Notes:

(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 2016 to March 2017.



Notes:

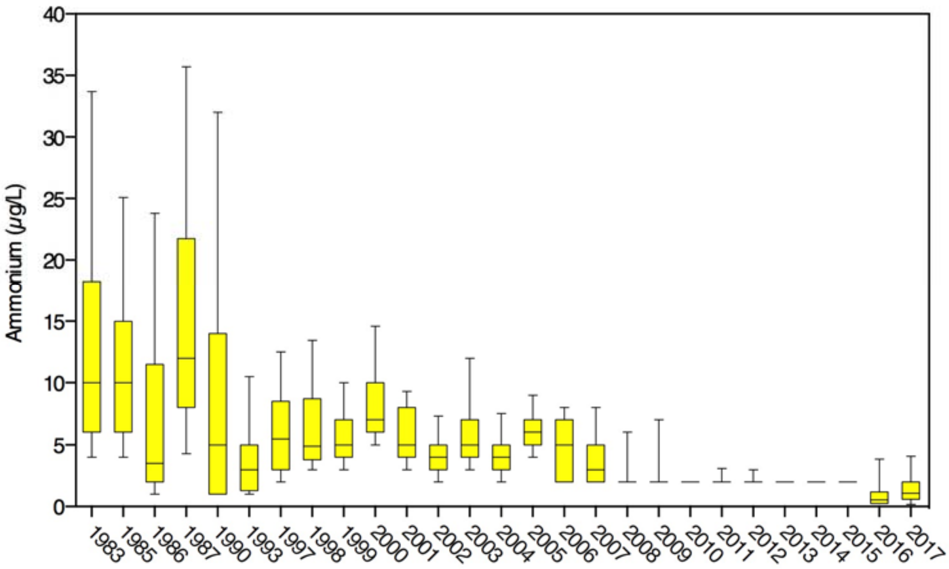
(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(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 2016 to March 2017.

Appendix B: Variations and Trends over Time in Nutrient Concentrations

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 2017). The variability between sites within years has also decreased over that time. The median ammonium concentration at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 in 2016–17 was not significantly different to the median concentrations recorded in 2009–10 to 2015–16, but was significantly lower than in the years prior to this period.



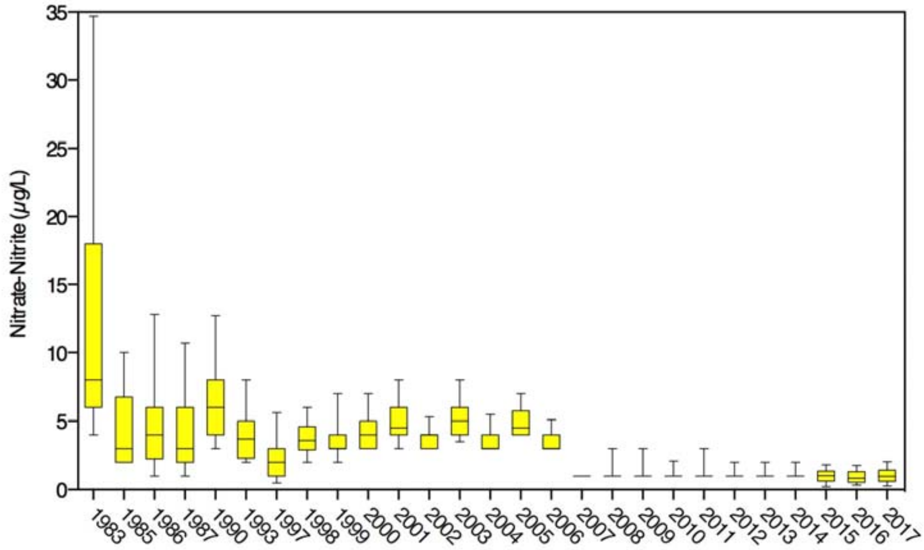
Notes:

(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 2017.

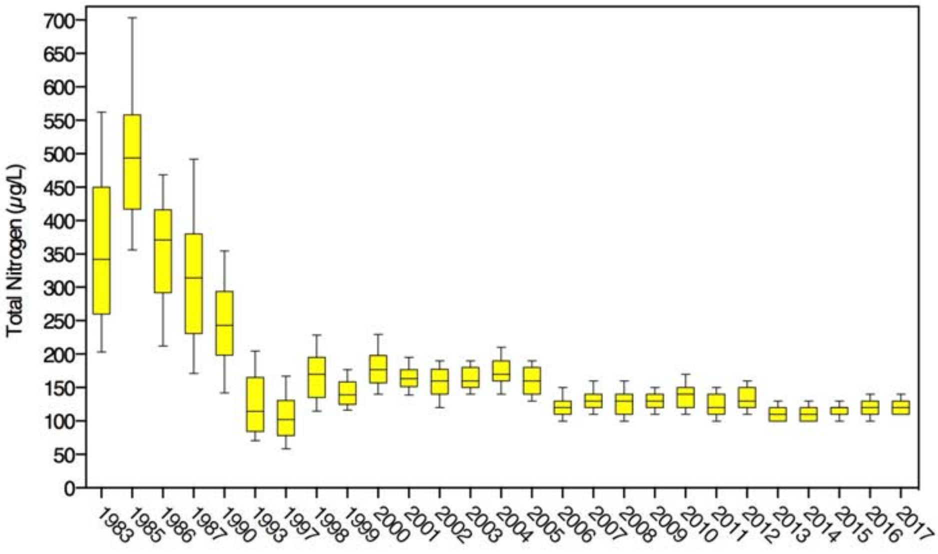
Median non river-flow period nitrate–nitrite concentrations were highest in the early 1980s, with the lowest concentrations recorded since 2006–07 (Figure B2; Cossington and Wienczugow 2017). The within-year variation in nitrate–nitrite concentrations has also decreased over time. The median nitrate-nitrite concentration at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 in 2016–17 was not significantly different to the concentrations recorded between 2006–07 to 2015–16, but was significantly lower than in the years prior to this period.



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 2017.

Median non river-flow period total nitrogen concentrations have generally decreased since monitoring began in Cockburn Sound, as has the variability within years (Figure B.3; Cossington and Wienczugow 2017). The median total nitrogen concentration at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 in 2016–17 was not significantly different to the median total nitrogen concentrations recorded in 1992–93 and 1996–97 and between 2005–06 to 2008–09 and 2010–11 to 2015–16. Median concentrations in 2016–17 were significantly lower than in 2009–10 and the other years in which total nitrogen concentrations were measured. Plots of median total nitrogen concentrations at each site over time are presented in Figure B.4.



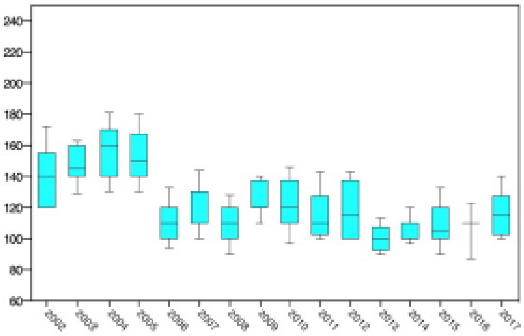
Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

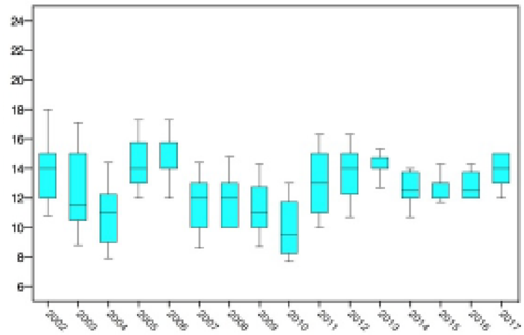
Figure B.3. Median total nitrogen concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2017.

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

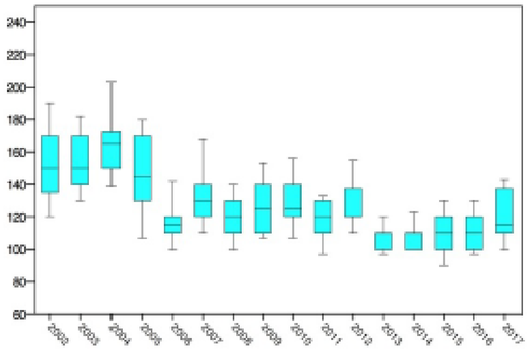
High Ecological Protection Area - North

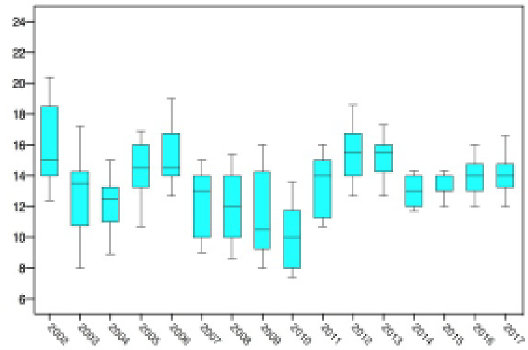
CS4



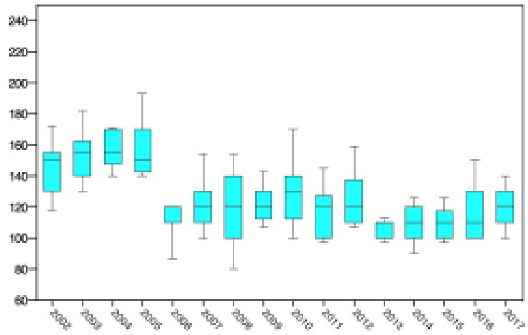


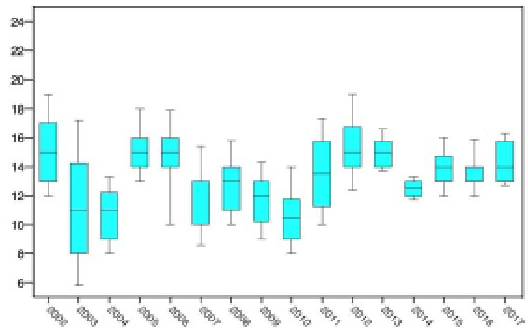
CS5



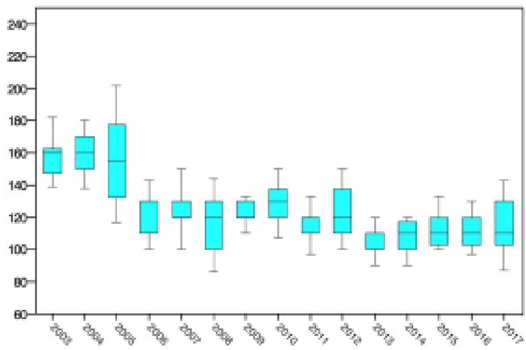


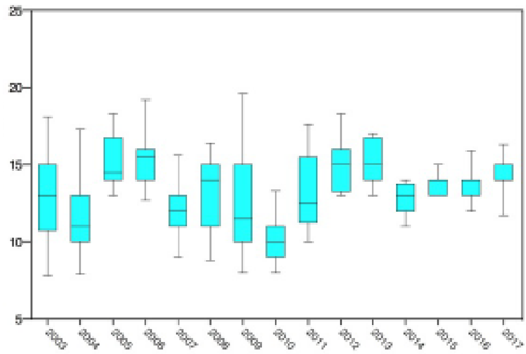
CS8



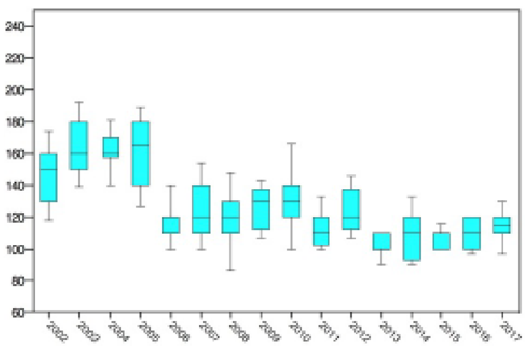


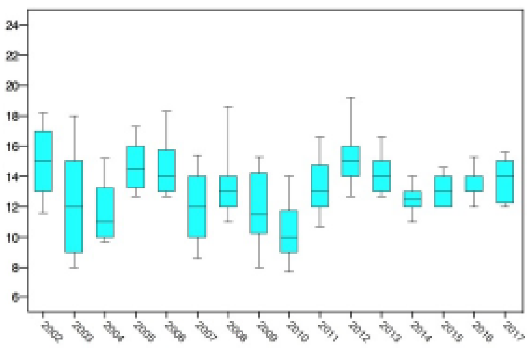
CB

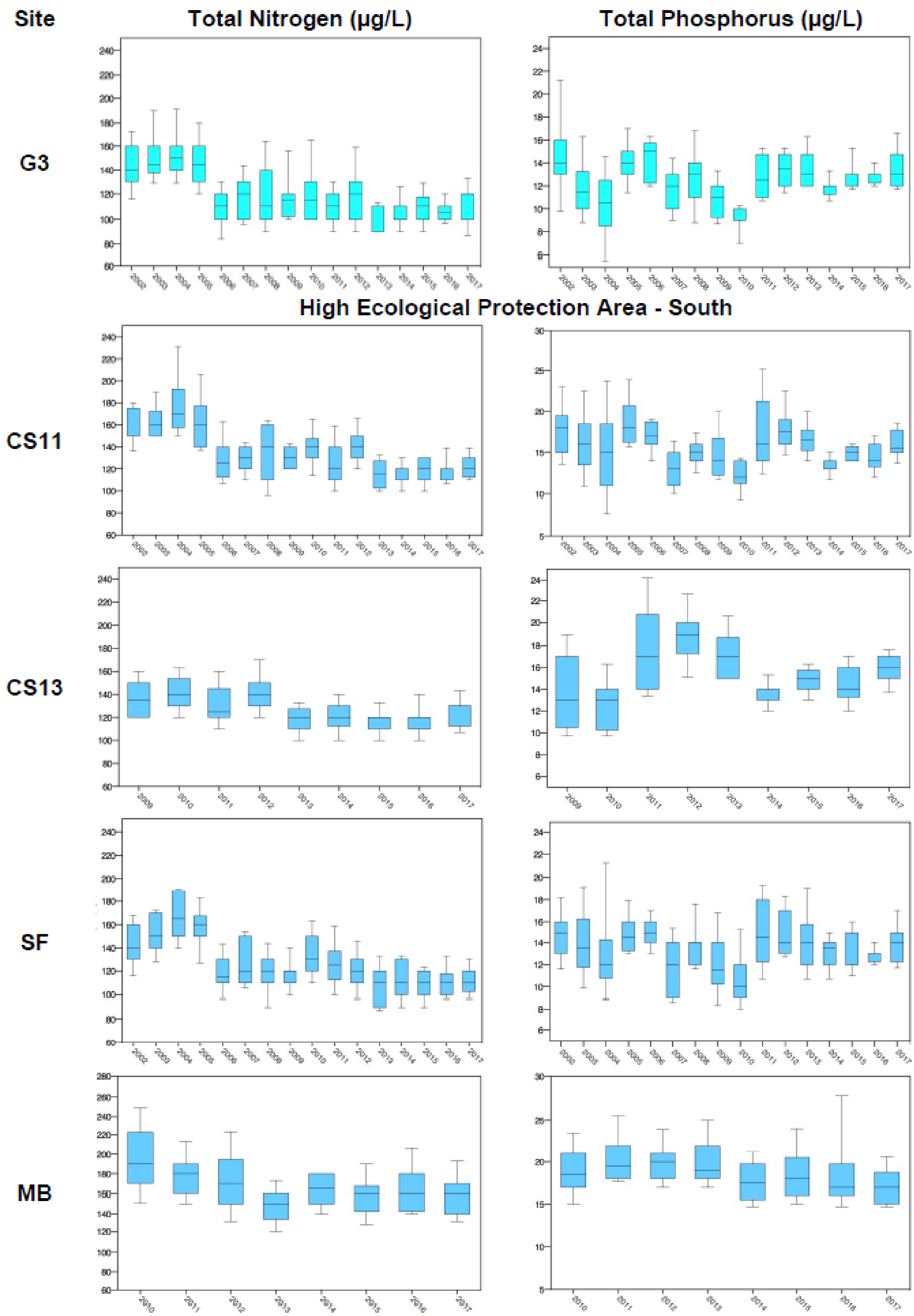




G2



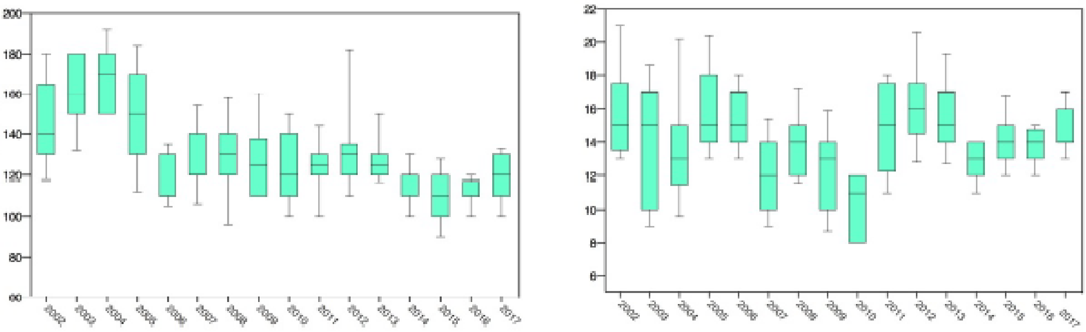



Site
Total Nitrogen (µg/L)
Total Phosphorus (µg/L)
G3
High Ecological Protection Area - South
CS11
CS13
SF
MB

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

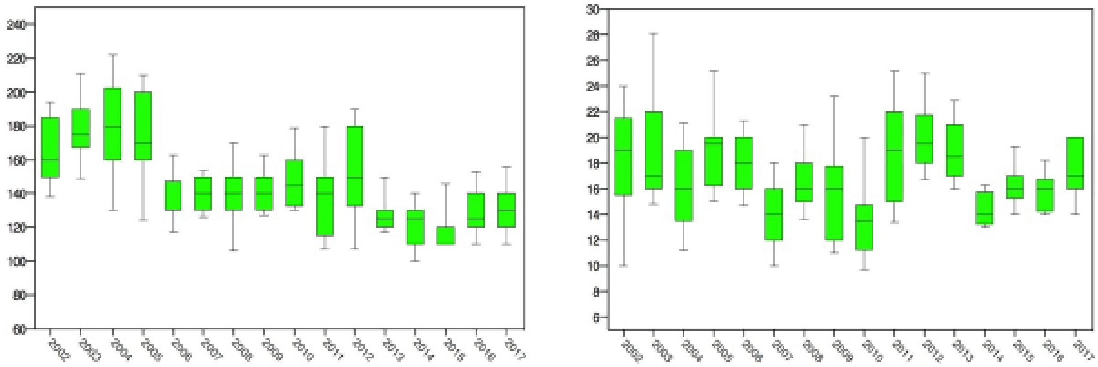
Moderate Ecological Protection Area – Careening Bay

G1

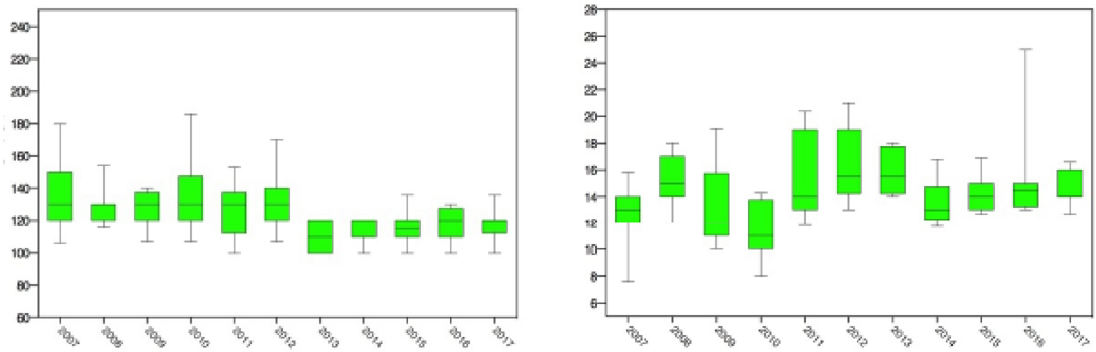


Moderate Ecological Protection Area – Eastern Sound

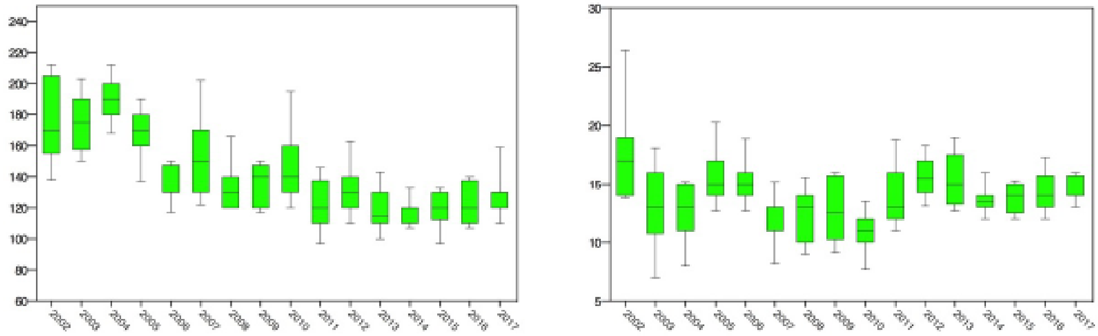
CS10



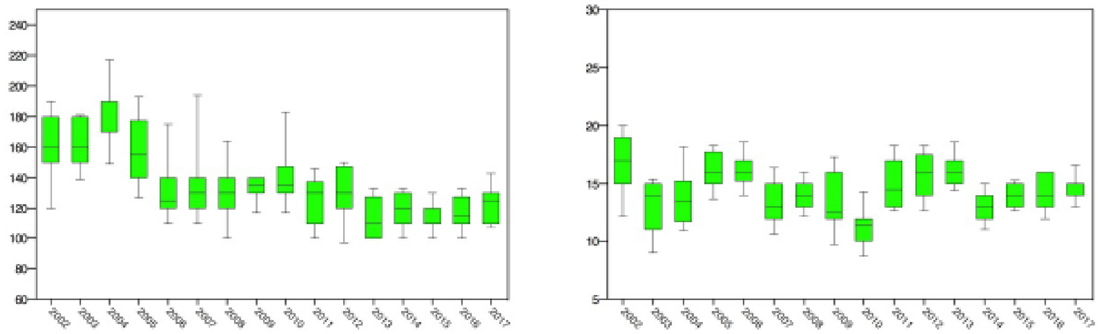
CS12

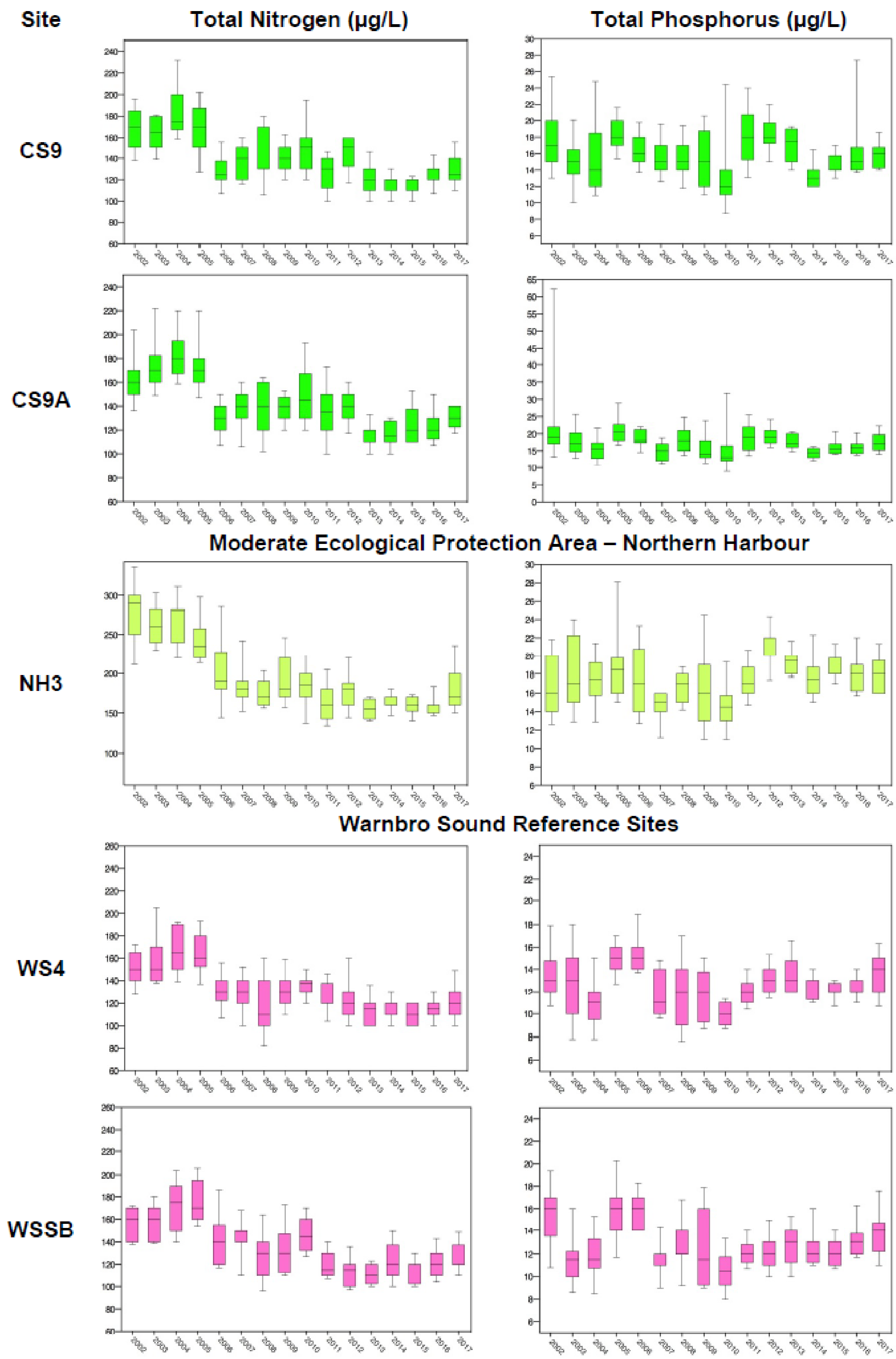


CS6A



CS7

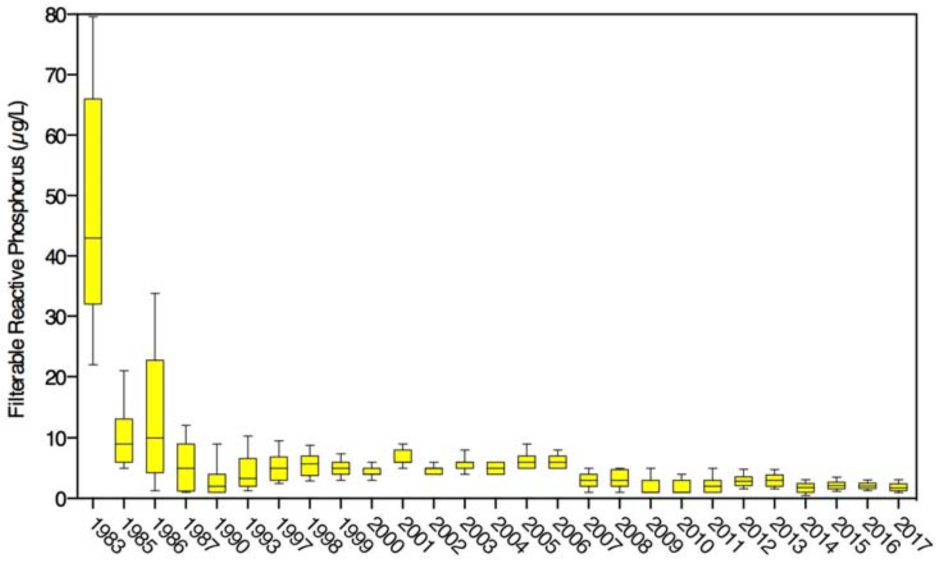




Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure B.4. Median total nitrogen and total phosphorus concentrations at the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound.

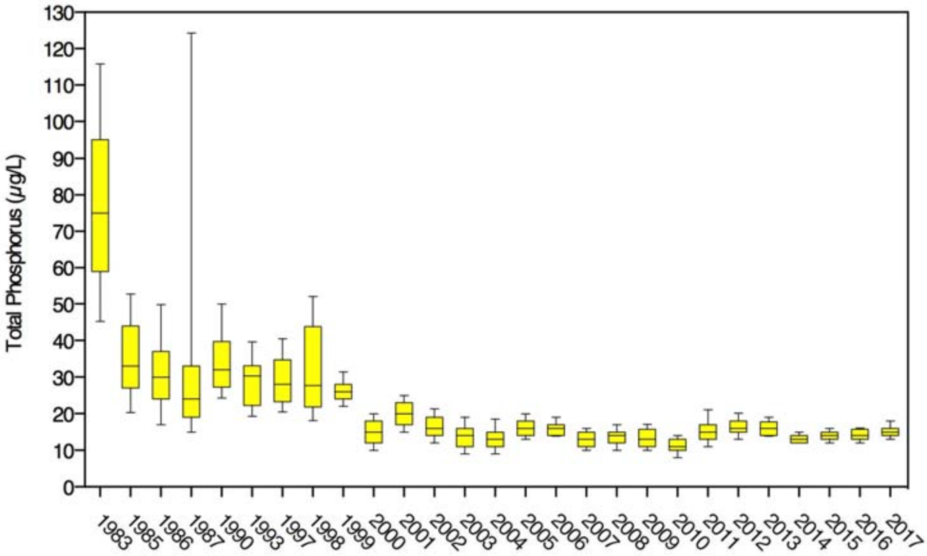
Median non river-flow period filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 have decreased over the past 35 years, although concentrations have generally remained unchanged over the past 11 years (Figure B.5; Cossington and Wienczugow 2017). The median filterable reactive phosphorus concentration in 2016–17 was significantly lower than the concentrations recorded in 2011–12 and 2012–13; there were no significant differences in concentrations between 2008–09 and 2010–11 and between 2013–14 and 2015–16. The median filterable reactive phosphorus concentration in 2016–17 was significantly lower than in all years prior to 2008–09 with the exception of 1990, when there was no significant difference.



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

Figure B.5. Median filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2017.

Median non river-flow period total phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 have decreased significantly since monitoring began, although concentrations have remained relatively constant over the last 11 years with some year-to-year fluctuation (Figure B.6; Cossington and Wienczugow 2017). The variation in total phosphorus concentrations within years has also decreased. The median total phosphorus concentration in 2016–17 was significantly lower than in the 1980s and 1990s and was not significantly different to subsequent years with the exception of 2000–01, 2006–07, 2009–10 and 2013–14. Plots of median total phosphorus concentrations at each site over time are presented in Figure B.4.

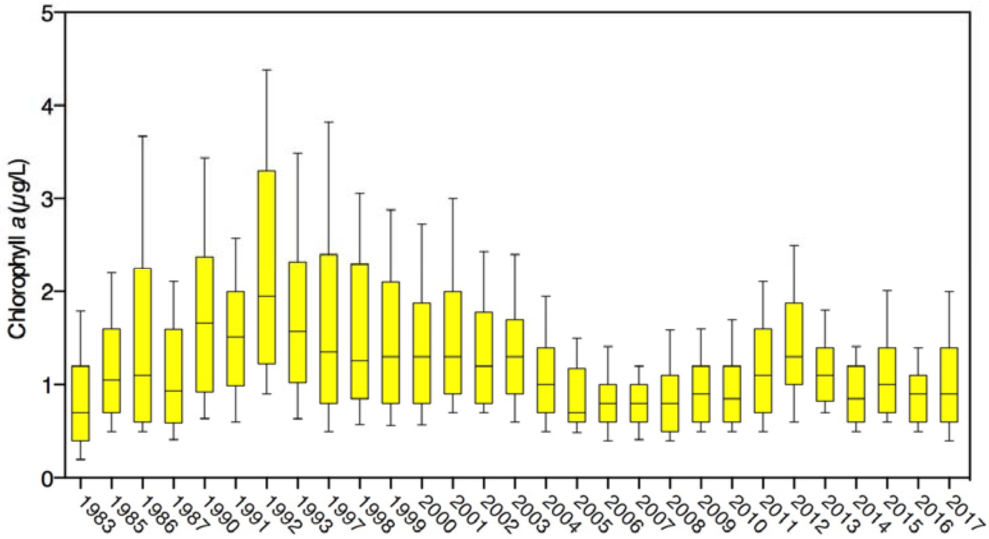


Note: The ‘box’ represents the 25th and 75th percentiles and the ‘whiskers’ the 10th and 90th percentiles.

Figure B.6. Median total phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2017.

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

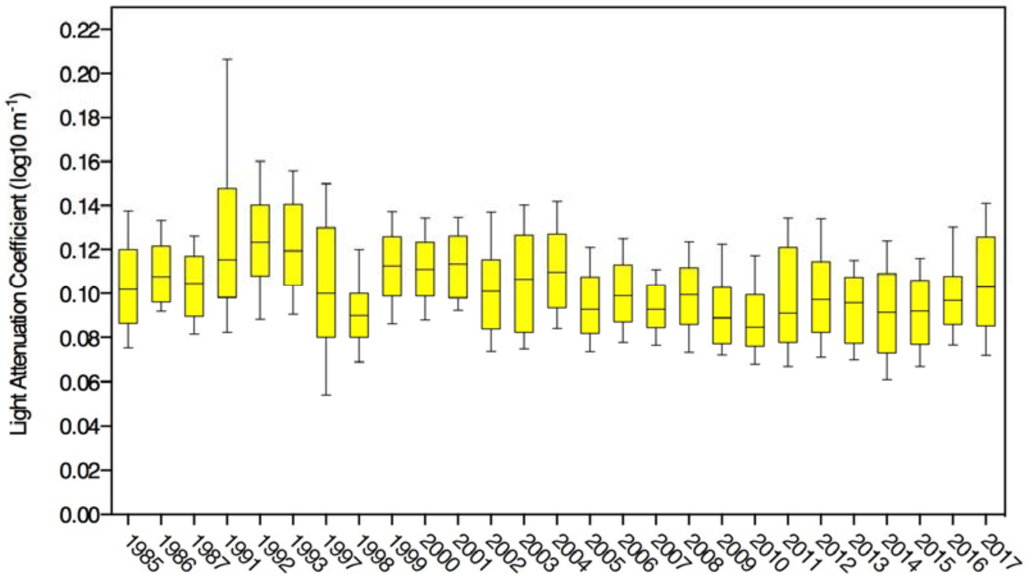
Median chlorophyll *a* concentrations in Cockburn Sound generally increased from the 1980s to the 1990s, remained high in the early 2000s, decreased during the mid-2000s, increased between 2010–11 and 2012–13 and then decreased again (Figure C.1; Cossington and Wienczugow 2017). The median chlorophyll *a* concentration in 2016–17 was not significantly different to the concentrations reported in 1982–83, 1984–85, 1985–86 and 1986–87, significantly lower than concentrations reported between 1989–90 and 2002–03, and not significantly different to the concentrations reported in all the subsequent years with the exception of 2011–12 when a significantly median higher concentration was reported.



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 2017.

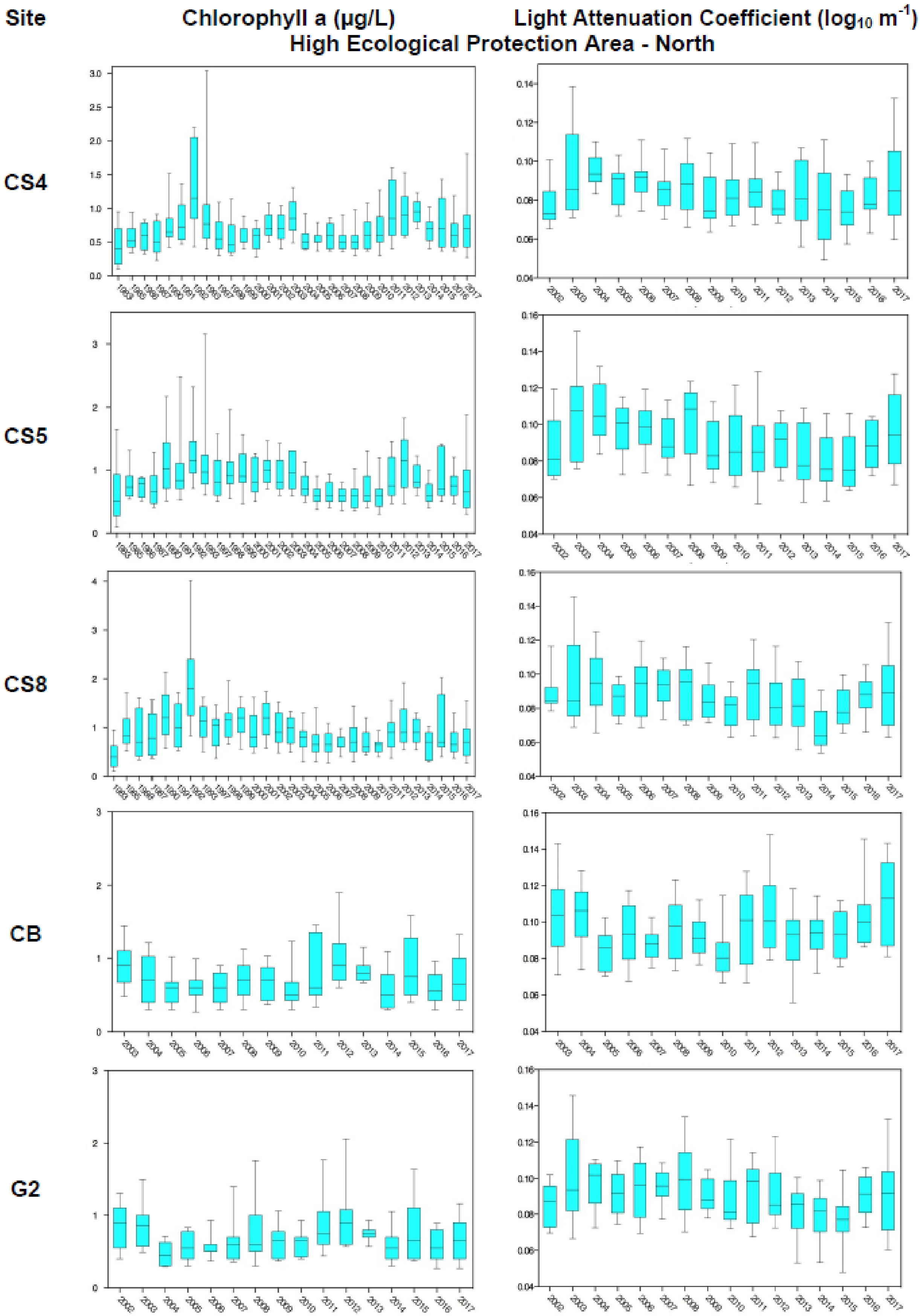
There were similar trends in median light attenuation coefficients, which generally increased to the early 1990s, decreased in the mid-2000s, with a slight increase between 2010–11 and 2012–13, and again in 2016–17 (Figure C.2). The median light attenuation coefficient in 2016–17 was significantly higher than in 1997–98, 2008–09, 2009–10, 2013–14 and 2014–15 and significantly lower than in 1991–92 and 1992–93.

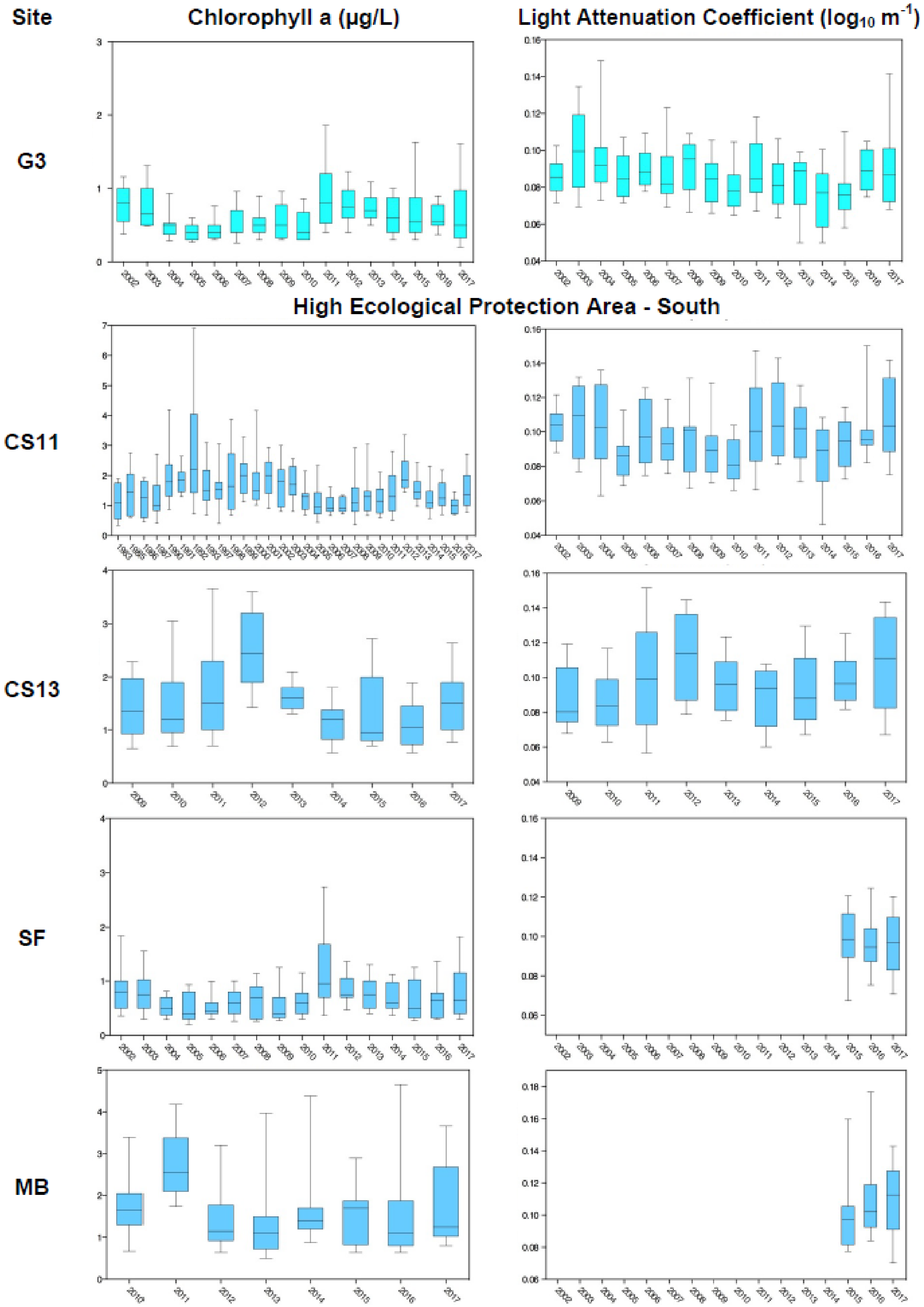


Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure C.2. Median light attenuation coefficients at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1985 to 2017.

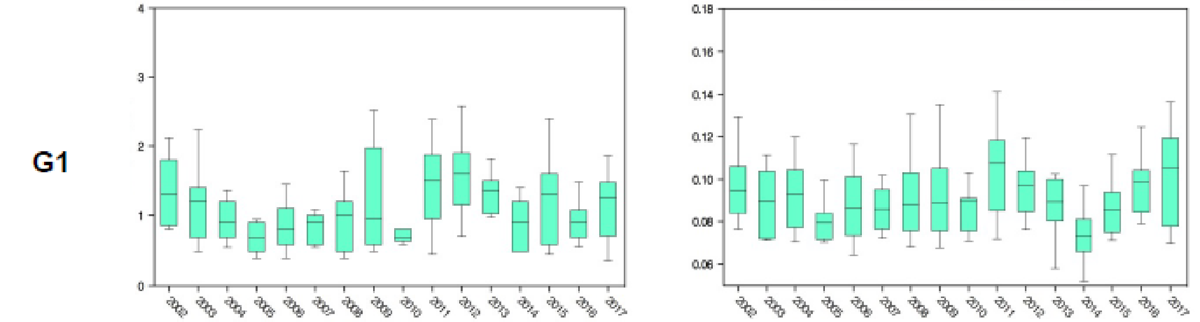
Plots of median chlorophyll *a* concentrations and median light attenuation coefficients at each site over time are presented in Figure C.3.


Site
Chlorophyll a (µg/L)
Light Attenuation Coefficient (log10 m-1)
High Ecological Protection Area - North
CS4
CS5
CS8
CB
G2

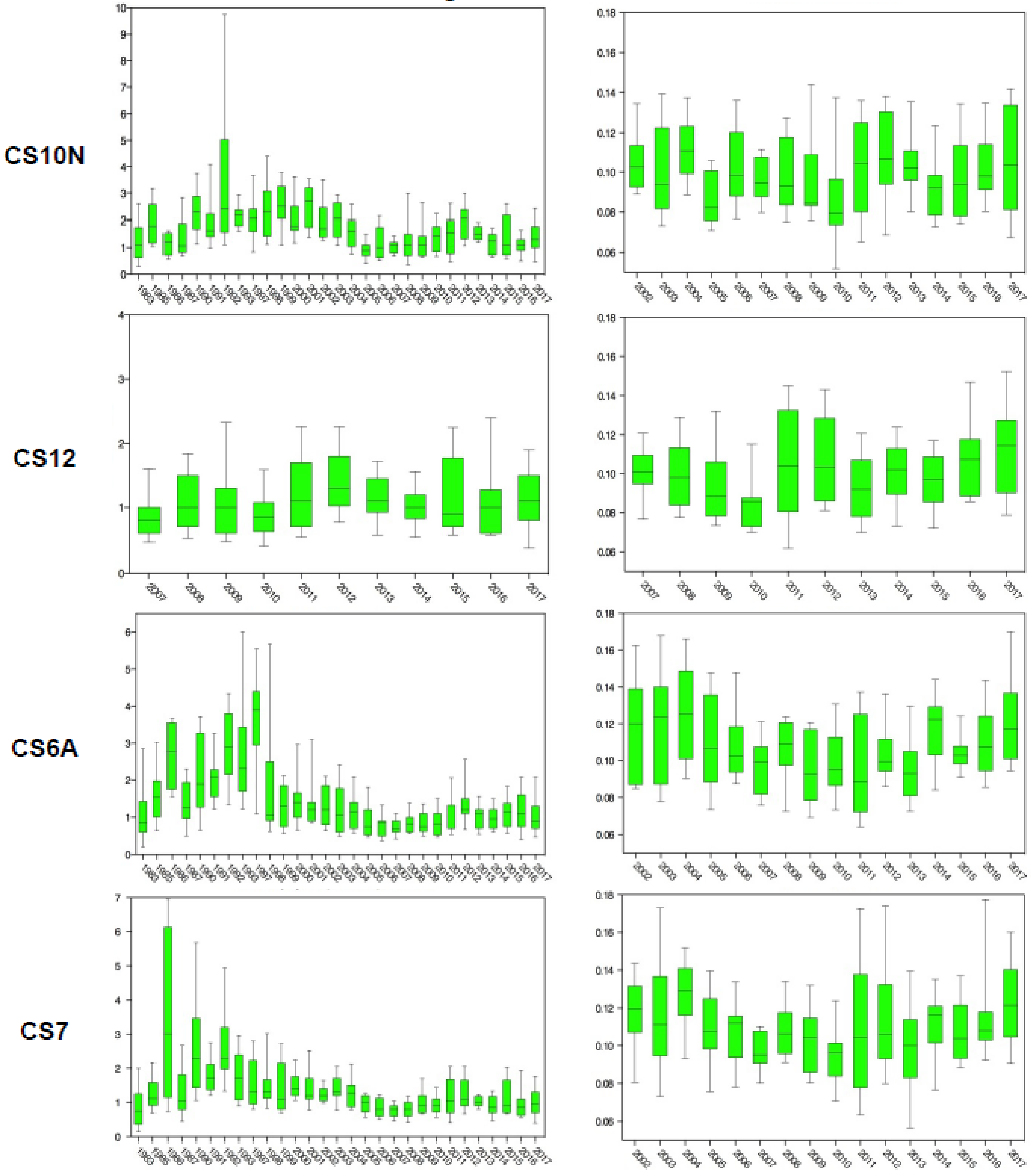

Site
Chlorophyll a (µg/L)
Light Attenuation Coefficient (log10 m-1)
G3
High Ecological Protection Area - South
CS11
CS13
SF
MB

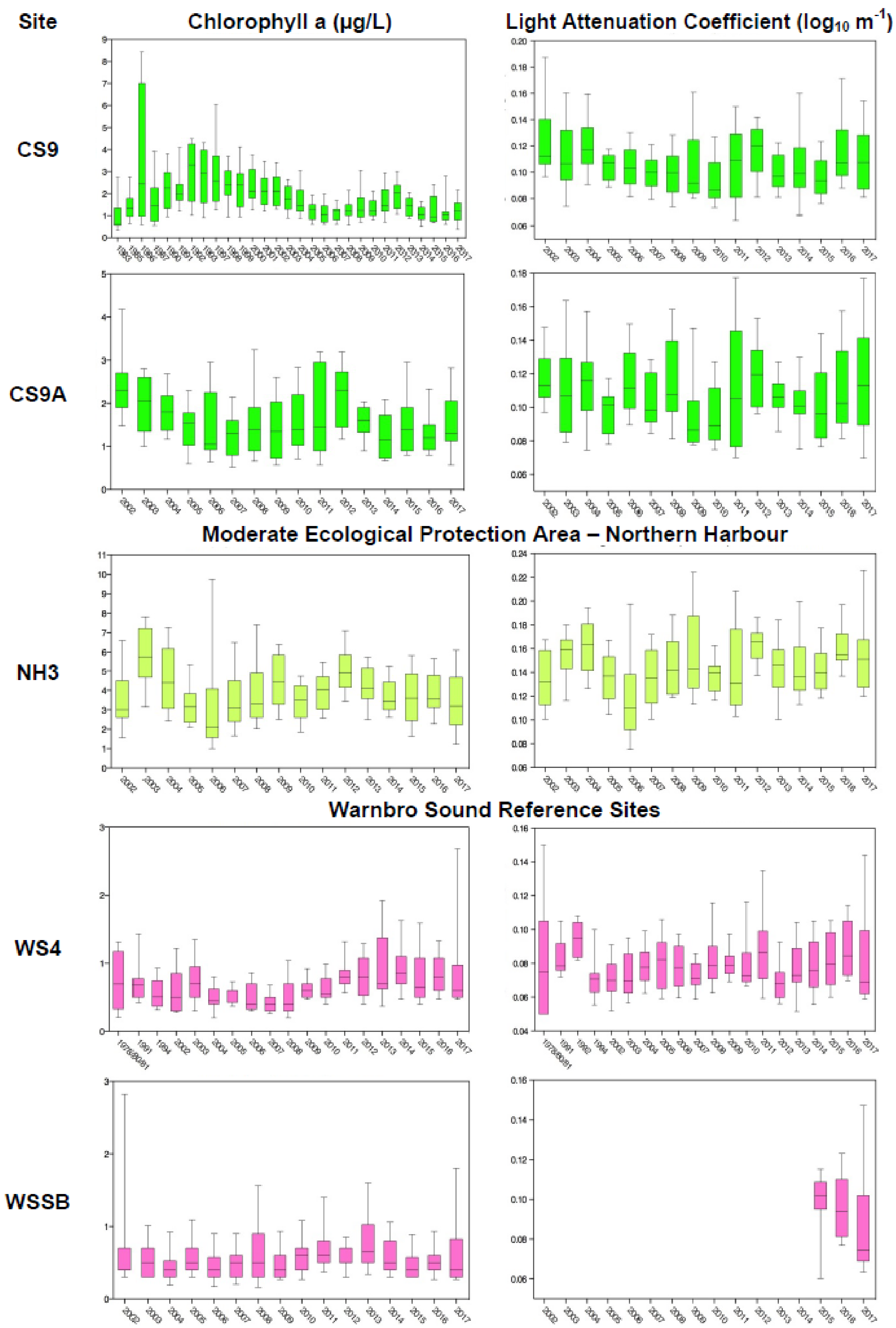
Site | **Chlorophyll a (µg/L)** | **Light Attenuation Coefficient ($\log_{10}$ m^{-1})**

Moderate Ecological Protection Area – Careening Bay



Moderate Ecological Protection Area – Eastern Sound





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

Figure C.3. Median chlorophyll *a* concentrations and light attenuation coefficients at the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound.

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

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

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

Ecological Protection Area	Site	Seagrass Shoot Density (shoots/m^2)			
		Mean shoot density		Median shoot density	
		Mann-Kendall Statistic	*p*-value (two-tailed test)	Mann-Kendall Statistic	*p*-value (two-tailed test)
HPA-N	Garden Island 2.0 m	-0.03	0.913	0	1.000
	Garden Island 2.5 m	0.01	1.000	0.03	0.921
	Garden Island 3.2 m	-0.31	*0.125*	-0.31	*0.125*
	Garden Island 5.5 m	-0.60	**0.002**	-0.58	**0.003**
	Garden Island 7.0 m	-0.29	0.235	-0.29	*0.151*
	Luscombe Bay	-0.02	0.451	-0.29	0.216
	Garden Island Settlement	-0.49	**0.034**	-0.39	*0.086*
	Kwinana	-0.46	**0.033**	-0.56	**0.010**
HPA-S	Southern Flats	-0.35	*0.075*	-0.35	*0.082*
	Mangles Bay	-0.21	0.360	-0.12	0.619
MPA-ES	Jervoise Bay	-0.36	*0.100*	-0.37	*0.087*
Sites Outside Cockburn Sound	Carnac Island	-0.06	0.837	-0.03	0.945
	Coogee	-0.24	0.350	-0.24	0.347
	Woodman Point	-0.27	0.244	0.05	0.891
	Bird Island	-0.12	0.631	-0.17	0.490
	Mersey Point	-0.18	0.451	-0.15	0.535
Reference Sites	Warnbro Sound 2.0 m	-0.54	**0.006**	-0.50	**0.015**
	Warnbro Sound 2.5 m	-0.24	0.235	-0.19	0.346
	Warnbro Sound 3.2 m	-0.43	**0.030**	-0.42	**0.033**
	Warnbro Sound 5.2 m	-0.37	*0.060*	-0.33	*0.101*
	Warnbro Sound 7.0 m	-0.21	0.360	-0.23	0.318

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

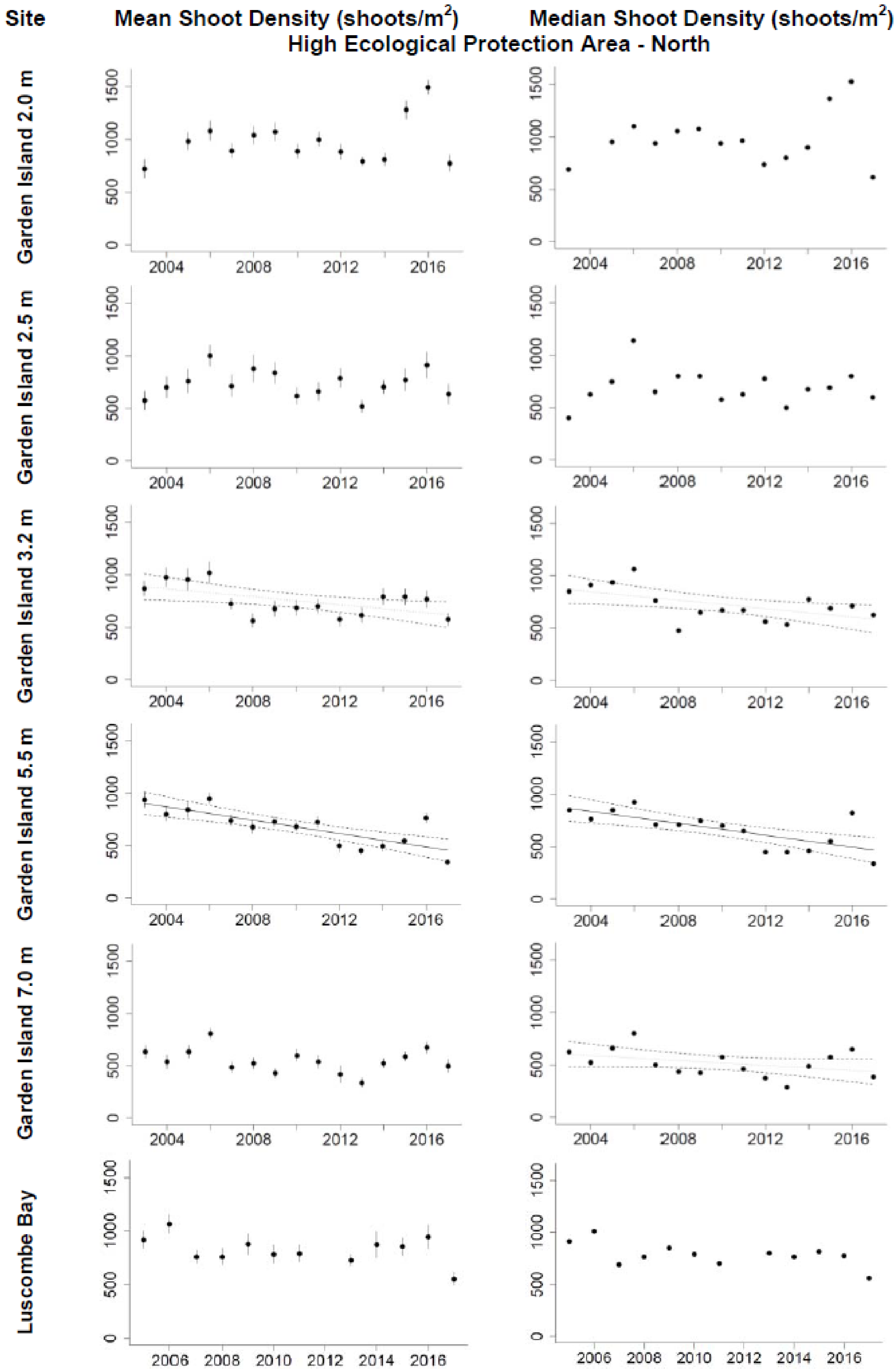
There were significant (α = 0.05) downward trends in mean and median shoot density at two sites in Cockburn Sound, Garden Island 5.5 m and Kwinana, and in mean shoot density at Garden Island Settlement. There were potential[34] downward trends (α = 0.2) in mean and median shoot density at Garden Island 3.2 m, Southern Flats and Jervoise Bay, and in median shoot density at Garden Island 7.0 m and Garden Island Settlement. There were no significant increases in shoot density reported at any site.

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

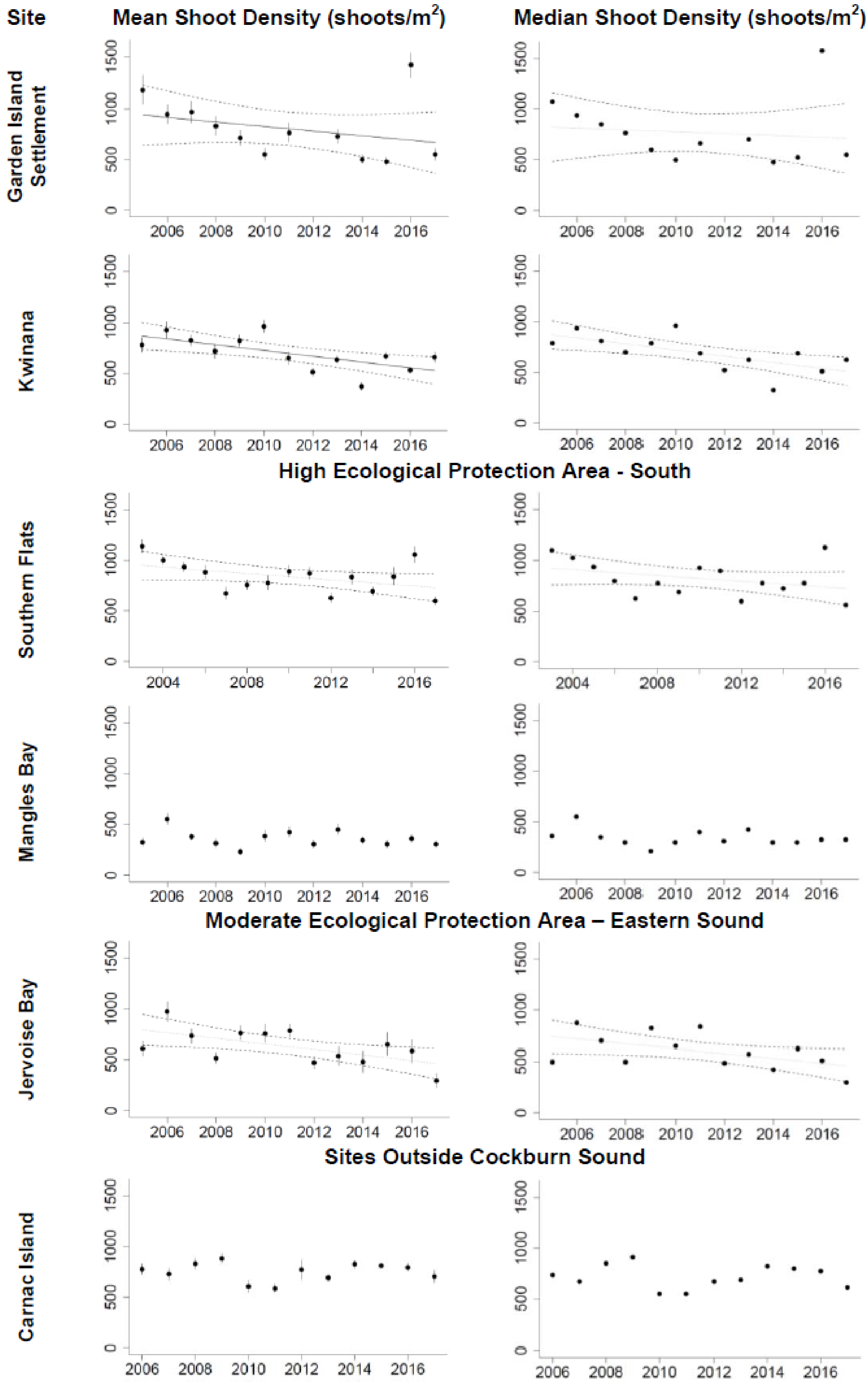
[34] Trends are assessed as 'significant trends' at α = 0.05 and 'potential trends' at α = 0.2. This ensures that potential declining trends that are not statistically significant are nevertheless identified early on as a potential future issue.

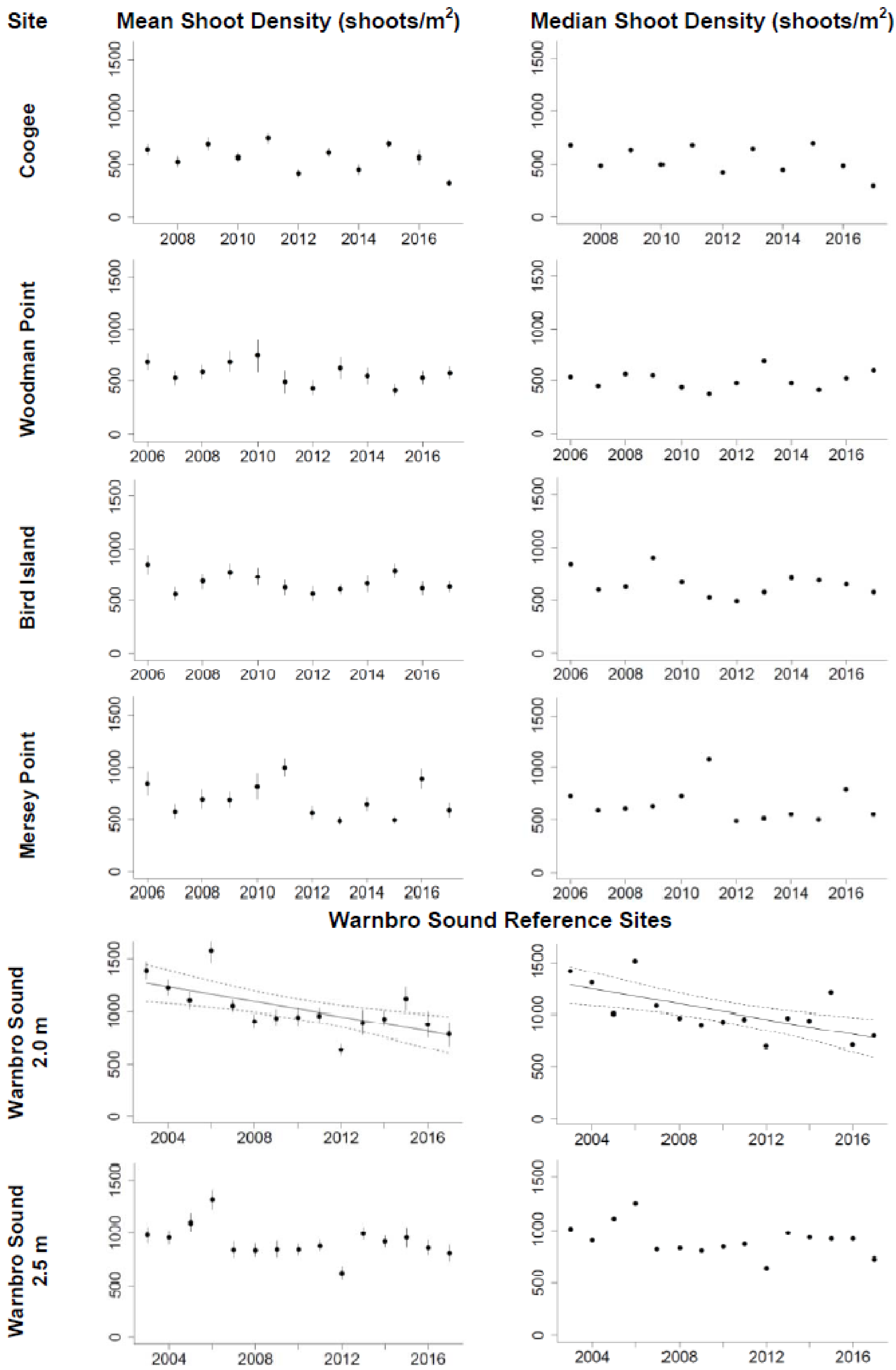
Mersey Point, Bird Island).

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

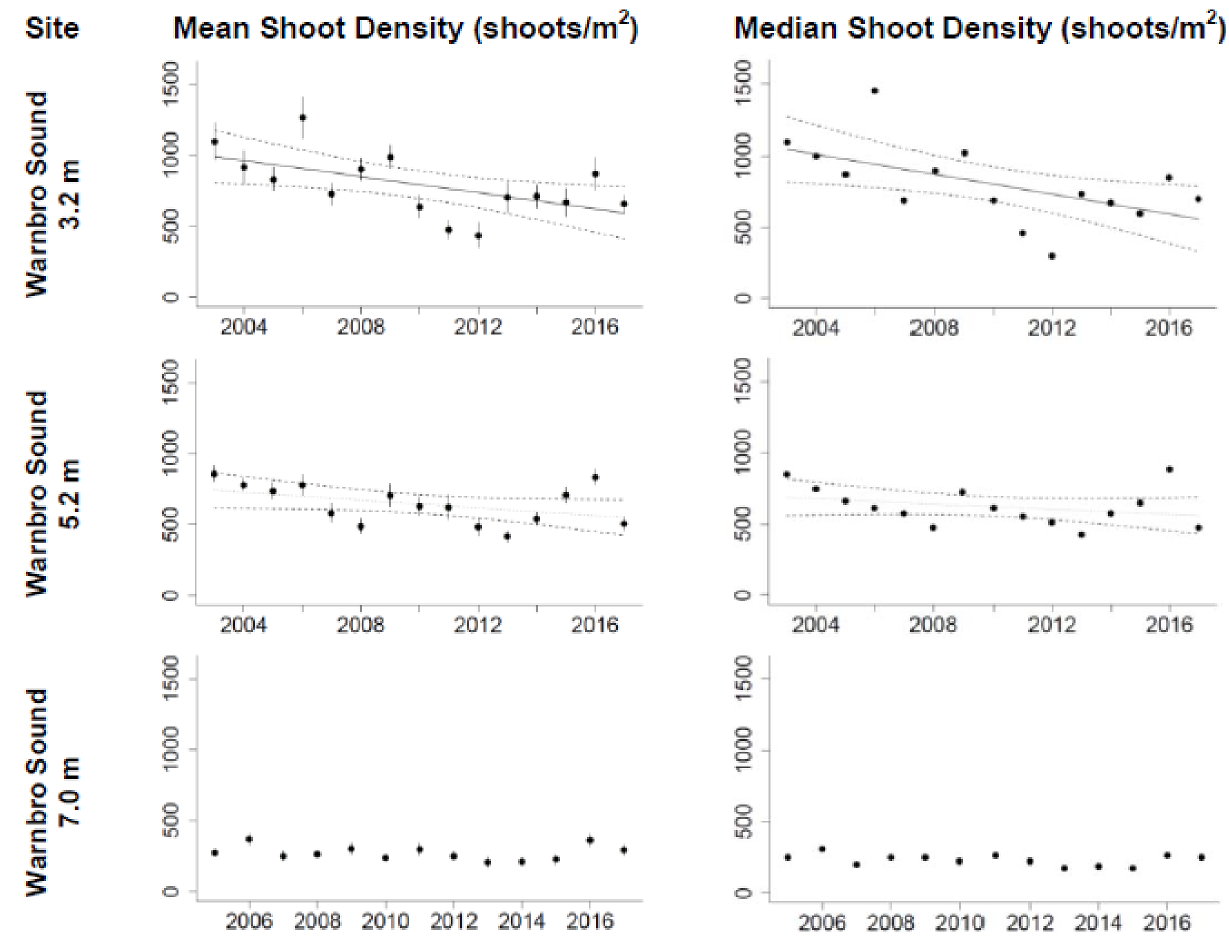


Site
Mean Shoot Density (shoots/m2)
Median Shoot Density (shoots/m2)
High Ecological Protection Area - North
Garden Island 2.0 m
Garden Island 2.5 m
Garden Island 3.2 m
Garden Island 5.5 m
Garden Island 7.0 m
Luscombe Bay
0
500
1000
1500
2004
2006
2008
2010
2012
2014
2016


Site
Mean Shoot Density (shoots/m2)
Median Shoot Density (shoots/m2)
Garden Island Settlement
Kwinana
High Ecological Protection Area - South
Southern Flats
Mangles Bay
Moderate Ecological Protection Area – Eastern Sound
Jervoise Bay
Sites Outside Cockburn Sound
Carnac Island



Site
Mean Shoot Density (shoots/m2)
Median Shoot Density (shoots/m2)
Coogee
Woodman Point
Bird Island
Mersey Point
Warnbro Sound Reference Sites
Warnbro Sound 2.0 m
Warnbro Sound 2.5 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.

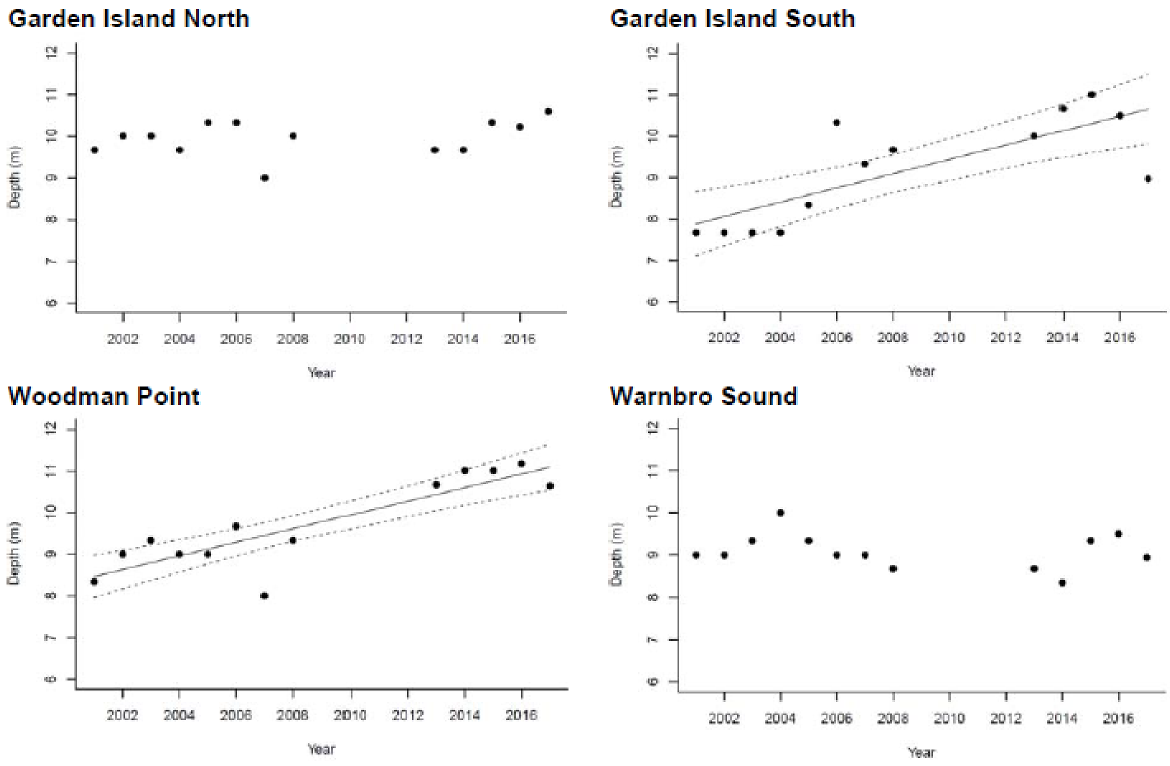
Figure D.1. Trends in mean (± standard error) and median shoot density at the 11 seagrass monitoring sites in Cockburn Sound, five monitoring sites outside Cockburn Sound and five reference sites in Warnbro Sound.

The results of the Mann-Kendall trend analyses of the mean Lower Depth Limit (LDL) at the four ‘depth limit’ sites are presented in Table D.2. Plots of the mean LDL at each site over time are presented in Figure D.2. The mean LDLs have increased significantly at Garden Island South and Woodman Point over the 17 years that the sites have been monitored. There were no significant trends in the mean LDLs at the Garden Island North or Warnbro Sound ‘depth limit’ sites.

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	0.28	0.232
Garden Island South	0.64	**0.0036**
Woodman Point	0.62	**0.0046**
Warnbro Sound	-0.19	0.416

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



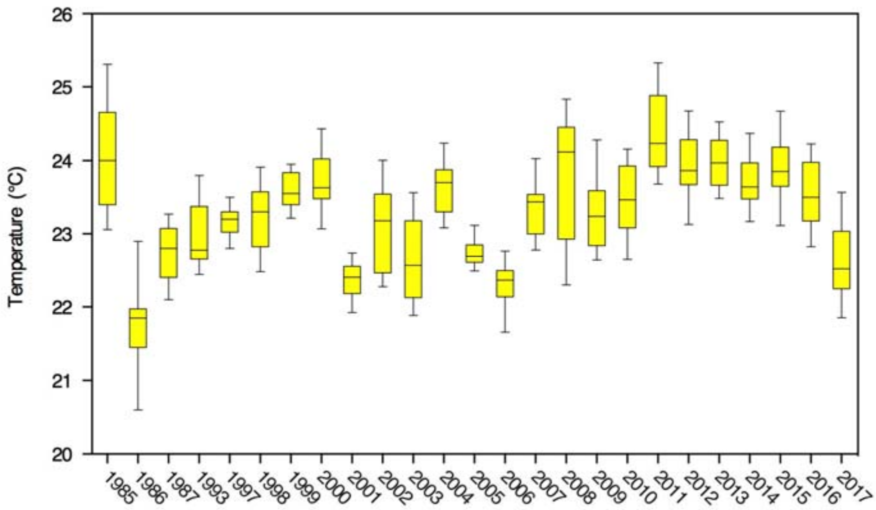
Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands. Note the missing data between 2009 and 2012.

Figure D.2. Trends in mean Lower Depth Limit (LDL) of seagrass meadows at the ‘depth limit’ sites in and around Cockburn Sound and the reference ‘depth limit’ site in Warnbro Sound.

Over the long-term the LDLs have increased or remained stable, however, seagrass LDLs decreased (were shallower) at the Garden Island South, Woodman Point and Warnbro Sound ‘depth limit’ sites in 2017 compared to recent years. This suggests that “thinning” of the seagrass meadows is occurring at the depth extents at these sites (Fraser *et. al* 2017). This is potentially a result of reduced light availability associated with increased turbidities observed at the sites during the 2017 sampling program. The LDL was deeper at Garden Island North in 2017.

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

Considering only the eight sites in Cockburn Sound for which there are long-term data available (CS4, CS5, CS8, CS6/CS6A, CS7, CS9, CS10/10N and CS11), there has been a significant upward trend (Mann-Kendall statistic = 0.189, $p < 0.0001$) in February bottom water temperatures in Cockburn Sound since 1987 (Figure E.1).[35] Over the last 10 years, however, there has been a significant downward trend (Mann-Kendall statistic = -0.088, $p = 0.015$) in February bottom water 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 1983 to 2017.

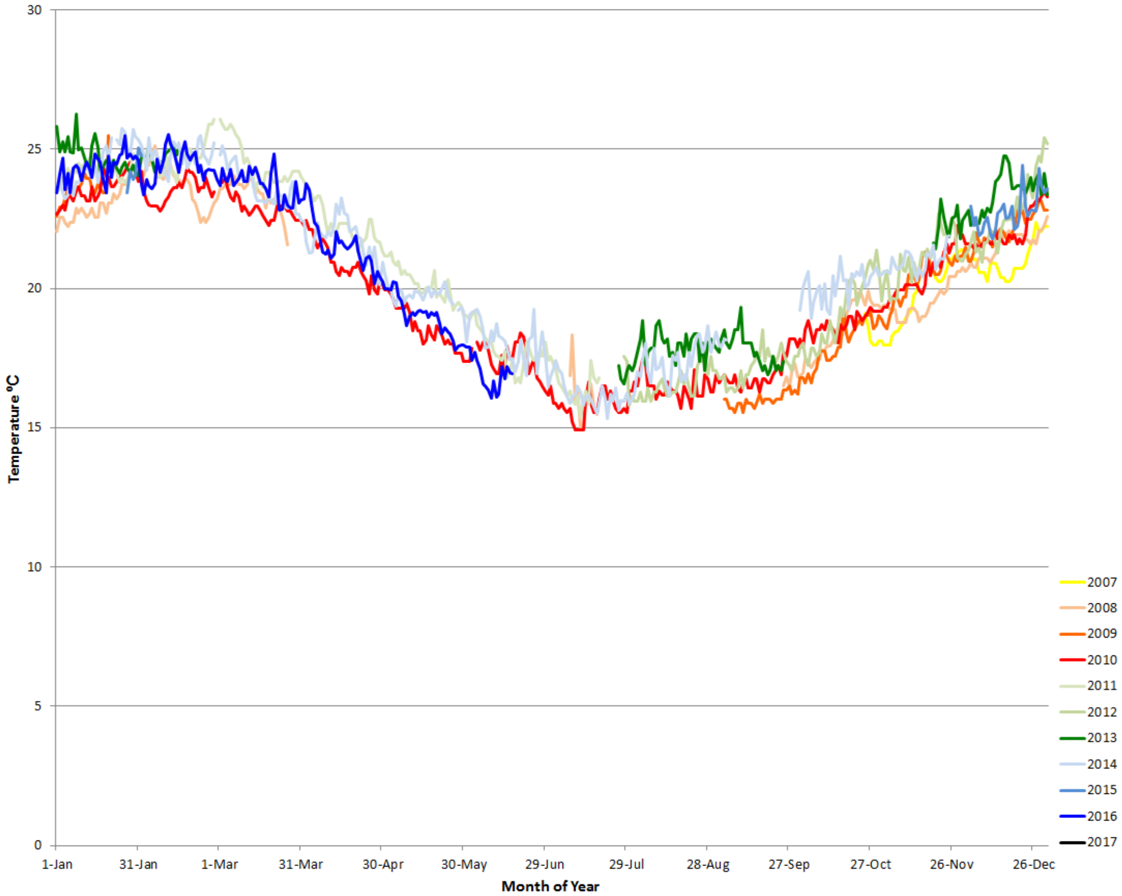
Keesing *et al*. (2016) reported a significant increase in both surface and bottom water temperatures in Cockburn Sound between 1985 and 2014,[36] with an increase in surface water temperature of 0.0325 ± 95% Confidence Interval 0.016°C and in bottom water temperature of 0.0295 ± 95% Confidence Interval 0.014°C per year. These rates of changes are similar to those reported elsewhere off the Western Australian coastline and are attributed to global climate change (Keesing *et al*. 2016). The 2010–11 mean surface water temperature of 24°C was significantly ($p < 0.0001$) warmer than other years between 2008–14 (consistent with the marine heat wave which occurred in early 2011), while 2008–09 was significantly cooler (mean 22.7°C) than other years between 2008–14 (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 2008–14 (Keesing *et al*. 2016).

[35] February bottom water temperatures were analysed as February is usually the month when water temperatures are highest, providing for more reliable comparisons of maximum temperatures over time (Cossington and Wienczugow 2017). Bottom water temperatures were analysed as these provide a more accurate representation of the average water column temperature at any one time; surface water temperatures can fluctuate significantly over a few centimetres depth, in particular during very hot and calm conditions.

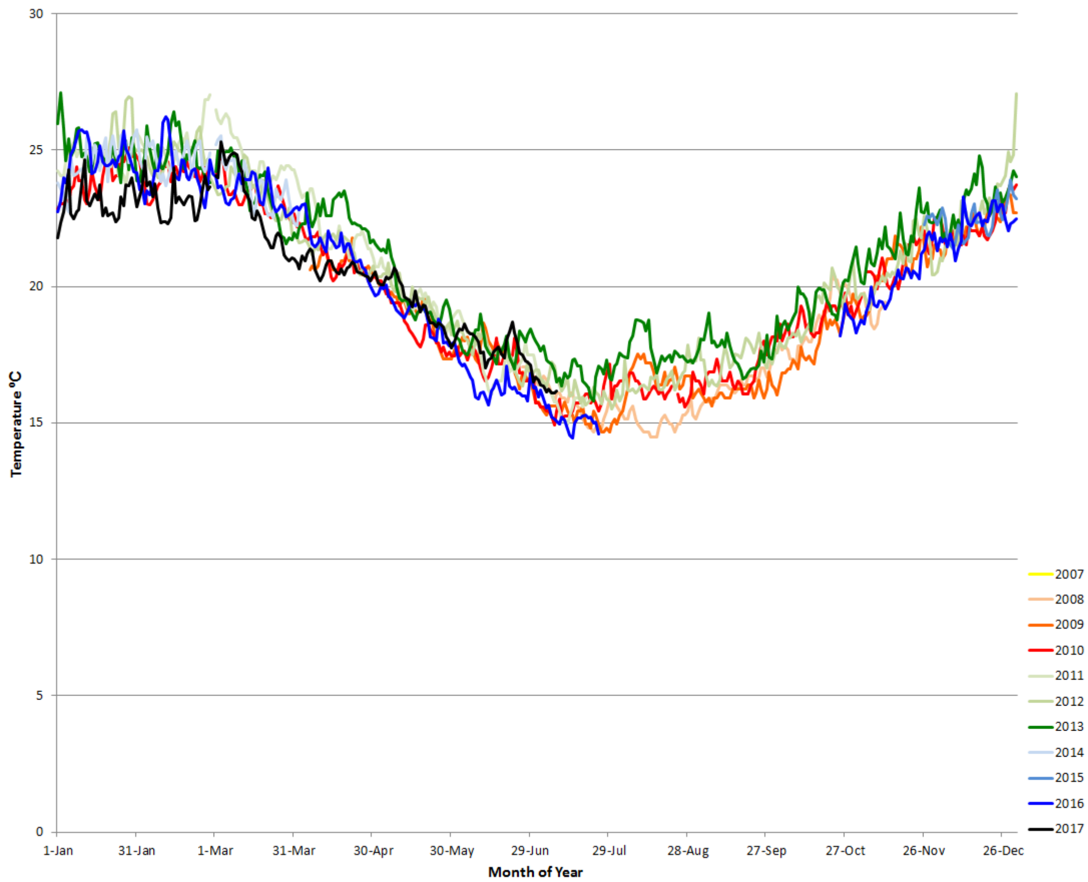
[36] Based on analysis of the data for CS4 and CS5 – the sites closest to the open ocean – for which there are long-term data available. Only March data were analysed as the effect of climate change in south-western Australia involves a lengthening of the warm season and this is when the climate change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

The Department of Primary Industries and Regional Development maintains Onset Tidbit temperature loggers at three sites (Navy Ammunition Jetty [depth 9.5 m]; Alcoa Jetty [depth 5 m]; and Mangles Bay South [depth 1 m]) in Cockburn Sound to support ongoing fisheries management. Plots of daily temperature at each site over the period 2007 to 2016–17 are presented in Figure E.2.

(a)



(b)



(c)

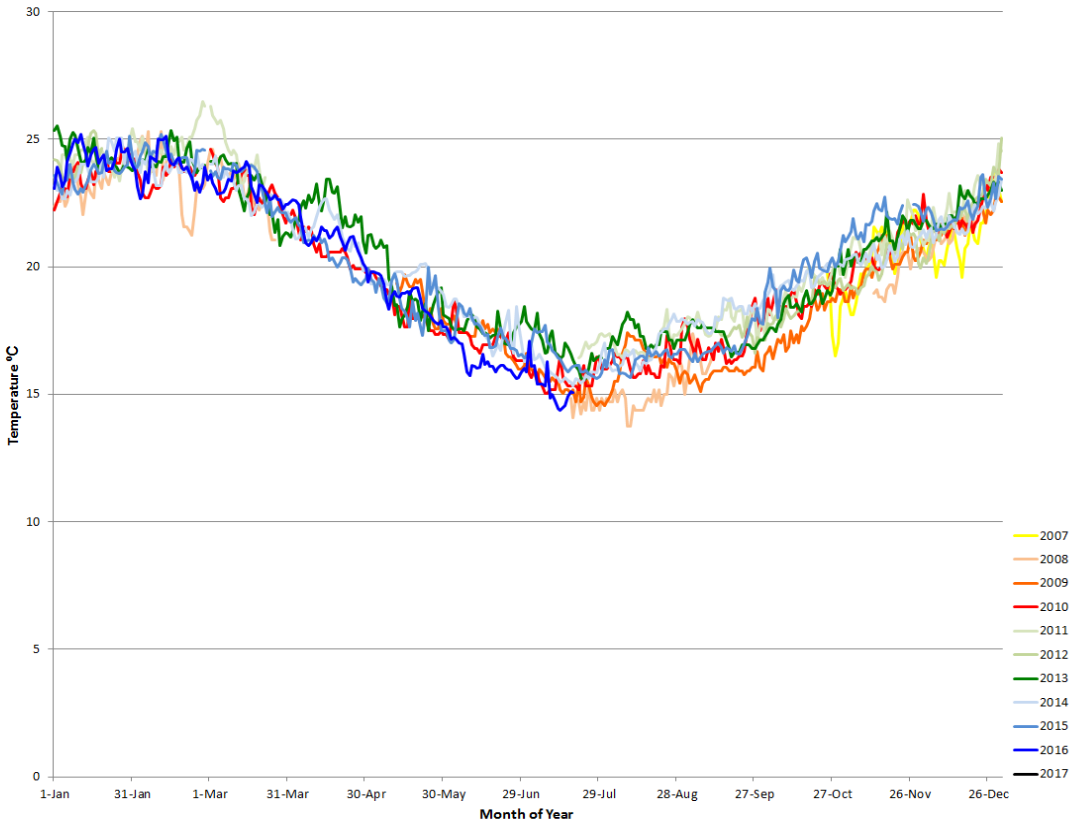


Figure E.2. Daily temperatures at (a) the Navy Ammunition Jetty, (b) the Alcoa Jetty and (c) Mangles Bay South between 2007 and 2016–17.