GOVERNMENT OF
WESTERN AUSTRALIA

Cockburn Sound Annual Environmental Monitoring Report 2015–2016

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

Cockburn Sound Management Council

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Accessibility
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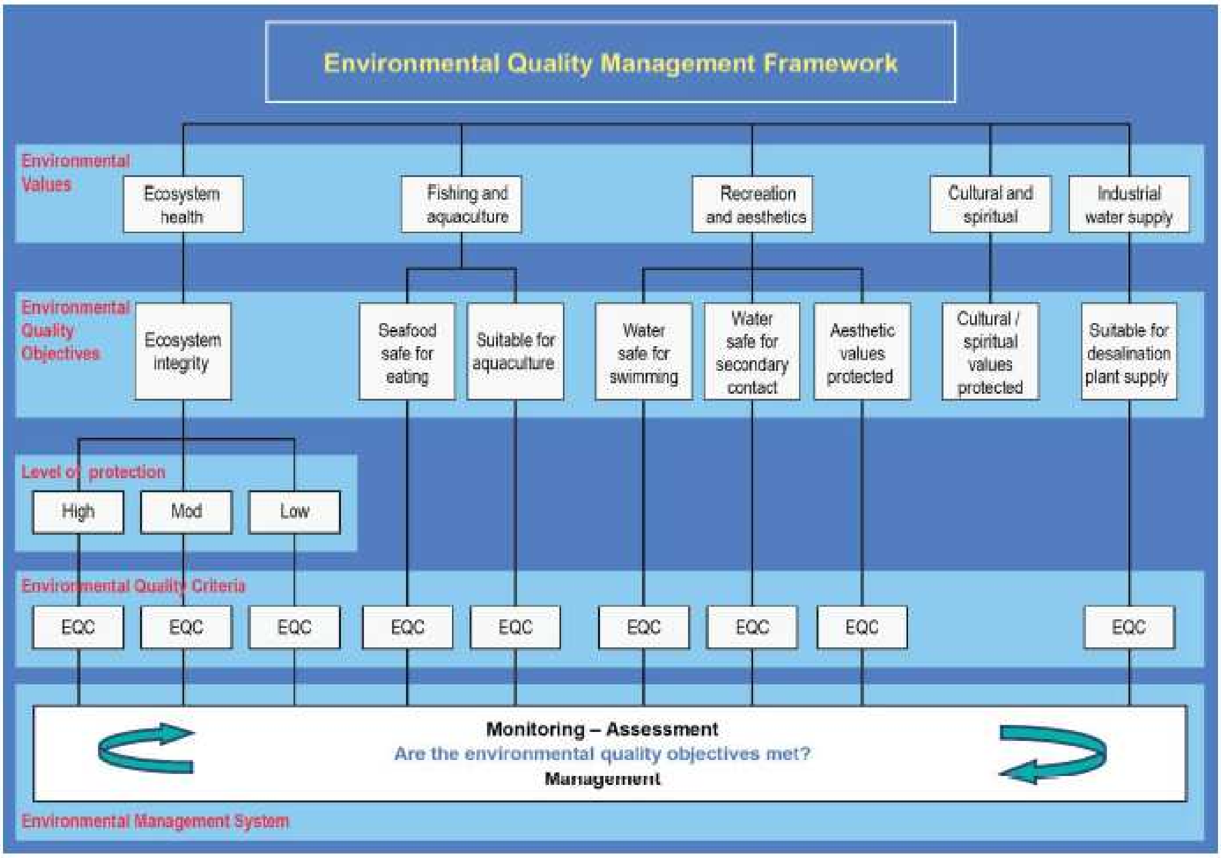
1. Introduction

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 2015–16 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) (Policy). 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 2015).



(Source: Environmental Protection Authority 2015)

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 societal 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 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 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 2015).

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 2015). 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.

Responsibility for monitoring against the EQC is shared across a number of public

authorities based on their roles and responsibilities. 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. As well as the routine monitoring undertaken by public authorities over the 2015–16 reporting period, additional sampling was undertaken as part of the investigation into the November–December 2015 fish kill in Cockburn Sound and the data from this investigation are included in this report.

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 2015–16.

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 Environment Regulation (DER) Department of Defence
		Other physical and chemical stressors	Dissolved oxygen concentration Water temperature Salinity pH	DER Department of Defence Water Corporation Fremantle Ports Department of Fisheries
	Toxicants (marine waters)	Metals and metalloids	Aluminium, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, Vanadium, Zinc	Fremantle Ports Department of Fisheries DER
		Non-metallic inorganics	Ammonia	
		Organics	Benzene, toluene, ethylbenzene, xylene (BTEX), Total BTEX Polycyclic aromatic hydrocarbons (PAHs)	
		Organochlorine and Organophosphorus pesticides	Aldrin, Chlordane, Chlorpyrifos, Dichloro-diphenyltrichloroethane (DDT), Dichlorodiphenyl-dichloroethylene (DDE), Dieldrin, Endosulfan, Endrin, Fenitrothion, Heptachlor, Malathion	
		Oils and petroleum hydrocarbons	Total petroleum hydrocarbons (TPHs) Total recoverable hydrocarbons (TRHs)	

Environmental Quality Objective	Environmental Quality Criteria		Indicator	Data Source
	Toxicants (sediment)	Metals and metalloids	Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Selenium, Zinc	Fremantle Ports
		Organometallics	Tributyltin (TBT), dibutyltin (DBT), monobutyltin (MBT)	
		Organics	PAHs	
		Oils and petroleum hydrocarbons	TPHs	
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 Department of Fisheries
	Chemicals	Metals	Inorganic arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Selenium, Zinc	Blue Lagoon Mussels Fremantle Ports Department of Fisheries
		Organometallics	TBT, DBT, MBT	
		Organic chemicals	Polychlorinated biphenyls (PCBs) PAHs	
		Pesticides	Organochlorine pesticides (Aldrin and Dieldrin, Benzene hexachloride [BHC], Lindane, Chlordane, DDT, DDE, Dichlorodiphenyl-dichloroethane [DDD], Heptachlor, Hexachlorobenzene [HCB]) Organophosphate pesticides	
Maintenance of aquaculture	Physico-chemical stressors		Dissolved oxygen pH	DER
	Toxicants	Non-metallic inorganic chemicals	Ammonia, Nitrate–Nitrite	DER Fremantle Ports
		Metals and metalloids	Copper	
Maintenance of primary contact recreation values	Biological		Faecal pathogens	City of Cockburn, City of Kwinana, City of Rockingham Department of Defence
	Physical		pH Water clarity	DER Department of Defence
	Toxic chemicals	Inorganic chemicals	Copper Nitrate–Nitrite	DER Fremantle Ports
		Organic chemicals	BTEX	
Maintenance of secondary contact recreation values	Biological		Faecal pathogens	City of Cockburn, City of Kwinana, City of Rockingham Department of Defence
	Physical and chemical		pH	DER Department of Defence
			Toxic chemicals	DER

Environmental Quality Objective	Environmental Quality Criteria	Indicator	Data Source
			Department of Defence Fremantle Ports
Maintenance of water quality for industrial use	Biological	*Escherichia coli* (*E. coli*)	Water Corporation
	Physical and chemical	Temperature pH Dissolved oxygen Total suspended solids Hydrocarbons 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 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 2015). 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 2015). Achieving the Environmental Quality Objective is dependent on ensuring that environmental quality is maintained within acceptable levels.

2.2 Levels of Protection

The 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 2015). The levels of ecological protection represent the minimum acceptable level of environmental quality to be achieved through management of Cockburn Sound. They do not necessarily describe the current, or preferred, environmental condition of Cockburn Sound.

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

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

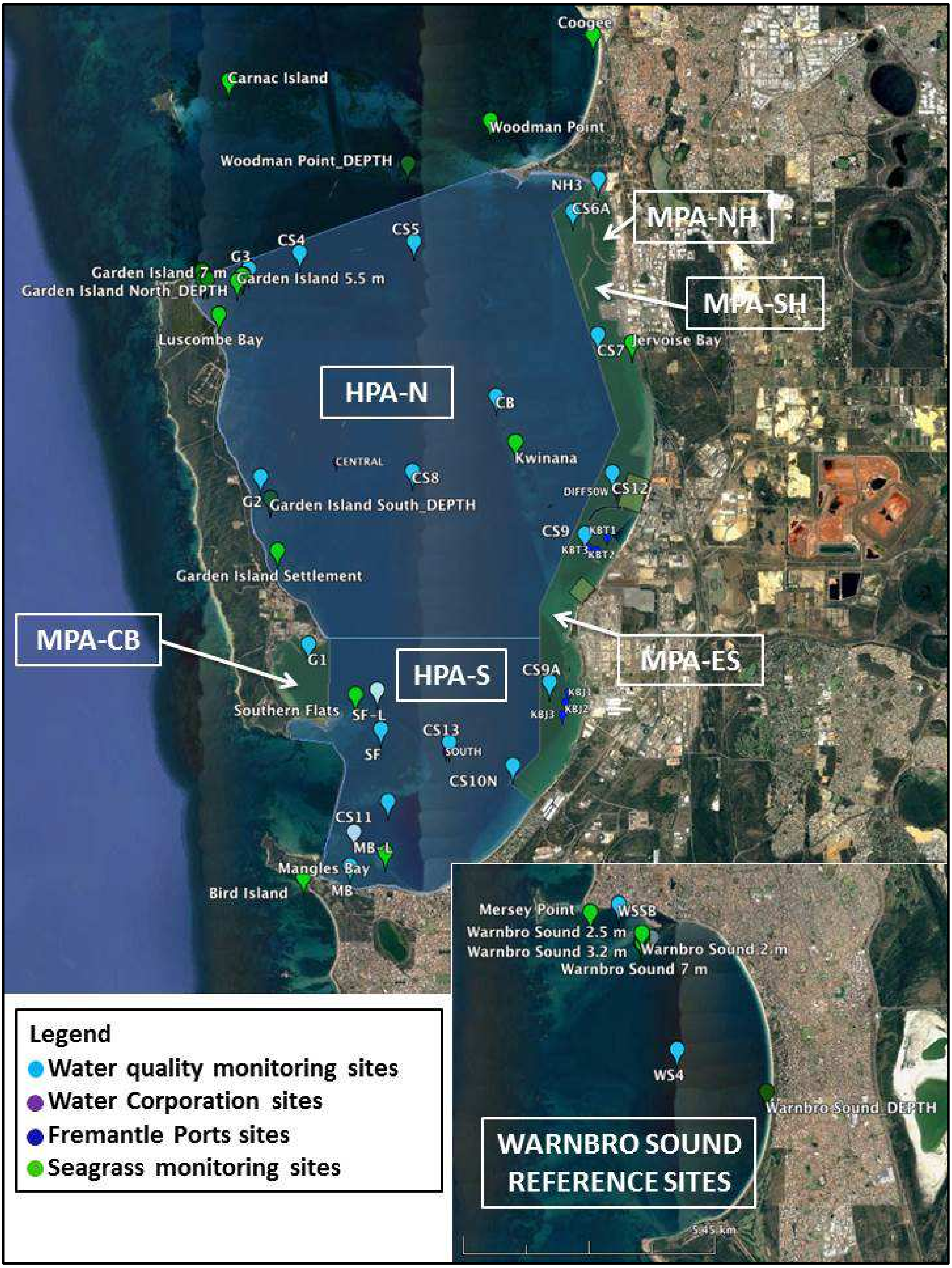


Figure 2. The ecological protection areas in Cockburn Sound and the location of water quality, sediment quality and seagrass health monitoring sites in Cockburn Sound and reference sites in Warnbro Sound.

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

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

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

2.3 Water Quality and Sediment Quality Monitoring

Water quality was monitored on 16 occasions, generally at weekly intervals, between 1 December 2015 and 29 March 2016 (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*. Duplicate and replicate samples were collected on two sampling occasions as part of the field sampling quality assurance and quality control. 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.
- 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 Tuner 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 (July 2015, October 2015, January 2016 and April 2016) measurements of the physical-chemical parameters dissolved oxygen, salinity and temperature as depth profiles through the water column using a Sea-Bird Electronics SBE19*plus* Profiler CTD 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) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2 and KBJ3) (Figure 2). Water quality samples were collected on 3 March 2016. Sediment samples were collected over the period 9–10 March 2016. 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 3 March 2016.

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 and the National Measurement Institute (NMI) for nutrients, chlorophyll *a*, dissolved copper, total petroleum hydrocarbons (TPHs) and benzene, toluene, ethylbenzene and xylene (BTEX).

Five 100 millimetres (mm) diameter sediment cores were collected within one square metre (m^2) at each site. The top two centimetres of each core was collected and homogenised into one composite sample from each site. The samples were analysed by NMI 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 TPHs.

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; and five reference sites and one ‘depth limit’ site in Warnbro Sound (Figure 2; Table 2). The Garden Island sites were surveyed over the period 3–5 February 2016, with the other sites surveyed between 15 April and 5 May 2016. Seasonal fluctuations in *Posidonia sinuosa* shoot density are not typically apparent in Cockburn Sound and, noting there were no consistent increases or decreases in shoot density across the data, the later timing of part of the 2016 survey, compared to previous years, is considered to have had limited impact (Fraser *et al*. 2016a).

The numbers of *Posidonia sinuosa*[3] and *Posidonia australis* shoots were recorded in each of 24 fixed 20 cm x 20 cm quadrats located along four[4] 10 m transects at each ‘potential impact’ and reference site. 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 four ‘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 line was recorded, as well as the depth at that point.

Monitoring was undertaken by MAFRL, the University of Western Australia and the Department of Parks and Wildlife 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 deal with the issue of nutrient enrichment and were derived to achieve three key objectives:

- protection of the remaining seagrass meadows in Cockburn Sound;

[3] Only counts of *Posidonia sinuosa* were assessed against the seagrass health EQC.
[4] Except at Woodman Point and Warnbro Sound 3.2 m, where there are five transects.

- 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 2015).

2.5.1 Re-calculation of the 2015–16 EQC for Chlorophyll *a*, Light Attenuation Coefficient, Phytoplankton Biomass and Seagrass Shoot Density

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 2015–16 and the five previous summers. Where the reference site data are outside the 'normal bounds'[5], new data are not incorporated into the historical reference dataset or used to recompute a new set of 'rolling' percentile-based EQG.

For the 2015–16 monitoring period, the chlorophyll *a* and light attenuation coefficient annual medians at WS4 were within their respective historical ranges[6] (Table 3) and the 2015–16 data were therefore included in the re-calculation of the EQG (Table 4).

Table 3. Assessment of the 2015–16 chlorophyll *a* concentrations 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)
Historical dataset 20th percentile	0.40	0.066
Historical dataset 80th percentile	0.81	0.090
2015–16 median	0.80	0.084
Assessment	Met criteria specified in the Reference Document	Met criteria specified in the Reference Document
	2015–16 data included in the 2015–16 EQG calculations	

Table 4. The 2015–16 high protection and moderate protection EQG for chlorophyll *a* concentration and light attenuation coefficient (LAC).

Indicator	High Protection rolling 6-year 80th percentile	Moderate Protection rolling 6-year 95th percentile
Chlorophyll *a* (µg/L)	1.00	1.53
LAC ($\log_{10}$ /m)	0.097	0.113

The EQG for chlorophyll *a* have been increasing in recent years. The high protection EQG was:

- 0.7 micrograms per litre (µg/L) in 2009–10;
- 0.9 µg/L in 2013–14; and

[5] 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'.
[6] Excluding those datasets that have been determined on previous occasions not to be within the historical ranges.

- 1.0 µg/L in 2014–15.

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.

Keesing *et al.* (2016) reported a significant increase in chlorophyll *a* concentration in 2011 at the Warnbro Sound reference site WS4. For the first time since 2003, chlorophyll *a* concentration at WS4 increased to above the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[7] default trigger value of 0.7 µg/L for chlorophyll *a* in inshore marine ecosystems in south-west Australia. This increase was sustained in the four subsequent years, which were included in the analysis undertaken by Keesing *et al.* (2016).

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

Table 5. The 2015–16 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	1.00
Conversion factor[8]	x 3	x 3
EQG	2.10	3.00

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

Table 6. The 2016 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	550	49	25
Warnbro Sound 2.5 m	690	358	73
Warnbro Sound 3.2 m	280	95	50

7 Australian and New Zealand Environment and Conservation Council (ANZECC)/Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000). *National Water Quality Management Strategy, Paper No. 4, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines* (Chapters 1–7).

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

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 5.2 m	400	169	49
Warnbro Sound 7.0 m	100	29	25

The reference sites in Warnbro Sound are experiencing greater declines in shoot density than at most of the 'potential impact' sites (Fraser *et al*. 2016a). Negative trends in median shoot density were recorded at three of the reference sites (Warnbro Sound 2.0 m, Warnbro Sound 3.2 m and Warnbro Sound 7.0 m) in 2016, similar to trends reported in 2015 (Rule 2015). 'Blow outs' have been identified as a potential cause of the decline in shoot densities at the reference sites, with some sites (for example, Warnbro Sound 2.0 m) experiencing sediment erosion that has resulted in the loss of transects (Rule 2015). 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 declines (Fraser *et al*. 2016b). The Cockburn Sound Management Council is working with researchers from the University of Western Australia and the Department of Parks and Wildlife to identify new reference sites.

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 (Figure 2) over the 2015–16 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 2015–16 non river-flow period is not to exceed a chlorophyll a concentration of 1.00 µg/L or a light attenuation coefficient of 0.097 log_{10}/m.*

Moderate protection: *The median chlorophyll a concentration/light attenuation coefficient in MPA-ES and MPA-CB during the 2015–16 non river-flow period is not to exceed a chlorophyll a concentration of 1.53 µg/L or a light attenuation coefficient of 0.113 log_{10}/m.*

The results are presented in Table 7 and Figures 3, 4, 5 and 6. The 'Nutrient enrichment' EQG for chlorophyll *a* and light attenuation were met in HPA-N, HPA-S, MPA-CB and MPA-ES, indicating that nutrient enrichment was not an issue in most of Cockburn Sound. This was the first monitoring period since 2007–08 for which the median chlorophyll *a* concentration in HPA-S did not exceed the high protection EQG. It was also the first monitoring period since 2010–11 for which the median light attenuation coefficient in HPA-S did not exceed the high protection EQG.

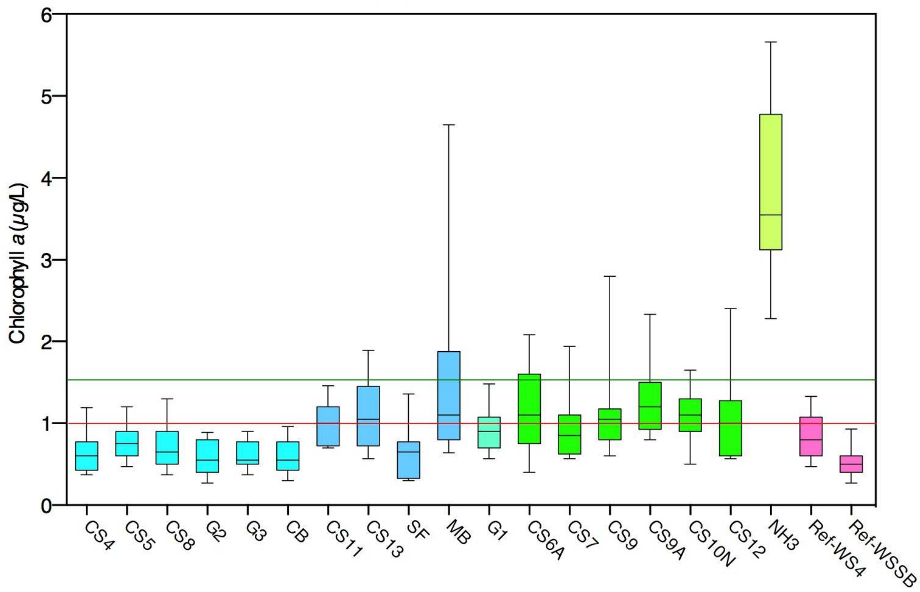
Elevated chlorophyll *a* concentrations and/or light attenuation coefficients were recorded at CB in HPA-N and at CS13 and Mangles Bay (MB) in HPA-S, which is indicative of nutrient enrichment.

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 (refer to EPA 2015).

Table 7. Assessment of the 2015–16 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)			Assessment
		2015–16 EQG	2015–16 Site median	2015–16 Ecological Protection Area median	2015–16 EQG	2015–16 Site median	2015–16 Ecological Protection Area median	
HPA-N	CS4	1.00	0.6	0.6	0.097	0.078	0.090	EQG met
	CS5		0.8			0.089		
	CS8		0.7			0.088		
	CB		0.6			0.100		
	G2		0.6			0.091		
	G3		0.6			0.089		
HPA-S	CS11	1.00	1.0	0.9	0.097	0.095	0.096	EQG met
	CS13		1.1			0.096		
	SF		0.7			0.095		
	MB/MB-L		1.1			0.102		
MPA-CB	G1	1.53	0.9	0.9	0.113	0.099	0.099	EQG met
MPA-ES	CS10N	1.53	1.1	1.1	0.113	0.098	0.106	EQG met
	CS12		1.0			0.108		
	CS6A		1.1			0.108		
	CS7		0.9			0.108		
	CS9		1.1			0.107		
	CS9A		1.2			0.102		
MPA-NH	NH3	N/A	3.6	3.6	N/A	0.155	0.155	N/A

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



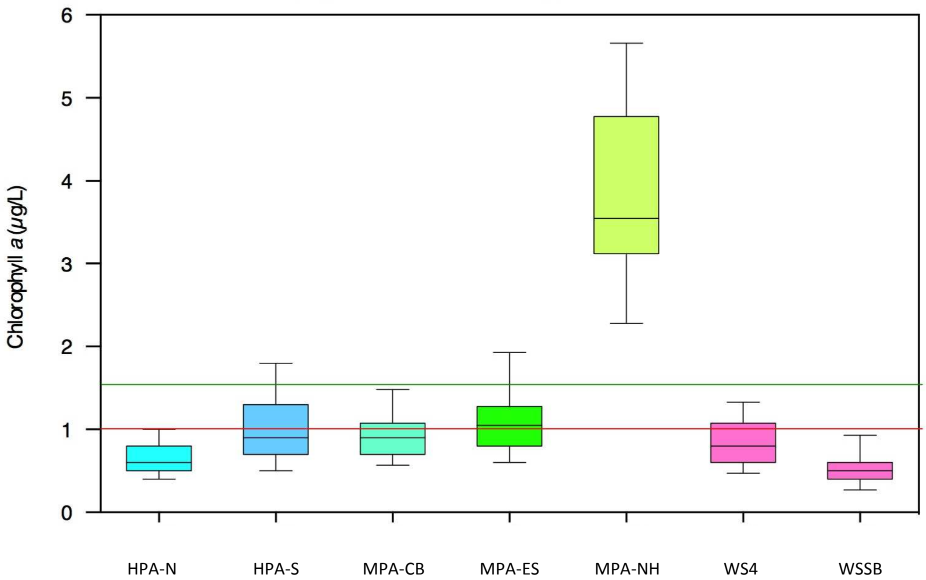
Notes:

(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; green bars = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2.

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

Figure 3. Median chlorophyll *a* concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2015 to March 2016.

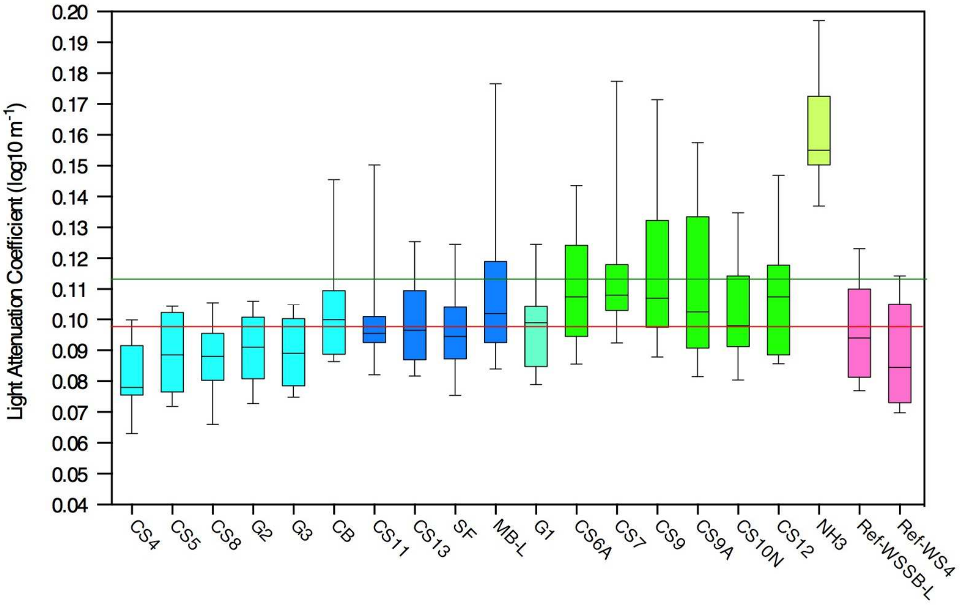


Notes:

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

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

Figure 4. Median chlorophyll *a* concentration for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2015 to March 2016.



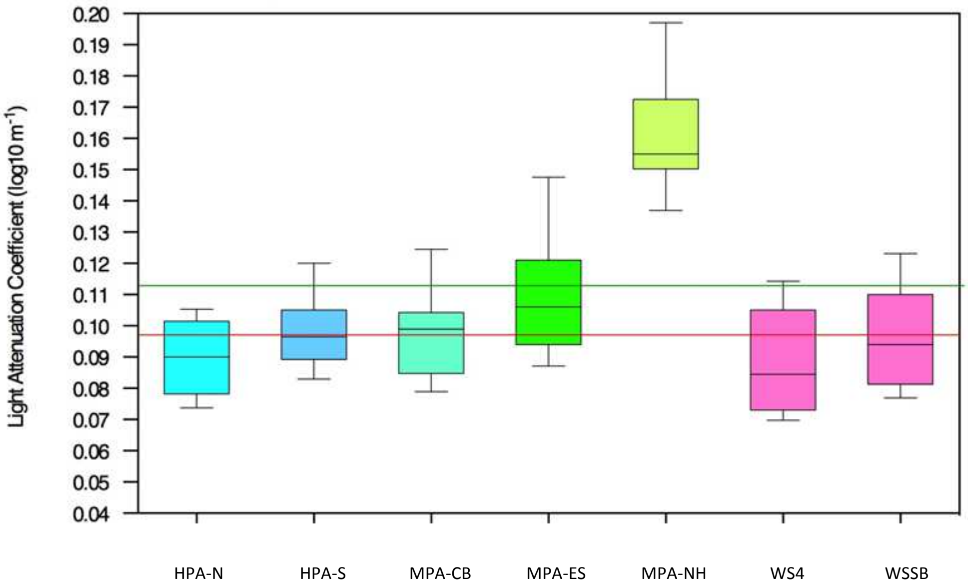
Notes:

(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; green bars = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2.

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

Figure 5. Median light attenuation coefficient at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2015 to March 2016.



Notes:

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

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

Figure 6. Median light attenuation coefficient for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2015 to March 2016.

There has been a significant reduction in dissolved inorganic nutrient concentrations in Cockburn Sound since around 2006–07. 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 (Keesing *et al.* 2016; Wienczugow 2016). Dissolved inorganic nutrient concentrations (in particular ammonium and filterable reactive phosphorus) were still relatively high in HPA-S and the south-eastern part of MPA-ES compared to HPA-N and the Warnbro Sound reference sites (Wienczugow 2016). 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).

Information on median nutrient concentrations (total nitrogen, nitrate–nitrite, ammonium, total phosphorus and filterable reactive phosphorus) at each of the 20 water quality monitoring sites over the 2015–16 non river-flow period is presented in Appendix A. Information on variations and trends over time in median chlorophyll *a* concentrations, light attenuation coefficients and nutrient concentrations is included in Appendix B.

Seagrass Shoot Density at Sites within and outside Cockburn Sound

While there were no exceedances of the ‘Nutrient enrichment’ EQG, which would trigger more detailed assessment against the ‘Nutrient enrichment’ EQS, median shoot densities at each of the seagrass monitoring sites in Cockburn Sound, as well as those outside Cockburn Sound, were assessed against the relevant ‘absolute minimum’ shoot density and the ‘rolling’ four-year 20th (high protection) or 5th (moderate protection) percentiles of shoot densities at the Warnbro Sound reference sites (Table 8).

Table 8. Assessment of median seagrass shoot density at 11 seagrass monitoring sites in Cockburn Sound and at 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 or 5th percentile (shoots/m^2)	2016 median shoot density (shoots/m^2)
HPA-N	Garden Island Settlement	WS 2.0 m	666	550	1,575
	Kwinana	WS 5.2 m	419	400	513
	Garden Island 2.0 m	WS 2.0 m	666	550	1,525
	Garden Island 2.5 m	WS 2.5 m	500	690	800
	Garden Island 3.2 m	WS 3.2 m	171	280	713
	Garden Island 5.5 m	WS 5.2 m	419	400	825
	Garden Island 7.0 m	WS 7.0 m	59	100	650
	Luscombe Bay	WS 2.0 m	666	550	775
HPA-S	Southern Flats	WS 2.5 m	500	690	1,125
	Mangles Bay	WS 3.2 m	171	280	325
MPA-ES	Jervoise Bay	WS 2.5 m	275	358	513
Sites	Coogee	WS 5.2 m	419	400	488

Ecological Protection Area	Seagrass Monitoring Site	Reference Site	'Absolute minimum' seagrass shoot density (shoots/m^2)	Rolling 4-year 20th or 5th percentile (shoots/m^2)	2016 median shoot density (shoots/m^2)
outside Cockburn Sound	Bird Island	WS 2.0 m	666	550	650
	Mersey Point	WS 3.2 m	500	280	800
	Carnac Island	WS 5.2 m	419	400	775
	Woodman Point	WS 2.5 m	500	690	525

In 2016, median seagrass shoot densities at all sites in Cockburn Sound were higher than the 'absolute minimum' and the respective 'rolling' four-year percentiles of the Warnbro Sound reference sites. Significant declines in median shoot density were reported at two of the sites – Kwinana and Garden Island 5.5 m (Fraser *et al.* 2016a).

The median seagrass shoot density at Woodman Point was higher than the 'absolute minimum', but lower than the 'rolling' four-year 20th percentile shoot density of the relevant Warnbro Sound reference site. The median seagrass shoot density at Bird Island was higher than the 'rolling' four-year 20th percentile shoot density, but lower than the 'absolute minimum' shoot density.

The Lower Depth Limit (LDL) of seagrass has increased significantly at the Garden Island South and Woodman Point 'depth limit' sites over the previous 15 years, where the LDL depth increased from around eight metres in 2001 to around 11 m in 2016 (Fraser *et al.* 2016a). There was no significant trend in LDL recorded at the Warnbro Sound or Garden Island North 'depth limit' sites, where the LDL depth remained at around nine metres and 10 m respectively. The increase or stability in the distribution of seagrass in deeper waters suggests that water quality and light availability are generally adequate for seagrass growth given that seagrass is growing near its depth limit in Cockburn Sound. The seagrass declines and lack of recovery in Cockburn Sound, Owen Anchorage and Warnbro Sound are possibly being driven by factors other than water quality and light availability, such as sediment stressors, hydrodynamics or temperature changes (Mohring and Rule 2013; Fraser *et al.* 2016b).

Information on temporal trends in seagrass shoot density and the LDL is provided in Appendix C.

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 (Figure 2) over the 2015–16 non river-flow period was assessed against the 'Phytoplankton biomass' EQG (EQG C, Table 1a, Reference Document):

High protection:

i. *The median phytoplankton biomass in HPA-N and HPA-S is not to exceed 2.10 µg/L on any occasion during the 2015–16 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 2015–16 non river-flow period.*

Moderate protection:

i. *The median phytoplankton biomass in MPA-ES is not to exceed 3.00 µg/L on more than one occasion during*

the 2015–16 non river-flow period.

ii. *Phytoplankton biomass at any site is not to exceed 3.00 µg/L on 50% or more occasions during the 2015–16 non river-flow period.*

The results of the assessment against the EQG are presented in Table 9 and Table 10. The 'Phytoplankton biomass' EQG were met in the three ecological protection areas and at all sites in Cockburn Sound, with the exception of Jervoise Bay Northern Harbour (NH3) where the moderate protection 'Phytoplankton biomass' EQG(ii) was exceeded.

Table 9. Assessment of median chlorophyll *a* concentrations in HPA-N, HPA-S and MPA-ES on each sampling occasion during the 2015–16 non river-flow period against the 'Phytoplankton biomass' EQG(i).

Sampling date	HPA-N Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	HPA-S Chlorophyll *a* concentration (µg/L) EQG: 2.10 µg/L	MPA-ES Chlorophyll *a* concentration (µg/L) EQG: 3.00 µg/L
1/12/2015	0.6	1.0	1.2
7/12/2015	0.8	1.6	1.7
14/12/2015	0.7	1.2	1.2
21/12/2015	0.6	0.8	0.9
4/01/2016	0.5	0.8	0.6
11/01/2016	0.4	0.7	0.8
18/01/2016	0.5	0.9	1.1
25/01/2016	0.4	0.8	0.8
1/02/2016	0.9	1.1	1.4
8/02/2016	0.4	0.7	0.7
15/02/2016	0.6	1.0	1.0
29/02/2016	0.5	0.6	0.6
7/03/2016	0.7	1.3	1.3
14/03/2016	0.7	1.2	1.1
21/03/2016	0.8	1.4	1.1
29/03/2016	1.2	1.8	2.5
Assessment	EQG(i) met in all three ecological protection areas and on all sampling occasions		

Table 10. Assessment of chlorophyll *a* concentrations (µg/L) at 18 water quality monitoring sites in Cockburn Sound against the 'Phytoplankton biomass' EQG(ii).

Ecological Protection Areas	Site	2015–16 EQG	Number of sampling occasions	Number of occasions EQG was exceeded	Per cent (%) of occasions EQG was exceeded	Assessment
HPA-N	CS4	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	16	0	0%	EQG(ii) met
	CS5		16	0	0%	EQG(ii) met
	CS8		16	0	0%	EQG(ii) met
	CB		16	0	0%	EQG(ii) met
	G2		16	0	0%	EQG(ii) met
	G3		16	0	0%	EQG(ii) met
HPA-S	CS11	Phytoplankton biomass not to exceed 2.10 µg/L on 25% or more occasions	16	0	0%	EQG(ii) met
	CS13		16	0	0%	EQG(ii) met
	SF		16	0	0%	EQG(ii) met

Ecological Protection Areas	Site	2015–16 EQG	Number of sampling occasions	Number of occasions EQG was exceeded	Per cent (%) of occasions EQG was exceeded	Assessment
	MB		16	3	18.75%	EQG(ii) met
MPA-CB	G1	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	16	0	0%	EQG(ii) met
MPA-ES	CS10N	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	16	0	0%	EQG(ii) met
	CS12		16	0	0%	EQG(ii) met
	CS6A		16	0	0%	EQG(ii) met
	CS7		16	0	0%	EQG(ii) met
	CS9		16	0	0%	EQG(ii) met
	CS9A		16	1	6.25%	EQG(ii) met
MPA-NH	NH3	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	16	13	81.25%	EQG(ii) exceeded

Assessment against the Environmental Quality Standard

Exceedance of the ‘Phytoplankton biomass’ EQG(ii) at Jervoise Bay Northern Harbour (NH3) triggered more detailed assessment against the moderate protection ‘Phytoplankton biomass’ EQS (EQS C(ii), Table 1a, Reference Document):

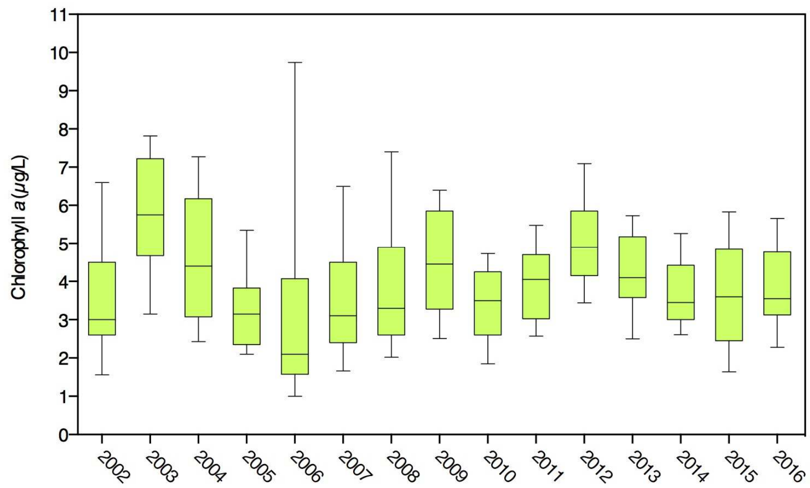
> *Phytoplankton biomass at NH3 is not to exceed the annually updated criterion for this indicator on 50% or more occasions during the non river-flow period and in two consecutive years.*

The results are presented in Table 11.

Table 11. Assessment of chlorophyll *a* concentrations (µg/L) at NH3 against the ‘*Phytoplankton biomass*’ EQS over two consecutive years (2014–15 and 2015–16).

Site	Year	EQG	Number of occasions EQG was exceeded	Per cent (%) of occasions EQG was exceeded	Assessment
NH3	2014–15	Phytoplankton biomass not to exceed 3.0 µg/L on 50% or more occasions	10 (out of 16)	62.50%	EQS exceeded
	2015–16	Phytoplankton biomass not to exceed 3.0 µg/L on 50% or more occasions	13 (out of 16)	81.25%	

The ‘Phytoplankton biomass’ EQS was exceeded which triggered the requirement to initiate a management response. The response would normally focus on identifying the cause or source of nutrients and then reducing nutrient loads to restore environmental quality to comply with the objectives within specified time frames. Exceedances of the moderate protection ‘Phytoplankton biomass’ EQC, as well as elevated chlorophyll *a* concentrations and decreased light attenuation at the monitoring site in Jervoise Bay Northern Harbour (NH3), have been recorded since 2003 when reporting began. The median chlorophyll *a* concentrations at NH3 since 2002 are presented in Figure 7. There has been no significant shift in the stable mean of chlorophyll *a* at NH3 over the period 2002 to 2014 (Keesing *et al.* 2016).



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

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

Algal blooms were identified within the Northern Harbour immediately after completion of construction of the northern breakwater in December 1997 and continued in the summer months of 1999, 2000 and 2001, with the impacts being primarily visual impairment and health issues associated with potential growth of toxic phytoplankton (Parsons Brinckerhoff 2011). The algal blooms were attributed to the high levels of nitrogen in groundwater flowing into the Northern Harbour and the increased residence times associated with the construction of the breakwater. Nitrogen point sources were removed in the early 2000s and a groundwater recovery scheme was constructed in 2000 to reduce the amount of nitrogen-rich groundwater discharging into the Northern Harbour.

Based upon marine water quality monitoring inside and outside the Northern Harbour, as well as modelling to predict the likely future concentrations of nutrients, Parsons Brinckerhoff (2011) concluded that:

- the median total nitrogen levels and associated chlorophyll *a* concentrations in the Northern Harbour had decreased by 58 percent (%) over the previous 13 years;
- the 90th percentile chlorophyll *a* concentration had decreased by 73% and major algal blooms with chlorophyll *a* concentrations in the range 20 to 40 µg/L no longer occurred; and
- assuming there is no significant reduction in the diffuse background nitrogen, median chlorophyll *a* concentrations will likely remain within the range 2.2–2.9 µg/L and chlorophyll *a* concentration in the Northern Harbour is unlikely to ever consistently meet the existing EQG or EQS for 'Phytoplankton biomass'.

In 2007, in response to concerns about the state of water and sediment quality and the environmental conditions in Northern Harbour, the Cockburn Sound Management Council formed the multi-stakeholder Jervoise Bay Northern Harbour Working Group (Working Group). The Working Group developed the *Jervoise Bay Northern Harbour Management Action Plan* (Management Action Plan; Cockburn Sound Management Council 2012). The Management Action Plan provides a road-map to address environmental issues affecting the Northern Harbour, with recommendations on future management actions to improve water and sediment quality.

In response to the exceedance of the 'Phytoplankton biomass' EQS in the 2013–14 reporting period (*The State of Cockburn Sound Report 2014*; Cockburn Sound Management Council 2015), the Council reviewed the Management Action Plan and consulted with key stakeholders in 2015–16. Noting it is anticipated that further reduction in the nitrogen load into the harbour will continue over time but that it will be slow, the Council determined that no further consideration of the recommendations in the Management Action Plan was necessary at that time. The Council continues to monitor water quality in Jervoise Bay Northern Harbour, reporting against the 'Phytoplankton biomass' EQC and providing advice to the Minister for Environment on appropriate management responses. The Council did not consider it appropriate to seek to modify the EQC for Jervoise Bay Northern Harbour in order to avoid triggering further consideration of appropriate management actions in the future.

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

2.6.1 Dissolved Oxygen Concentration

Weekly measurements of dissolved oxygen concentrations recorded in the bottom waters[9] at the 18 water quality monitoring sites (Figure 2) over the 2015–16 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 12 and Figure 8. Note that, given the frequency of sampling (weekly), dissolved oxygen concentrations at each site on each sampling occasion, rather than median concentrations, were compared against the EQC.

Table 12. 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 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	3	0	EQG not met, EQS(i) met
	CS5 (19 m)	16	2	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	0	-	EQG met
	G3 (13 m)	16	2	0	EQG not met, EQS(i) met
	CS11 (18 m)	16	8	0	EQG not met, EQS(i) met

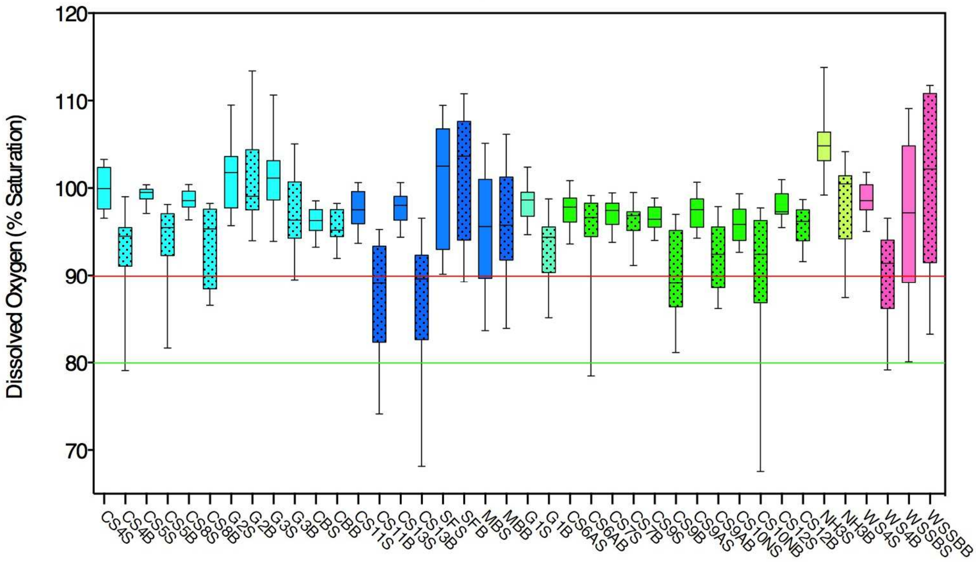
[9] Waters within 50 cm of the sediment surface.

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
HPA-S	CS13 (20.5 m)	16	9	0	EQG not met, EQS(i) met
	SF (3.5 m)	16	2	0	EQG not met, EQS(i) met
	MB (1.5 m)	16	3	0	EQG not met, EQS(i) met
MPA-CB	G1 (15 m)	16	1	0	EQG not met, EQS(i) met
MPA-ES	CS10N (14 m)	16	3	1	EQG not met, EQS(i) not 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	0	-	EQG met
	CS9 (13 m)	16	1	0	EQG not met, EQS(i) met
	CS9A (16.5 m)	16	0	-	EQG met
MPA-NH	NH3 (10 m)	16	0	-	EQG met
Reference Sites	WS4 (17.5 m)	16	6	0	N/A
	WSSB (2.5 m)	16	4	0	N/A

Dissolved oxygen concentrations in the bottom waters at 12 of the 18 monitoring sites in Cockburn Sound were below the relevant high and moderate protection ‘Dissolved Oxygen concentration’ EQG on between one and nine occasions during the 2015–16 non river-flow period. The greatest incidences of low dissolved oxygen concentrations were recorded in early and mid-January, the end of February and the end of March 2016. In early and mid-January, the lowest dissolved oxygen concentrations were recorded at CS13 (63% saturation) in HPA-S and at CS5 (71%) and CS4 (75%) in HPA-N on 11 January 2016. On 29 February 2016, the lowest concentrations were recorded at CS10N (45%) and CS6A (72%) in MPA-ES and at CS13 (70%) and CS11 (71%) in HPA-S. At the end of March, the lowest concentrations were recorded at CS11 (76%) and CS13 (78%) on 21 March 2016 and at CS9 (78%) in MPA-ES on 29 March 2016.

The dissolved oxygen concentration recorded at CS10N in MPA-ES was below the moderate protection ‘Dissolved Oxygen concentration’ EQS(i) (60% saturation) on 29 February 2016.

Low dissolved oxygen concentrations were also recorded at both reference sites in Warnbro Sound in January to early February 2016 (76% saturation recorded at WS4 on 11 January and 78% at WSSB on 18 January) and at WS4 on 29 February 2016 (80%). The low dissolved oxygen concentrations at the reference sites occurred during a period of four to five weeks when dissolved oxygen concentrations were below 90% saturation.



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; 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; hatched bars and site label 'B' = bottom waters.

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

Figure 8. Median dissolved oxygen concentrations (% saturation) in surface and bottom waters at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2015 to March 2016.

The results of the assessment of the dissolved oxygen concentrations in bottom waters measured quarterly over the 2015–16 monitoring period at the three Water Corporation sites in Cockburn Sound, and two sites located outside Cockburn Sound, are presented in Table 13. The high protection 'Dissolved Oxygen concentration' EQG was not met on two occasions at the site South and on one occasion at the site Central. The 'Dissolved Oxygen concentration' EQS(i) was met on all occasions.

Table 13. 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 2015	October 2015	January 2016	April 2016
HPA-N	Central (21 m)	EQG met	EQG met	EQG met	EQG not met; EQS(i) met
HPA-S	South (20 m)	EQG met	EQG not met; EQS(i) met	EQG not met; EQS(i) met	EQG met
MPA-ES	DIFF50W (10 m)	EQG met	EQG met	EQG met	EQG met
Sites outside Cockburn Sound	Parmelia Bank (7 m)	> 90%	> 90%	> 90%	< 90%; > 60%
	Owen Anchorage (14 m)	> 90%	> 90%	> 90%	> 90%

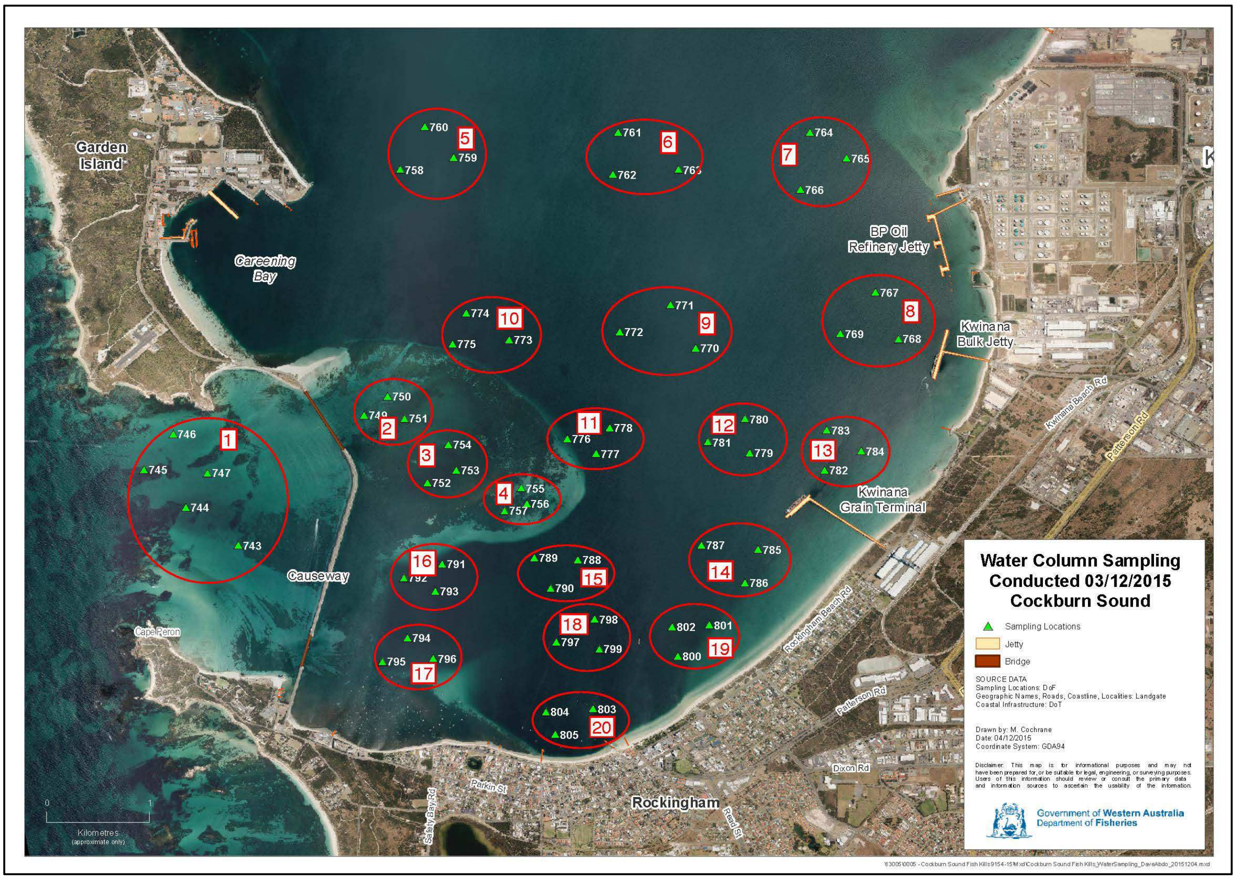
The moderate protection 'Dissolved Oxygen concentration' EQG was met in the bottom waters at three sites around the Kwinana Bulk Terminal[10] and three sites

[10] Depths varied between approximately 10 metres to 13 metres.

around the Kwinana Bulk Jetty[11] surveyed by Fremantle Ports in March 2016.

As part of the investigation into the environmental conditions associated with the Cockburn Sound fish kill in November–December 2015, the Department of Fisheries undertook a synoptic survey of physical-chemical water column characteristics in the southern Cockburn Sound on 3 December 2015. The physical-chemical parameters water temperature, salinity, pH, total dissolved solids, turbidity, dissolved oxygen and chlorophyll *a* were measured using a HydroLab DS5 multi-parameter datasonde at each of 57 sites in 19 locations in southern Cockburn Sound and five sites west of the causeway (Figure 9).

The high protection 'Dissolved Oxygen concentration' EQG was met in the bottom waters at all 57 sites[12] in southern Cockburn Sound surveyed on 3 December 2015. Dissolved oxygen concentrations were greater than 110% saturation at all the locations and higher than 125% saturation at 15 sites.



(Source: Department of Fisheries 2016)

Figure 9. Water column sampling locations in southern Cockburn Sound.

Assessment against the Environmental Quality Standard

Exceedance of the 'Dissolved Oxygen concentration' EQG triggered more detailed assessment against the 'Dissolved Oxygen concentration' EQS (EQS D, Reference

[11] Depths varied between approximately 12 metres and 16 metres.
[12] Depths varied between approximately one and two metres to 19 metres.

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.

There was an exceedance of the moderate protection 'Dissolved Oxygen concentration' EQS(i) at one site (CS10N) over the 2015–16 non river-flow period (Table 12). CS10N is a relatively shallow site (14 m) located outside the deeper central basin (17–22 m) and would therefore be expected to be relatively well mixed and not subject to significant stratification, which is usually a prerequisite for low dissolved oxygen concentrations.

There were no reports of deaths of marine organisms during the periods when low dissolved oxygen concentrations were recorded over the 2015–16 non river-flow period that may have been attributable to deoxygenation ('Dissolved Oxygen concentration' EQS(iii)).

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 Environment 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.

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 eight non river-flow periods (2008–2009 onwards), exceedances of the 'Dissolved Oxygen concentration' EQG have been recorded at most sites on one or more occasions during each non river-flow period (Table 14). The high protection 'Dissolved Oxygen concentration' EQG was exceeded in the non river-flow period on between zero and 10 occasions at sites in HPA-S, with the greatest incidence of exceedances

occurring at the two deeper sites CS11 and CS13; and on between zero and six occasions at sites in HPA-N, with the greatest incidence of exceedances occurring at the three deeper sites, CS4, CS5 and CS8.

The moderate protection ‘Dissolved Oxygen concentration’ EQG was exceeded in the non river-flow period on between zero and three occasions, with the greatest incidence of exceedances occurring at CS9 and CS9A in 2010–2011 and at Jervoise Bay Northern Harbour (NH3) in 2011–2012 (Table 14). Exceedances of the ‘Dissolved Oxygen concentration’ EQG have been recorded at CS10N on one or more occasions over the last eight non river-flow periods; however, 2015–16 was the first time over this period that an exceedance of the ‘Dissolved Oxygen concentration’ EQS(i) has been recorded at this site.

Since the 2008–09 non river-flow period, there have been two other occasions when an exceedance of the ‘Dissolved Oxygen concentration’ EQS(i) has been recorded:

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

Since 2008–09, dissolved oxygen concentrations less than 90% saturation have been recorded on between zero and six occasions at the two reference sites in Warnbro Sound, with the greatest incidence of exceedances at the deeper site WS4 (Table 14).

Table 14. Number of occasions during each non river-flow period since 2008–2009 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 exceeded the ‘Dissolved Oxygen concentration’ EQC.

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

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 EQC to be met.

Comparing the median dissolved oxygen concentrations calculated for rolling six week intervals over the 2015–16 non river-flow period against the 'Dissolved Oxygen concentration' EQG, fewer exceedances were generally recorded and at fewer sites. Exceedances of the 'Dissolved Oxygen concentration' EQG were recorded at CS8 in HPA-N, CS11, CS13 and Mangles Bay [MB] in HPA-S and the two reference sites in Warnbro Sound. No exceedances were recorded at any of the sites in the moderate protection areas (MPA-ES, MPA-CB or MPA-NH). There were no exceedances of the 'Dissolved Oxygen concentration' EQS(i) recorded at any site.

Exceedance of the 'Dissolved Oxygen concentration' EQS(i) at CS10N in MPA-ES triggered the requirement to initiate a management response, which would normally focus on identifying the cause or source of the exceedance and then implementing appropriate source control. Noting the dissolved oxygen concentrations recorded over the past eight non river-flow periods, 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 downward trend in the oxygen status of Cockburn Sound.

2.6.2 Water Temperature

Weekly measurements of surface[13] and bottom[14] water temperatures recorded at the 18 water quality monitoring sites[15] (Figure 2), over the 2015–16 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 2015–16 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 2015–16 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.*

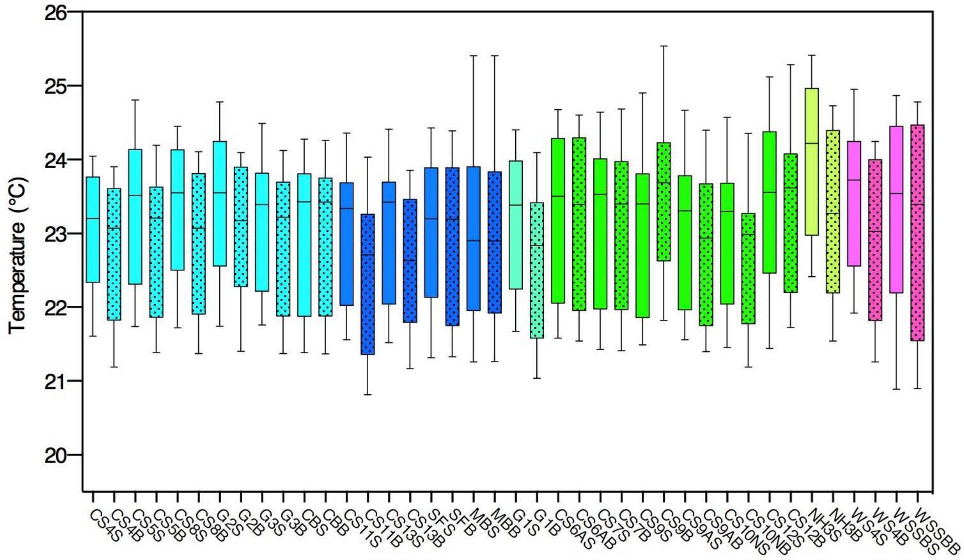
[13] Measured at 50 cm below the water surface.
[14] Measured at 50 cm above the sediment surface.
[15] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2015).

The results of the assessment against the EQG are presented in Table 15. Median surface and bottom water temperatures at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound are shown in Figure 10. At all sites, the median temperatures recorded over the 2015–16 non river-flow period met the 'Temperature' EQG.

Table 15. Assessment of median surface and bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound over the 2015–16 non river-flow period against the 'Temperature' EQG.

Ecological Protection Area	Site	Temperature (º C)				Assessment
		2015–16 EQG (Surface)	2015–16 median (Surface)	2015–16 EQG (Bottom)	2015–16 median (Bottom)	
HPA-N	CS4	≤ 24.25	23.21	≤ 24.09	23.07	EQG met
	CS5		23.51		23.21	EQG met
	CS8		23.55		23.07	EQG met
	CB		23.43		23.42	EQG met
	G2		23.55		23.18	EQG met
	G3		23.39		23.22	EQG met
HPA-S	CS11	≤ 24.25	23.34	≤ 24.09	22.72	EQG met
	CS13		23.43		22.64	EQG met
	SF	≤ 24.53	23.20	≤ 24.53	23.19	EQG met
	MB		22.91		22.90	EQG met
MPA-CB	G1	≤ 24.90	23.38	≤ 24.23	22.84	EQG met
MPA-ES	CS10N	≤ 24.90	23.30	≤ 24.23	22.99	EQG met
	CS12		23.55		23.61	EQG met
	CS6A		23.50		23.39	EQG met
	CS7		23.53		23.40	EQG met
	CS9		23.40		23.69	EQG met
	CS9A		23.31		22.94	EQG met
MPA-NH	NH3	≤ 24.90	24.22	≤ 24.23	23.27	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; 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; hatched bars and site label 'B' = bottom waters.

Figure 10. 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 2015 to March 2016.

Information on trends in water temperature over time in Cockburn Sound is provided in Appendix D.

2.6.3 Salinity

Weekly measurements of surface[16] and bottom[17] water salinities recorded at the 18 water quality monitoring sites[18] (Figure 2), over the 2015–16 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 2015–16 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 2015–16 non river-flow period, measured according to the Standard Operating Procedures, is not to deviate beyond the 5th and 95th percentiles of the natural salinity range measured at the Warnbro Sound reference sites WS4 or WSSB for the same period.*

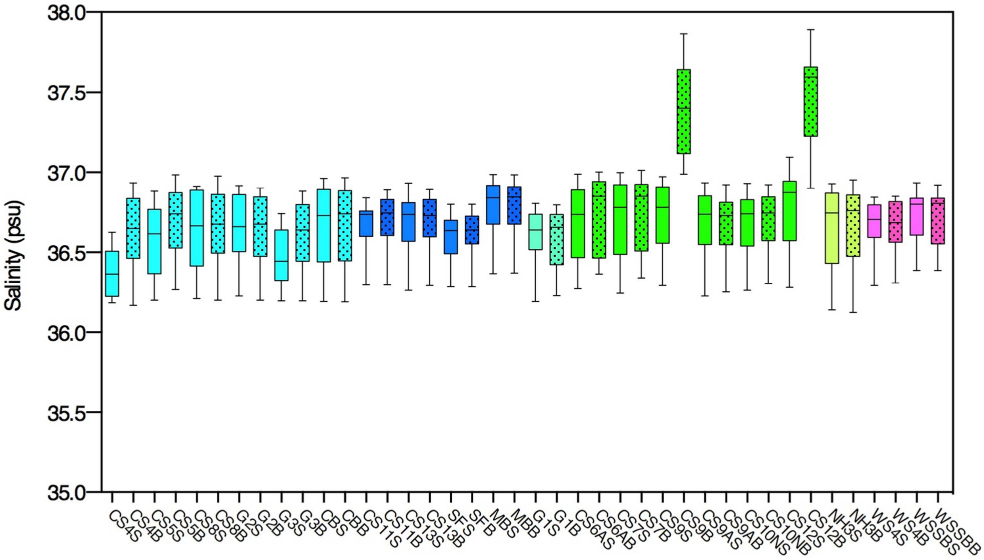
[16] Measured at 50 cm below the water surface.
[17] Measured at 50 cm above the sediment surface.
[18] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2015).

The results of the assessment against the EQG are presented in Table 16. Median surface and bottom water salinities at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound are shown in Figure 11. The median salinities recorded over the 2015–16 non river-flow period met the 'Salinity' EQG at all sites with the exception of CS4 and G3 in HPA-N and CS9 and CS12 in MPA-ES.

Table 16. Assessment of median surface and bottom salinities at 18 water quality monitoring sites in Cockburn Sound over the 2015–16 non river-flow period against the 'Salinity' EQG.

Ecological Protection Area	Site	Salinity (practical salinity units [psu])				Assessment
		2015–16 EQG (Surface)	2015–16 median (Surface)	2015–16 EQG (Bottom)	2015–16 median (Bottom)	
HPA-N	CS4	36.57 ≤ x ≤ 36.80	36.37	36.55 ≤ x ≤ 36.82	36.65	EQG not met in surface waters
	CS5		36.61		36.74	EQG met
	CS8		36.66		36.68	EQG met
	CB		36.73		36.74	EQG met
	G2		36.66		36.68	EQG met
	G3		36.44		36.64	EQG not met in surface waters
HPA-S	CS11	36.57 ≤ x ≤ 36.80	36.74	36.55 ≤ x ≤ 36.82	36.74	EQG met
	CS13		36.74		36.73	EQG met
	SF	36.57 ≤ x ≤ 36.84	36.64	36.49 ≤ x ≤ 36.84	36.64	EQG met
	MB		36.84		36.84	EQG met
MPA-CB	G1	36.29 ≤ x ≤ 36.85	36.64	36.31 ≤ x ≤ 36.85	36.65	EQG met
MPA-ES	CS10N	36.29 ≤ x ≤ 36.85	36.74	36.31 ≤ x ≤ 36.85	36.74	EQG met
	CS12		36.88		37.60	EQG not met in surface and bottom waters
	CS6A		36.74		36.85	EQG met
	CS7		36.78		36.85	EQG met
	CS9		36.78		37.40	EQG not met in bottom waters
	CS9A		36.73		36.73	EQG met
MPA-NH	NH3	36.29 ≤ x ≤ 36.85	36.74	36.31 ≤ x ≤ 36.85	36.76	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).



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; 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; hatched bars and site label 'B' = bottom waters.

Figure 11. 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 2015 to March 2016.

The results of the assessment of salinity in bottom waters measured quarterly over the 2015–16 monitoring period at the three Water Corporation sites in Cockburn Sound, and two sites located outside Cockburn Sound, are presented in Table 17. Slightly elevated salinities were recorded in bottom waters at DIFF50W in October 2015 and January 2016 compared to Central and South in Cockburn Sound, and Parmelia Bank and Owen Anchorage located outside Cockburn Sound.

Table 17. 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 2015	October 2015	January 2016	April 2016
HPA-N	Central	35.44	35.38	36.54	36.87
HPA-S	South	35.48	35.42	36.60	36.82
MPA-ES	DIFF50W	35.34	35.76	37.14	36.79
Sites outside Cockburn Sound	Parmelia Bank	35.40	35.43	35.93	36.76
	Owen Anchorage	35.15	35.49	35.89	36.32

Assessment against the Environmental Quality Standard

Exceedance of the 'Salinity' EQG triggered more detailed assessment against the 'Salinity' EQS (EQS F, Table 1a, Reference Document):

High Protection: *i.* *No 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.

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

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

Median surface salinities at CS4 and G3 in north-western Cockburn Sound were lower than the 'Salinity' EQG by less than one practical salinity unit (psu) and were above the default high protection salinity trigger value[19] in the Reference Document. The lower salinities recorded at these sites are likely to reflect increased exchange and mixing with waters from outside Cockburn Sound. Salinity in Cockburn Sound varies slightly from that of the open ocean (about 35 parts per thousand [ppt]), declining to about 34 ppt in winter due to outflow from the Swan River, and reaching 36 ppt in autumn due to evaporation during the summer (D.A. Lord & Associates Pty Ltd. 2001)

Median bottom salinities at CS9 and CS12, and median surface salinity at CS12, exceeded the 'Salinity' EQG. Median bottom water salinities at CS9 and CS12 exceeded the 'Salinity' EQG by less than one psu and were below the default moderate protection salinity trigger value[20] in the Reference Document. Median surface water salinity at CS12 exceeded the 'Salinity' EQG by less than one psu and was below the default moderate protection salinity trigger value.[21] 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 2006–2007 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 2015–16 non river-flow period that may have been attributable to anthropogenically-sourced salinity stress ('Salinity' EQS(ii)).

2.6.4 pH

Weekly measurements of surface[22] and bottom[23] water pH recorded at the 18 water

[19] High protection surface waters = 35.40 psu (the median of suitable reference site data ± 1.3; 36.70 - 1.3).
[20] Moderate protection bottom waters = 38.09 psu (the median of suitable reference site data ± 1.4; 36.69 + 1.4).
[21] Moderate protection surface waters = 38.10 psu (the median of suitable reference site data ± 1.4; 36.70 + 1.4).
[22] Measured at 50 cm below the water surface.
[23] Measured at 50 cm above the sediment surface.

quality monitoring sites[24] (Figure 2) over the 2015–16 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 2015–16 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 2015–16 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 18. At all sites, the median pH recorded over the 2015–16 non river-flow period met the 'pH' EQG.

Table 18. Assessment of median surface and bottom pH at 18 water quality monitoring sites in Cockburn Sound over the 2015–16 non river-flow period against the 'pH' EQG.

Ecological Protection Area	Site	pH (pH units)				Assessment
		2015–16 EQG (Surface)	2015–16 median (Surface)	2015–16 EQG (Bottom)	2015–16 median (Bottom)	
HPA-N	CS4	8.2 ≤ x ≤ 8.3	8.3	8.2 ≤ x ≤ 8.3	8.2	EQG met
	CS5		8.3		8.2	EQG met
	CS8		8.2		8.2	EQG met
	CB		8.2		8.2	EQG met
	G2		8.3		8.3	EQG met
	G3		8.3		8.2	EQG met
HPA-S	CS11	8.2 ≤ x ≤ 8.3	8.2	8.2 ≤ x ≤ 8.3	8.2	EQG met
	CS13		8.3		8.2	EQG met
	SF	8.1 ≤ x ≤ 8.3	8.2	8.1 ≤ x ≤ 8.3	8.2	EQG met
	MB		8.2		8.3	EQG met
MPA-CB	G1	8.2 ≤ x ≤ 8.4	8.2	8.1 ≤ x ≤ 8.4	8.2	EQG met
MPA-ES	CS10N	8.2 ≤ x ≤ 8.4	8.2	8.1 ≤ x ≤ 8.4	8.2	EQG met
	CS12		8.2		8.2	EQG met
	CS6A		8.3		8.3	EQG met
	CS7		8.2		8.2	EQG met
	CS9		8.2		8.1	EQG met
	CS9A		8.2		8.2	EQG met
MPA-NH	NH3	8.2 ≤ x ≤ 8.4	8.2	8.1 ≤ x ≤ 8.4	8.2	EQG met

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

[24] Note that this indicator has been developed for use at the local scale (for example around an outfall) rather than broader scales (EPA 2015).

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

Two samples were collected for analysis of potential toxicants in marine waters as part of the investigation into the November–December 2015 fish kill in Cockburn Sound by the Department of Fisheries. One sample was collected at the Kwinana Bulk Jetty in MPA-ES on 19 November 2015. The sample was analysed for ammonia, polycyclic aromatic hydrocarbons (PAHs) and total recoverable hydrocarbons (TRHs). A second sample was collected in Mangles Bay in HPA-S on 4 December 2015 and analysed for ammonia, dissolved metals, pesticides and herbicides. Samples were analysed by the ChemCentre.

As part of its annual monitoring, Fremantle Ports collected surface marine water samples at six sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) in MPA-ES (Section 2.3; Figure 2) once in March 2016. The samples were analysed for ammonia, dissolved copper, total petroleum hydrocarbons (TPHs) and benzene, toluene, ethylbenzene and xylene (BTEX).

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. In addition, 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). The results are presented in Table 19 and Table 20.

Table 19. Assessment of toxicants in water samples collected in Mangles Bay and at the Kwinana Bulk Jetty against the high protection or moderate protection EQG or LRV for ‘Toxicants in marine waters’.

Toxicant	EQG/LRV	Kwinana Bulk Jetty	Mangles Bay
Non-metallic inorganics (milligrams/litre [mg/L])			
Ammonia	High Protection EQG: 0.5	-	0.02
	Moderate Protection EQG: 1.2	0.41	-
Metals and metalloids (mg/L)[1]			
Aluminium	LRV: 0.0005	-	< 0.005
Arsenic	As III LRV: 0.0023 As V LRV: 0.0045	-	< 0.010
Cadmium	EQG: 0.0007	-	0.0011
Chromium	Cr III EQG: 0.0077 Cr IV EQG: 0.00014	-	< 0.005
Cobalt	EQG: 0.001	-	< 0.001
Copper	EQG: 0.0003	-	< 0.001
Lead	EQG: 0.0022	-	< 0.001
Manganese	LRV: 0.08	-	< 0.001
Mercury (total)	Inorganic EQG: 0.0001	-	< 0.001
Molybdenum	LRV: 0.023	-	0.014
Nickel	EQG: 0.007	-	< 0.01
Selenium	Se IV LRV: 0.003 Se VI LRV: 0.003	-	< 0.01

Toxicant	EQG/LRV	Kwinana Bulk Jetty	Mangles Bay
Silver	EQG: 0.0008	-	< 0.001
Vanadium	EQG: 0.05	-	0.002
Zinc	EQG: 0.007	-	0.013
Polycyclic aromatic hydrocarbons (PAHs) (µg/L)[2]			
Anthracene	LRV: 1.5	< 1	-
Benzo(a)pyrene	LRV: 0.4	< 1	-
Fluoranthene	LRV: 1.7	< 1	-
Naphthalene	EQG: 90	< 1	-
Phenanthrene	LRV: 4	< 1	-
Organochlorine and Organophosphorus Pesticides (µg/L)[1]			
Aldrin	LRV: 0.003	-	< 0.01
Chlordane	LRV: 0.0001	-	< 0.01
Chlorpyrifos	EQG: 0.0005	-	< 0.1
DDE	LRV: 0.0005	-	< 0.01
DDT	LRV: 0.0004	-	< 0.01
Dieldrin	LRV: 0.01	-	< 0.01
Endosulfan	EQG: 0.005	-	α = < 0.01 β = < 0.01 sulfate = < 0.01
Endrin	EQG: 0.004	-	< 0.01
Fenitrothion	LRV: 0.001	-	< 0.1
Heptachlor	LRV: 0.0004	-	< 0.01
Malathion	LRV: 0.05	-	< 0.10
Petroleum Hydrocarbons (µg/L)			
Total recoverable hydrocarbons (TRHs)	-	< 280	-

Notes: '<' signifies the result is less that the limit of quantitation for the method. 1. High protection EQG or LRV; 2. Moderate protection EQG or LRV.

Concentrations of PAHs, TRHs, pesticides and herbicides in water samples collected in November–December 2015 were all below the laboratory analytical limits of reporting. In the case of the PAHs anthracene, fluoranthene, naphthalene and phenanthrene, and the organochlorine pesticide dieldrin, the analytical limits of reporting were equivalent to or below the relevant EQG or LRV (Table 19). The potential for toxicity of most of the pesticides and the PAH benzo(a)pyrene for which there are EQG or LRV could not be assessed because the analytical limits of reporting were not low enough to confirm exceedance of, or compliance with, the EQG or LRV. Consistent with the Reference Document, it was assumed the contaminants were not detected and therefore constitute a low risk.

Concentrations of most of the metals in the Mangles Bay sample were below the analytical limits of reporting (Table 19) but the potential for toxicity could not be assessed because the analytical limits of reporting were not low enough to confirm exceedance of, or compliance with, the EQG or LRV. Concentrations of total dissolved cobalt, lead, manganese, molybdenum and vanadium were equivalent to or below the relevant high protection EQG or LRV. Concentrations of total dissolved cadmium and zinc in the sample slightly exceeded the relevant high protection EQG, but were below the moderate protection EQG (0.014 milligrams per litre [mg/L] and 0.023 mg/L respectively). This was an unexpected result and it is noted that concentrations of cadmium and zinc reported in previous studies of contaminants in water samples collected in Mangles Bay were below the relevant EQG (Department of Environment 2004; Parsons Brinckerhoff 2009). It should also be noted that the result was not confirmed by further sampling or analysis. The Cockburn Sound Management Council

will undertake further sampling and analysis of water samples collected in Mangles Bay and the results will be reported in the 2016–17 Annual Report.

Concentrations of ammonia in both samples were below the relevant EQG for toxic effects.

Table 20. Assessment of toxicants in water samples collected 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
Copper (filtered)	EQG: 3.0	0.6	0.3	0.5	0.4	0.4	0.3
Ammonia	EQG: 1,200	8	4	<3	<3	<3	<3
Benzene	EQG: 900	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Toluene	LRV: 230	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Ethylbenzene	LRV: 5.0[1]	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Xylene	o-xylene LRV: 350[1] m-xylene LRV: 75[1] p-xylene LRV: 200[1]	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Total BTEX	-	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
TPH	LRV: 7[1]	<250	<250	<250	<250	<250	<250
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 (no moderate protection 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 20). Concentrations of BTEX were below the analytical limits of reporting and below the relevant EQG values or LRVs. The potential for toxicity of TPHs could not be directly assessed because the analytical limit of reporting was not low enough to confirm exceedance or non-exceedance of the LRV.

At all sites, the Total Toxicity of the Mixture (TTM)[25], based on the effects of ammonia, copper and benzene, was below one (Table 20). 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.

Over the 2015–16 non river-flow period, concentrations of ammonium at 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 11 µg N/L at Mangles Bay (MB) on 18 January 2016 and CS9 on 1 February 2016. The highest concentrations (14 µg N/L and 16 µg N/L) were recorded in bottom waters at CS13 in HPA-S.

The 95th percentiles of the ammonium concentrations at sites in HPA-N varied

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

between 0.5 µg N/L and 1.5 µg N/L and between 1.6 µg N/L and 6.7 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 percentiles of the sample concentrations for the sites in MPA-ES varied between 0.9 µg N/L and 6.7 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 percentile of the sample concentrations were 3.5 µg N/L and 0.9 µg N/L, respectively.

2.8 Assessment against the Environmental Quality Criteria for Toxicants in Sediments

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 2016 (Section 2.3; Figure 2). The samples were analysed 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 total petroleum hydrocarbons (TPHs).

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 results for sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty are presented in Table 21.

The median concentrations of arsenic, cadmium, chromium, copper, lead, mercury and zinc in both sampling areas were below the relevant EQG values. While there were elevated concentrations of chromium and copper at KBT1, zinc at KBT3, and cadmium and chromium at KBJ1, none exceeded the relevant re-sampling triggers. There is no EQG value for selenium, but concentrations at all the sites were below the analytical limit of reporting.

After normalisation to 1% Total Organic Carbon[26], median concentrations of TBT were below the EQG value (Table 21). The concentrations of TBT at all the sites sampled were below the EQG value.

The median concentrations of PAHs were below the relevant EQG values (Table 21). The concentrations of PAHs at all the sites sampled were below the EQG values; at most sites the concentrations were below the analytical limits of reporting. There are no EQG values for TPHs, however the concentrations of TPHs at all the sites were below the analytical limit of reporting.

[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 EQS. Note that contaminant concentrations less than the analytical limit of reporting were not normalised.

Table 21. Assessment of toxicants in sediment collected from three sites around the Kwinana Bulk Terminal (KBT) and three sites around the Kwinana Bulk Jetty (KBJ) against the EQG and the re-sampling trigger for 'Toxicants in sediments'.

		Metals (milligrams per kilogram [mg/kg])								Tributyltin (µg Sn/kg normalised to 1% TOC)	Dibutyltin (µg Sn/kg normalised to 1% TOC)	Total petroleum hydrocarbons (TPHs) (mg/kg)	Total polycyclic aromatic hydrocarbons (PAHs) (mg/kg)
		Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc				
EQG		20	1.5	80	65	50	0.15	-	200	5	-	-	4.0
Re-sampling trigger		70	10	370	270	220	1	-	410	70	-	-	45.0
Monitoring site	KBT1	< 0.5	0.8	85	71	31	< 0.1	< 0.5	160	0.6	< 0.5	< 275	< 0.16
	KBT2	< 0.5	0.4	55	59	19	< 0.1	< 0.5	79	2.4	< 0.5	< 275	< 0.16
	KBT3	< 0.5	1.4	46	54	20	< 0.1	< 0.5	220	4.3	0.38	< 275	< 0.16
	Median	**< 0.5**	**0.8**	**55**	**59**	**20**	**< 0.1**	**< 0.5**	**160**	**2.4**	**0.5**	**< 275**	**< 0.16**
	KBJ1	< 0.5	8.4	88	47	21	< 0.1	< 0.5	190	4.9	0.42	< 275	< 0.16
	KBJ2	< 0.5	0.6	42	5.3	3.9	< 0.1	< 0.5	9.5	0.4	< 0.5	< 275	< 0.16
	KBJ3	< 0.5	1.1	41	18	11	< 0.1	< 0.5	58	1.7	< 0.5	< 275	< 0.16
	Median	**< 0.5**	**1.1**	**42**	**18**	**11**	**< 0.1**	**< 0.5**	**58**	**1.7**	**0.5**	**< 275**	**< 0.16**

		Polycyclic aromatic hydrocarbons (PAHs) (mg/kg normalised to 1% TOC)											
		Naphthalene	Acena-phthylene	Acena-phthene	Fluorene	Phenan-threne	Anthracene	Fluoranthene	Pyrene	Benz(a)-anthracene	Chrysene	Benzo(a)-pyrene	Dibenz(a,h)-anthracene
EQG		0.16	0.044	0.016	0.019	0.240	0.085	0.6	0.665	0.261	0.384	0.43	0.063
Re-sampling trigger		2.1	0.64	0.5	0.54	1.5	1.1	5.1	2.6	1.6	2.8	1.6	0.26
	KBT1	< 0.01	< 0.01	< 0.01	< 0.01	0.007	< 0.01	0.010	0.010	< 0.01	< 0.01	< 0.01	< 0.01
	KBT2	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.008	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	KBT3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	346101	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Median	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**0.01**	**< 0.01**	**0.01**	**0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**
	KBJ1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	KBJ2	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	KBJ3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.10	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Median	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**

2.9 Conclusion

Based on the results from the 2015–16 monitoring program in Cockburn Sound, the 'Nutrient enrichment' EQG were met in the northern high ecological protection area (HPA-N), the southern high ecological protection area (HPA-S), the Careening Bay moderate protection area (MPA-CB) and the eastern Cockburn Sound moderate protection area (MPA-ES). The 'Phytoplankton biomass' EQG were met in HPA-N, HPA-S and MPA-ES, as well as at all sites in these areas, and at G1 in MPA-CB. It can therefore be concluded that in terms of nutrients there is a high degree of certainty that the Environmental Quality Objective 'Maintenance of ecosystem integrity' is being achieved in most of Cockburn Sound. Routine monitoring should be continued.

While there have been improvements in water quality in Cockburn Sound over the last 30 years, analysis of trends in seagrass shoot densities indicates that there have been significant declines over the past 11 to 14 years at a number of sites in Cockburn Sound. This suggests that other environmental factors may be playing an important role in seagrass decline or lack of recovery in Cockburn Sound.

Similar to previous reporting periods (for example, the *Cockburn Sound Annual Environmental Monitoring Report 2014–2015*; Cockburn Sound Management Council 2016), the 'Phytoplankton biomass' EQS was not met at Jervoise Bay Northern Harbour (NH3). This indicates there is a high risk that the Environmental Quality Objective has not been achieved in that harbour. Exceedance of the 'Phytoplankton biomass' EQS in Jervoise Bay Northern Harbour triggered the requirement to identify the cause or source of the exceedance and initiate a management response to reduce nutrient loads. The Cockburn Sound Management Council has previously prepared the *Jervoise Bay Northern Harbour Management Action Plan* in response to concerns about the state of water and sediment quality and the environmental conditions in Northern Harbour. The Council has reviewed the Management Action Plan in consultation with key stakeholders and continues to monitor water quality in Jervoise Bay Northern Harbour to report against the 'Phytoplankton biomass' EQC and to provide advice to the Minister for Environment on appropriate management responses.

The 'Dissolved Oxygen concentration' EQG were not met in the bottom waters at 12 of the 18 water quality monitoring sites in Cockburn Sound on one or more occasions over the 2015–16 non river-flow period and the 'Dissolved Oxygen concentration' EQS(i) was exceeded once at one site (CS10N) in MPA-ES. There were no reports of deaths of marine organisms during the periods when low dissolved oxygen concentrations were recorded over the 2015–16 non river-flow period that may have been attributable to deoxygenation.

With the exception of localised elevated salinities in bottom or surface waters at two sites (CS9 and CS12) in MPA-ES, the EQC for protecting the marine ecosystem from the effects of the other physical and chemical stressors were met. The results from the 2015–16 monitoring program in Cockburn Sound do not indicate that there is a significant risk that the Environmental Quality Objective 'Maintenance of ecosystem integrity' is not being achieved in most of Cockburn Sound. Routine monitoring should be continued.

The EQC for toxicants in sediments and marine waters were met around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty in MPA-ES. It can therefore be concluded that with respect to the effects of toxicants in marine waters and sediments, there is a

high level of confidence that in these areas, the Environmental Quality Objective ‘Maintenance of ecosystem integrity’ is being achieved. Routine monitoring should be continued.

In November–December 2015, there was a fish kill in Cockburn Sound with an estimated 2,000 fish and invertebrates (representing 15 species) affected, including more than 250 large Pink snapper (*Pagrus auratus*) which congregate in Cockburn Sound for spawning at that time of the year (Department of Fisheries 2016). Modelling based on water currents and the distribution of dead fish identified the source area of the fish kill was likely to be in the southern Cockburn Sound (Department of Fisheries 2016).

The most likely cause of the event was attributed to a combination of a spike in the densities of the diatom *Chaetoceros* (a potentially harmful phytoplankton taxon) coupled with other contributory factors such as low dissolved oxygen concentrations and unseasonably high water temperatures (Department of Fisheries 2016; Helleren 2016; Pattiaratchi 2016). A widespread and persistent algal bloom (defined as an unusual and exceptionally large biomass of algae significant enough to cause adverse water quality conditions, including discolouration and deoxygenation) was ruled out as a potential cause. Examination of the available physical oceanographic data identified a series of events that may have resulted in the southwards movement of anoxic bottom water in Cockburn Sound and upwelling at the southern end of Cockburn Sound (Pattiaratchi 2016). Routine water quality monitoring over the non river-flow period commenced on 1 December 2015 and the data do not therefore provide information as to the potential cause of the fish kill.

There were no other known reports of deaths of marine organisms over the 2015–16 reporting period that may have been attributable to deoxygenation or anthropogenically-sourced stress.

The Department of Fisheries is continuing to monitor crabs, and snapper larvae and juveniles in Cockburn Sound as part of its fisheries management activities and this information will assist in determining the impact of the event on the crab and fish populations in the Sound (Department of Fisheries 2016).

Government agencies at the inter-agency debrief into the investigation of the November–December 2015 fish kill in Cockburn Sound recommended the need for greater alignment of monitoring and research activities in Cockburn Sound. The Cockburn Sound Management Council has collated information on recent or current monitoring programs and research/investigative studies in Cockburn Sound in order to identify gaps and prioritise future monitoring and research requirements for Cockburn Sound. This information will be published on the Council’s website.

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 2015).

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 (EPA 2015). 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); and
- the health and productivity of aquaculture species is maintained (EPA 2015).

To protect wild seafood populations from the effects of environmental contamination, the EQC for the ‘Maintenance of ecosystem integrity’ are recommended (EPA 2015).

3.2 Water Quality and Seafood Monitoring

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 12). Sampling over the 2015–16 monitoring period was undertaken by Blue Lagoon Mussels and administered by the Department of Health.

Between July 2015 and June 2016, water samples for bacteriological monitoring were collected on six occasions from five sites (SF6, SF8, SF9, SF10, SF11) in the Southern Flats harvesting area[27] and 13 occasions from five sites (KGT1, KGT2, KGT3, KGT4, KGT5) in the Kwinana Grain Terminal harvesting area.[28] Shellfish samples were also collected for bacteriological testing on 13 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.

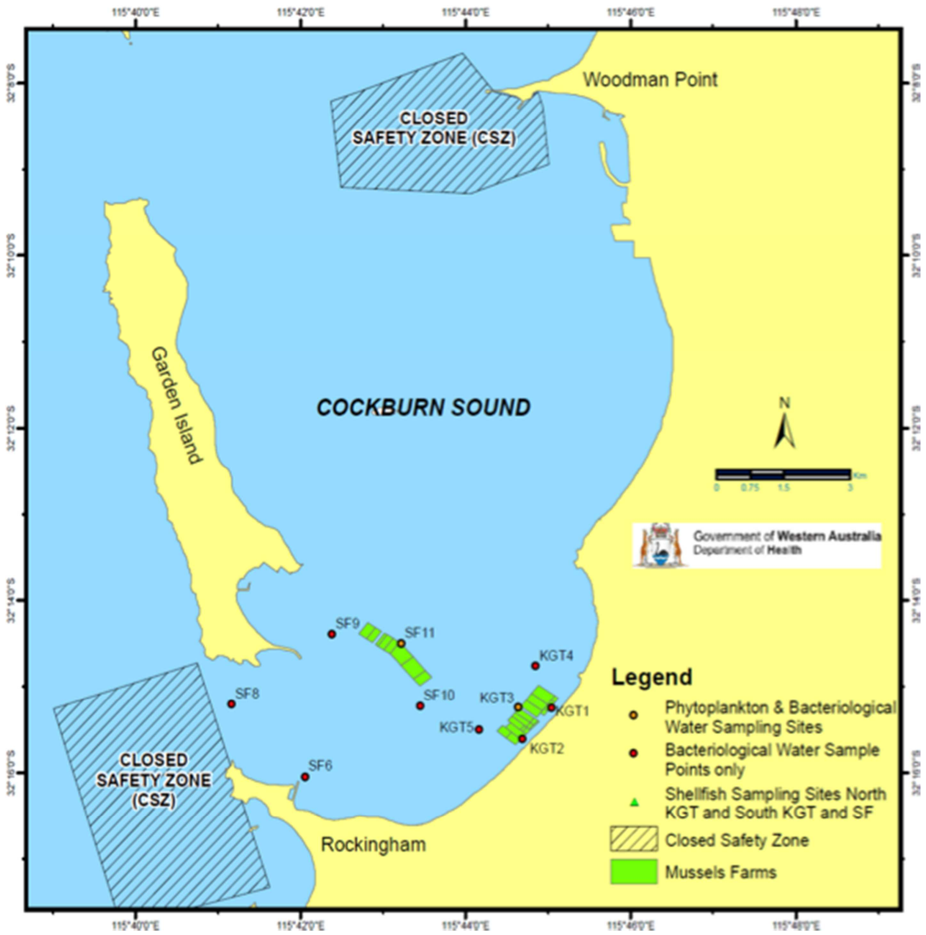
Depth-integrated water samples for phytoplankton identification and enumeration were collected twice monthly on scheduled dates (during periods when shellfish were being harvested) at one of the Kwinana Grain Terminal sites (KGT3) and one of the Southern Flats sites (SF11). Samples were collected from as close to the shellfish as possible and at the location where shellfish samples for flesh testing were taken. The samples were analysed by SGS Australia Pty Ltd or Dalcon Environmental (WA) for specific groups of phytoplankton species that are known to potentially produce toxins

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

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). During the November–December 2015 fish kill in Cockburn Sound, the shellfish growers, in consultation with the Department of Health, undertook increased monitoring, including phytoplankton analysis and biotoxin testing.

Representative samples of shellfish flesh from the Kwinana Grain Terminal harvesting area and the Southern Flats harvesting area were collected in November 2015 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 12. Sampling locations associated with shellfish harvesting areas in Cockburn Sound.

Fremantle Ports deployed sentinel mussels on mussel lines in mesh baskets

suspended approximately one metre below the water surface at the Kwinana Bulk Terminal (KBT1, KBT2, KBT3; Figure 2) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3; Figure 2) over the period 19 February–30 March/1 April 2016 (approximately six weeks). Approximately 15 mussels (55–90 mm shell length) were contained in each mesh basket, with two baskets attached per line. The mesh baskets were cleaned after approximately three weeks to prevent the accumulation of algal growth. 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 were undertaken by the National Measurement Institute (NMI).

As part of the investigation into the November–December 2015 fish kill in Cockburn Sound by the Department of Fisheries, samples of fish were screened for biotoxins and analysed for metals (inorganic arsenic, copper, lead, mercury, selenium and zinc) and pesticides. Analyses were undertaken by Advanced Analytical Australia Pty Ltd (biotoxins) and the ChemCentre (contaminants).

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 two shellfish harvesting areas in Cockburn Sound over the 2015–16 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 22. Over the 2015–16 monitoring period both components of the ‘Faecal pathogens in water’ EQG were met at all sites other than one of the Kwinana Grain Terminal sites (KGT3).

Table 22. 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 2015 and June 2016 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	2.6	EQG met
KGT2	1	4.4	EQG met
KGT3	1	27	EQG not met
KGT4	1	1.8	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

Assessment against the Environmental Quality Standard

Exceedance of the 'Faecal pathogens in water' EQG at KGT3 triggered more detailed assessment against the 'Faecal pathogens in water' EQS (EQS A, Table 4, Reference Document):

> *The median faecal coliform concentration in samples from a single site must not exceed 70 CFU/100 mL and the estimated 90th percentile must not exceed 85 CFU/100 mL measured using the membrane filtration method.*

The median faecal coliform concentration in samples from KGT3 (1 CFU/100 mL) and the 90th percentile faecal coliform concentration (27 CFU/100 mL) were below both components of the EQS.

In the event of an exceedance of the 'Faecal pathogens in water' EQG, assessment against the '*Escherichia coli* (*E. coli*) in fish flesh' EQS is also triggered (refer to Section 3.3.3).

3.3.2 Assessment of Compliance with the 'Algal biotoxins' EQC

Concentrations of toxic phytoplankton recorded in the two shellfish harvesting areas in Cockburn Sound over the 2015–16 monitoring period were assessed against the 'Algal biotoxins' EQG (Table 23). 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 23. 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 24. On 8 February 2016, the cumulative levels of *Pseudo-nitzschia delicatissima* group and *Pseudo-nitzschia seriata* group exceeded 50,000 cells per litre (cells/L) at both the Kwinana Grain Terminal site and the Southern Flats site.

Table 24. Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2015 and June 2016 against the 'Algal biotoxins' EQG.

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	Toxic algae recorded	Cell density (cells/L)	Cell density (cells/L)
6/07/2015	*Dinophysis acuminata*	20	-
	Dinophysis caudata var. *pediculata*	20	20
	Pseudo-nitzschia delicatissima group	160	340
	Pseudo-nitzschia seriata group	40	-
21/07/2015	*Dinophysis caudata* var. *pediculata*	20	20
	Pseudo-nitzschia delicatissima group	860	1,640
	Pseudo-nitzschia seriata group	60	1,800
4/08/2015	*Dinophysis acuminata*	20	20
	Pseudo-nitzschia delicatissima group	22,000	14,000
	Pseudo-nitzschia seriata group	12,000	22,000
24/08/2015	*Dinophysis acuminata*	20	60
	Pseudo-nitzschia delicatissima group	2,400	2,000
	Pseudo-nitzschia seriata group	3,000	3,000
7/09/2015	*Dinophysis acuminata*	20	60
	Pseudo-nitzschia delicatissima group	700	5,400
	Pseudo-nitzschia seriata group	9,000	22,000
22/09/2015	*Dinophysis acuminata*	60	20
	Pseudo-nitzschia delicatissima group	5,800	2,100
	Pseudo-nitzschia seriata group	2,000	1,200
6/10/2015	*Dinophysis acuminata*	1	80
	Pseudo-nitzschia delicatissima group	9,400	3,200
	Pseudo-nitzschia seriata group	3,500	3,400
20/10/2015	*Dinophysis acuminata*	40	20
	Pseudo-nitzschia delicatissima group	2,400	1,600
	Pseudo-nitzschia seriata group	3,800	1,900
3/11/2015	*Pseudo-nitzschia delicatissima* group	1,300	2,800
	Pseudo-nitzschia seriata group	520	2,800
17/11/2015	*Pseudo-nitzschia delicatissima* group	1,300	1,700
	Pseudo-nitzschia seriata group	4,500	4,400
23/11/2015	*Dinophysis acuminata*	20	20
	Gymnodinium/Karenia complex	20	620
	Pseudo-nitzschia delicatissima group	2,600	3,100
	Pseudo-nitzschia seriata group	1,500	4,000
2/12/2015	*Pseudo-nitzschia delicatissima* group	4,400	6,000
	Pseudo-nitzschia seriata group	2,000	3,600
15/12/2015	*Pseudo-nitzschia delicatissima* group	250	800
	Pseudo-nitzschia seriata group	1,600	5,200
17/12/2015	*Gymnodinium/Karenia* complex	1	80
	Pseudo-nitzschia delicatissima group	1,300	1,700
	Pseudo-nitzschia seriata group	4,500	4,400
6/01/2016	*Pseudo-nitzschia delicatissima* group	1,200	4,600
	Pseudo-nitzschia seriata group	7,600	2,600
20/01/2016	*Pseudo-nitzschia delicatissima* group	460	6,000
	Pseudo-nitzschia seriata group	60	260
8/02/2016	*Pseudo-nitzschia delicatissima* group	58,000	52,000
	Pseudo-nitzschia seriata group	22,000	19,000

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	Toxic algae recorded	Cell density (cells/L)	Cell density (cells/L)
15/02/2016	*Pseudo-nitzschia delicatissima* group	7,000	7,200
	Pseudo-nitzschia seriata group	200	320
24/02/2016	*Dinophysis caudata* var. *pediculata*	40	20
	Pseudo-nitzschia delicatissima group	1,600	2,000
	Pseudo-nitzschia seriata group	140	120
8/03/2016	*Pseudo-nitzschia delicatissima* group	24,000	3,600
21/03/2016	*Pseudo-nitzschia delicatissima* group	33,000	4,800
	Pseudo-nitzschia seriata group	60	20
16/05/2016	*Dinophysis acuminata*	10	10
	Dinophysis caudata var. *pediculata*	10	-
	Pseudo-nitzschia delicatissima group	-	1,000
8/06/2016	*Pseudo-nitzschia delicatissima* group	2,500	3,700
	Pseudo-nitzschia seriata group	2,000	1,100
22/06/2016	*Dinophysis acuminata*	10	50
	Dinophysis caudata var. *pediculata*	160	120
	Pseudo-nitzschia delicatissima group	10	20
	Pseudo-nitzschia seriata group	-	10
Assessment	Alert level to initiate flesh testing exceeded on 8 February 2016		

Assessment against the Environmental Quality Standard

The exceedance of the 'Algal biotoxins' EQG on 8 February 2016 at both the Kwinana Grain Terminal site and the Southern Flats site triggered shellfish flesh testing for amnesic shellfish poisoning (ASP) biotoxin. The results of the screening for ASP were negative and the routine screening for diarrhoetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP) biotoxins were also negative.

Under WASQAP, routine biotoxin screening was introduced in 2015 for all harvesting areas. All the samples for Cockburn Sound in the 2015–16 reporting period were negative for PSP, DSP and ASP biotoxins. In addition, flesh samples tested during the November–December 2015 fish kill were negative for PSP, DSP and ASP biotoxins and the neurotoxic shellfish poisoning (NSP) biotoxin.

Biotoxin concentrations in fish flesh, liver and kidney were assessed against the 'Algal biotoxins' EQS (EQS C, Table 4, Reference Document)[29]:

> *Toxin concentrations in seafood should not exceed the following environmental quality standards in any samples:*
>
> *Paralytic shellfish poison (PSP)* — *0.8 mg saxitoxin equivalents/kg*
>
> *Diarrhoetic shellfish poison (DSP)* — *0.2 mg/kg*
>
> *Neurotoxic shellfish poison (NSP)* — *200 mouse units/kg*
>
> *Amnesic shellfish poison (ASP)* — *20 mg/kg.*

[29] The 'Algal biotoxins' EQS for seafood is based on the maximum levels of non-metal contaminants in bivalve molluscs in Schedule 19 of the *Australia New Zealand Food Standards Code*. Bivalve molluscs are filter feeders and can accumulate biotoxins when the water contains sufficient levels of toxin-producing phytoplankton. Fish can also be affected by algal biotoxins, either by direct uptake from the water column or by bioaccumulation through the food chain. In the absence of maximum levels for algal biotoxins in other seafood, the Reference Document requires assessment of biotoxin concentrations in other seafood against those for bivalve molluscs.

The results of the assessment against the EQS are presented in Table 25. All the samples were negative for PSP, DSP, ASP and NSP biotoxins.

Table 25. Assessment of toxin concentrations counts in Pink snapper flesh, liver and kidney against the 'Algal biotoxins' EQS.

Toxin	EQS	Pink snapper #2 Kidney and liver	Pink snapper #3 Flesh, kidney and liver	Pink snapper #5 Flesh and liver	Flathead Liver
Paralytic shellfish poison (PSP)	< 0.8 mg Saxitoxin equivalents/ kg	PSP screen negative (equivalent to < 0.1 mg/kg saxitoxin equivalents)	PSP screen negative (equivalent to < 0.1 mg/kg saxitoxin equivalents) *Not tested in liver and kidney*	PSP screen negative (equivalent to < 0.1 mg/kg saxitoxin equivalents)	PSP screen negative (equivalent to < 0.1 mg/kg saxitoxin equivalents)
Diarrhoetic shellfish poison (DSP)	< 0.2 mg/kg	DSP screen negative (equivalent to < 0.025 mg/kg okadaic acid equivalents)	DSP screen negative (equivalent to < 0.025 mg/kg okadaic acid equivalents)	DSP screen negative (equivalent to < 0.025 mg/kg okadaic acid equivalents)	DSP screen negative (equivalent to < 0.025 mg/kg okadaic acid equivalents)
Neurotoxic shellfish poison (NSP)	200 mouse units/kg	Brevetoxin-2 (PbTx-2) < 0.20 mg/kg Brevetoxin-3 (PbTx-3) < 0.10 mg/kg (negative is equivalent to < 0.2 mg/kg)	Brevetoxin-2 (PbTx-2) < 0.20 mg/kg Brevetoxin-3 (PbTx-3) < 0.10 mg/kg (negative is equivalent to < 0.2 mg/kg)	Brevetoxin-2 (PbTx-2) < 0.20 mg/kg Brevetoxin-3 (PbTx-3) < 0.10 mg/kg (negative is equivalent to < 0.2 mg/kg)	Brevetoxin-2 (PbTx-2) < 0.20 mg/kg Brevetoxin-3 (PbTx-3) < 0.10 mg/kg (negative is equivalent to < 0.2 mg/kg)
Amnesic shellfish poison (ASP)	< 20 mg/kg	ASP screen negative (equivalent to < 1 mg/kg)	ASP screen negative (equivalent to < 1 mg/kg)	ASP screen negative (equivalent to < 1 mg/kg)	ASP screen negative (equivalent to < 1 mg/kg)

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 two shellfish harvesting areas in Cockburn Sound over the 2015–16 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 26. Both components of the EQS were met at all three sites over the 2015–16 monitoring period.

Table 26. Assessment of *E. coli* counts in mussel flesh collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2015 and June 2016 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			
6/07/2015	<1.8	<1.8	<1.8	EQS met
21/07/2015	<1.8	2		EQS met
25/08/2015	<1.8	<1.8		EQS met
7/09/2015	<1.8	<1.8	<1.8	EQS met
6/10/2015	<1.8	<1.8		EQS met
2/11/2015	<1.8	<1.8	<1.8	EQS met
1/12/2015	<1.8	<1.8		EQS met
6/01/2016	<1.8	<1.8	<1.8	EQS met
2/02/2016	<1.8	<1.8		EQS met
8/02/2016	<1.8	<1.8		EQS met
8/03/2016	<1.8	<1.8	<1.8	EQS met
19/04/2016	4	2		EQS met
16/05/2016	<1.8	<1.8	<1.8	EQS met

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

Concentrations of chemicals in mussel or fish 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)*
	2.0 mg/kg	*(fish)*
Selenium	*1.0 mg/kg*	*(molluscs)*
	2.0 mg/kg	*(fish)*
Zinc	*290 mg/kg*	*(oysters)*
	15 mg/kg	*(fish).*

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)*
	2.0 mg/kg	*(fish)*
Cadmium	*2.0 mg/kg*	*(molluscs)*
Lead	*2.0 mg/kg*	*(molluscs)*
	0.5 mg/kg	*(fish)*

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 and certain fish).

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 27 and Table 28.

The concentrations of metals in mussel flesh at sites in Cockburn Sound were all below the relevant EQG or EQS (Table 27). There are no EQC for TBT, but the concentrations in all the samples were below the analytical limit of reporting. 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, the limits of reporting were equivalent to or below the relevant EQS.

For those metals for which there are EQC, the concentrations in fish flesh were all below the relevant EQG or EQS (Table 28). The mean mercury concentration in the samples was 0.26 mg/kg, which is below the EQS of 0.5 mg/kg. The concentrations of all the pesticides were below the analytical limits of reporting. In the case of dichlorodiphenyltrichloroethane (DDT) and lindane, the limits of reporting were below the relevant EQS. The analytical limits of reporting for the other pesticides for which there are EQS were not low enough to confirm exceedance of, or compliance with, the EQS.

[30] Maximum levels of contaminants sourced from Schedule 19, Maximum residue limits from Schedule 20 and Extraneous residue limits from Schedule 21 of *Australia New Zealand Food Standards Code* (accessed on 28 June 2016).

Table 27. 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)	-	-	2.8	1.7	1.9	-	2.4	1.8	1.9	-	1.7	1.7
Arsenic (inorganic)[1]	-	**1.0**	0.28	0.17	0.19	-	0.24	0.18	0.19	-	0.17	0.17
Cadmium	-	**2.0**	0.22	0.16	0.14	-	0.18	0.16	0.15	-	0.16	0.15
Chromium	-	-	0.11	0.07	0.07	-	0.08	0.08	0.06	-	Not measured	
Copper	**30**	-	0.78	0.47	0.55	**0.55**	0.55	0.63	0.58	**0.58**	2.3	2.3
Lead	-	**2.0**	0.11	0.07	0.08	-	0.08	0.08	0.07	-	< 0.1	< 0.1
Mercury	-	**0.5 (mean level)**	0.01	< 0.01	< 0.01	**0.01 (mean)**	< 0.01	0.01	< 0.01	**0.01 (mean)**	< 0.01	< 0.01
Selenium	**1.0**	-	0.48	0.36	0.49	**0.48**	0.49	0.42	0.41	**0.42**	Not measured	
Zinc (EQG for oysters)	**290**	-	37	33	32	**33**	35	26	33	**33**	24	26
Tributyltin	-	-	< 0.001	< 0.001	< 0.001	-	< 0.001	< 0.001	< 0.001	-	Not measured	
Organics												
Polychlorinated Biphenyls (PCBs) (fish)	-	**0.5**	Not measured				Not measured				All < 0.01	All < 0.01
Polycyclic aromatic hydrocarbons (PAHs)	-	-	All below limits of reporting				All below limits of reporting				Not measured	
Organochlorine Pesticides												
Aldrin and Dieldrin	-	**0.1**[2]	Not measured				Not measured				Aldrin < 0.01 Dieldrin < 0.1	Aldrin < 0.01 Dieldrin < 0.1
BHC (sum of isomers, excluding gamma-isomer Lindane)	-	**0.01**[2]	Not measured				Not measured				BHC-α < 0.01 BHC-β < 0.01 BHC-δ < 0.01	BHC-α < 0.01 BHC-β < 0.01 BHC-δ < 0.01
Chlordane (sum of cis- and trans-)	-	**0.05**[2]	Not measured				Not measured				cis- < 0.01 trans- < 0.01	cis- < 0.01 trans- < 0.01
DDT (sum of p,p'-DDT, o,p'-DDT, p,p'-DDE and p,p'-DDD)	-	**1.0**[2]	Not measured				Not measured				pp-DDD < 0.01 pp-DDE < 0.01 pp-DDT < 0.01	pp-DDD < 0.01 pp-DDE < 0.01 pp-DDT < 0.01
Heptachlor (sum of heptachlor and heptachlor epoxide)	-	**0.05**[2]	Not measured				Not measured				Heptachlor < 0.01 Heptachlor epoxide < 0.01	Heptachlor < 0.01 Heptachlor epoxide < 0.01
Hexachlorobenzene (HCB)	-	**0.1**[2]	Not measured				Not measured				<0.01	<0.01

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

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

Table 28. Assessment of chemicals in the flesh of fish collected from Cockburn Sound against the 'Chemical concentration in seafood flesh' EQC.

Chemical (mg/kg)	Environmental Quality Criteria		Pink snapper #1	Pink snapper #2	Pink snapper #3	Pink snapper #4	Pufferfish	Boxfish	Flathead
	EQG	EQS							
Metals									
Arsenic (Total)	-	-	not measured	2.0	2.2	2.0	4.4	1.1	0.49
Arsenic (inorganic)[1]	-	2.0	-	0.20	0.22	0.20	0.44	0.11	0.049
Copper	2.0	-	not measured	0.12	0.13	0.93	0.24	0.93	0.19
Lead	-	0.5	not measured	0.015	< 0.005	< 0.025	< 0.005	< 0.005	< 0.005
Mercury	-	0.5 (mean level)	not measured	0.53	0.30	0.59	0.03	0.09	0.02
Selenium	2.0	-	not measured	0.43	0.49	0.56	0.33	0.43	0.10
Zinc	15	-	not measured	4	4	<5	9	7	4
Organochlorine Pesticides									
Aldrin and Dieldrin	-	0.1[2]	Aldrin < 0.03 Dieldrin < 0.03	Aldrin < 0.03 Dieldrin < 0.03	Aldrin < 0.09 Dieldrin < 0.09	Aldrin < 0.14 Dieldrin < 0.14	Aldrin < 0.03 Dieldrin < 0.03	Aldrin < 0.03 Dieldrin < 0.03	Aldrin < 0.03 Dieldrin < 0.03
BHC (sum of isomers, excluding gamma-isomer Lindane)	-	0.01[2]	BHC-α < 0.03 BHC-β < 0.03	BHC-α < 0.03 BHC-β < 0.03	BHC-α < 0.09 BHC-β < 0.09	BHC-α < 0.14 BHC-β < 0.14	BHC-α < 0.03 BHC-β < 0.03	BHC-α < 0.03 BHC-β < 0.03	BHC-α < 0.03 BHC-β < 0.03
Chlordane (sum of cis- and trans-chlordane and including oxychlordane)	-	0.05[2]	a-Chlordane < 0.03 g-Chlordane < 0.03 Oxy-chlordane < 0.03	a-Chlordane < 0.03 g-Chlordane < 0.03 Oxy-chlordane < 0.03	a-Chlordane < 0.09 g-Chlordane < 0.09 Oxy-chlordane < 0.09	a-Chlordane < 0.14 g-Chlordane < 0.14 Oxy-chlordane < 0.14	a-Chlordane < 0.03 g-Chlordane < 0.03 Oxy-chlordane < 0.03	a-Chlordane < 0.03 g-Chlordane < 0.03 Oxy-chlordane < 0.03	a-Chlordane < 0.03 g-Chlordane < 0.03 Oxy-chlordane < 0.03
DDT (sum of p,p'-DDT, o,p'-DDT, p,p'-DDE and p,p'-DDD)	-	1[2]	DDD < 0.03 DDE < 0.03 DDT < 0.03	DDD < 0.03 DDE < 0.03 DDT < 0.03	DDD < 0.09 DDE < 0.09 DDT < 0.09	DDD < 0.14 DDE < 0.14 DDT < 0.14	DDD < 0.03 DDE < 0.03 DDT < 0.03	DDD < 0.03 DDE < 0.03 DDT < 0.03	DDD < 0.03 DDE < 0.03 DDT < 0.03
Heptachlor (sum of heptachlor and heptachlor epoxide)	-	0.05[2]	Heptachlor < 0.03 Heptachlor epoxide < 0.03	Heptachlor < 0.03 Heptachlor epoxide < 0.03	Heptachlor < 0.09 Heptachlor epoxide < 0.09	Heptachlor < 0.14 Heptachlor epoxide < 0.14	Heptachlor < 0.03 Heptachlor epoxide < 0.03	Heptachlor < 0.03 Heptachlor epoxide < 0.03	Heptachlor < 0.03 Heptachlor epoxide < 0.03
Hexachlorobenzene (HCB)	-	0.1[2]	< 0.03	< 0.03	< 0.09	< 0.14	< 0.03	< 0.03	< 0.03
Lindane (gamma-BHC)	-	1[2]	< 0.03	< 0.03	< 0.09	< 0.14	< 0.03	< 0.03	< 0.03

Notes: '<' signifies the result is less than the limit of quantitation for the method. Note that detection limits for some analytes were adjusted for some samples due to low sample weights.

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

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 2015–16 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 2015–16 non river-flow period should meet the following environmental quality guideline values:

Dissolved oxygen	≥ *5* mg/L
pH	*6–9.*

Dissolved oxygen 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 29. 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 2015–16 non river-flow period.

Table 29. 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 2015–16 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])	1/12/2015	7.0	7.0	7.1	7.1	**7.0**	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	7/12/2015	7.0	6.9	7.1	7.0	**7.0**		
	14/12/2015	7.2	7.1	7.1	7.2	**7.2**		
	21/12/2015	6.9	6.8	7.1	7.0	**7.0**		
	4/01/2016	6.7	6.6	6.7	6.8	**6.7**		
	11/01/2016	6.5	6.3	6.7	6.7	**6.6**		
	18/01/2016	6.4	6.4	6.3	6.4	**6.4**		
	25/01/2016	6.5	6.3	6.5	6.7	**6.5**		
	1/02/2016	6.5	6.4	6.5	6.5	**6.5**		
	8/02/2016	6.6	6.7	6.7	6.9	**6.7**		
	15/02/2016	6.7	6.5	6.7	6.6	**6.6**		
	29/02/2016	6.9	6.8	7.0	6.4	**6.9**		
	7/03/2016	6.7	6.6	6.8	6.8	**6.7**		
	14/03/2016	6.5	6.7	6.5	6.7	**6.6**		
	21/03/2016	6.8	6.6	6.7	6.7	**6.7**		
	29/03/2016	6.9	6.6	6.9	6.8	**6.9**		
Depth waters dissolved oxygen (mg/L)	1/12/2015	7.0	7.0	7.1	7.1	**7.1**	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	7/12/2015	7.1	7.0	7.1	7.0	**7.0**		
	14/12/2015	7.2	7.0	7.1	7.1	**7.1**		
	21/12/2015	6.9	6.8	7.1	7.0	**7.0**		
	4/01/2016	6.7	6.5	6.7	6.7	**6.7**		
	11/01/2016	6.4	6.3	6.6	6.8	**6.5**		
	18/01/2016	6.4	6.4	6.3	6.4	**6.4**		
	25/01/2016	6.5	6.4	6.6	6.6	**6.5**		
	1/02/2016	6.4	6.3	6.2	6.4	**6.4**		
	8/02/2016	6.6	6.7	6.8	6.7	**6.7**		
	15/02/2016	6.7	6.4	6.6	6.5	**6.6**		
	29/02/2016	6.9	6.6	7.0	7.0	**6.9**		
	7/03/2016	6.6	6.6	6.7	6.7	**6.7**		
	14/03/2016	6.5	6.6	6.5	6.7	**6.6**		
	21/03/2016	6.8	6.5	6.7	6.7	**6.7**		
	29/03/2016	6.7	6.3	6.4	6.7	**6.5**		
Surface waters pH	1/12/2015	8.2	8.2	8.2	8.2	**8.2**	6–9	EQG met on all sampling occasions and at all sites
	7/12/2015	8.3	8.3	8.3	8.3	**8.3**		
	14/12/2015	8.2	8.1	8.2	8.2	**8.2**		
	21/12/2015	8.2	8.2	8.2	8.2	**8.2**		
	4/01/2016	8.3	8.3	8.3	8.3	**8.3**		
	11/01/2016	8.2	8.2	8.2	8.2	**8.2**		
	18/01/2016	8.2	8.1	8.2	8.2	**8.2**		
	25/01/2016	8.2	8.1	8.2	8.2	**8.2**		
	1/02/2016	8.2	8.2	8.2	8.2	**8.2**		
	8/02/2016	8.2	8.2	8.2	8.3	**8.2**		
	15/02/2016	8.3	8.3	8.3	8.3	**8.3**		
	29/02/2016	8.3	8.4	8.4	8.4	**8.4**		
	7/03/2016	8.3	8.3	8.3	8.3	**8.3**		

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
	14/03/2016	8.3	8.3	8.2	8.3	**8.3**		
	21/03/2016	8.3	8.3	8.3	8.3	**8.3**		
	29/03/2016	8.2	8.2	8.3	8.2	**8.2**		
Depth waters pH	1/12/2015	8.2	8.2	8.2	8.2	**8.2**	6–9	EQG met on all sampling occasions and at all sites
	7/12/2015	8.3	8.3	8.3	8.3	**8.3**		
	14/12/2015	8.2	8.1	8.2	8.2	**8.2**		
	21/12/2015	8.2	8.2	8.2	8.2	**8.2**		
	4/01/2016	8.3	8.3	8.3	8.3	**8.3**		
	11/01/2016	8.2	8.2	8.2	8.2	**8.2**		
	18/01/2016	8.2	8.1	8.2	8.2	**8.2**		
	25/01/2016	8.2	8.2	8.2	8.2	**8.2**		
	1/02/2016	8.2	8.2	8.2	8.2	**8.2**		
	8/02/2016	8.2	8.2	8.2	8.2	**8.2**		
	15/02/2016	8.3	8.3	8.3	8.3	**8.3**		
	29/02/2016	8.3	8.3	8.4	8.4	**8.4**		
	7/03/2016	8.3	8.3	8.3	8.3	**8.3**		
	14/03/2016	8.3	8.3	8.3	8.3	**8.3**		
	21/03/2016	8.3	8.3	8.3	8.3	**8.3**		
	29/03/2016	8.2	8.2	8.2	8.2	**8.2**		

3.4.2 Assessment of Compliance with the 'Toxicants' EQG

The concentrations of selected toxicants (ammonia, nitrate–nitrite and copper) in surface water samples collected at sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) once in March 2016 (Section 2.3; Figure 2) were assessed against the 'Toxicants' EQG for the maintenance of aquaculture production (EQG B, Table 5, Reference Document). Concentrations of ammonium 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 2015–16 non river-flow period (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, ammonium 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 30. The toxicant concentrations recorded at all the sites were below the relevant EQG values.

Table 30. Assessment of concentrations of ammonia, nitrate–nitrite and copper 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)	
	EQG	Surface	Bottom	EQG	Surface	Bottom	EQG	Surface
KBT1	≤1,000	8	5	Nitrite-N ≤100 Nitrate-N ≤100,000	3	3	≤5	0.6
KBT2		4	5		3	2		0.3
KBT3		< 3	5		< 2	6		0.5
KBJ1		< 3	< 3		< 2	< 2		0.4
KBJ2		< 3	5		< 2	< 2		0.4
KBJ3		< 3	< 3		< 2	< 2		0.3
CS13		0.7	14.5		< 2	5		Not measured
CS9A		95th percentile = 6.1			95th percentile = < 2			Not measured
CS10N		95th percentile = 6.7			95th percentile = < 2			Not measured
CS11		95th percentile = 1.6			95th percentile = < 2			Not measured
Assessment	EQG met at all sites							

3.5 Conclusions

Based on the results from the 2015–16 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 limited 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 recommends only eating shellfish harvested commercially under strict quality assurance monitoring programs (Department of Health 2010, 2016).

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 2015).

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 2015).

4.2 Water Quality Monitoring

The cities of Cockburn, Kwinana, and Rockingham and the Australian Department of Defence undertook bacterial water sampling at a number of popular recreational beaches (program sites) around Cockburn Sound in the 2015–16 monitoring period (Figure 13). The sampling was administered by the Department of Health. A minimum collection of 65 samples between November and 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 to13 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 may 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

[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

Medical Research Council (2008).

Figure 13. 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 13 locations around Cockburn Sound over the 2015–16 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.*

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 31. The 'Faecal pathogens' EQG for both primary and secondary contact recreation were met at all the sites monitored over the 2015–16 monitoring period. Two of the sites (North Hymus Street and Jervoise Bay Beach)

met the minimum sample size of 65 samples collected over a five year period.

Table 31. Assessment of the 95th percentile of enterococci counts at 13 locations around Cockburn Sound against the 'Faecal pathogens' EQG.

Location	Type of Site	Number of measurements	EQG Primary contact	EQG Secondary contact	Rolling 5-year 95th percentile of enterococci counts (MPN/100 ml)
North Hymus Street	Program	82	200	2,000	130
Jervoise Bay Beach	Program	74			75
Naval Base	Program	55			10
Rockingham Jetty	Program	54			176
Kwinana Beach	Program	53			20
Palm Beach Jetty	Program	32			52
Cliff Head	Program	17			10
Pig Trough Bay	Program	17			17
Herring Cove	Program	16			10
Camp Markam	Program	15			10
Jervoise Bay Boat Ramp	Reference	54			39
Palm Beach	Reference	34			76
CBH Jetty	Reference	11			61
Assessment		EQG met at all sites			

Note: The 95th percentiles were calculated using the Hazen method.

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 2015–16 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 32. Water clarity and pH met the relevant 'Physical' EQC for primary and secondary contact recreation at all the sites.

[32] The Office of the Environmental Protection Authority advised that in marine waters it is considered reasonable to use vertical Secchi disc measurements.

Table 32. Assessment of pH and water clarity (Secchi disc) at 18 water quality monitoring sites in Cockburn Sound over the 2015–16 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	8.2	>1.6 m	6.4 – 13.0	EQC met at all sites
CS5		8.3	8.2		4.0 – 13.1	
CS6A		8.3	8.3		3.7 – 10.0	
CS7		8.2	8.2		4.2 – 9.9	
CS8		8.2	8.2		4.5 – 13.4	
CS9		8.2	8.1		3.5 – 9.5	
CS10N		8.2	8.2		4.0 – 10.5	
CS11		8.2	8.2		5.3 – 11.8	
CS12		8.2	8.2		4.1 – 9.5	
CS13		8.3	8.2		5.2 – 12.2	
CS9A		8.2	8.2		3.2 – 10.0	
CB		8.2	8.2		4.7 – 9.0	
G1		8.2	8.2		3.2 – 11.2	
G2		8.3	8.3		4.3 – 9.3+	
G3		8.3	8.2		5.2 – 11.2	
SF		8.2	8.2		5.3 – 12.4+	
MB		8.2	8.3		4.5 – 10.8+	
NH3		8.2	8.2		1.9 – 4.2	

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

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

4.4 Indicators of Aesthetic Quality

Cockburn Sound is highly valued by the community for its ecological, recreational and aesthetic attributes and EQC have been developed to protect the aesthetic values of the Sound (EPA 2015). 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 2015 to March 2016 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;

- natural reflectance of the water;
- surface films (for example oil and petrochemical films on the water);
- surface or submerged debris (for example seagrass seeds, grain); and
- odours.

The results are summarised in Table 33.

On 1 December 2015, dead fish were observed at sites in the south-western Cockburn Sound, in Careening Bay and on the eastern side of Garden Island, with large numbers of dead blowfish and one Pink snapper observed at the Mangles Bay light attenuation monitoring site (MB-L). The only other observation of faunal deaths was on 25 January 2016 when a single Northwest blowfish was observed at the Mangles Bay monitoring site (MB).

Algal blooms were observed at two sites in Cockburn Sound on 7 March 2016, 11 sites on 15 February and 14 March 2016, and at 13 sites on 29 March 2016, with effects on water clarity and water colour also reported on these occasions. An algal bloom was also observed at the Warnbro Sound reference sites on 15 February 2016.

Grain was observed on the water surface at CS10N adjacent to the Kwinana Grain Jetty on 11 occasions over the 2015–16 non river-flow period. Odours were reported at sites adjacent to the industrial area on the eastern margin of Cockburn Sound (CB, CS9, CS9A and CS12) on six occasions.

Observations of aesthetic quality will be undertaken over the 2016–2017 monitoring period.

4.5 Conclusions

Based on the results from the 2015–16 monitoring programs in Cockburn Sound, there were no recorded exceedances of the EQC for the Environmental Quality Objectives 'Maintenance of primary contact recreation values' and 'Maintenance of secondary contact recreation values'. There is, therefore, a high degree of certainty that the Environmental Quality Objectives have been achieved and the waters are safe for recreational activities.

Table 33. 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 2015–16 non river-flow period.

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour	Natural reflectance	Surface films	Surface or submerged debris	Odours
1/12/2015	-	-	MB-L, SF, G1 and G2	-	-	-	-	CS10N (grain)	CB, CS9A
7/12/2015	-	-	-	-	-	-	-	CS10N (grain)	-
14/12/2015	-	-	-	CS7 (transient event associated with ship movements)	-	-	-	-	-
21/12/2015	-	-	-	-	-	-	-	CS10N (grain)	CS9
4/1/2016	-	-	-	-	-	-	-	-	-
11/1/2016	-	CB (possible)	-	-	CB (slight green colouration)	-	-	CS10N (grain)	-
18/1/2016	-	-	-	-	-	-	-	-	-
25/1/2016	-	-	MB	-	-	-	-	CS10N (grain)	-
1/2/2016	CS6A (filamentous algae on filter)	-	-	-	G1 ("milky colour")	-	-	-	-
8/2/2016	-	-	-	-	-	-	-	CS10N (grain)	CS12
15/2/2016	CS6A (algae on filter)	CS5, CS11, CS13, G1, CS10N, CS12, CS6A, CS7, CS9, CS9A, NH3; WS4 and WSSB	-	CS7 (transient event associated with ship movements)	CS5, CS11, CS13, G1, CS10N, CS12, CS6A, CS7, CS9, CS9A, NH3; WS4 and WSSB (green colouration)	-	-	-	CB, CS12
29/2/2016	-	-	-	-	-	-	-	CS10N (grain)	-
7/3/2016	CS6A (filamentous algae on filter)	MB, G2	-	-	MB, G2 (green colouration)	-	-	CS10N (grain)	-
14/3/2016	CS6A (filamentous algae on filter)	G2, CS11, SF, MB, CS10N, CS12, CS6A, CS7, CS9, CS9A, NH3	-	G2, CS11, SF, MB, CS10N, CS12, CS6A, CS7, CS9, CS9A and NH3	G2, CS11, SF, MB, CS10N, CS12, CS6A, CS7, CS9, CS9A, NH3 (green colouration)	-	-	CS10N (grain), G1 (grain)	CS12, CS9, CS9A,
21/3/2016	-	-	-	-	-	-	-	CS10N (grain)	-
29/3/2016	CS6A (filamentous algae on filter)	CS8, CB, CS11, CS13, MB, G1, CS10N, CS12, CS6A, CS7, CS9, CS9A, NH3	-	CS8, CB, CS11, CS13, MB, G1, CS10N, CS12, CS6A, CS7, CS9, CS9A, NH3	CS8, CB, CS11, CS13, MB, G1, CS10N, CS12, CS6A, CS7, CS9, CS9A, NH3	-	-	CS10N (grain)	CS12

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 2015).

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 17 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 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 2015).

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 *Escherichia coli* (*E. coli*) and total suspended solids (TSS) which were monitored weekly; and boron and bromide which were monitored quarterly. For these parameters, water samples were collected by an in-house process chemist and sent to laboratories accredited to undertake the analyses.

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 2015–16 monitoring period. A positive result as low as 1 CFU/100 mL triggers an immediate re-sample and analysis. The Water Corporation advised there have been no *E. coli* results in excess of 32 CFU/100 mL since the Desalination Plant commenced operation in 2006.

5.3.2 Physical and Chemical Indicators

Over the 2015–16 monitoring period, the temperature of the intake seawater was below the EQG of 28°C (Figure 14) and pH was below the EQG of 8.5 (Figure 15). Dissolved oxygen concentrations were above the EQG of 2 milligrams per litre (mg/L) over the monitoring period (Figure 16). All equipment at the Desalination Plant is routinely recalibrated to ensure accuracy and reliability.

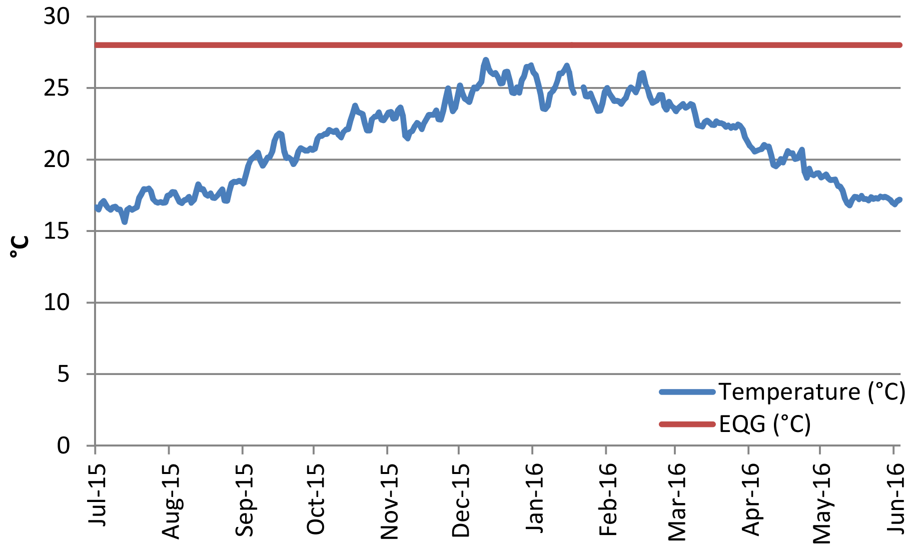


Figure 14. Daily average temperature of the intake seawater over the 2015–16 monitoring period.

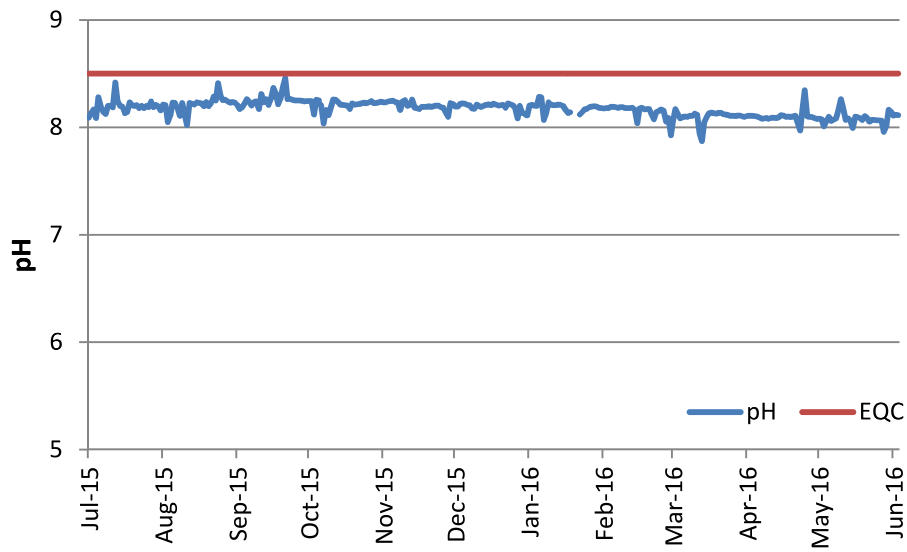


Figure 15. Daily average pH of the intake seawater over the 2015–16 monitoring period.

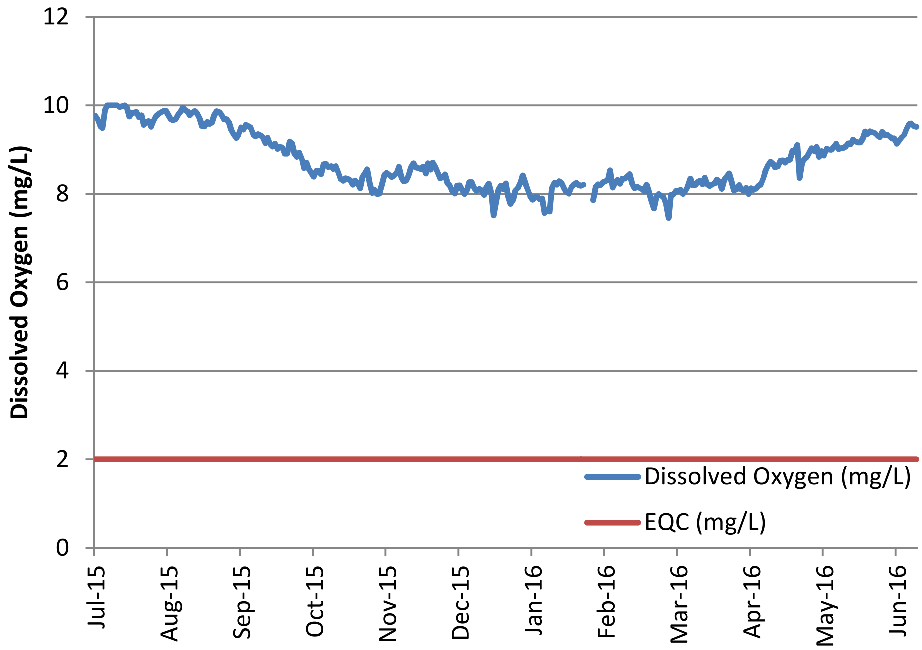


Figure 16. Daily average dissolved oxygen concentration of the intake seawater over the 2015–16 monitoring period.

The ‘rolling’ four-week median concentration of TSS did not exceed the EQG of 4.5 mg/L on any occasion over the 2015–16 monitoring period (Figure 17). 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.

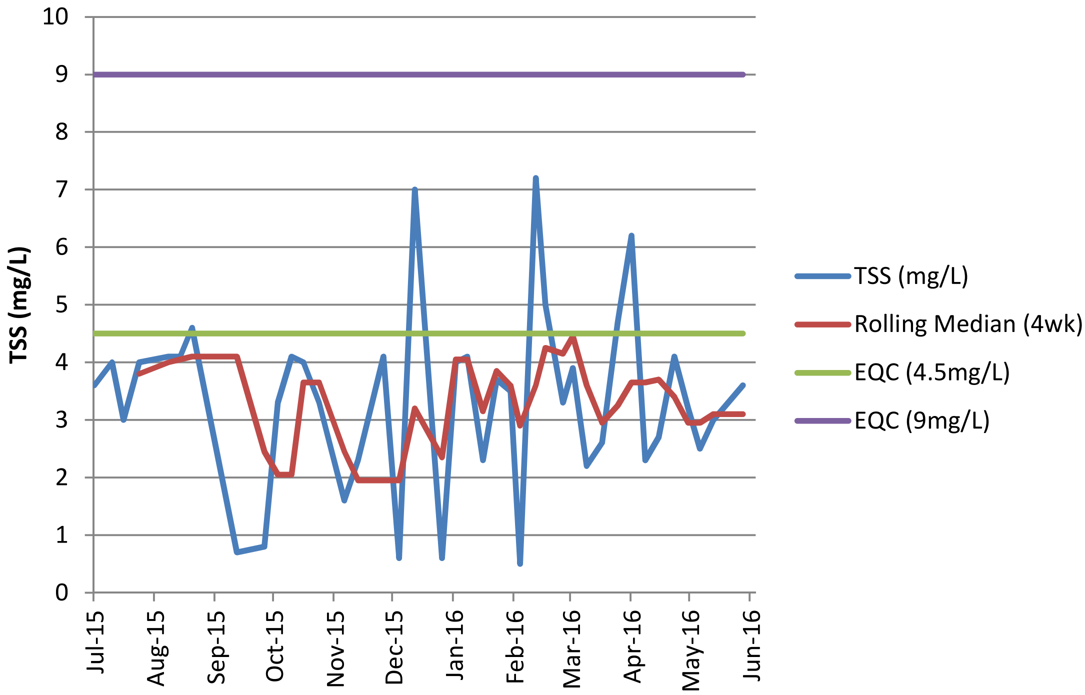


Figure 17. Weekly and rolling four-weekly median total suspended solids concentration in the intake seawater over the 2015–16 monitoring period.

Over the 2015–16 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 34). On two occasions the concentration of boron exceeded the EQG of 5.2 mg/L – on one of these occasions the concentration recorded was 5.3 mg/L; and on the other a concentration of 6 mg/L was recorded. Concentrations were below the EQG in the second half of the 2015–16 monitoring period. The Water Corporation advised that boron is removed by the reverse osmosis process.

Table 34. Quarterly concentrations of boron and bromide in the intake seawater over the 2015–16 monitoring period.

Sampling Occasion	Boron (mg/L)		Bromide (mg/L)	
	EQG	Concentration	EQG	Concentration
July 2015	5.2	5.3	77	65
October 2015		6.0		61
January 2016		4.9		66
April 2016		4.9		68

The Water Corporation advised that it did not report a significant reduction in efficiency of the desalination process or a significant increase in the maintenance requirements demonstrably caused by the variance in the intake seawater quality during the 2015–16 monitoring period. Natural variation in the quality of the intake seawater was observed by the Water Corporation over the 2015–16 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 2015–16 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant indicated there were minor exceedances in one parameter. 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.
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.
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	A specific management goal for a part of the environment, which is

Objective	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).
Initial Management Trigger	Assists in assessing the urgency of implementing a management response upon discovery of a significant contamination event and may be used to set a limit to the ongoing degradation of water resources while investigations against an Environmental Quality Standard are underway.
Light attenuation in water	The exponential decay of light intensity with increasing depth due to absorption and scattering.
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.
Marine biotoxins	Toxic compounds produced by some species of phytoplankton.
Maximum residue limit	The highest concentration of a chemical residue that is legally permitted or accepted in a food.
Mean shoot height	The 80th percentile of shoot heights within quadrats, thus the tallest 20% of shoots inside a quadrat was 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 indicating the middle number in a sorted sequence of numbers.
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 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 80th percentile is greater than or equal to 80% of all values; conversely, 80% of all values are less than or equal to the 80th percentile.
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.
Seagrass	Submerged flowering plants that mainly occur in shallow marine

	areas and estuaries.
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.

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Appendix A: 2015–16 Nutrient Concentrations

Total nitrogen concentrations over the 2015–16 non river-flow period varied between 80 micrograms per litre (µg/L) at CS4 in north-western Cockburn Sound on 7 December 2015 and 220 µg/L at Mangles Bay (MB) on 21 March 2016 (Wienczugow 2016). Total phosphorus concentrations varied between 10 µg/L at Southern Flats (SF) on 21 March 2016 and 47 µg/L at the eastern Sound site CS9 on 7 December 2015.

The highest median total nitrogen and total phosphorus concentrations were recorded at Jervoise Bay Northern Harbour (NH3) and Mangles Bay (MB), where higher median chlorophyll *a* concentrations were also reported (Figure A.1 and Figure A.2; Wienczugow 2016). Median total nitrogen and total phosphorus 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 CS6A, CS9, CS9A and CS10N in MPA-ES (Wienczugow 2016). Other sites with elevated total phosphorus concentrations included CS9, CS9A, CS10N and CS12 in MPA-ES, as well as CS11 and CS13 in HPA-S. Total phosphorus concentrations were significantly higher at CS9, CS9A and CS10N than HPA-N sites CS4 and G3, the HPA-S site Southern Flats (SF) and the two Warnbro Sound reference sites. Median concentrations at CS10N were also significantly higher than the HPA-N site G2. The lowest total nitrogen and total phosphorus median concentrations were recorded at sites in the north-western and northern parts of Cockburn Sound (for example CS4 and G3) 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 and the Warnbro Sound reference site WS4 (Wienczugow 2016).

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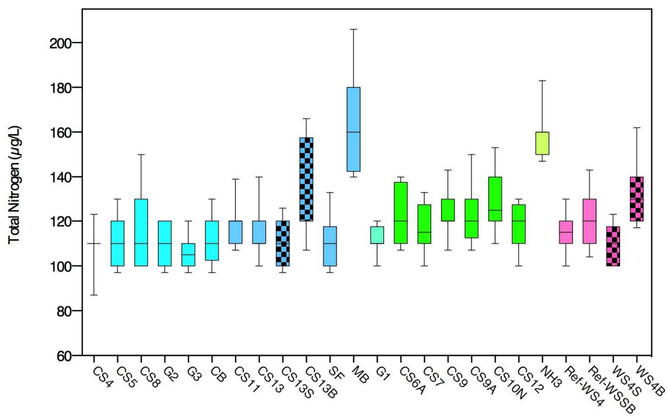
[33] Results of non-parametric Kruskal-Wallis one-way analysis of variance by ranks with Dunn's *post hoc* test. Results identified as being significant are those with a p value of less than 0.05 (that is $\alpha < 0.05$).

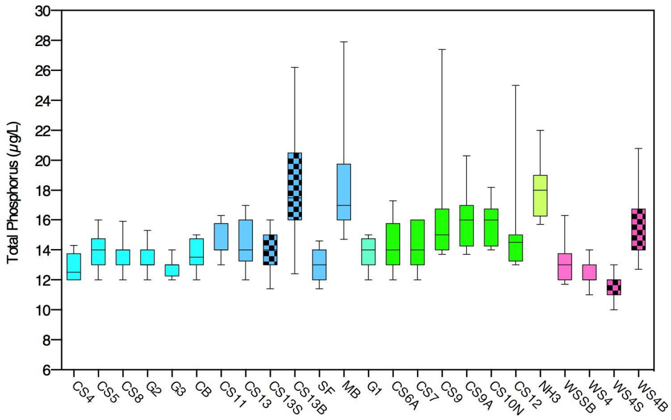


Notes:

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

(2) Light blue bar = HPA-N; dark blue bar = HPA-S; blue/green bar = MPA-CB; green bar = MPA-ES; pale green bar = MPA-NH; 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 2015 to March 2016.



Notes:

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

(2) Light blue bar = HPA-N; dark blue bar = HPA-S; blue/green bar = MPA-CB; green bar = MPA-ES; pale green bar = MPA-NH; 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 2015 to March 2016.

Nitrate–nitrite concentrations varied between below the laboratory reporting limit (< 2 µg/L), recorded at all sites on most occasions, to 7 µg/L at Southern Flats (SF) on 1 February 2016. Ammonium concentrations varied between below the analytical reporting limit (< 0.5 µg/L), recorded at most sites on a number of occasions, to 11 µg/L at Mangles Bay (MB) on 18 January 2016 and CS9 on 1 February 2016. Similarly, filterable reactive phosphorus concentrations varied between below the analytical reporting limit (<2 µg/L) recorded at most sites on a number of occasions and 30 µg/L at CS9 on 7 December 2015.

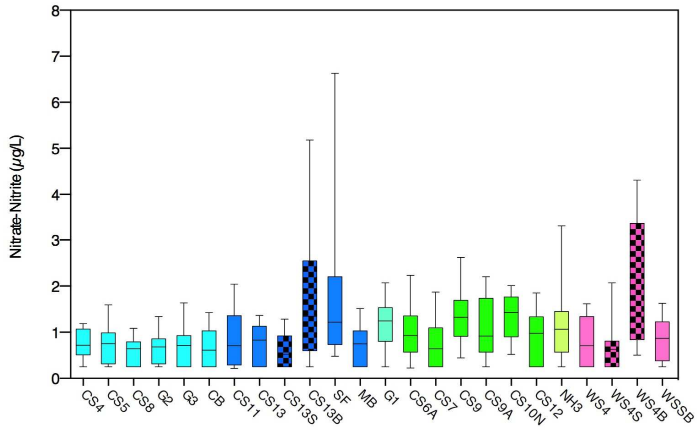
Median nitrate–nitrite concentrations were below the laboratory reporting limit at all

sites and there were no significant differences between the sites (Figure A.3; Wienczugow 2016). The highest nitrate–nitrite concentrations have generally been recorded at Southern Flats (SF) and Jervoise Bay Northern Harbour (NH3) since monitoring at these sites commenced.

The highest median ammonium concentrations were recorded at CS9, CS9A and CS10N in MPA-ES, with consistently higher ammonium concentrations recorded at CS10N throughout the 2015–16 non river-flow period (Wienczugow 2016). Significantly higher concentrations of ammonium were recorded at CS10N in MPA-ES compared to most of the other sites, with the exception of CS11, CS13, Mangles Bay (MB) and Southern Flats (SF) in HPA-S, G1 in MPA-CB, CS9 and CS9A in MPA-ES and the Warnbro Sound reference site WSSB (Figure A.4). Median concentrations were also significantly higher at CS9, CS9A and Mangles Bay (MB) than at CS5, CS8 and G3 in HPA-N, CS7 in MPA-ES and Jervoise Bay Northern Harbour (NH3) and significantly higher at CS9 than at CS4, G2 and CB in HPA-N and CS12 in MPA-ES.

Concentrations of filterable reactive phosphorus were generally higher in the southern and south-eastern Cockburn Sound compared to the northern and north-eastern Sound (Wienczugow 2016). The lowest median filterable reactive phosphorus concentration was recorded at Jervoise Bay Northern Harbour (NH3), where low concentrations of nitrate-nitrite and ammonium were also recorded. Median concentrations of filterable reactive phosphorus at CS10N and CS9A in the southern MPA-ES were significantly higher than median concentrations at sites in the northern MPA-ES (CS6A and CS7) and NH3 (Figure A.5). Median concentrations at CS9 were also significantly higher than at NH3. Median concentrations at CS10N were significantly higher than at both the Warnbro Sound reference sites (WS4 and WSSB) and median concentrations at CS9 and CS9A were significantly higher than at WS4. Median concentrations of filterable reactive phosphorus at CS4 in HPA-N, and CS13, Southern Flats (SF) and Mangles Bay (MB) in HPA-S, were significantly higher than at NH3 and the reference site WS4, while concentrations at CS5 and CB in HPA-N and CS11 in HPA-S were significantly higher than at NH3.

Median nitrate–nitrite and ammonium concentrations were significantly lower in surface waters than in bottom waters at both CS13 and the reference site WS4 (Figure A3 and Figure A4; Wienczugow 2016). Median filterable reactive phosphorus concentrations in bottom waters at CS13 were significantly higher than in surface waters, but there was no significant difference between the bottom or surface waters at the Warnbro Sound reference site WS4 (Figure A.5).



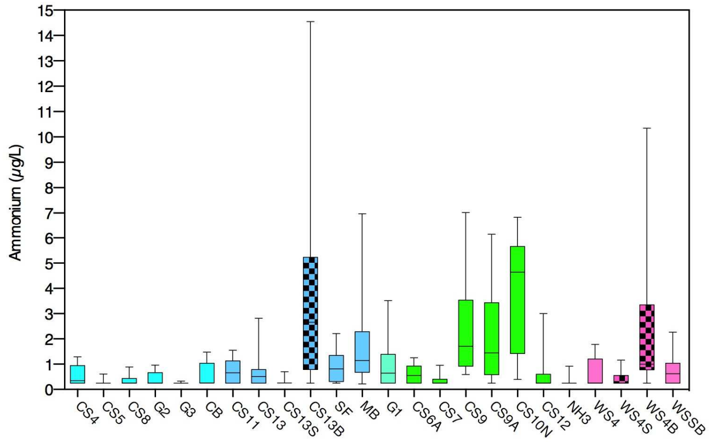
Notes:

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

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

(3) Concentrations at most sites below the laboratory limit of reporting (< 2 µg/L).

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 2015 to March 2016.



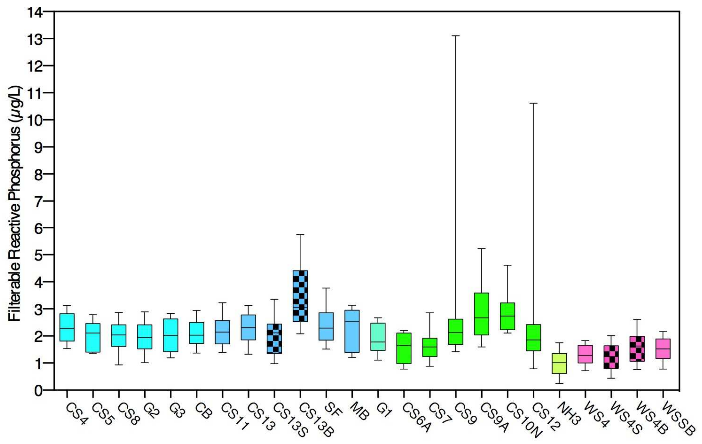
Notes:

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

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

(3) Concentrations at most sites below the laboratory limit of reporting (< 0.5 µg/L).

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 2015 to March 2016.



Notes:

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

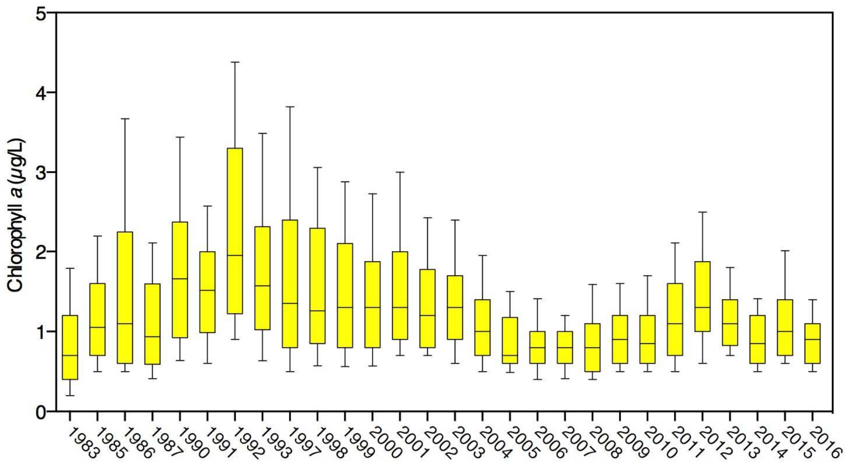
(2) Light blue bar = HPA-N; dark blue bar = HPA-S; blue/green bar = MPA-CB; green bar = MPA-ES; pale green bar = MPA-NH; pink bars = Warnbro Sound reference sites. For site locations refer to Figure 2. Hatched bars = concentrations in discrete surface (S) and bottom (B) waters.

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 2015 to March 2016.

Appendix B: Variations and Trends over Time in Chlorophyll *a*, Light Attenuation and Nutrient Concentrations

Median chlorophyll *a* concentrations in Cockburn Sound generally increased from the 1980s to the 1990s, remained high in the early 2000s and decreased during the mid-2000s, with a further increase between 2011 and 2013 (Figure B.1; Wienczugow 2016).

In 2016, the median chlorophyll *a* concentration at the eight sites (CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11) for which there are long-term data (since 1983) was not significantly[34] different to the median concentrations recorded in 1983, 1985, 1986 and 1987 (Wienczugow 2016). Median chlorophyll *a* concentration was significantly lower in 2016 than between 1990 and 2003 (for the years when chlorophyll *a* was measured) and not significantly different to all subsequent years with the exception of 2012, when the median chlorophyll *a* concentration was significantly higher.

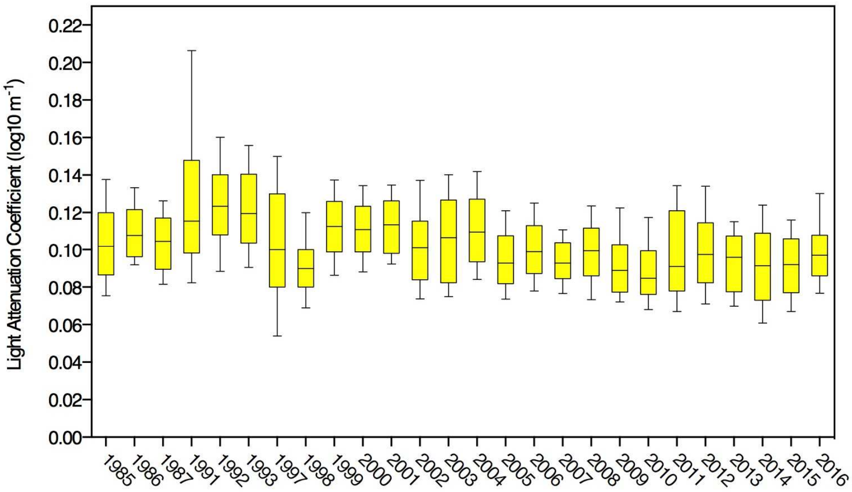


Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure B.1. Median chlorophyll *a* concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2016.

The median light attenuation coefficient at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 in 2016 was significantly lower than in 1991 to 1993, 1999 to 2001 and 2004, and significantly higher than the median light attenuation coefficient in 2010 (Figure B.2; Wienczugow 2016).

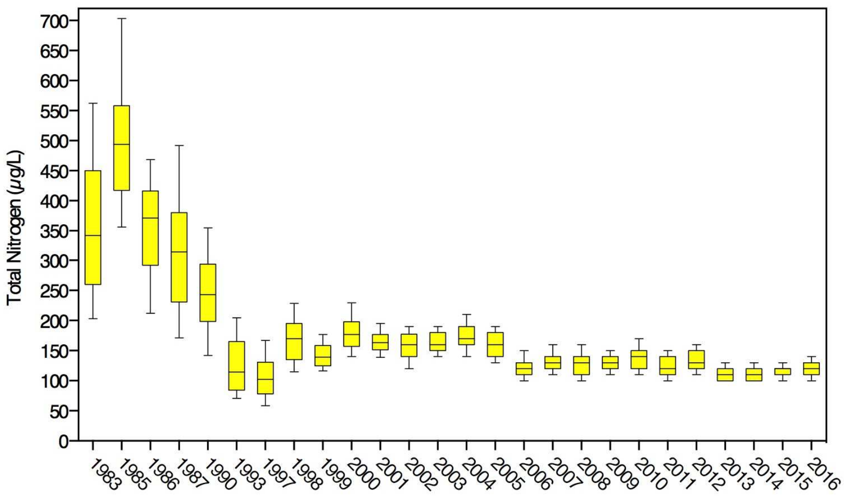
[34] Results of non-parametric Kruskal-Wallis one-way analysis of variance by ranks with Dunn's *post hoc* test. Results identified as being significant are those with a *p* value of less than 0.05 (that is $\alpha < 0.05$).



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

Figure B.2. Median light attenuation coefficient at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1985 to 2016.

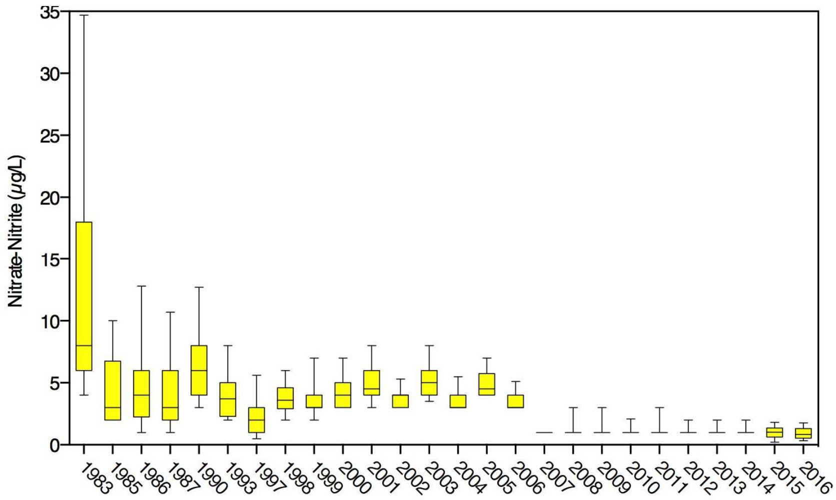
Median total nitrogen concentrations have generally decreased since monitoring began, as has the variability within years (Wienczugow 2016). The median total nitrogen concentration at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 in 2016 was not significantly different to the median concentrations in 1993, 1997, 2006, 2008, 2011, 2013, 2014 and 2015, but was significantly lower than in other years when total nitrogen was measured (Figure B.3).



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 2016.

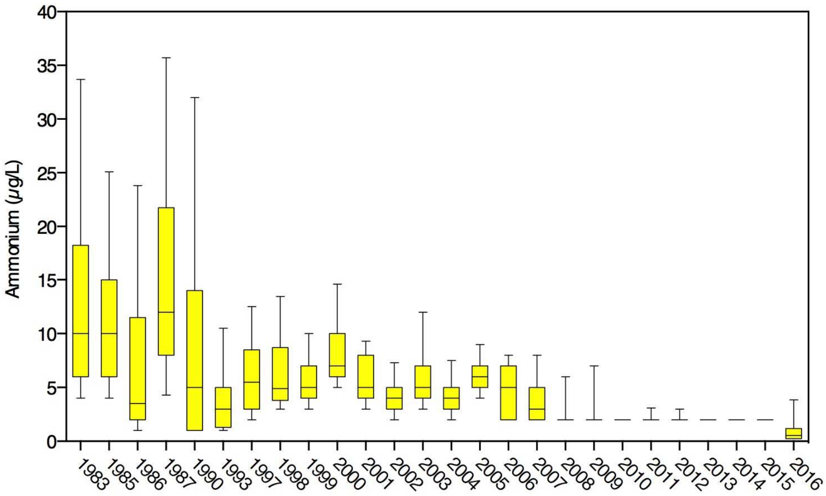
The median nitrate–nitrite concentration at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 in 2016 was not significantly different to the previous nine years (2007 to 2015), but was significantly lower than in the earlier years (Figure B.4; Wienczugow 2016). The within-year variation in nitrate–nitrite concentrations has also decreased over time.



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

Figure B.4. Median nitrate–nitrite concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2016.

Median ammonium concentrations have declined from the 1980s to the 1990s and 2000s, and again from around 2008 onwards (Wienczugow 2016). 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 was not significantly different to the years 2008 to 2015 and was significantly lower than in all other years (Figure B.5).



Note:

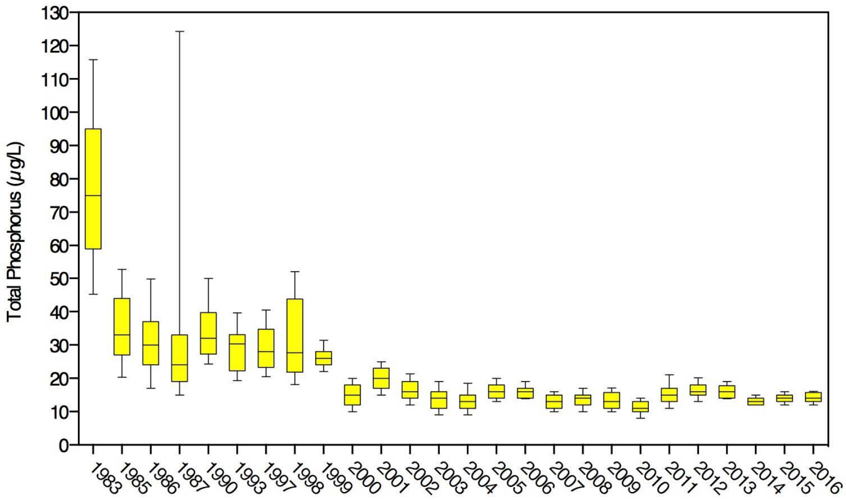
(1) The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

(2) The results in 2016 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.5. Median ammonium concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2016.

Median 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 10 years with some year-to-year fluctuation (Figure B.6; Wienczugow 2016). The variation in total

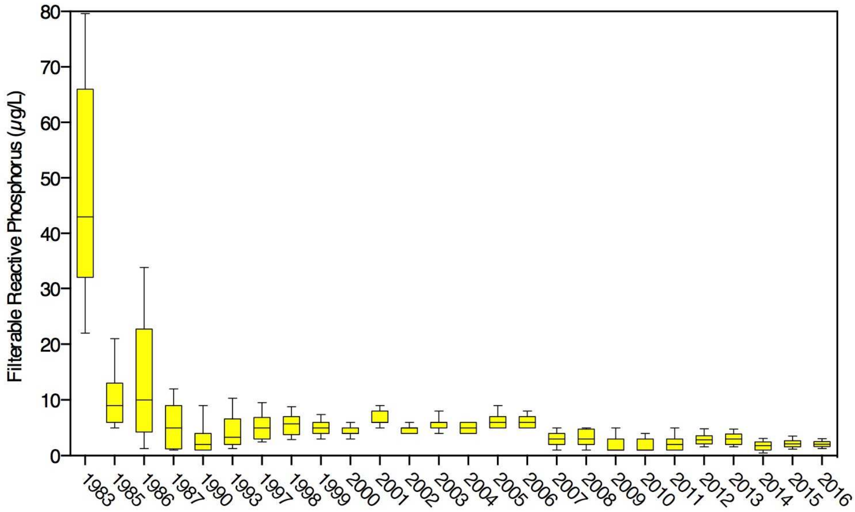
phosphorus concentrations within years has also decreased. The median total phosphorus concentration in 2016 was significantly lower than in the 1980s and 1990s (for the years for when total phosphorus was measured) and was not significantly different to subsequent years with the exception of 2001, 2002, 2005, 2010 and 2012.



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 2016.

Median filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 have decreased over the past 33 years, although concentrations have generally remained unchanged over the past 10 years (Figure B.7; Wienczugow 2016). The median filterable reactive phosphorus concentration in 2016 was not significantly different to the previous eight years (2008 to 2015) and was significantly lower than all years prior to 2008, 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.

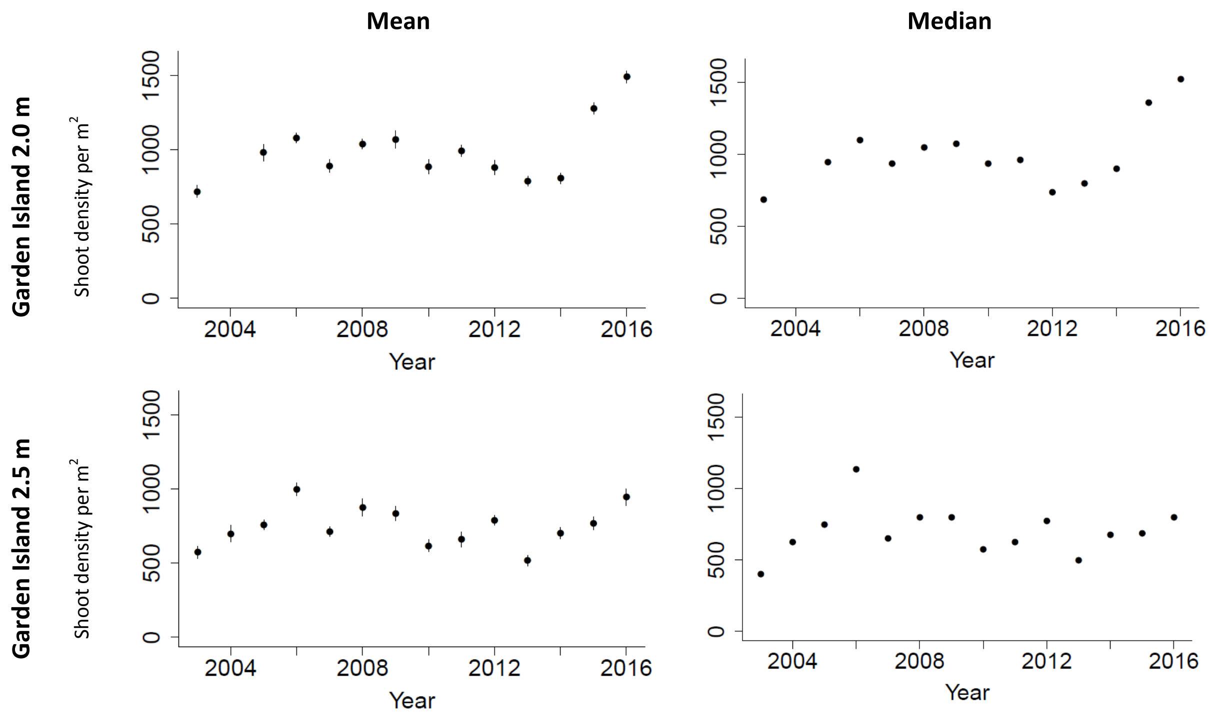
Figure B.7. Median filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 over the period 1983 to 2016.

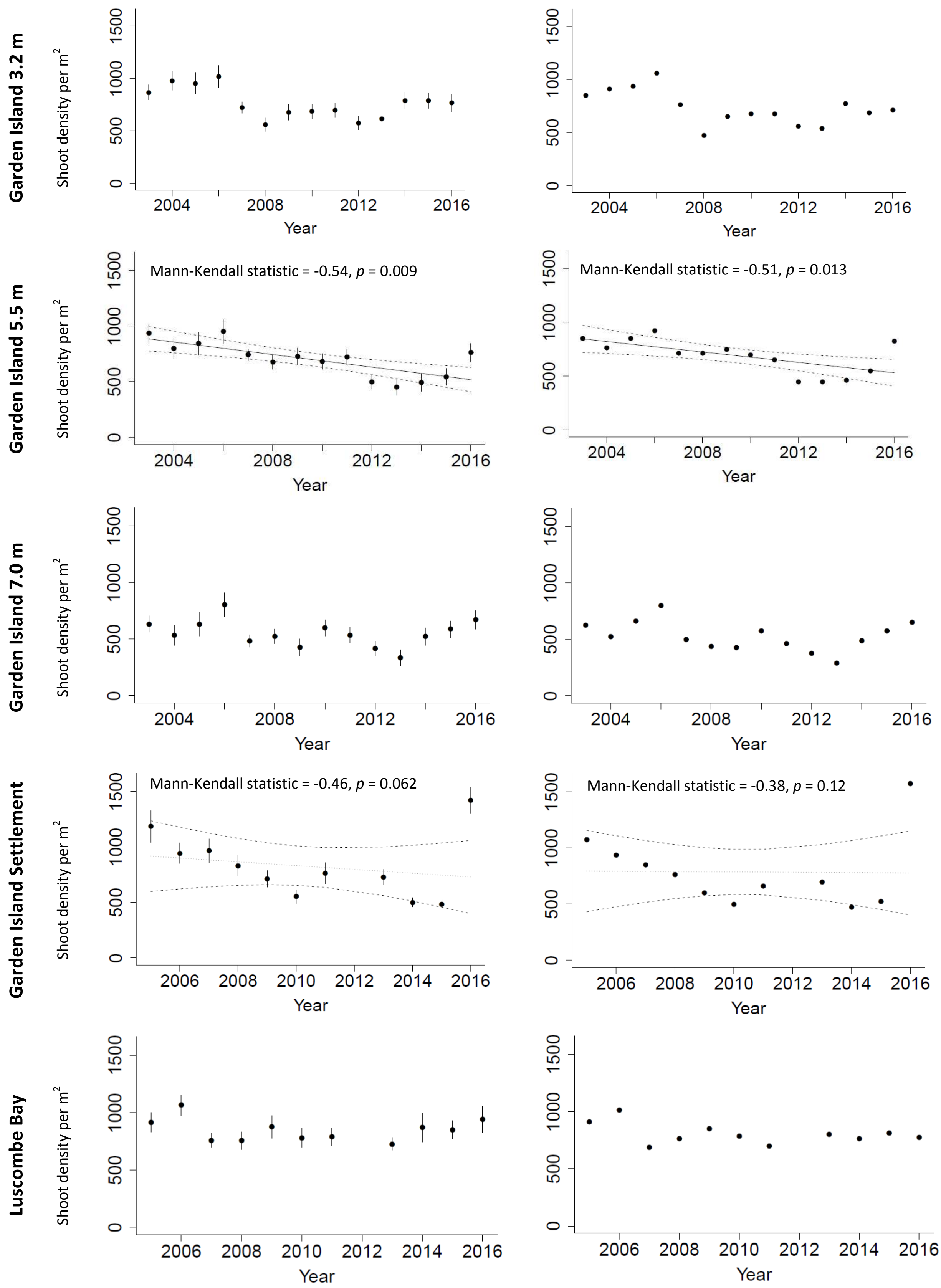
Appendix C: Temporal Trends in Seagrass Shoot Density and Lower Depth Limit

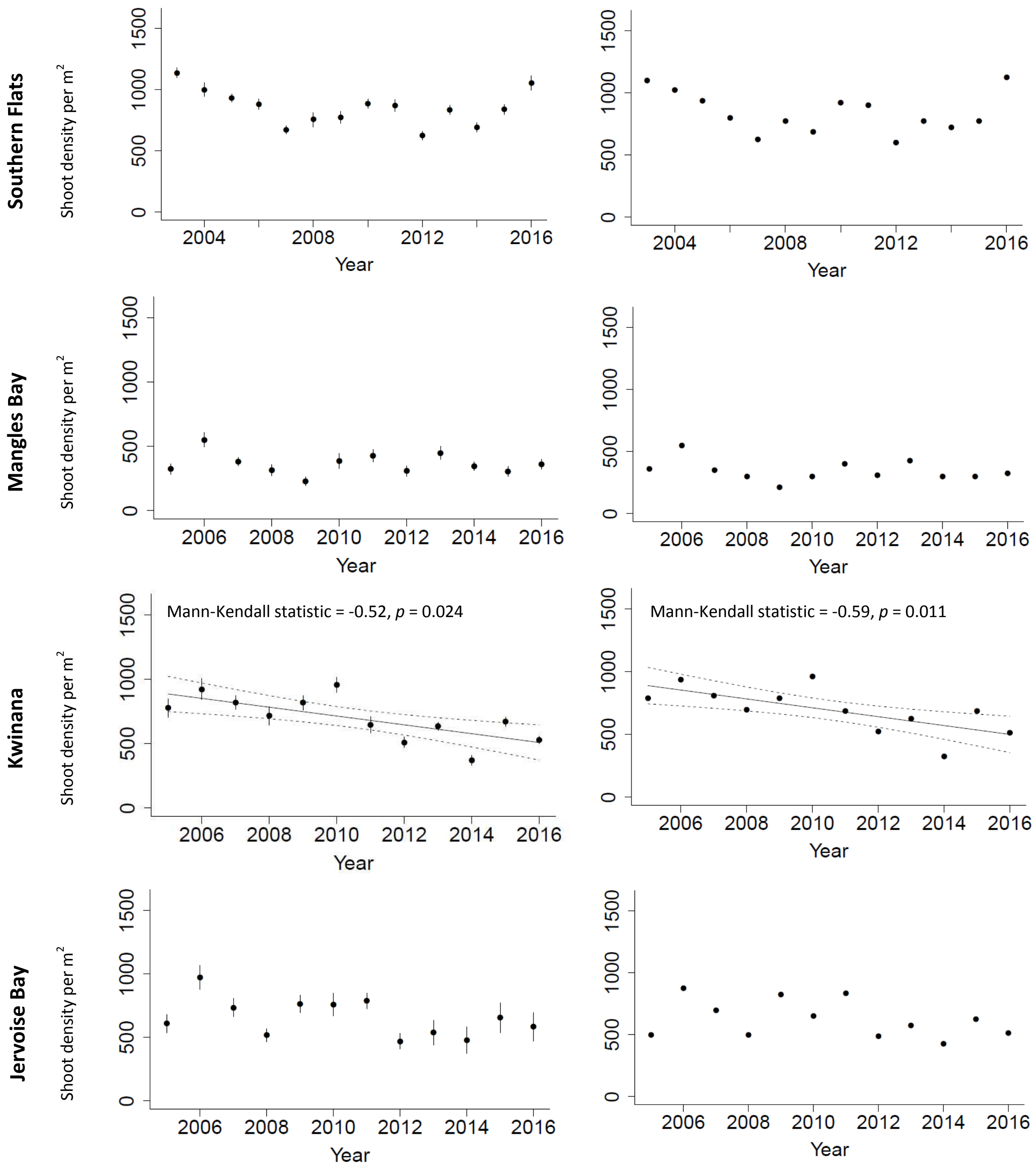
There were no significant trends (Mann-Kendall trend analysis, α = 0.05) in mean or median *Posidonia sinuosa* shoot density at the seagrass monitoring sites Garden Island 2.0 m, Garden Island 2.5 m, Garden Island 3.2 m, Garden Island 7.0 m, Luscombe Bay, Southern Flats, Mangles Bay or Jervoise Bay (Figure C.1) in Cockburn Sound over 11–14 years of monitoring (Fraser *et al.* 2016a). Similarly, there were no significant trends in mean or median shoot density at four of the monitoring sites outside Cockburn Sound (Coogee, Carnac Island, Mersey Point or Bird Island; Figure C.2).

There were significant (α = 0.05) negative trends in mean and median shoot density at two sites, Garden Island 5.5 m and Kwinana (Figure C.1; Fraser *et al*. 2016a). There were also negative trends (α = 0.2) in mean shoot density at Garden Island Settlement and Woodman Point, and in median shoot density at Garden Island Settlement. There were no significant increases in shoot density recorded at any of the sites.

Higher shoot densities were recorded in 2016 than in the previous five to 10 years at eight of the monitoring sites in Cockburn Sound (for example Garden Island 2.0 m, Garden Island 2.5 m, Southern Flats and Mersey Point) (Fraser *et al.* 2016a). The largest increase was recorded at Garden Island Settlement, where mean shoot density increased from 500 shoots per square metre (shoots/m^2) in 2015 to 1,500 shoots/m^2 in 2016 and median shoot density increased from 525 shoots/m^2 in 2015 to 1,575 shoots/m^2 in 2016.

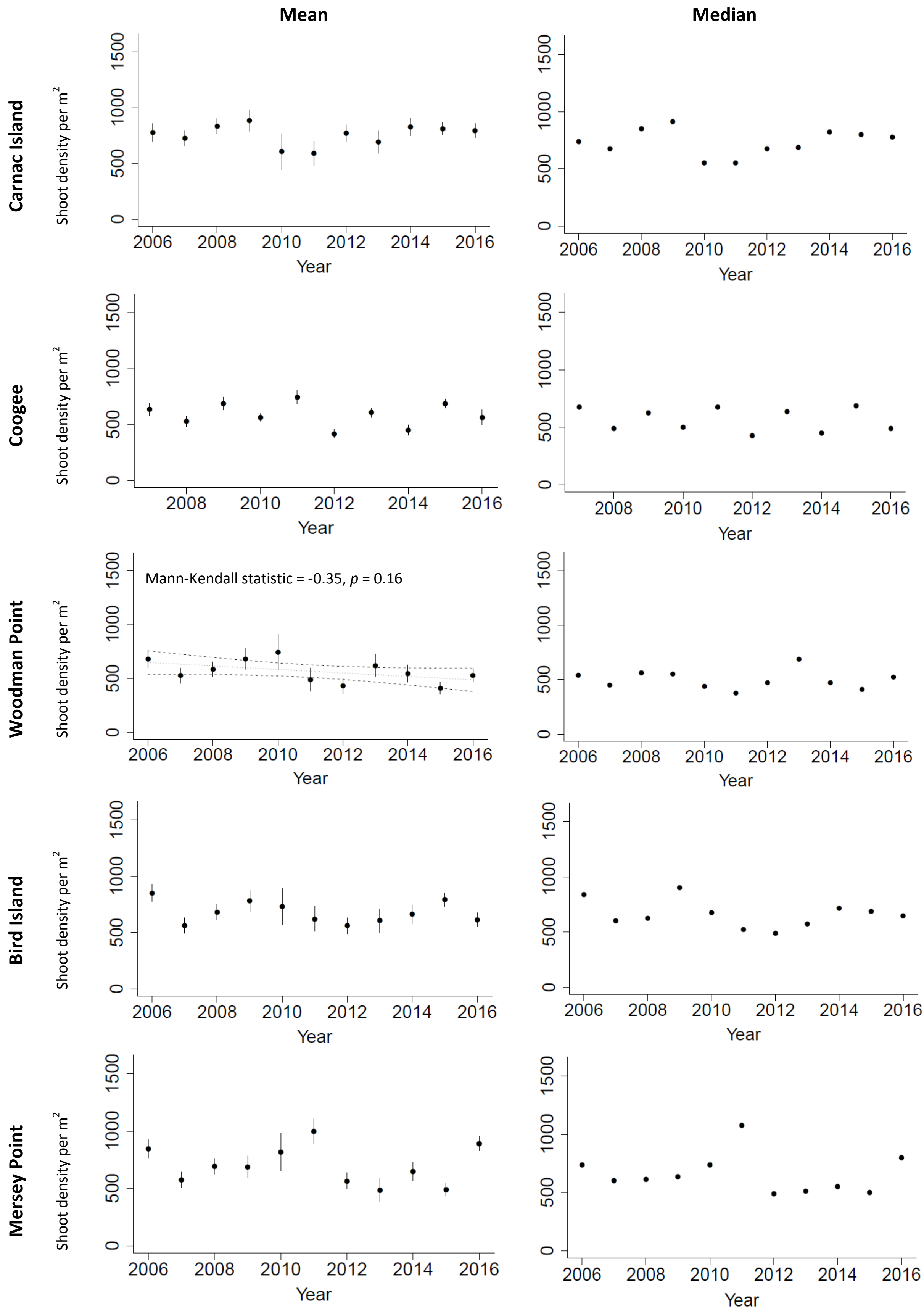



Garden Island 3.2 m
Shoot density per m2
Year
Garden Island 5.5 m
Mann-Kendall statistic = -0.54, p = 0.009
Mann-Kendall statistic = -0.51, p = 0.013
Garden Island 7.0 m
Garden Island Settlement
Mann-Kendall statistic = -0.46, p = 0.062
Mann-Kendall statistic = -0.38, p = 0.12
Luscombe Bay



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

Figure C.1. Trends in mean (± standard error) and median shoot density at Cockburn Sound monitoring sites.

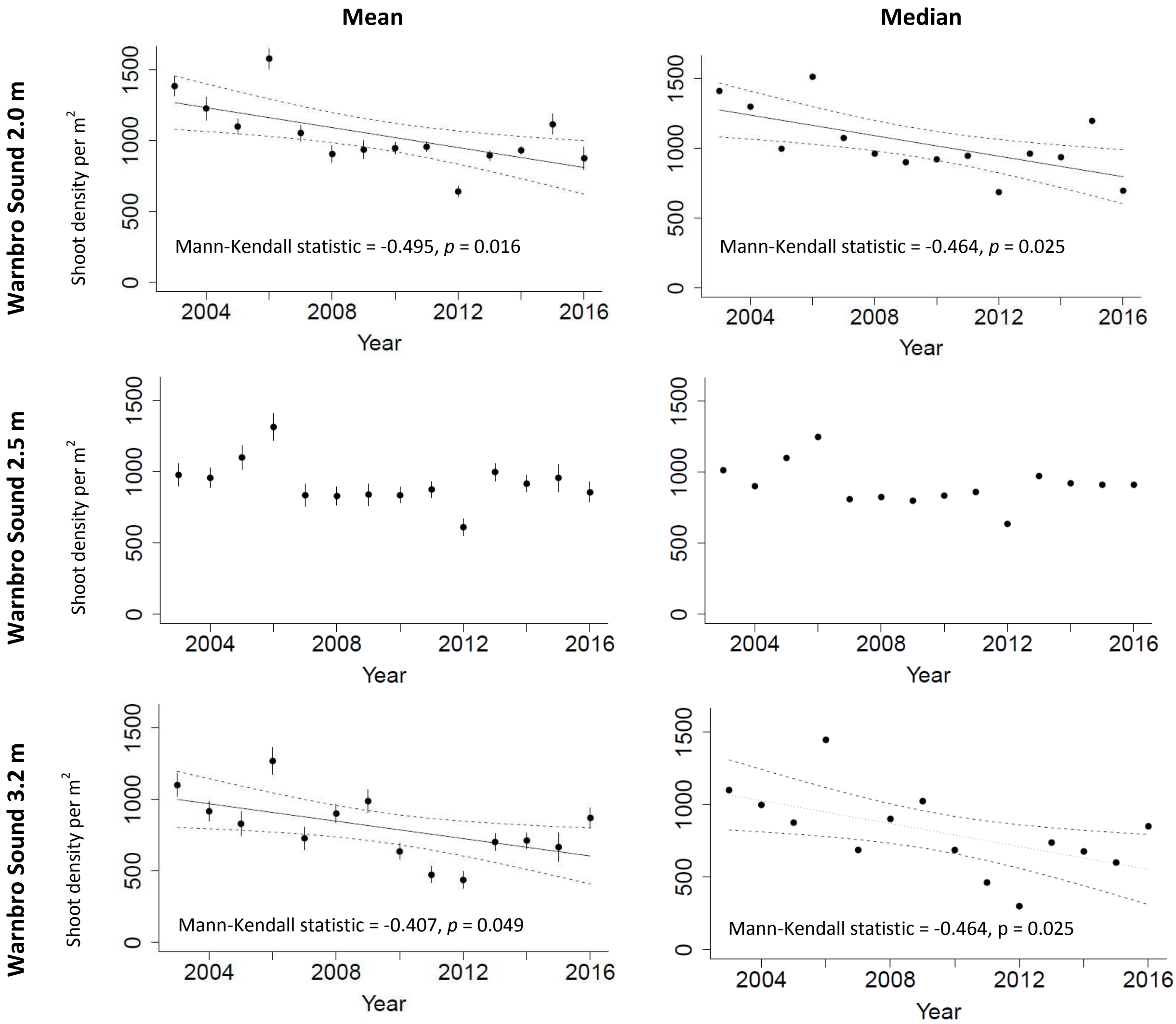


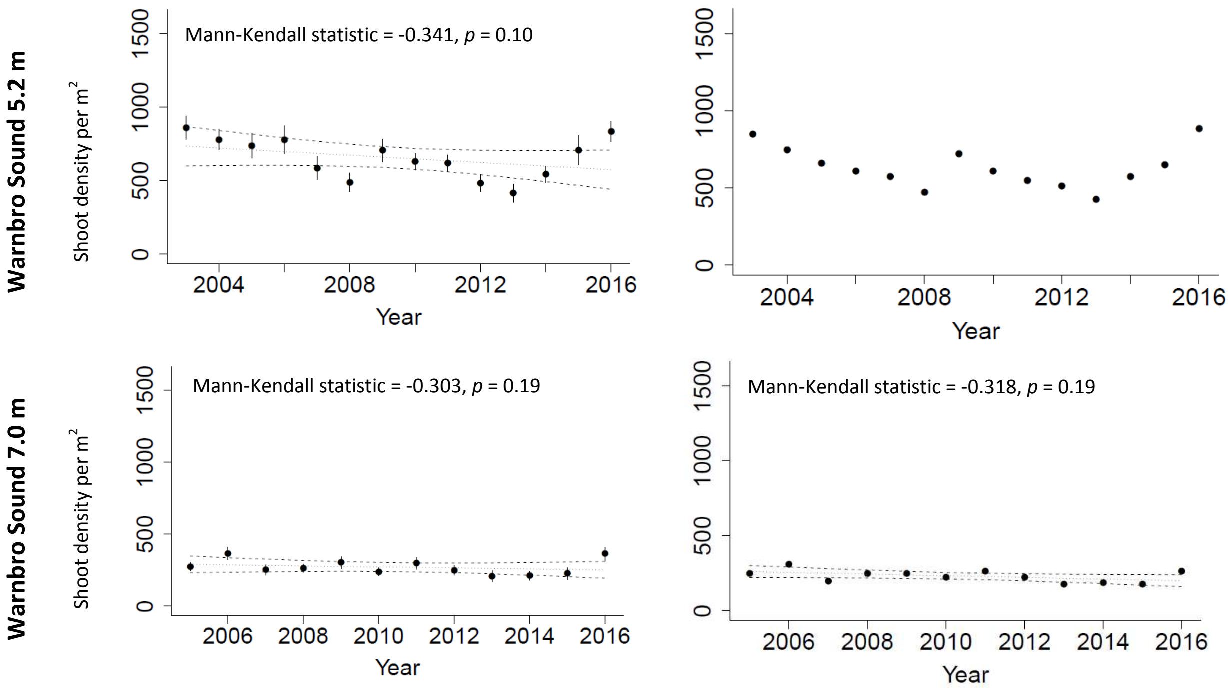
Note: Solid lines show significant trends (α = 0.05), dotted lines show trends were α = 0.2, and dashed lines show the 95% confidence bands.

Figure C.2. Trends in mean (± standard error) and median shoot density at monitoring sites outside Cockburn Sound.

There were significant (α = 0.05) negative trends in mean and median shoot density at the Warnbro Sound 2.0 m and Warnbro Sound 3.2 m reference sites (Figure C.3; Fraser *et al.* 2016a). Negative trends (α = 0.2) in mean shoot density were also recorded at Warnbro Sound 5.2 m and in mean and median shoot density at Warnbro Sound 7.0 m. There were no significant trends in mean or median shoot density at Warnbro Sound 2.5 m. Mean and median shoot density increased at the Warnbro Sound 3.2 m, Warnbro Sound 5.2 m and Warnbro Sound 7.0 m sites compared to 2015, but decreased at Warnbro Sound 2.0 m and Warnbro Sound 2.5 m.

Trend analysis of the 20th, 5th and 1st percentiles for each of the Warnbro Sound reference sites (against which median shoot densities are compared in an assessment against the EQS) indicated that, with the exception the Warnbro Sound 3.2 m 5th percentile and the Warnbro Sound 7.0 m 1st percentile, there have been significant (α = 0.05) negative trends since the monitoring program began (Fraser *et al.* 2016a).

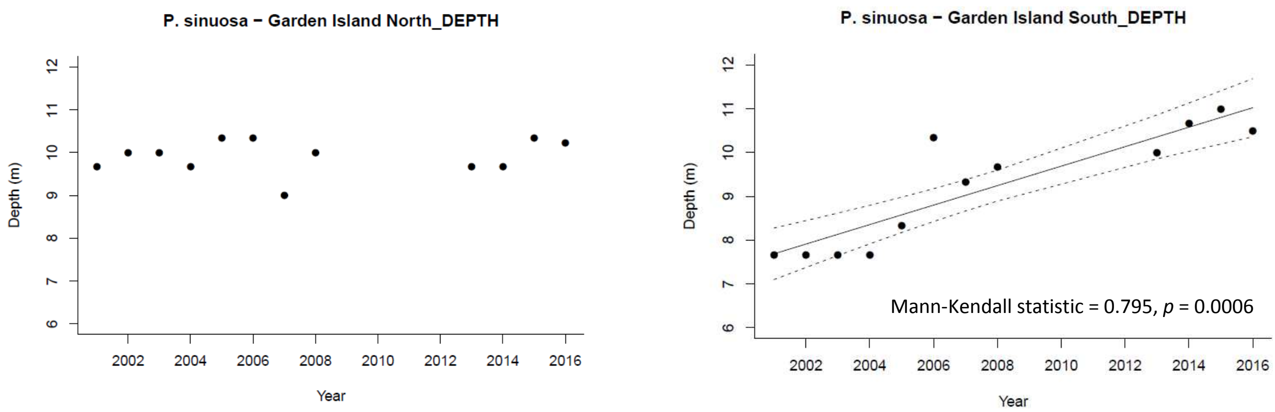




Note: Solid lines show significant trends (α = 0.05), dotted lines show trends were α = 0.2, and dashed lines show the 95% confidence bands.

Figure C.3. Trends in mean (± standard error) and median shoot density at the Warnbro Sound reference sites.

Lower Depth Limits (LDL) decreased (were shallower) at the Garden Island North and Garden Island South ‘depth limit’ sites in 2016 compared to 2015, and were deeper at Woodman Point and Warnbro Sound ‘depth limit’ sites (Fraser *et al.* 2016a). The mean Lower Depth Limit (LDL) has increased significantly (α = 0.05) at Garden Island South and Woodman Point over the previous 15 years (Figure C.4). The maximum seagrass depth distribution has remained stable at the Garden Island North and Warnbro Sound.



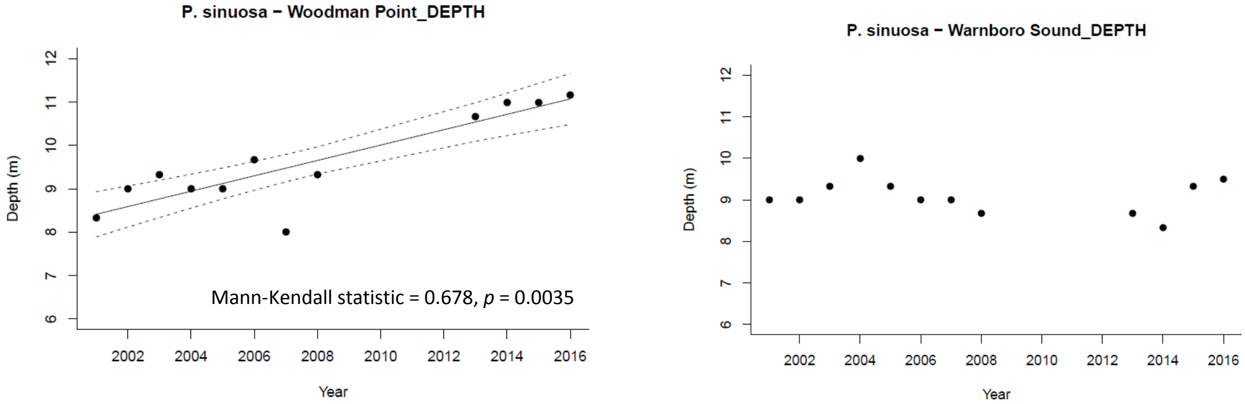


Figure C.4. Mean Lower Depth Limit of seagrass between 2001 and 2016.

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

There has been a significant increase in both surface and bottom water temperatures in Cockburn Sound,[35] with an increase in surface water temperature of 0.0325 ± 0.016°C and in bottom water temperature of 0.0295 ± 0.014°C per year between 1985 and 2014 (Keesing *et al*. 2016). These rates of changes are similar to those reported elsewhere off the Western Australian coastline and are attributed to global climate change.

The 2010–2011 mean surface water temperature of 24°C was significantly warmer than other years between 2008–14 (consistent with the marine heat wave which occurred in early 2011), while 2008–09 was significantly cooler (22.7°C) than other years (Keesing *et al*. 2016). There were similar patterns in water temperatures at the seabed, with 2010–11 being the warmest and 2008–2009 the coolest.

The Department of Fisheries maintains Onset Tidbit temperature loggers at three sites (Navy Ammunition Jetty [NAJ] depth 9.5 m; Alcoa Jetty [JBM] depth 5 m; and Mangles Bay South [MBS] depth 1 m) in Cockburn Sound (Figure D.1) to support ongoing fisheries management. Plots of daily temperature at each site over the period July–August 2007 to November–December 2015 (NAJ and JBM) or June 2016 (MBS) are presented in Figure D.2, Figure D.3 and Figure D.4.

Figure D.1. Location of temperature loggers in Cockburn Sound.

[35] 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).

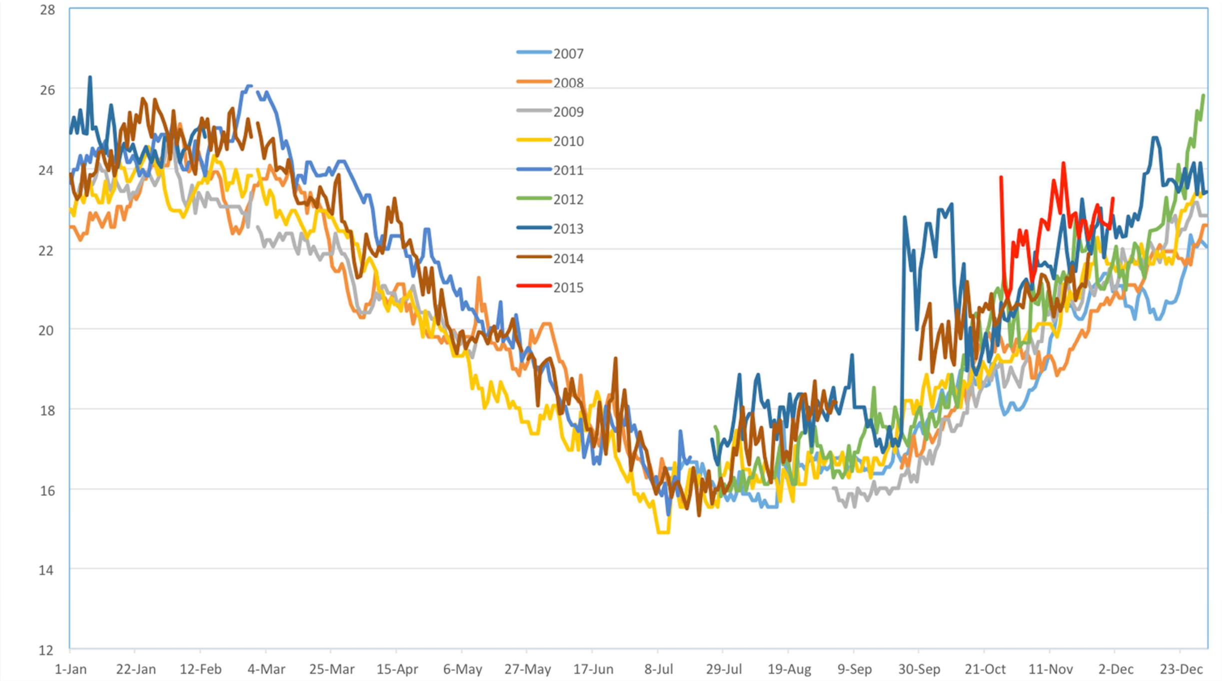


Figure D.2. Daily temperature at NAJ between July 2007 and December 2015.

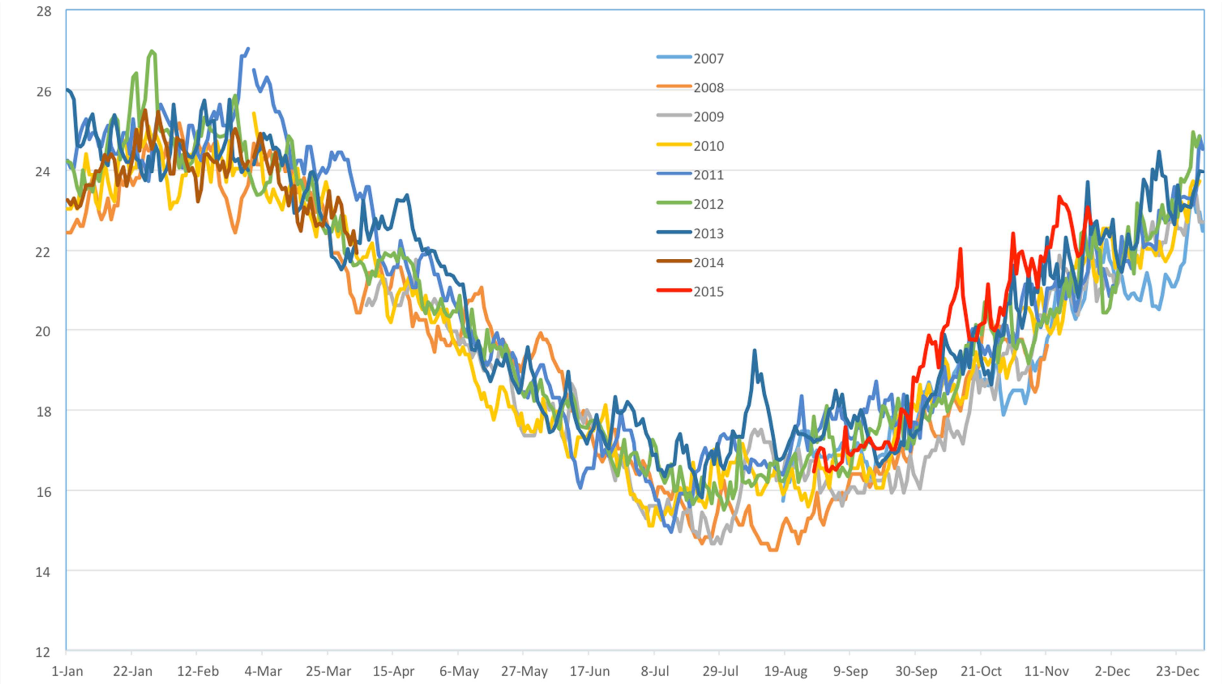


Figure D.3. Daily temperature at JBM between August 2007 and November 2015.

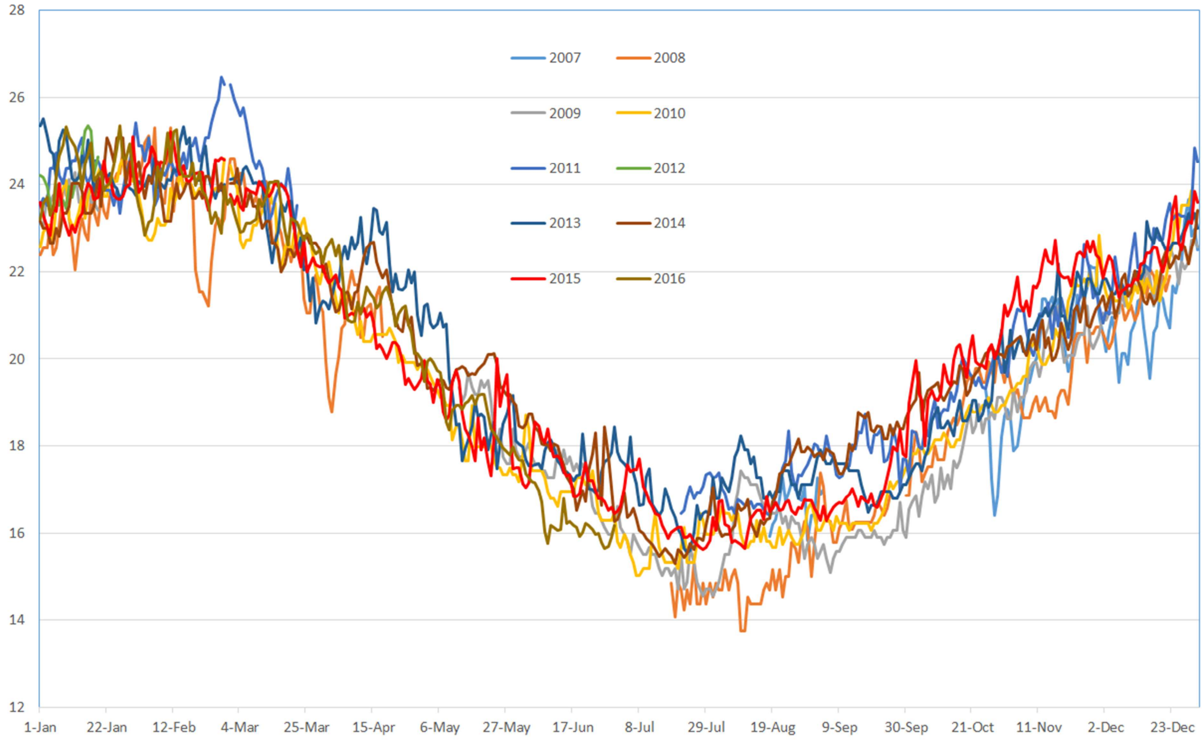


Figure D.4. Daily temperature at MBS between August 2007 and June 2016.