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WESTERN AUSTRALIA

Cockburn Sound annual environmental monitoring report 2019–20

Assessment against the environmental quality objectives and criteria set in the State Environmental (Cockburn Sound) Policy

Cockburn Sound Management Council

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This publication is available on the Cockburn Sound Management Council's website, or for those with special needs it can be made available in alternative formats such as audio, large print, or Braille.

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Executive summary

The Environmental Protection Authority (EPA) has established an environmental quality management framework for the Cockburn Sound marine area through the *State Environmental (Cockburn Sound) Policy 2015* (Government of Western Australia 2015). An essential component of the framework is environmental quality monitoring. This provides data for the measurement of environmental performance against the Cockburn Sound environmental quality criteria (EQC) as described in the *Environmental quality criteria reference document for Cockburn Sound* (EPA 2017). Each year the Cockburn Sound Management Council reports to the Minister for Environment on the environmental quality monitoring results for Cockburn Sound with specific reference to the Cockburn Sound EQC. This report presents the findings of the environmental quality monitoring for the period 1 July 2019 to 30 June 2020.

Environmental value: Ecosystem Health

Nutrient enrichment and phytoplankton biomass

The relevant environmental quality guidelines (EQG) for nutrient enrichment were met at all of the Cockburn Sound water quality monitoring sites, except for the Jervoise Bay Northern Harbour site located in the Moderate Protection Area Northern Harbour (MPA-NH).

The relevant 'phytoplankton biomass' (measured as chlorophyll *a*) EQG (i) was met in the Moderate Protection Area Eastern Sound (MPA-ES) and High Protection Area North (HPA-N), but not in MPA-NH and the High Protection Area South (HPA-S), where it was exceeded on 9 March 2020. The relevant 'phytoplankton biomass' EQG (ii) was met at all Cockburn Sound water quality monitoring sites, except at the Jervoise Bay Northern Harbour site. A more detailed assessment found that HPA-S met the high protection 'phytoplankton biomass' environmental quality standard (EQS), while MPA-NH did not meet the moderate protection EQS.

Median seagrass shoot densities at seagrass monitoring sites in Cockburn Sound were lower in 2020 than in 2019, except for Bird Island which remained the same. This suggests that regional-scale environmental factors may be impacting on seagrass shoot density. The seagrass shoot densities at the Warnbro Sound seagrass reference sites continued to decline, with a complete loss of seagrass at the 2.0 m depth site and at two-thirds of the quadrats at the 3.2 m depth site.

Other physical and chemical stressors

The relevant EQG for dissolved oxygen concentration was met at three of 10 water monitoring sites in the high protection areas and four of eight water monitoring sites in the moderate protection areas. The water monitoring sites that exceeded the relevant 'dissolved oxygen (DO) concentration' EQG, were found to have met the relevant 'DO concentration' EQS.

DO concentrations were also measured by the Water Corporation in the bottom waters at three monitoring sites in Cockburn Sound in September 2019, December

2019, April 2020 and June 2020. The ‘DO concentration’ EQG was met at all three Water Corporation monitoring sites, except at the Water Corporation ‘South’ monitoring site in December 2019. This monitoring site did meet the relevant ‘DO concentration’ EQS.

DO concentrations were measured by Fremantle Ports in the bottom waters at three sites around the Kwinana Bulk Jetty and three sites around the Kwinana Bulk Terminal on 29 January 2020. The relevant ‘DO concentration’ EQG was met at all sites.

The relevant ‘salinity’ EQG was met at all sites, except for the surface and bottom waters at the Mangles Bay site in HPA-S and the bottom waters at the CS9 and CS12 sites in MPA-ES. There were no known deaths of marine organisms attributed to salinity stress from anthropogenic sources on the 2019–20 sampling days.

The surface and bottom waters at all water quality monitoring sites in Cockburn Sound met the relevant ‘temperature’ EQG, except for the bottom waters of Mangles Bay. A more detailed assessment found the Mangles Bay site did meet the ‘temperature’ EQS.

The ‘pH’ EQG was met at four of 10 sites in the high protection areas and five of eight sites in the moderate protection areas. The pH measurements for the surface and bottom waters across all monitored sites in Cockburn Sound ranged between 8.02 and 8.31 pH units (Cossington & Wienczugow 2020). For the inshore coastal waters of Western Australia, the default trigger pH value is 8.0 for the lower limit and 8.4 for the upper limit (ANZECC & ARMCANZ 2000). Therefore the risk of a persistent and significant change beyond natural variation in any ecological or biological indicators from changes in pH is considered low.

Toxicants in marine waters

The ammonium concentrations measured in the depth-integrated water samples collected from the 18 Cockburn Sound water monitoring sites were below the relevant EQG values. Discrete surface and bottom water samples were also taken at site CS13 in HPA-S and Warnbro Sound reference site WS4. At both sites, the median ammonium concentration of the discrete bottom water samples was significantly higher than that of the discrete surface and integrated water samples for the same site.

Water samples from the marine waters near the Kwinana Bulk Terminal and Kwinana Bulk Jetty were analysed for a range of toxicants, including ammonia, filtered copper, total recoverable hydrocarbons (TRHs) and benzene, toluene, ethylbenzene and xylene (BTEX). Concentrations of the toxicants in these samples were below the relevant EQG values or the ‘low reliability value’ (LRV) where relevant.

Toxicants in sediments

The median concentrations of arsenic, chromium, copper, lead, mercury and zinc in both sampling areas – the Kwinana Bulk Terminal and Kwinana Bulk Jetty – were below the relevant EQG values.

In the Kwinana Bulk Jetty sampling area, the copper concentration at one of the three sites was above the EQG value, but below the re-sampling trigger value. Elevated cadmium concentrations were reported in the sediment at two Kwinana Bulk Jetty sites, with the median concentration of cadmium in the sampling area above the EQG, but below the re-sampling trigger value. A slightly elevated concentration of mercury was recorded in one of the Kwinana Bulk Jetty samples.

Elevated concentrations of tributyltin (TBT), a highly toxic biocide previously used in anti-fouling paint, were also found in the sediment samples from one Kwinana Bulk Terminal site and all three Kwinana Bulk Jetty sites. An analysis of the elevated TBT sediment samples showed the TBT concentrations were below the EQG re-sampling value. It is likely the elevated TBT concentrations are from historical contamination.

These environmental monitoring results indicate a high degree of certainty that the environmental quality objective ***Maintenance of ecosystem integrity*** is being achieved in Cockburn Sound.

Environmental value: Fishing and Aquaculture

Water and shellfish tissue samples were taken as part of the Western Australian Shellfish Quality Assurance Program (WASQAP). There were no exceedences of the 'faecal pathogens in water' EQG. The 'algal biotoxins' EQG was met on all sampling occasions in the Kwinana Grain Terminal and Southern Flats shellfish harvesting areas, except for 11 and 18 May 2020. All the Cockburn Sound shellfish samples taken as part of the WASQAP monthly screening program were found to be negative for biotoxins. The EQC for chemical concentration in seafood flesh were also met in those areas where sampling and analysis were undertaken.

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

Based on these findings, there is a high degree of certainty that the **Fishing and Aquaculture** environmental quality objectives were achieved during the reporting period.

Environmental value: Recreational and Aesthetics

There were no recorded exceedences of the EQC for the environmental quality objectives ***Maintenance of primary contact recreation values*** and ***Maintenance of secondary contact recreation values***. As such, there is a high degree of certainty that the environmental quality objectives were achieved and the waters are safe for recreational activities.

Environmental value: Industrial Water Supply

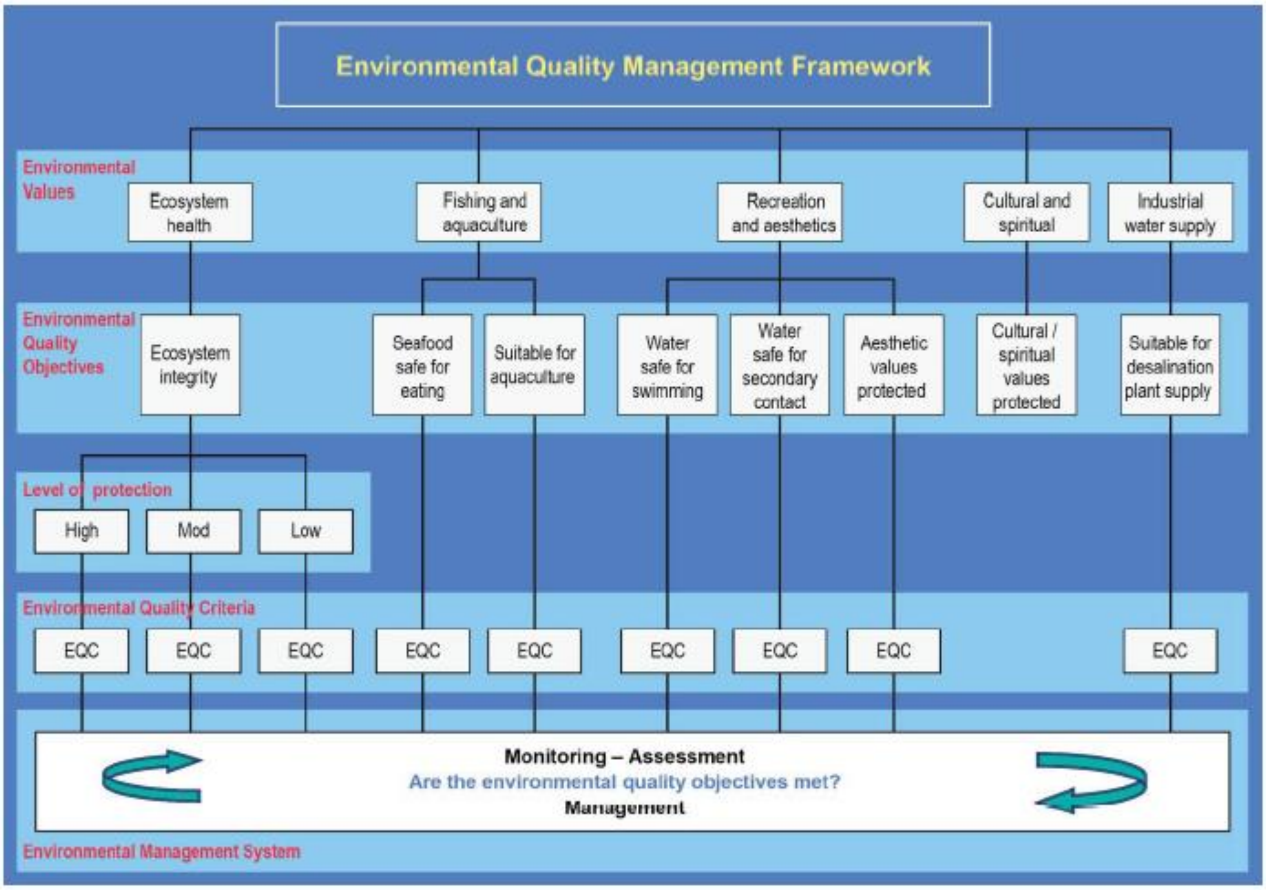
The 2019–20 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant found minor exceedences of the EQG for total suspended solids. The suitable quality of the intake seawater for the desalination process was not considered to have been compromised. Hence, there is a high degree of certainty that the environmental quality objective ***Maintenance of water quality for industrial use*** was achieved during the reporting period.

1. Introduction

Each year the Cockburn Sound Management Council reports 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 environmental quality objectives and criteria in the *State Environmental (Cockburn Sound) Policy 2015*. This report presents the results for the 2019–20 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 through the *State Environmental (Cockburn Sound) Policy 2015* (Government of Western Australia 2015) (Figure 1). This framework has been in place since 2005 under the first *State Environmental (Cockburn Sound) Policy 2005* (Government of Western Australia 2005). The framework's objective is to maintain Cockburn Sound's environmental quality to protect the integrity and biodiversity of the marine ecosystems, and current and projected future societal uses of these waters, from the effects of pollution, waste discharges and deposits (EPA 2017).



Source: Environmental Protection Authority (2017)

Figure 1: Environmental quality management framework for Cockburn Sound

Environmental quality criteria for Cockburn Sound

The environmental quality management framework is underpinned by environmental values, environmental quality objectives and environmental quality criteria (EQC) (Figure 1). The EQC provide the quantitative benchmarks against which environmental quality and the performance of environmental management can be measured.

The EQC consist of environmental quality guidelines (EQG) and environmental quality standards (EQS). EQG are threshold numerical values or narrative statements which, if met, indicate 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, a more comprehensive assessment against an EQS is required.

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. If EQS are not met, investigation of the cause(s) is needed and an adaptive management response is triggered if the exceedence continues.

The EPA has defined EQC for Cockburn Sound to enable assessment of whether the environmental quality meets the objectives set in the State Environmental Policy. 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 2017). The framework adopted for applying EQC to Cockburn Sound was developed to be consistent with the recommended approaches and guideline values in the *Australian and New Zealand guidelines for fresh and marine waters* (ANZECC & ARMCANZ 2000).

1.2 Levels of ecological protection

The State Environmental Policy describes three levels of ecological protection (high protection, moderate protection and low protection) 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. 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). These two areas within HEPA are delineated as High Protection Area North (HPA-N) and High Protection Area South (HPA-S). EQC for maintaining a high level of environmental quality apply to these areas.

Two moderate ecological protection areas have been designated where waste disposal and other societal uses preclude a high level of ecological protection – Careening Bay at Garden Island (Moderate Protection Area Careening Bay [MPA-CB]); and the eastern margin of Cockburn Sound adjacent to the industrial area

(Moderate Protection Area – Eastern Sound [MPA-ES]). MPA-ES also includes several harbours and marinas, which are assessed individually as Moderate Protection Area Southern Harbour (MPA-SH) and Moderate Protection Area Northern Harbour (MPA-NH) EQC for maintaining a moderate level of environmental quality apply in these areas.

The reference document (EPA 2017) identifies that it may be appropriate to monitor a subset of indicators for some marinas and harbours, depending on potential threats to environmental quality and the benthic habitats present. For example, monitoring and assessment of chlorophyll *a* concentrations and light attenuation coefficients in a marina may be unnecessary if seagrass is not present.

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

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

1.3 Monitoring programs for measuring environmental performance

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

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

Assessment against EQC for Cockburn Sound

Tables 1 to 3 summarise the environmental quality indicators measured by the monitoring programs for comparison against the EQC for Cockburn Sound, as well as the sources of these data.

The results are summarised and discussed in this report in the context of meeting the environmental quality objectives and EQC for Cockburn Sound and encompass:

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

Ensuring the quality of Cockburn Sound's waters is sufficient to protect ecosystem integrity and the quality of seafood, allow people to recreate safely, and maintain aesthetic values, may go some way towards maintaining cultural values in regard to the environmental value **Cultural and Spiritual** (EPA 2017). It is difficult to define spiritual values in terms of environmental quality requirements.

Table 1: Environmental quality indicators and data sources for 2019–20 reporting against the environmental quality objective ***Maintenance of ecosystem integrity***

Environmental quality criteria		Indicator	Data source
Physical and chemical stressors	Nutrients	Nutrient enrichment Chlorophyll *a* concentration Light attenuation coefficient Seagrass shoot density Seagrass lower depth limit Phytoplankton biomass	Department of Water and Environmental Regulation (DWER)
	Other physical and chemical stressors	Dissolved oxygen concentration Water temperature Salinity pH	DWER, Water Corporation and Fremantle Ports
Toxicants (marine waters)	Metals and metalloids	Copper, lithium	DWER, Fremantle Ports
	Non-metallic inorganics	Ammonia	
	Organics	Benzene, toluene, ethylbenzene, xylene (BTEX)	
	Oils and petroleum hydrocarbons	Total recoverable hydrocarbons (TRHs)	
Toxicants (sediments)	Metals and metalloids	Arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc	Fremantle Ports
	Organometallics	Tributyltin (TBT), dibutyltin (DBT), monobutyltin (MBT)	
	Organics	Polycyclic aromatic hydrocarbons (PAHs)	
	Oils and petroleum hydrocarbons	TRHs	
	Per- and polyfluoroalkyl substances (PFAS)	Perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), and perfluorohexane sulfonate (PFHxS)	

Table 2: Environmental quality indicators and data sources for 2019–20 reporting against the environmental quality objectives ***Maintenance of seafood safe for human consumption*** *and* ***Maintenance of aquaculture****.*

Environmental Quality Objective	Environmental quality criteria		Indicator	Data Source
Maintenance of seafood safe for human consumption	Biological contaminants		Faecal pathogens in water *Escherichia coli* (*E. coli*) in shellfish flesh Algal biotoxins	WA Shellfish Quality Assurance Program (data supplied by Department of Health)
	Chemicals	Metals	Arsenic, cadmium, chromium, copper, lead, mercury, selenium, zinc	WASQAP (Harvest Road Export), Fremantle Ports
		Organic chemicals	Polychlorinated biphenyls (PCBs) PAHs	
		Organometallics	TBT, DBT, MBT	
Maintenance of aquaculture	Physical and chemical stressors		Dissolved oxygen, pH	DWER
	Toxicants	Non-metallic inorganic chemicals	Ammonia, nitrate–nitrite	DWER and Fremantle Ports
		Metals and metalloids	Copper	

*Table 3: Environmental quality indicators and data sources for 2019–20 reporting against the environmental quality objectives **Maintenance of primary contact recreation values**, **Maintenance of secondary contact recreation values** and **Maintenance of water quality for industrial use**.*

<table>
<tr><th>Environmental quality objective</th><th colspan="2">Environmental quality criteria</th><th>Indicator</th><th>Data source</th></tr>
<tr><td rowspan="4">Maintenance of primary contact recreation values</td><td colspan="2">Biological</td><td>Faecal pathogens (mainly enterococci)</td><td>Department of Health (DoH)</td></tr>
<tr><td colspan="2">Physical</td><td>pH, water clarity</td><td>DWER</td></tr>
<tr><td rowspan="2">Toxic chemicals</td><td>Inorganic chemicals</td><td>Copper, nitrate–nitrite</td><td rowspan="2">DWER, Fremantle Ports</td></tr>
<tr><td>Organic chemicals</td><td>BTEX</td></tr>
<tr><td rowspan="3">Maintenance of secondary contact recreation values</td><td colspan="2">Biological</td><td>Faecal pathogens (mainly enterococci)</td><td>DoH</td></tr>
<tr><td colspan="2" rowspan="2">Physical and chemical</td><td>pH</td><td>DWER</td></tr>
<tr><td>Toxic chemicals</td><td>DWER, Fremantle Ports</td></tr>
<tr><td rowspan="2">Maintenance of water quality for industrial use</td><td colspan="2">Biological</td><td>E. coli / enterococci</td><td rowspan="2">Water Corporation</td></tr>
<tr><td colspan="2">Physical and chemical</td><td>Temperature, pH, dissolved oxygen, total suspended solids, hydrocarbons, boron, bromide</td></tr>
</table>

2. Assessment against environmental value: Ecosystem Health

2.1 Environmental quality objective

The environmental quality objective for the environmental value **Ecosystem Health** is ***Maintenance of ecosystem integrity***. Ecosystem integrity is considered in terms of structure (e.g. biodiversity, biomass and abundance of biota) and function (e.g. food chains and nutrient cycles) (EPA 2017). Achieving the environmental quality objective depends on ensuring that environmental quality is maintained within acceptable levels.

See Figure 2 and Table 4 for details of the water quality, sediment contaminant and seagrass monitoring sites in each ecological protection area.

2.2 Water quality monitoring

The Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University conducted water quality sampling at 18 water quality monitoring sites in Cockburn Sound and two reference water quality monitoring sites in Warnbro Sound – see Figure 2 (Cossington & Wienczugow 2020). Depth-integrated water samples were collected at weekly intervals from each site from 2 December 2019 to 30 March 2020. Discrete surface and bottom water samples were collected at Cockburn Sound site CS13 and Warnbro Sound site WS4.

The depth-integrated water samples were analysed for nutrients (ammonium, nitrate–nitrite, filterable reactive phosphorus, total nitrogen and total phosphorus) and chlorophyll *a*. The discrete water samples were analysed for the same nutrients and analysis results were used to identify differences between the surface water and the water near the water/sediment interface at the two sites. Statistical comparisons for ammonium were made using a low-level ammonium fluorescence method with a laboratory reporting limit of less than 0.5 µg/L. For the statistical analyses, all samples below the limit of reporting were assigned half of the limit of reporting for the measured nutrients and chlorophyll *a*.

In addition to these analyses, physical and chemical parameters (water depth, water temperature, salinity, pH, turbidity, dissolved oxygen and chlorophyll *a* by fluorescence) were measured *in situ* at each site (Cossington & Wienczugow 2020).

Water Corporation water quality monitoring

The Water Corporation undertook quarterly measurements (17 September 2019, 12 December 2019, 2 April 2020 and 19 June 2020) of the physical-chemical parameters dissolved oxygen, salinity and temperature as depth profiles through the water column. This was done at three sites in Cockburn Sound (South, Central, DIFF50W; Figure 2), as well as sites on Parmelia Bank and in Owen Anchorage. Additional measurements were taken at Cockburn Sound water quality monitoring sites CS9 and CS12 on these sampling occasions.

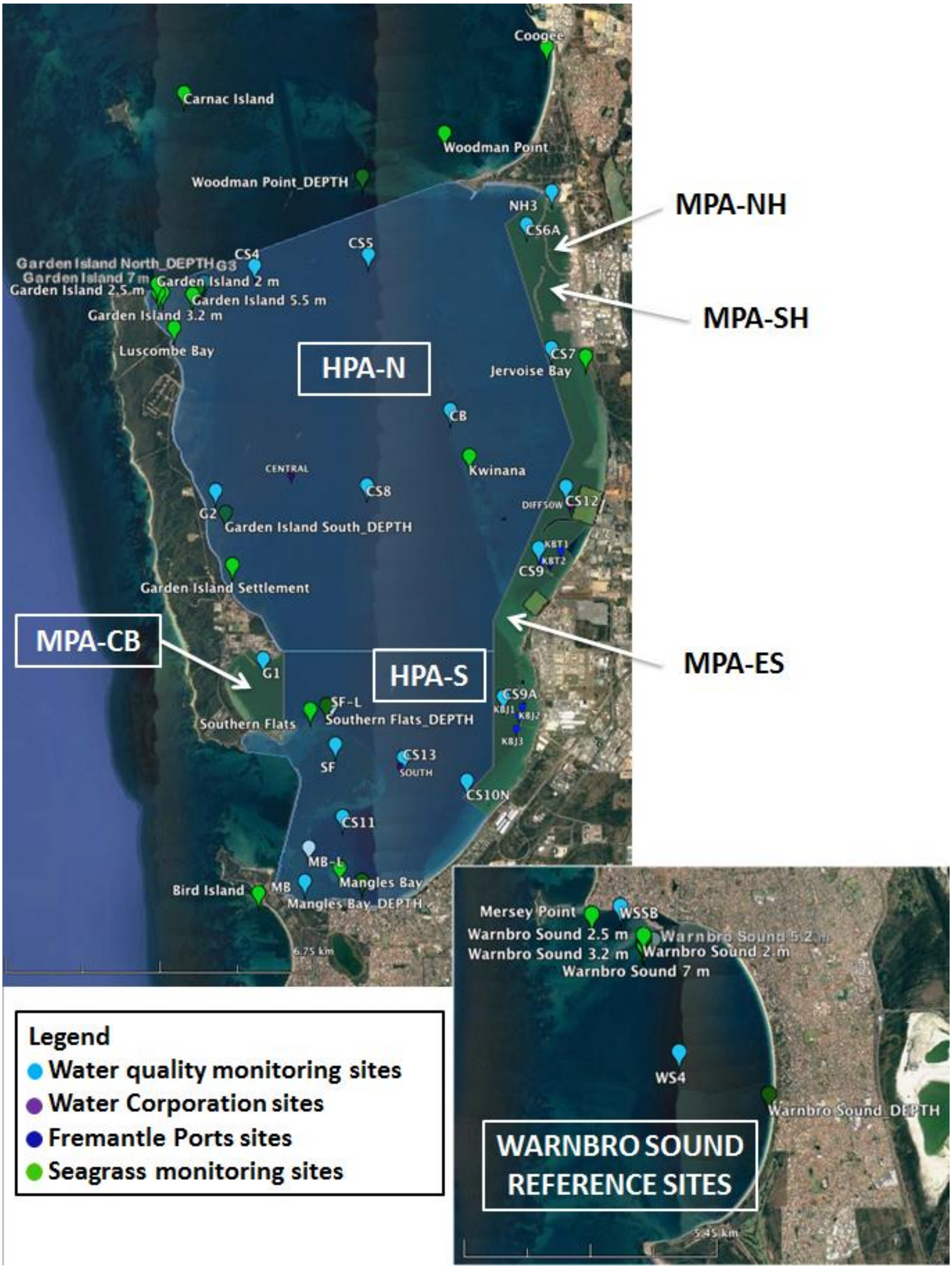


Figure 2: The ecological protection areas in Cockburn Sound and the location of water quality, sediment quality and seagrass monitoring sites in Cockburn Sound and reference sites in Warnbro Sound.

Table 4: The high and moderate ecological protection areas for Cockburn Sound and the associated water quality, marine sediment and seagrass monitoring sites.

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

Ecological protection area	Water quality monitoring sites	Seagrass monitoring sites	Marine sediment and water monitoring sites
		monitored: Coogee, Woodman Point, Carnac Island, Bird Island, Mersey Point, Woodman Point_DEPTH	

Fremantle Ports water quality monitoring

Fremantle Ports undertook monitoring of toxicants in marine waters at three sites around the Kwinana Bulk Terminal (KBT1, KBT2 and KBT3; Figure 2) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2 and KBJ3; Figure 2). Water quality samples were collected on 29 January 2020, as well as measurements of the physical-chemical parameters dissolved oxygen, salinity and temperature as depth profiles through the water column. The water quality samples were collected at each site from about 0.5 m below the surface and above the seabed.

The samples were processed in the field and stored on ice for transport to the laboratory. Samples were analysed by MAFRL for nutrients, chlorophyll *a* and filtered copper. Samples were analysed by ChemCentre for total recoverable hydrocarbons (TRHs), benzene, toluene, ethylbenzene and xylene (BTEX).

2.3 Marine sediment monitoring

Fremantle Ports undertook monitoring of toxicants in marine sediments at three sites around the Kwinana Bulk Terminal (KBT1, KBT2 and KBT3; Figure 2) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2 and KBJ3; Figure 2).

Sediment samples were collected on 19 March 2020 at all six sites. Five 100 millimetre (mm) diameter sediment cores were collected within one square metre (m^2) at each site using polycarbonate corers. The top 2 cm of each core was separated and homogenised into one composite sample from each site. The sediment samples were stored on ice for transport to the laboratory. The samples were analysed by ChemCentre for total organic carbon, metals (arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (tributyltin [TBT], dibutyltin [DBT] and monobutyltin [MBT]), polycyclic aromatic hydrocarbons (PAHs), per- and polyfluoroalkyl substances (PFAS) and TRHs.

Methods following those outlined in the standard operating procedures and standard laboratory analytical procedures were employed throughout. Laboratories with NATA-accredited methods (or laboratories with demonstrated quality assurance/quality control procedures in place) undertook the analyses.

2.4 Seagrass monitoring

The University of Western Australia, with support from the Department of

Biodiversity, Conservation and Attractions, undertook seagrass health surveys between February and March 2020 (Martin, Fraser, Kendrick & Strydom 2020). Monitoring was undertaken in accordance with Lavery and Gartner (2008) and the standard operating procedures.

A total of 27 seagrass sites were surveyed (Figure 2). Sixteen sites were 'potential impact' sites and five sites were 'reference' sites. There were six sites designated as 'depth transect' sites, two of which were established at Mangles Bay and Southern Flats during the 2017 sampling period. See Lavery and Gartner (2008) for a description of these sites.

2.5 Assessment against the 'nutrient enrichment' and 'phytoplankton biomass' environmental quality criteria

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

- protect the remaining seagrass meadows in Cockburn Sound
- maintain 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
- minimise the occurrence and extent of phytoplankton blooms in Cockburn Sound (EPA 2017).

2.5.1 Re-calculation of the 2019–20 EQC for chlorophyll *a*, light attenuation coefficient, phytoplankton biomass and seagrass shoot density

Chlorophyll *a*, light attenuation coefficient and phytoplankton biomass

EQC for chlorophyll *a*, light attenuation coefficient and phytoplankton biomass are based on 'rolling' percentiles and recalculated and updated each year using the monitoring results collected at Warnbro Sound reference site (WS4) (EPA 2017). The 2019–20 EQC were calculated using data from the 2019–20 summer and the sampling periods from the five previous summers (tables 5, 6 and 7). The chlorophyll *a* and light attenuation coefficient annual medians at WS4 were within their respective historical ranges and therefore included in the recalculation of the EQG (Table 5).

Table 5: Assessment of the 2019–20 chlorophyll a concentration and light attenuation coefficient (LAC) medians against the 20th and 80th percentiles of the WS4 historical dataset.

	Chlorophyll a (micrograms per litre [µg/L])	**LAC (log_{10} m^{-1})**
Historical dataset 20th percentile	0.40	0.067
Historical dataset 80th percentile	0.90	0.091
2019–20 median	0.60	0.080
Assessment	Met criteria specified in the reference document (EPA 2017)	Met criteria specified in the reference document (EPA 2017)
	2019–20 data included in the 2019–20 EQG calculations	

Table 6: The 2019–20 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	1.500
LAC (log_{10} m^{-1})	0.097	0.115

For the duration of the monitoring program, chlorophyll *a* concentrations have increased at the Warnbro Sound reference site WS4. It is likely multiple factors have contributed to this increase. As the EQG are recalculated annually using the previous five years of summer data from the reference site, the EQG values have increased due to higher chlorophyll *a* concentrations. The higher the EQG value, the less protection afforded to the ecological protection area. The high protection EQG for chlorophyll *a* has increased from 0.7 µg/L in 2009–10 to 1.0 µg/L in 2019–20, while the moderate protection EQG for chlorophyll *a* has increased from 1.0 µg/L in 2009–10 to 1.5 µg/L in 2019–20. The highest high protection EQG calculated for chlorophyll *a* was 1.1 µg/L in 2016–17 and 2017–18. The highest moderate protection EQG calculated for chlorophyll *a* was 1.8 µg/L for the period from 2016–17 to 2018–19.

Table 7: The 2019–20 high protection and moderate protection EQC for phytoplankton biomass.

Indicator	High protection Rolling 6-year median	Moderate protection Rolling 6-year 80th percentile
Chlorophyll *a* (µg/L)	0.70	1.00
Conversion factor[1]	x 3	x 3
EQG	2.10	3.00

Seagrass shoot density

The EQS for *Posidonia sinuosa* shoot densities (the dominant seagrass in Cockburn Sound) are based on 'rolling' four-year percentiles and recalculated and updated each year using the monitoring results for each monitored depth at the Warnbro Sound reference site (EPA 2017).

Seagrass shoot densities at the reference sites in Warnbro Sound continued to exhibit significant declines in shoot density (Mohring & Rule 2014; Rule 2015; Martin, Fraser, Kendrick & Strydom 2020). Quadrats have been lost at some sites due to sediment scouring. A reduced number of quadrats were therefore used to calculate the 'rolling' four-year percentiles.

See Table 8 for the recalculated EQS for each depth. Percentiles were calculated using data from 2017 to 2020. Percentiles calculated at WS 2.0 m and 3.2 m should be considered in the context of complete loss of shoot density in and around 2.0 m depth and 40% loss of shoot density at 3.2 m depth.

[1] The reference document (EPA 2017) sets out that the EQC is three times the median chlorophyll *a* concentration of the reference site for high ecological protection areas and three times the 80th percentile of chlorophyll *a* concentration at the reference site for moderate ecological protection areas.

Table 8: The 2020 high protection and moderate protection EQS for seagrass shoot density.

Reference site	Number of quadrats	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	2	720	686	677
Warnbro Sound 2.5 m	92	480*	183*	25
Warnbro Sound 3.2 m	49	165*	25*	25
Warnbro Sound 5.2 m	96	350*	225*	195
Warnbro Sound 7.0 m	92	200	89	48

Note: values below the absolute minimum criteria (AMC) outlined in the reference document (EPA 2017) are denoted by *.

The reference document (EPA 2017) recommends the EQS are calculated using 100 data points, which allows the first percentile to be calculated with a high degree of confidence (Lavery & McMahon 2011). The ‘rolling’ four-year percentiles for the Warnbro Sound 2.0 m site were calculated using data from two quadrats, which is considerably less than that recommended in EPA (2017).

To guard against a declining trend in seagrass shoot density at the Warnbro Sound reference site significantly influencing the numerical EQS over time, shoot density at Cockburn Sound seagrass sites are required to meet both the reference site rolling four-year percentiles and the absolute minimum criteria (AMC) based on historical baseline data for Cockburn Sound (EPA 2017).

There were significant downward trends in seagrass shoot density for reference sites WS 2.0 m, 2.5 m and 3.2 m for all percentiles (Table 9). A potential downward trend was observed for WS 7.0 m for all percentiles (p-value less than 0.2). The percentiles calculated for WS 2.0 m and 3.2 m reflect the complete loss of shoot density in and around 2.0 m depth and in two-thirds of the quadrats at 3.2 m depth.

Table 9: Results of Mann-Kendall trend analyses of the high protection and moderate protection EQS for seagrass shoot density.

Reference site	Rolling 4-year 20th percentiles of seagrass shoot density (shoots per square metre [shoots/m^2])		Rolling 4-year 5th percentiles of seagrass shoot density (shoots/m^2)		Rolling 4-year 1st percentiles of seagrass shoot density (shoots/m^2)	
	Mann-Kendall statistic	*p*-value (two-tailed test)	Mann-Kendall statistic	*p*-value (two-tailed test)	Mann-Kendall statistic	*p*-value (two-tailed test)
Warnbro Sound 2.0 m	-0.65	**<0.001**	-0.51	**0.01**	-0.43	**0.03**
Warnbro Sound 2.5 m	-0.48	**0.02**	-0.72	**<0.001**	-0.93	**<0.001**
Warnbro Sound 3.2 m	-0.52	**<0.01**	-0.49	**0.01**	-0.81	**<0.001**
Warnbro Sound 5.2 m	-0.19	0.37	-0.06	0.80	-0.10	0.65
Warnbro Sound 7.0 m	-0.30	0.15*	-0.20	0.34	-0.08	0.75

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

Sediment erosion and the development of 'blow outs' have been identified as potential causes of the decline in shoot densities at the Warnbro Sound reference sites, with some sites (e.g. WS 2.0 m) experiencing rapid erosion that has resulted in the loss of transects (Mohring & Rule 2014; Rule 2015; Fraser & Kendrick 2017). Sand scour was identified as a possible cause of shoot density decline at WS 2.0 m in 2005, only two years after the reference sites were established (Lavery & Westera 2005). The intrusion of potentially toxic sediment sulfides into seagrass tissues has been reported at the reference sites and may be contributing to shoot density decline at these sites (Fraser & Kendrick 2017; Olsen *et al*. 2018).

2.5.2 Assessment of compliance with the 'nutrient enrichment' EQC

Chlorophyll *a* and light attenuation

Chlorophyll *a* concentrations and light attenuation coefficients were recorded at the 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.3; Figure 2). They were assessed against the 'nutrient enrichment' EQG (EQG A, Table 1a, EPA 2017) over the 2019–20 non river-flow period:

High protection: *The median chlorophyll a concentration/light attenuation coefficient in HPA-N and HPA-S during the 2019–20 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^{-1}.*

Moderate protection: *The median chlorophyll a concentration/light attenuation coefficient in MPA-ES and MPA-CB during the 2019–20 non river-flow period is not to exceed a chlorophyll a concentration of 1.50 µg/L or a light attenuation coefficient of 0.115 log_{10} m^{-1}.*

The ‘nutrient enrichment’ EQG for chlorophyll *a* and light attenuation were met at all of the ecological protection areas except for Jervoise Bay Northern Harbour (site NH3) in MPA-NH (Table 10; figures 3 to 6). The ‘nutrient enrichment’ EQG were not applied to MPA-NH because of the absence of macro-benthic primary producers, such as seagrass, within the harbour.

Table 10: Assessment of the 2019–20 individual site and ecological protection area chlorophyll a concentrations and light attenuation coefficients (LAC) against the ‘nutrient enrichment’ EQG.

Ecological protection area	Site	Chlorophyll a (µg/L)			LAC (log_{10} m^{-1})			Assessment
		2019–20 EQG	2019–20 site median	2019–20 ecological protection area median	2019–20 EQG	2019–20 site median	2019–20 ecological protection area median	
HPA-N	CS4 CS5 CS8 CB G2 G3	1.0	0.6 0.6 0.7 0.6 0.5 0.5	0.6	0.097	0.081 0.079 0.080 0.097 0.080 0.080	0.081	EQG met
HPA-S	CS11 CS13 SF MB/MB-L	1.0	1.0 1.1* 0.5 1.1*	0.8	0.097	0.099* 0.100* 0.081 0.102*	0.096	EQG met
MPA-CB	G1	1.5	0.6	0.6	0.115	0.089	0.089	EQG met
MPA-ES	CS10N CS12	1.5	1.0 0.9	0.9	0.115	0.099 0.103	0.108	EQG met

	CS6A		0.7			0.099		
	CS7		0.9			0.114		
	CS9		1.0			0.108		
	CS9A		1.1			0.117*		
MPA-NH	NH3	-	4.3	4.3	-	0.159	0.159	-

Note: exceedence of the EQG denoted by *

See Appendix A for information on nutrient concentrations (total nitrogen, nitrate–nitrite, ammonium, total phosphorus and filterable reactive phosphorus) at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound over the 2019–20 non river-flow period. For information on variations and trends over time for nutrient concentrations, see Appendix B; for chlorophyll *a* concentrations and light attenuation, see Appendix C.

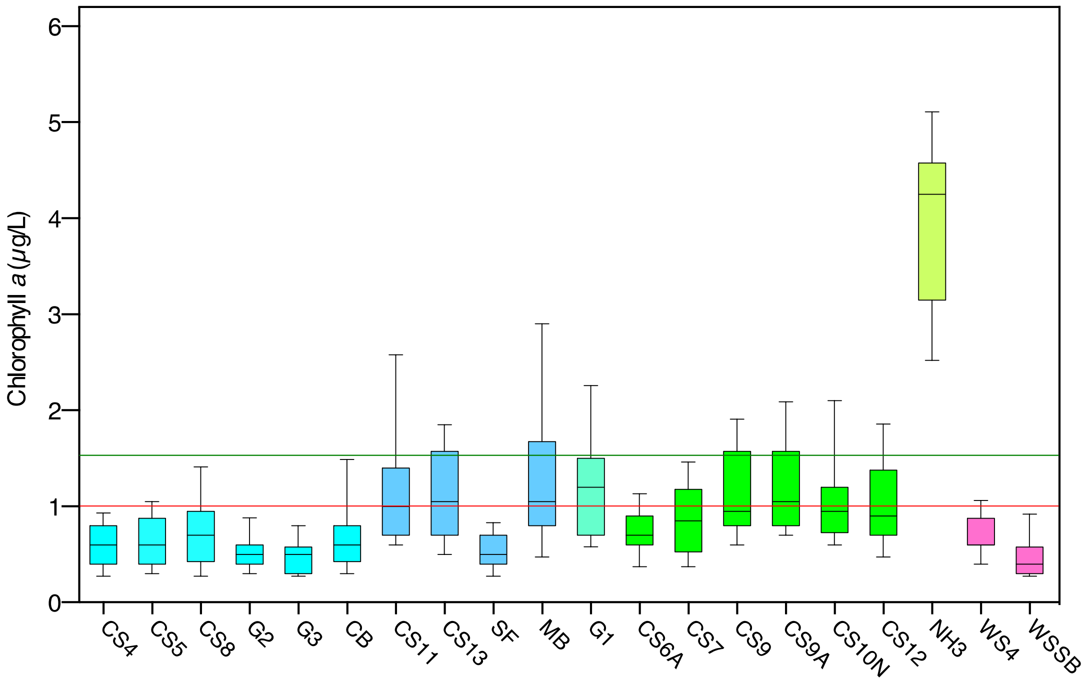


Figure 3: Median chlorophyll a concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2019 to March 2020.

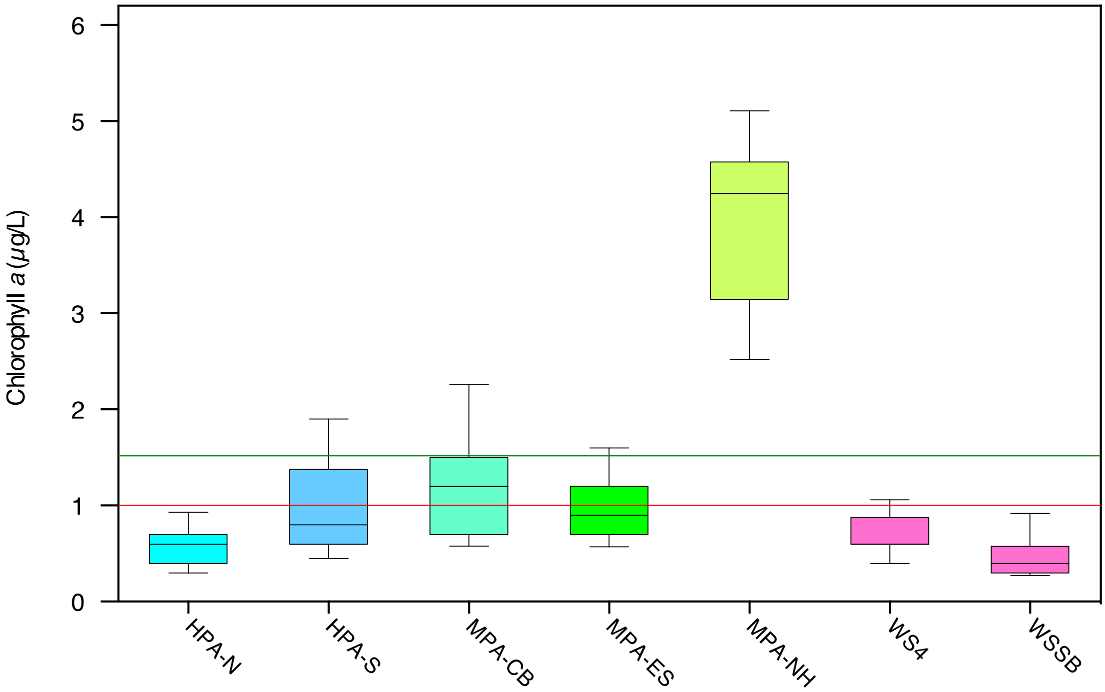


Figure 4: Median chlorophyll a concentration for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2019 to March 2020.

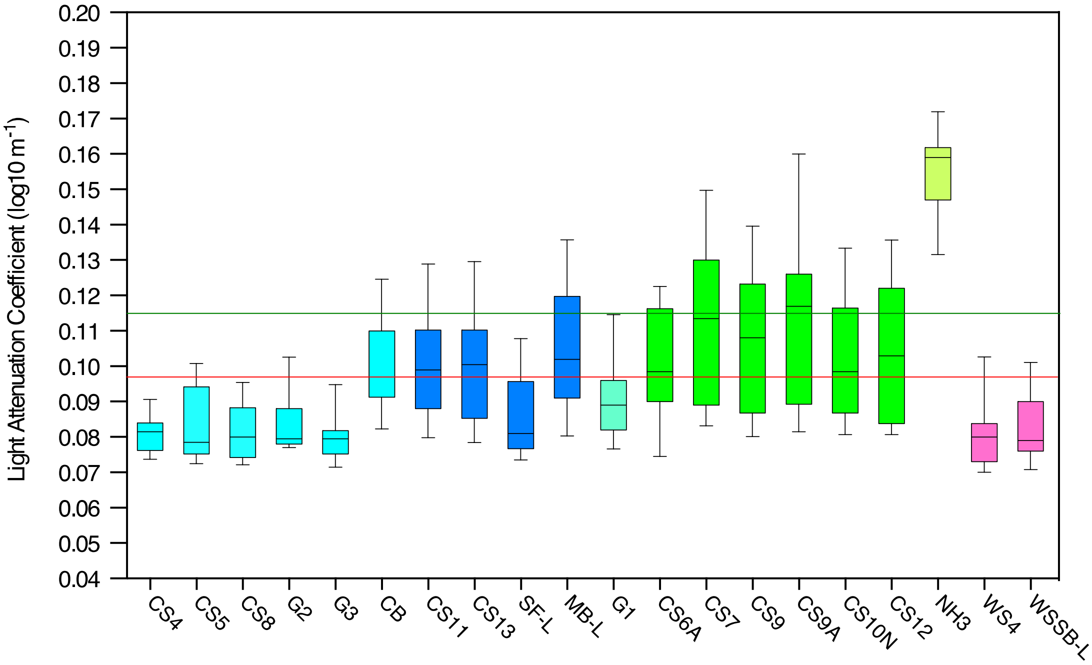


Figure 5: Median light attenuation coefficient at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2019 to March 2020.

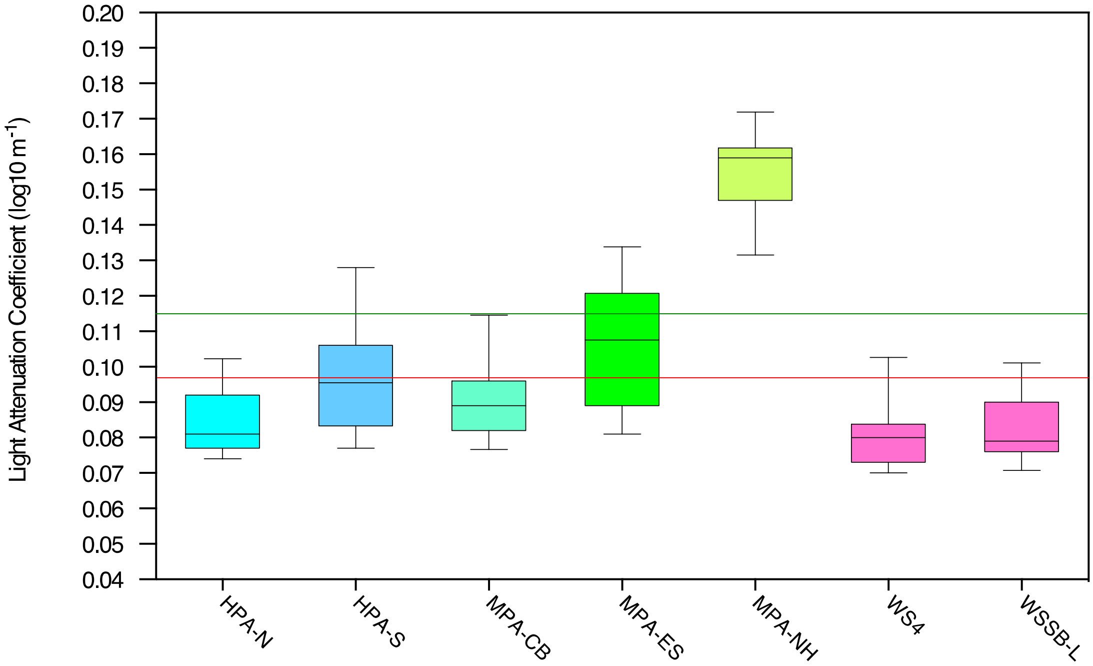


Figure 6: Median light attenuation coefficient for each of the ecological protection areas in Cockburn Sound and the reference sites in Warnbro Sound over the period December 2019 to March 2020.

Seagrass shoot density at other sites within and outside Cockburn Sound

Median shoot densities at each of the seagrass monitoring sites were compared with and the 'rolling' four-year 20th percentiles of seagrass shoot densities at the relevant Warnbro Sound reference sites and the AMC for seagrass shoot densities (Table 11). Median shoot densities at five sites outside Cockburn Sound were also compared with the relevant AMC seagrass shoot densities and the 'rolling' four-year 20th percentiles of seagrass shoot densities at the reference sites.

There were four sites that did not meet the AMC or 'rolling' four-year 20th percentiles: Southern Flats, Luscombe Bay, Garden Island Settlement and Garden Island 2.5 m. All four sites are shallow, with a depth of 2.5 m or less.

Median shoot densities at sites outside Cockburn Sound were lower in 2020 than in 2019, except for Bird Island which remained the same. This suggests regional-scale environmental factors may be impacting on seagrass shoot densities. See Appendix D for the long-term trends in seagrass shoot densities.

Table 11: Comparison of median seagrass shoot densities within and outside Cockburn Sound to 'rolling' four-year 20th percentiles at Warnbro Sound reference sites and the absolute minimum criteria

Ecological protection area	Site	Reference site	N	2019 median shoot density (shoots/m^2)	2020 median shoot density (shoots/m^2)	Rolling 4-year 20th percentile (shoots/m^2)	Absolute minimum criteria (shoots/m^2)
HPA-N	**Garden Island Settlement**	WS 2.0 m	24	913	425*	720	666
	Kwinana	WS 5.2 m	24	813	850	350	419
	Garden Island 2.0 m	WS 2.0 m	24	1300	875	720	666
	Garden Island 2.5 m	WS 2.5 m	21	775	475*	480	500
	Garden Island 3.2 m	WS 3.2 m	23	613	425	165	171
	Garden Island 5.5 m	WS 5.2 m	24	700	463	350	419
	Garden Island 7.0 m	WS 7.0 m	23	375	425	200	59
	Luscombe Bay	WS 2.0 m	23	1275	520*	720	666
HPA-S	**Southern Flats**	WS 2.0 m	22	838	550*	720	666
	Mangles Bay	WS 3.2 m	22	325	388	165	171
MPA-ES	Jervoise Bay	WS 3.2 m	7	500	175	25	100
Sites outside Cockburn Sound	Coogee	WS 5.2 m	24	575	588	NA	NA
	Bird Island	WS 2.0 m	23	675	675	NA	NA

Ecological protection area	Site	Reference site	N	2019 median shoot density (shoots/m^2)	2020 median shoot density (shoots/m^2)	Rolling 4-year 20th percentile (shoots/m^2)	Absolute minimum criteria (shoots/m^2)
	Mersey Point	WS 2.5 m	24	1100	600	NA	NA
	Carnac Island	WS 3.2 m	24	650	388	NA	NA
	Woodman Point	WS 3.2 m	9	113	100	NA	NA

Notes: (1) N is the number of replicates used to calculate the 2020 median shoot density.

(2) Shoot densities less than the ‘absolute minimum criteria’ and/or the ‘rolling’ four-year percentile are denoted by *.

Phytoplankton biomass

Phytoplankton biomass (measured as chlorophyll *a*) recorded at the 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Section 2.3; Figure 2) over the 2019–20 non river-flow period was assessed against the ‘phytoplankton biomass’ EQG (EQG C, Table 1a, EPA 2017):

High protection:

i. Median phytoplankton biomass in HPA-N and HPA-S is not to exceed 2.10 µg/L on any occasion during the 2019–20 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 2019–20 non river-flow period.

Moderate protection:

i. Median phytoplankton biomass in MPA-ES is not to exceed 3.00 µg/L on more than one occasion during the 2019–20 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 2019–20 non river-flow period.

The relevant ‘phytoplankton biomass’ EQG(i) were met in HPA-N and MPA-ES, but not in HPA-S during the 2019–20 non river-flow period (Table 12). On 2 March 2020, three of the four sites in HPA-S exceeded the ‘phytoplankton biomass’ EQG(i). The highest recorded chlorophyll *a* concentration on that day was 3.7 µg/L at site CS11 and the lowest recorded was 0.9 µg/L at site CSSF.

Table 12: Assessment of median chlorophyll a concentrations in HPA-N, HPA-S and MPA-ES on each sampling occasion during the 2019–20 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
2/12/2019	0.35	0.55	0.60
9/12/2019	0.40	0.60	0.85
16/12/2019	0.30	0.80	0.55
23/12/2019	0.70	1.60	1.00
6/01/2020	0.30	0.70	0.75
13/01/2020	0.60	1.25	0.85
20/01/2020	0.65	1.15	1.40
28/01/2020	0.40	0.55	0.50
3/02/2020	0.50	0.65	0.95
10/02/2020	0.85	1.00	1.35
17/02/2020	0.60	1.25	1.20
24/02/2020	0.60	0.75	0.95
2/03/2020	0.90	1.45	1.55
9/03/2020	0.85	**2.90***	2.15
16/03/2020	0.75	1.00	0.70
30/03/2020	0.75	0.95	1.05
Assessment	EQG(i) met	EQG(i) not met	EQG(i) met

Note: exceedence of the EQG denoted by *

The relevant 'phytoplankton biomass' EQG(ii) were met in HPA-N, HPA-S and MPA-ES during the 2019–20 non river-flow period (Table 13). The 'phytoplankton biomass' EQG(ii) was not met at site NH3 in Jervoise Bay (MPA-NH).

Table 13: Assessment of chlorophyll a concentrations at 18 water quality monitoring sites in Cockburn Sound during the 2019–20 non river-flow period against the 'phytoplankton biomass' EQG(ii).

Ecological protection areas	Site	2019–20 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	16	1	6%	EQG(ii) met
	CS13		16	1	6%	EQG(ii) met

Ecological protection areas	Site	2019–20 EQG	Number of sampling occasions	Number of occasions EQG was exceeded	Per cent (%) of occasions EQG was exceeded	Assessment
	SF MB	exceed 2.10 µg/L on 25% or more occasions	16 16	0 3	0% 19%	EQG(ii) met 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 CS12 CS6A CS7 CS9 CS9A	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	16 16 16 16 16 16	1 0 0 0 0 0	6% 0% 0% 0% 0% 0%	EQG(ii) met EQG(ii) met EQG(ii) met EQG(ii) met EQG(ii) met EQG(ii) met
MPA-NH	NH3	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	16	**13**	**81%**	EQG(ii) not met

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

Assessment against the 'phytoplankton biomass' environmental quality standards

'Phytoplankton biomass' EQS at HPA-S

The high protection 'phytoplankton biomass' EQG was not met at HPA-S, which triggered a more detailed assessment against the high protection 'phytoplankton biomass' EQS (EQS C(i), Table 1a, EPA 2017). The 'phytoplankton biomass' EQS for high protection areas states that the median phytoplankton is not to exceed the EQC as updated annually on more than one occasion during the non river-flow period and in two consecutive years.

Assessment of phytoplankton biomass at HPA-S during the non river-flow period for 2018–19 and 2019–20 showed that phytoplankton biomass exceeded 2.10 µg/L on one occasion (2 March 2020) (Table 14). The 'phytoplankton biomass' EQS for high protection areas was therefore met at HPA-S.

Table 14: Assessment of chlorophyll a concentrations in HPA-S against the high protection 'phytoplankton biomass' EQS(i) over two consecutive years (2018–19 and 2019–20)

Ecological protection area	Year	EQS	Number of occasions EQS was exceeded	Assessment
HPA-S	2018–19	Phytoplankton biomass not to exceed 2.10 µg/L on more than one occasion	0 (out of 16)	EQS met
	2019–20	Phytoplankton biomass not to exceed 2.10 µg/L on more than one occasion	1 (out of 16)	

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

The moderate protection 'phytoplankton biomass' EQG was not met in Jervoise Bay (site NH3), which triggered a more detailed assessment against the moderate protection 'phytoplankton biomass' EQS (EQS C(ii), Table 1a, EPA 2017). The 'phytoplankton biomass' EQS for moderate protection areas states that the median phytoplankton is not to exceed the EQC that are updated annually on 50% or more occasions during the non river-flow period and in two consecutive years.

Assessment of phytoplankton biomass at site NH3 during the non river-flow period for 2018–19 and 2019–20 showed that phytoplankton biomass exceeded 3.00 µg/L on more than 50% of the sampling occasions in 2018–19 and 2019–20 (Table 15). The 'phytoplankton biomass' EQS for moderate protection was therefore not met.

Table 15: Assessment of chlorophyll a concentrations at Jervoise Bay Northern Harbour (NH3) against the moderate protection 'phytoplankton biomass' EQS(ii) over two consecutive years (2018–19 and 2019–20).

Site	Year	EQS	Number of occasions EQS was exceeded	Per cent (%) of occasions EQS was exceeded	Assessment
NH3	2018–19	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	11 (out of 16)	69%	EQS not met
	2019–20	Phytoplankton biomass not to exceed 3.00 µg/L on 50% or more occasions	13 (out of 16)	81%	

2.6 Assessment against the environmental quality criteria for other physical and chemical stressors

2.6.1 Dissolved oxygen concentration

Dissolved oxygen concentration (% saturation) at water quality monitoring sites

Measurements of dissolved oxygen (DO) concentrations (% saturation) recorded in the bottom waters[2] at the 18 water quality monitoring sites in Cockburn Sound (Section 2.3; Figure 2) over the 2019–20 non river-flow period were assessed against the 'DO concentration' EQG (EQG D, Table 1a, EPA 2017).

Each DO concentration recorded on each sampling occasion at each site was compared with the relevant 'DO concentration' EQG (Table 16). Sites not meeting the relevant 'DO concentration' EQG were also assessed against the relevant 'DO concentration' EQS. In all instances where a site did not meet the relevant EQG, the relevant EQS was met for the site (Table 17).

Two sites in the moderate protection area MPA-ES – sites CS12 and CS6A – met the high protection 'DO concentration' EQG of 90% saturation or greater on all sampling occasions.

[2] Waters within 50 centimetres (cm) of the sediment surface.

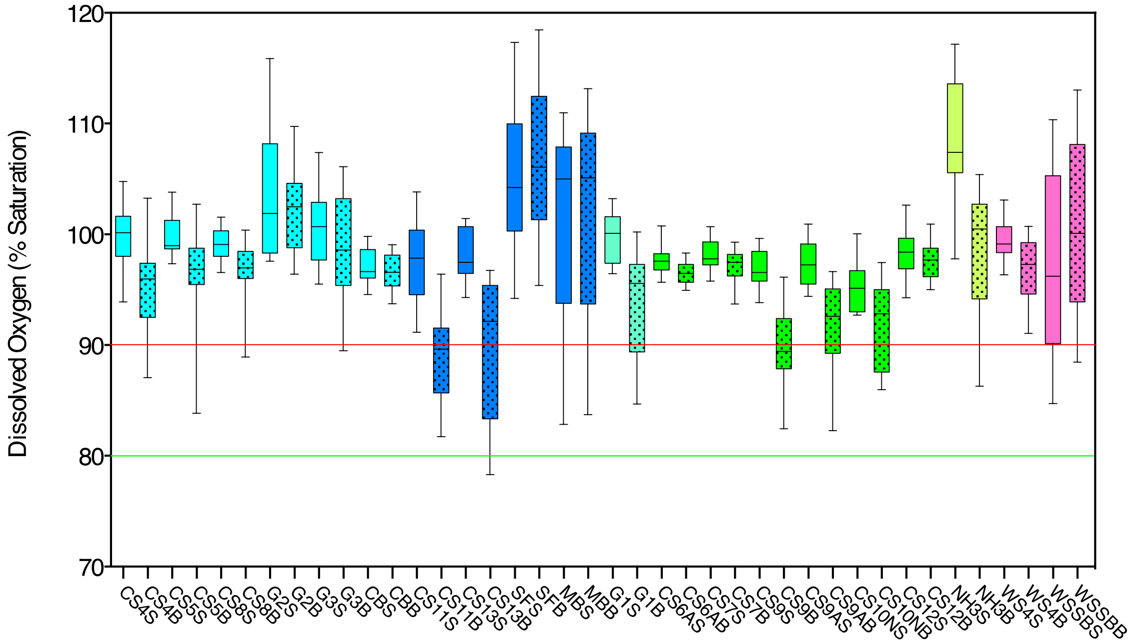
Table 16: Assessment of dissolved oxygen concentrations (% saturation) in bottom waters at sites in Cockburn Sound against the 'dissolved oxygen concentration' EQC for the 2019–20 non river-flow period.

Ecological protection area	EQG	EQS	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	Dissolved oxygen concentration not less than 90% saturation	Dissolved oxygen concentration not less than 60% saturation	CS4 (21 m)	16	1	0	EQG not met, EQS met
			CS5 (19 m)	16	2	0	EQG not met, EQS met
			CS8 (20 m)	16	2	0	EQG not met, EQS met
			CB (9.5 m)	16	0	-	EQG met
			G2 (10 m)	16	0	-	EQG met
			G3 (13 m)	16	1	0	EQG not met, EQS met
HPA-S	Dissolved oxygen concentration not less than 90% saturation	Dissolved oxygen concentration not less than 60% saturation	CS11 (18 m)	16	9	0	EQG not met, EQS met
			CS13 (20.5 m)	16	8	0	EQG not met, EQS met
			SF (3.5 m)	16	0	-	EQG met
			MB (1.5 m)	16	3	0	EQG not met, EQS met
MPA-CB	Dissolved oxygen concentration not less than 80% saturation	Dissolved oxygen concentration not less than 60% saturation	G1 (15 m)	16	1	0	EQG not met, EQS met
MPA-ES	Dissolved	Dissolved	CS10N (14 m)	16	0	-	EQG met

Ecological protection area	EQG	EQS	Site (approximate depth)	Number of sampling occasions	No. of occasions EQG was not met	No. of occasions EQS(i) was not met	Assessment
	oxygen concentration not less than 80% saturation	oxygen concentration not less than 60% saturation	CS12 (10 m)	16	0	-	EQG met
			CS6A (10.5 m)	16	0	-	EQG met
			CS7 (10.5 m)	16	0	-	EQG met
			CS9 (13 m)	16	1	0	EQG not met, EQS met
			CS9A (16.5 m)	16	1	0	EQG not met, EQS met
MPA-NH	Dissolved oxygen concentration not less than 80% saturation	Dissolved oxygen concentration not less than 60% saturation	NH3 (10 m)	16	0	-	EQG met

Table 17: Sampling occasions where the relevant 'DO concentration (% saturation) EQG were not met in 2019–20.

Ecological protection area	EQG	Site (approximate depth)	Date	DO (% saturation)
HPA-N	Dissolved oxygen concentration not less than 90% saturation	CS4 (21 m)	30/03/2020	78.1
		CS5 (19 m)	16/03/2020	84.5
			30/03/2020	82.3
		CS8 (20 m)	16/03/2020	87.1
			30/03/2020	89.7
		G3 (13 m)	30/03/2020	83.4
HPA-S	Dissolved oxygen concentration not less than 90% saturation	CS11 (18 m)	23/12/2019	85.2
			13/01/2020	89.3
			28/01/2020	89.9
			10/02/2020	89.4
			17/02/2020	82.0
			24/02/2020	85,1
			9/03/2020	87.4
			16/03/2020	87.2
			30/03/2020	81.2
		CS13 (20.5 m)	23/12/2019	86.6
			6/01/2020	82.5
			13/01/2020	89.8
			28/01/2020	82.3
			3/02/2020	85.9
			24/02/2020	88.9
			16/03/2020	79.7
			30/03/2020	75.1
		MB (1.5 m)	9/03/2020	84.4
			16/03/2020	84.6
			30/03/2020	82.1
MPA-CB	Dissolved oxygen concentration not less than 80% saturation	G1 (15 m)	16/03/2020	78.2
MPA-ES	Dissolved oxygen concentration not less than 80% saturation	CS9 (13 m)	16/03/2020	77.0
		CS9A (16.5 m)	6/01/2020	79.7



Notes:

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

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

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

Figure 7: Median dissolved oxygen concentrations (% saturation) in surface and bottom waters at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2019 to March 2020.

Only one site, CS12, has met the 'DO concentration' EQG during the non river-flow period in Cockburn Sound in the past decade (Table 18). Low DO concentrations have generally previously occurred at deeper sites located in the high protection areas (e.g. CS11 and CS13 in HPA-S; CS4, CS5 and CS8 in HPA-N).

Table 18: Number of occasions during each non river-flow period during the last 10 summers when DO concentrations (% saturation) in the bottom waters did not meet the 'DO concentration' EQG.

Ecological protection area	Site (approximate depth)	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
HPA-N	CS4 (21 m)	2	2	1	0	1	3	6	0	2	1
	CS5 (19 m)	2	3	0	1	0	2	3	0	3	2
	CS8 (20 m)	3	3	1	1	0	6	6	0	1	2
	CB (9.5 m)	0	1	0	1	0	0	0	0	0	0
	G2 (10 m)	2	1	0	0	1	0	1	1	2	0
	G3 (13 m)	0	1	1	0	1	2	2	0	1	1
HPA-S	CS11 (18 m)	7	4	5	4	10	8	11	6	6	9
	CS13 (20.5 m)	8	2	6	4	6	9	11	7	7	8
	SF (3.5 m)	1	0	0	1	2	2	0	0	1	0
	MB (1.5 m)	4	3	4	2	6	3	7	8	1	3
MPA-CB	G1 (15 m)	0	0	0	0	0	1	0	0	0	1
MPA-ES	CS10N (14 m)	2	1	0	2	0	3	2	0	0	0
	CS12 (10 m)	0	0	0	0	0	0	0	0	0	0
	CS6A (10.5 m)	0	0	0	0	0	1	1	0	0	0
	CS7 (10.5 m)	1	2	1	0	0	0	1	0	0	0
	CS9 (13 m)	3	1	0	0	0	1	3	0	1	1
	CS9A (16.5 m)	3	0	1	1	0	0	3	0	1	1
MPA-NH	NH3 (10 m)	1	3	1	0	0	0	4	0	2	0

Dissolved oxygen concentrations at Water Corporation monitoring sites

DO concentrations, measured as percentage saturation, were recorded quarterly in the bottom waters at three Water Corporation sites in Cockburn Sound and two sites located outside Cockburn Sound during the 2019–20 monitoring period (Table 19). Additional DO measurements were taken at Cockburn Sound water quality monitoring sites CS9 and CS12 in MPA-ES on each sampling occasion.

The high protection 'DO concentration' EQG was met in the bottom waters at the sites in HPA-N and HPA-S on all of the sampling occasions, except for site 'South' on 12 December 2019, when a DO concentration of 88% saturation was recorded at the site. The Cockburn Sound monitoring sites CS9 and CS12 met the high protection 'DO concentration' EQG on all of the sampling occasions.

The moderate protection 'DO concentration' EQG of not less than 80% saturation was met in the bottom waters at site DIFF50W. Site DIFF50W also met the high protection 'DO concentration' EQG.

Table 19: Assessment of dissolved oxygen concentrations (% saturation) in the bottom waters at Water Corporation monitoring sites in Cockburn Sound.

Ecological protection area	Site (approximate depth)	September 2019	December 2019	April 2020	June 2020
HPA-N	Central (21 m)	EQG met	EQG met	EQG met	EQG met
HPA-S	South (20 m)	EQG met	EQG not met EQS met	EQG met	EQG met
MPA-ES	DIFF50W (10 m)	EQG met	EQG met	EQG met	EQG met
Sites outside Cockburn Sound	Parmelia Bank (7 m) Owen Anchorage (14 m)	>90% >90%	>90% >90%	>90% >90%	>90% >90%

<u>Dissolved oxygen concentrations at Fremantle Port monitoring sites</u>

DO concentrations, measured as percentage saturation, were recorded at three Kwinana Bulk Jetty sites (Figure 2; KBJ1, KBJ2 and KBJ3) and three Kwinana Bulk Terminal sites (Figure 2; KBT1, KBT2 and KBT3) surveyed by Fremantle Ports on 29 January 2020. The Kwinana Bulk Jetty sites ranged in depth from 12 to 16.5 m and the Kwinana Bulk Terminal sites ranged in depth from 10.5 to 11.5 m.

The moderate protection 'DO concentration' EQG was met in the bottom waters at all Kwinana Bulk Jetty and Terminal sites. The DO concentrations in the bottom waters of the six sites also met the high protection 'DO concentration' EQG.

Assessment against the environmental quality standard

The 'DO concentration' EQG was not met at 10 of the 18 Cockburn Sound water quality monitoring sites, which triggered a more detailed assessment against the high and moderate protection 'DO concentration' EQS (EQS D, Table 1a, EPA 2017).

The 'DO concentration' EQS for high and moderate protection areas states that the median DO concentration in bottom waters at a site should be greater than 60% saturation (EQS(i)). The 'DO concentration' EQS(i) was considered to have been met, as the lowest DO concentration recorded was 75.1% saturation at site CS13 on 30 March 2020 (Table 17).

The 'DO concentration' EQS also states that there should be (1) no significant change in any ecological or biological indicators affected by poorly oxygenated water (EQS(ii)) and (2) no deaths of marine organisms resulting from the deoxygenation (EQS(iii)).

There were no reported deaths of marine organisms or significant changes in any ecological or biological indicators from poorly oxygenated water on the days that Cockburn Sound water quality sampling was undertaken during the 2019–20 monitoring season (EQS(ii) and EQS(iii)). The 'DO concentration' EQS(ii) and (iii) were therefore considered to have been met at the sites.

2.6.2 Water temperature

Measurements of surface[3] and bottom[4] water temperatures at the 18 water quality monitoring sites[5] (Section 2.3; Figure 2) over the 2019–20 non river-flow period were assessed against the 'water temperature' EQG (EQG E, Table 1a, EPA 2017):

High protection: *Median temperature at an individual site over the 2019–20 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 2019–20 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.*

See

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

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

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

Table 20 for the results of the assessment against the ‘temperature’ EQG. See Figure 8 for the median surface and bottom water temperatures at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound. The median surface and bottom water temperatures recorded over the 2019–20 non river-flow period met the ‘temperature’ EQG at all sites except the Mangles Bay site (site MB). The median temperature in the bottom waters of Mangles Bay exceeded the ‘temperature’ EQG.

Assessment against the environmental quality standard

The ‘temperature’ EQG was not met in the bottom waters of Mangles Bay, which triggered a more detailed assessment against the high protection ‘temperature’ EQS (EQS E, Table 1a, EPA 2017).

The high protection ‘temperature’ EQS states there should be (1) no significant change in any ecological or biological indicators affected by water temperature (EQS(i)) and (2) no deaths of marine organisms attributed to thermal stress from anthropogenic sources (EQS(ii)).

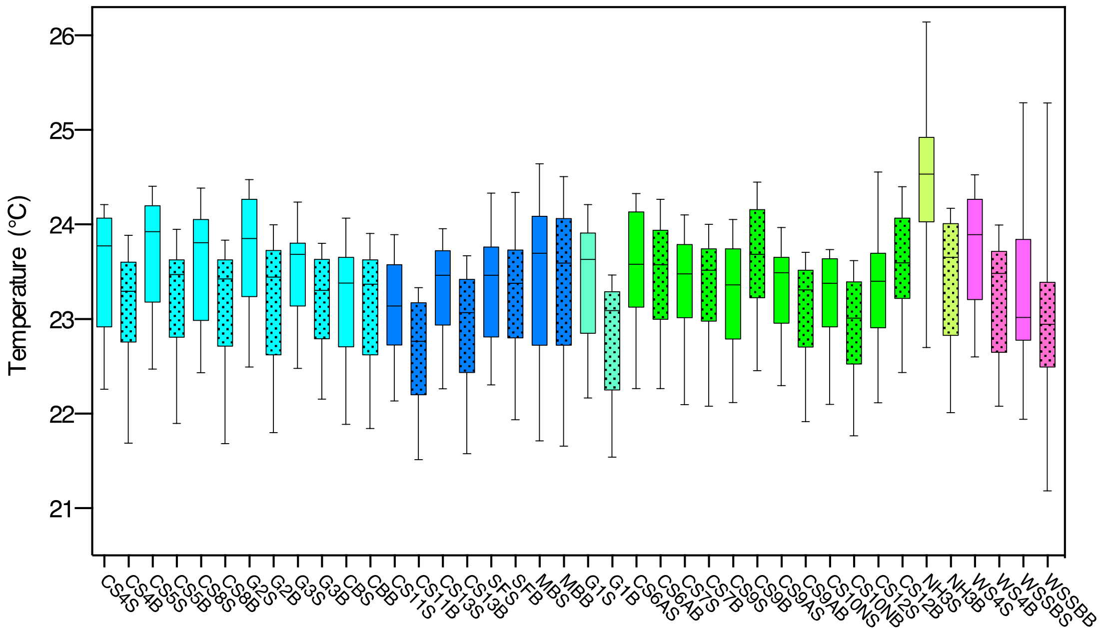
There were no reported deaths of marine organisms or significant changes in any ecological or biological indicators affected by water temperature on the days that Cockburn Sound water quality sampling was undertaken during the 2019–20 monitoring season (EQS(i) and EQS(ii)). The ‘temperature’ EQS was considered to have been met at the Mangles Bay site.

See Appendix E for information on variations and trends over time in water temperatures in Cockburn Sound.

Table 20: Assessment of median surface and bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound over the 2019–20 non river-flow period against the 'temperature' EQG.

Ecological protection area	Site	Temperature (º C)				Assessment
		2019–20 EQG (surface)	2019–20 median (surface)	2019–20 EQG (bottom)	2019–20 median (bottom)	
HPA-N	CS4	≤24.3	23.7	≤23.7	23.3	EQG met
	CS5		23.9		23.5	EQG met
	CS8		23.8		23.4	EQG met
	CB		23.4		23.4	EQG met
	G2		23.8		23.4	EQG met
	G3		23.7		23.3	EQG met
HPA-S	CS11	≤24.3	23.1	≤23.7	22.8	EQG met
	CS13		23.5		23.1	EQG met
	SF	≤23.9	23.5	≤23.4	23.4	EQG met
	MB		23.7		**23.6**	EQG not met; EQS met
MPA-CB	G1	≤24.5	23.7	≤24.0	23.1	EQG met
MPA-ES	CS10N	≤24.5	23.4	≤24.0	23.0	EQG met
	CS12		23.4		23.6	EQG met
	CS6A		23.6		23.6	EQG met
	CS7		23.5		23.5	EQG met
	CS9		23.4		23.7	EQG met
	CS9A		23.5		23.3	EQG met
MPA-NH	NH3	≤24.5	24.5	≤24.0	23.7	EQG met

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



Notes:

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

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

Figure 8: Median surface and bottom water temperatures at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2019 to March 2020.

2.6.3 Salinity

Measurements of surface[6] and bottom[7] water salinities recorded at the 18 water quality monitoring sites[8] (Section 2.3; Figure 2) over the 2019–20 non river-flow period were assessed against the 'salinity' EQG (EQG F, Table 1a, EPA 2017):

High protection: *Median salinity at an individual site over the 2019–20 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 2019–20 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*

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

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

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

same period.

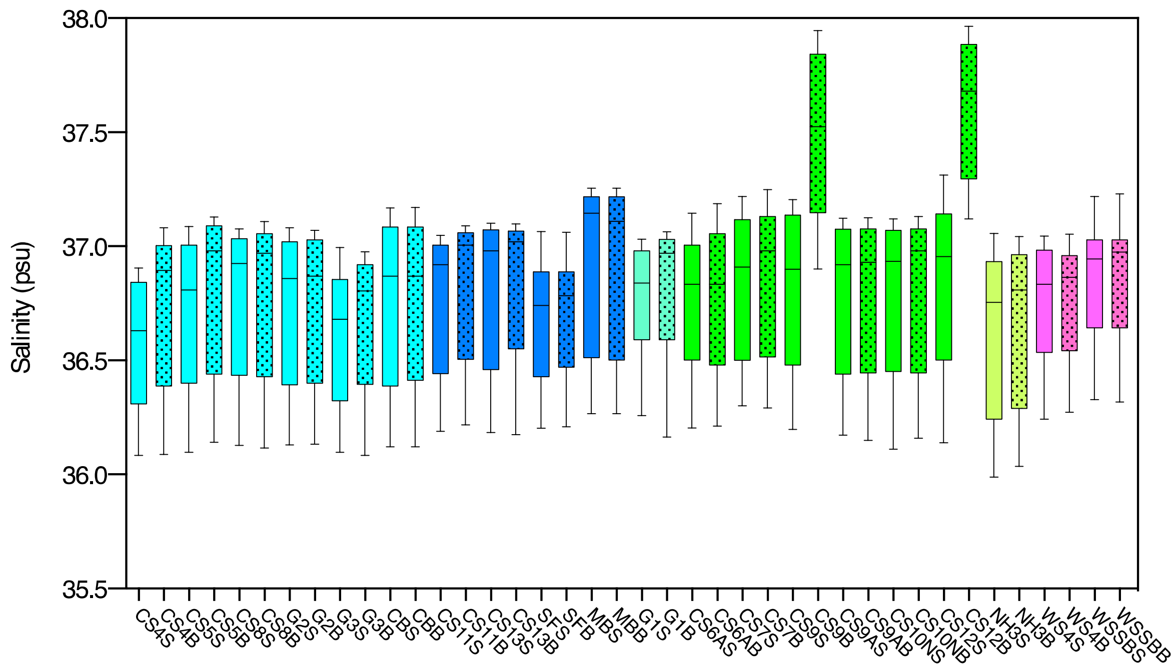
See Table 21 for the results of the assessment against the 'salinity' EQG. See Figure 9 for the median surface and bottom water salinity measurements at each of the water quality monitoring sites in Cockburn Sound and Warnbro Sound. The 'salinity' EQG was met at all sites except sites MB, CS9 and CS12. The median surface and bottom water salinity measurements at site MB in HPA-S exceeded the relevant 'salinity' EQG for high ecological protection areas. The median bottom water salinity measurements at CS9 and CS12 in MPA-ES exceeded the 'salinity' EQG for moderate ecological protection areas.

Table 21: Assessment of median surface and bottom salinity measurements at 18 water quality monitoring sites in Cockburn Sound over the 2019–20 non river-flow period against the 'salinity' EQG.

Ecological protection area	Site	Salinity (practical salinity units [psu])				Assessment
		2019–20 EQG (surface)	2019–20 median (surface)	2019–20 EQG (bottom)	2019–20 median (bottom)	
HPA-N	CS4	36.5 ≤ x ≤ 37.0	36.6	36.5 ≤ x ≤ 37.0	36.9	EQG met
	CS5		36.8		37.0	EQG met
	CS8		36.9		37.0	EQG met
	CB		36.9		36.9	EQG met
	G2		36.9		36.9	EQG met
	G3		36.7		36.8	EQG met
HPA-S	CS11	36.5 ≤ x ≤ 37.0	36.9	36.5 ≤ x ≤ 37.0	37.0	EQG met
	CS13		37.0		37.0	EQG met
	SF	36.6 ≤ x ≤ 37.0	36.7	36.6 ≤ x ≤ 37.0	36.8	EQG met
	MB		**37.1**		**37.1**	EQG not met
MPA-CB	G1	36.2 ≤ x ≤ 37.0	36.8	36.3 ≤ x ≤ 37.1	37.0	EQG met
MPA-ES	CS10N	36.2 ≤ x ≤ 37.0	36.9	36.3 ≤ x ≤ 37.1	37.0	EQG met
	CS12		37.0		**37.7**	EQG not met in bottom waters
	CS6A		36.8		36.8	EQG met
	CS7		36.9		37.0	EQG met

Ecological protection area	Site	Salinity (practical salinity units [psu])				Assessment
		2019–20 EQG (surface)	2019–20 median (surface)	2019–20 EQG (bottom)	2019–20 median (bottom)	
	CS9		36.9		**37.5**	EQG not met in bottom waters
	CS9A		36.9		36.9	EQG met
MPA-NH	NH3	36.2 ≤ x ≤ 37.0	36.8	36.3 ≤ x ≤ 37.1	36.8	EQG met

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



Notes:

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

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

Figure 9: Median surface and bottom water salinities at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2019 to March 2020.

Salinity measurements at Water Corporation monitoring sites

Salinity, measured in practical salinity units (psu), was recorded quarterly in the bottom waters at three Water Corporation sites in Cockburn Sound and two sites located outside Cockburn Sound during the 2019–20 monitoring period (Table 22).

Table 22: Median bottom water salinity (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	17 September 2019	12 December 2019	2 April 2020	19 June 2020
HPA-N	Central	35.3	36.1	36.7	35.7
HPA-S	South	35.3	36.2	36.7	35.7
MPA-ES	DIFF50W	35.6	36.8	37.4	36.3
Site outside Cockburn Sound	Parmelia Bank	35.4	36.1	36.4	35.7
	Owen Anchorage	35.5	36.2	36.6	35.8

The salinity measurements recorded in bottom waters at DIFF50W, located 50 m west of the Perth Seawater Desalination Plant diffuser, were slightly higher than those recorded at the other Water Corporation water quality monitoring sites on each sampling occasion.

Additional DO measurements were taken by the Water Corporation in bottom waters at Cockburn Sound water quality monitoring sites CS9 and CS12 on three of the same sampling occasions (Table 23). The salinity measurements at these two sites were generally slightly higher than those recorded at site DIFF50W.

Table 23: Bottom water salinity (practical salinity units [psu]) recorded at Cockburn Sound water quality monitoring sites CS9 and CS12.

Ecological protection area	Site	12 December 2019	2 April 2020	19 June 2020
MPA-ES	CS9	36.6	37.7	36.5
	CS12	37.0	37.7	36.7

Assessment against the environmental quality standard

The ‘salinity’ EQG were not met in the surface waters at site MB and bottom waters at sites MB, CS9 and CS12 (Table 21), which triggers more detailed assessment against the high and moderate protection ‘salinity’ EQS (EQS F, Table 1a, EPA 2017).

The ‘salinity’ EQS for high protection areas states that no significant change should occur and for moderate protection areas, no persistent (i.e. four weeks or longer) and significant change beyond natural variation in any ecological or biological indicators that are affected by changing salinity, unless demonstrably linked to another factor

(EQS(i)). The ‘salinity’ EQS for high and moderate protection areas also states that there should be no deaths of marine organisms attributed to salinity stress from anthropogenic sources (EQS(ii)).

Median surface water salinity at MB and bottom water salinities at MB, CS9 and CS12 were below the default moderate protection salinity trigger value[9] in the reference document (EPA 2017). The risk of a persistent and significant change beyond natural variation in any ecological or biological indicators as a result of elevated salinity is therefore considered to be low (‘salinity’ EQS(i)).

Median bottom salinities at CS9 and CS12 have exceeded the ‘salinity’ EQG since the 2006–07 monitoring period. These exceedences possibly reflect localised effects because the sites are close to the saline water discharge from the Perth Seawater Desalination Plant, which began operations in late 2006.

There were no reports of deaths of marine organisms over the 2019–20 non river-flow period attributed to salinity stress from anthropogenic sources (‘salinity’ EQS(ii)).

2.6.4 pH

Measurements of surface[10] and bottom[11] water pH recorded at the 18 water quality monitoring sites[12] (Section 2.3; Figure 2) over the 2019–20 non river-flow period were assessed against the ‘pH’ EQG (EQG G, Table 1a, EPA 2017):

High protection: *Median pH at an individual site over the 2019–20 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 2019–20 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.*

[9] High protection surface waters = 38.2 practical salinity units (the median of suitable reference site data ± 1.3; 36.9 + 1.3); moderate protection bottom waters = 38.3 practical salinity units (the median of suitable reference site data ± 1.4; 36.9 + 1.4); high protection bottom waters = 38.3 practical salinity units (the median of suitable reference site data ± 1.3; 37.0 + 1.3)

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

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

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

Table 24: Assessment of median surface and bottom pH at 18 water quality monitoring sites in Cockburn Sound over the 2019–20 non river-flow period against the 'pH' EQG.

Ecological protection area	Site	pH (pH units)				Assessment
		2019–20 EQG (surface)	2019–20 median (surface)	2019–20 EQG (bottom)	2019–20 median (bottom)	
HPA-N	CS4	8.17 ≤ x ≤ 8.21	**8.16**	8.16 ≤ x ≤ 8.21	8.16	EQG not met in surface waters
	CS5		**8.16**		**8.15**	EQG not met
	CS8		**8.16**		8.16	EQG not met in surface waters
	CB		**8.15**		**8.15**	EQG not met
	G2		8.17		8.18	EQG met
	G3		8.17		8.17	EQG met
HPA-S	CS11	8.17 ≤ x ≤ 8.21	**8.16**	8.16 ≤ x ≤ 8.21	**8.14**	EQG not met
	CS13		**8.16**		**8.15**	EQG not met
	SF	8.12 ≤ x ≤ 8.21	8.18	8.14 ≤ x ≤ 8.21	8.18	EQG met
	MB		8.18		8.18	EQG met
MPA-CB	G1	8.15 ≤ x ≤ 8.23	8.18	8.13 ≤ x ≤ 8.23	8.15	EQG met
MPA-ES	CS10N	8.15 ≤ x ≤ 8.23	8.16	8.13 ≤ x ≤ 8.23	8.15	EQG met
	CS12		8.16		**8.12**	EQG not met in bottom waters
	CS6A		**8.14**		8.14	EQG not met in surface waters
	CS7		8.15		8.15	EQG met
	CS9		8.15		**8.11**	EQG not met in bottom waters
	CS9A		8.16		8.15	EQG met
MPA-NH	NH3	8.15 ≤ x ≤ 8.23	8.18	8.13 ≤ x ≤ 8.23	8.14	EQG met

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

See Table 24 for the results of the assessment against the 'pH' EQG. The median surface and bottom water pH measurements at four of 10 sites in the high protection areas met the applicable high protection ‘pH’ EQG. The median surface water pH measurement at site CS6A and the median bottom water pH measurements at sites CS9 and CS12 did not meet the applicable moderate protection ‘pH’ EQG.

Assessment against the environmental quality standard

The ‘pH’ EQG were not met at several sites in the high and moderate protection areas (Table 24), which triggers a more detailed assessment against the high and moderate protection ‘pH’ EQS (EQS G, Table 1a, EPA 2017).

The ‘pH’ EQS for high protection areas states that there should be no significant change and for moderate protection areas, no persistent (i.e. four weeks or longer) and significant change beyond the natural variation in any ecological or biological indicators affected by changes in pH, unless demonstrably linked to another factor (EQS(i)). The ‘pH’ EQS for high and moderate protection areas also states that there should be no deaths of marine organisms attributed to changes in pH from anthropogenic sources (EQS(ii)).

The pH measurements for the surface and bottom waters across all monitored sites in Cockburn Sound and Warnbro Sound ranged between 8.02 and 8.31 pH units (Cossington & Wienczugow 2020). For inshore coastal waters of Western Australia, the default trigger pH value is 8.0 for the lower limit and 8.4 for the upper limit (ANZECC & ARMCANZ 2000). The risk of a persistent and significant change beyond natural variation in any ecological or biological indicators as a result of changes in pH is therefore considered low (‘pH’ EQS(i)).

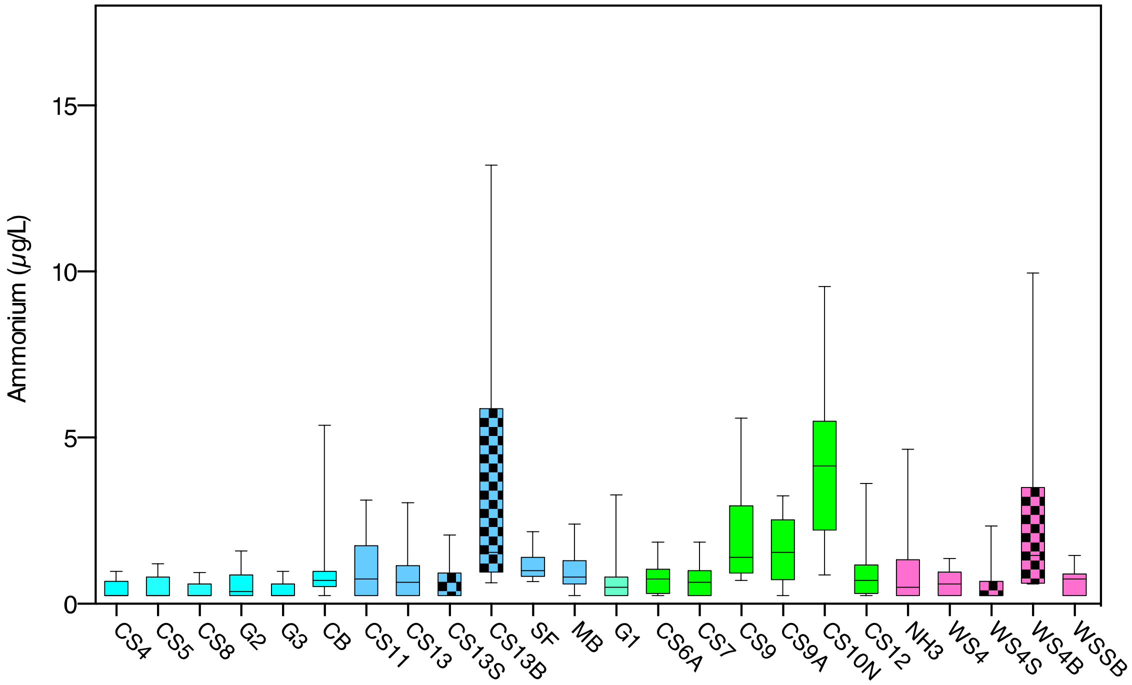
There were no known reports of deaths of marine organisms over the 2019–20 non river-flow period attributed to changes in pH due to anthropogenic sources (‘pH’ EQS(ii)).

2.7 Assessment against the environmental quality criteria for toxicants in marine waters

2.7.1 Non-metallic inorganics (ammonia) in marine waters of Cockburn Sound

Ammonium concentrations were measured at the 18 water quality monitoring sites (Section 2.3; Figure 2) in Cockburn Sound from December 2019 to March 2020. The ammonium concentrations in Cockburn Sound and at the two reference sites in Warnbro Sound ranged from below the limit of reporting of less than 0.5 µg/L to a maximum concentration of 11 µg/L. The maximum concentration was measured at sites CS9 and CS10N on 2 March 2020 and 16 March 2020 respectively, and at the Northern Harbour site (NH3) on 9 March 2020.

The median ammonium concentration at site CS10N in MPA-ES was significantly higher than the other sites, except for MPA-ES sites CS9 and CS9A and HPA-S sites MB and SF (Cossington & Wienczugow 2020).



Notes:

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

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

Figure 10: Median ammonium concentrations at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2019 to March 2020.

The median ammonium concentrations of the discrete bottom water samples taken at site CS13 and Warnbro Sound reference site WS4 were elevated and significantly higher than for the surface and integrated water samples for the same sites (Figure 10). The highest ammonium concentration measured in the discrete bottom water samples was 17 µg/L at site CS13 on 16 March 2020, the same day as the maximum ammonium concentration recorded at site CS10N.

Comparison to the ammonium EQG values

The reference document (Table 2a, EPA 2017) specifies that the 95th percentile of the sample concentrations from a single site or a defined area (either from one sampling run or all samples over an agreed period of time) should not exceed the EQG values. The high protection EQG value for ammonia is 500 µg/L and the moderate protection EQG value for ammonia is 1,200 µg/L. All sites met the ammonium EQG values for high and moderate protection areas.

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

Surface marine water samples were collected on 29 January 2020 at six sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) in MPA-ES (Section 2.3; Figure 2). The samples were analysed for ammonia, filtered copper, total recoverable hydrocarbons (TRHs), benzene, toluene, ethylbenzene and xylene (BTEX). Bottom marine water samples were also collected at the six sites and analysed for ammonia.

The reference document (EPA 2017) recommends a minimum of five samples should be taken 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 no EQG value was available, against the relevant 'low reliability value' (LRV).

Concentrations of copper and ammonia were below the relevant EQG values for toxic effects at all the sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty (Table 25). The ammonia concentrations in the bottom water samples at the six sites were also below the ammonia EQG value for toxic effects. Concentrations of BTEX were below the analytical limits of reporting and below the relevant EQG values or LRVs. Concentrations of TRHs were below the analytical limits of reporting.

At all sites, the total toxicity of the mixture (TTM)[13], based on the effects of ammonia, copper and benzene, was below one (Table 25). The combined additive effect of these contaminants was therefore not expected to result in adverse effects on marine flora or fauna near the sampling sites.

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

Toxicant (µg/L)	EQG/LRV (µg/L)	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Ammonia	EQG: 1,200	8^S	$<3^S$	4^S	$<3^S$	$<3^S$	$<3^S$
		$<3^B$	12^B	$<3^B$	8^B	6^B	$<3^B$
Copper (filtered)	EQG: 3.0	0.4	0.4	0.4	0.3	0.3	0.3
Benzene	EQG: 900	<1	<1	<1	<1	<1	<1
Toluene	LRV: 230	<1	<1	<1	<1	<1	<1
Ethylbenzene	LRV: 5.0[1]	<1	<1	<1	<1	<1	<1

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

Toxicant (µg/L)	EQG/LRV (µg/L)	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Xylene	m-xylene LRV: 75[1] p-xylene LRV: 200[1] o-xylene LRV: 350[1]	<1	<1	<1	<1	<1	<1
Total recoverable hydrocarbons (C10–C36)	LRV: 7[1, 2]	<250	<250	<250	<250	<250	<250
Total toxicity of mixture (TTM)	If TTM>1, mixture exceeded water quality guideline	<1	<1	<1	<1	<1	<1

Notes: '<' signifies the result is less that the limit of quantitation for the method; S = surface water sample; B = bottom water sample

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

2 LRV for total petroleum hydrocarbons.

2.8 Assessment against the environmental quality criteria for toxicants in sediments

Surface (top 2 cm) 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 on 19 March 2020 (Section 2.3; Figure 2). The samples were analysed for total organic carbon, metals (arsenic, cadmium, chromium, copper, lead, mercury and zinc), non-metals (selenium and phosphorus), organotins (tributyltin [TBT], dibutyltin [DBT] and monobutyltin [MBT]), polycyclic aromatic hydrocarbons (PAHs), total recoverable hydrocarbons (TRHs), perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA).

The concentrations of contaminants in sediments were compared against the EQG (Table 3, EPA 2017):

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

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

There are no EQG values for selenium.

The median concentrations of arsenic, chromium, copper, lead, mercury and zinc in both sampling areas, the Kwinana Bulk Terminal and Kwinana Bulk Jetty, were below the relevant EQG values (Table 26).

In the Kwinana Bulk Jetty sampling area, the copper concentration at site KBJ2 was above the EQG value, but below the re-sampling trigger value. Elevated cadmium concentrations were reported in the sediment at sites KBJ1 and 2, with the median concentration of cadmium in the sampling area above the EQG, but below the re-sampling trigger value. A slightly elevated concentration of mercury was recorded in one of the Kwinana Bulk Jetty samples (KBJ1).

After normalisation to 1% total organic carbon[14], median concentrations of TBT in the Kwinana Bulk Terminal samples were below the EQG value (Table 26). Elevated concentrations of TBT were recorded in one Kwinana Bulk Terminal sample (KBT3) and all three Kwinana Bulk Jetty samples. The TBT concentrations in these samples were below the EQG re-sampling trigger value.

There are no ECG values for the TBT breakdown products DBT or MBT. Two of the three Kwinana Bulk Terminal samples (KBT1 and 2) had a Butylin Degradation Index (BDI) greater than one (Table 26), suggesting that the TBT originally deposited in this area had been degraded into DBT and MBT. The BDI for the Kwinana Bulk Jetty samples were below one as a result of the elevated TBT concentrations in this sampling area.

The median concentrations of PAHs reported for all KBT and KBJ sites were below the relevant EQG values (Table 27). The concentrations of PAHs in most samples were below the analytical limit of reporting, except for KBJ1. The PAH concentrations reported for KBJ1 exceeded the relevant EQG values, except for acenaphthelene, dibenzo(a,b)anthracene and naphthalene which were below the analytical limits of reporting.

There are no EQG values for TRHs (Table 27). The concentrations of TRHs were below the analytical limit of reporting for all of the sites except KBJ2 and 3. The concentrations of PFOS and PFOA were below the analytical limit of reporting at all sites.

[14] Consistent with the reference document (EPA 2017), where total organic carbon concentrations were within the range of 0.5% to 10%, the concentrations of organometallic/organic contaminants were normalised to 1% organic carbon before assessing against the EQG. Note that contaminant concentrations less than the analytical limit of reporting were not normalised.

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

Chemical (milligrams per kilogram [mg/kg])	Environmental quality criteria		Kwinana Bulk Terminal				Kwinana Bulk Jetty			
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median
Metals										
Arsenic	20	70	8.3	7.4	7.2	7.4	6.1	6.3	2.9	6.1
Cadmium	1.5	10	0.2	0.1	0.1	0.1	**4.1**	**2.6**	0.4	**2.6**
Chromium	80	370	30	26	11	26	26	17	13	17
Copper	65	270	29	46	26	29	34	**78**	21	34
Lead	50	220	14	15	8	14	12	4	4	4
Mercury	0.15	1	0.14	0.12	<0.02	0.12	**0.16**	0.07	0.07	0.07
Selenium	-	-	0.47	0.41	0.12	0.41	0.54	0.48	0.48	0.48
Zinc	200	410	71	49	44	49	100	39	29	39
Organotins (µg Sn/kg normalised to 1% TOC)										
Tributyltin	5	70	0.4	1.3	9.3	1.3	25.5	15.18	14.15	15.18
Dibutyltin	-	-	0.6	1.1	2.9	1.1	5.4	3.7	5.1	5.1

Chemical (milligrams per kilogram [mg/kg])	Environmental quality criteria		Kwinana Bulk Terminal				Kwinana Bulk Jetty			
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median
Monobutyltin	-	-	0.3	0.5	1.9	0.5	0.7	0.8	0.6	0.6
Butylin Degradation Index (BDI)	-	-	2.3	1.2	0.5	-	0.2	0.3	0.4	-

Table 27: Assessment of toxicants (organics) in sediment collected from sites around the Kwinana Bulk Terminal (KBT) and the Kwinana Bulk Jetty (KBJ) against the EQG and the re-sampling trigger for 'toxicants in sediments'.

Chemical (milligrams per kilogram [mg/kg])	Environmental quality criteria		Kwinana Bulk Terminal				Kwinana Bulk Jetty			
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median
Organics (mg/kg normalised to 1% TOC)										
Acenaphthene	0.016	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Acenaphthelene	0.044	0.64	<0.1	<0.1	<0.1	<0.1	**0.1**	<0.1	<0.1	<0.1
Anthracene	0.085	1.1	<0.1	<0.1	<0.1	<0.1	**0.3**	<0.1	<0.1	<0.1
Benzo(a)anthracene	0.261	1.6	<0.1	<0.1	<0.1	<0.1	**0.5**	<0.1	<0.1	<0.1
Benzo(a)pyrene	0.43	1.6	<0.1	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	<0.1
Chrysene	0.384	2.8	<0.1	<0.1	<0.1	<0.1	**0.8**	<0.1	<0.1	<0.1
Dibenzo(a,h)anthracene	0.063	0.26	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fluoranthene	0.6	5.1	<0.1	<0.1	<0.1	<0.1	**1.9**	<0.1	<0.1	<0.1
Fluorene	0.019	0.54	<0.1	<0.1	<0.1	<0.1	**0.1**	<0.1	<0.1	<0.1
Naphthalene	0.16	2.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Phenathrene	0.24	1.5	<0.1	<0.1	<0.1	<0.1	**0.9**	<0.1	<0.1	<0.1

Chemical (milligrams per kilogram [mg/kg])	Environmental quality criteria		Kwinana Bulk Terminal				Kwinana Bulk Jetty			
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median
Pyrene	0.665	2.6	<0.1	<0.1	<0.1	<0.1	**1.0**	<0.1	<0.1	<0.1
Total recoverable hydrocarbons (C10–C36)	-	-	<250	<250	<250	<250	<250	270	310	270
Total perfluorooctane sulfonate	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Total perfluorooctanoic acid	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002

2.9 Conclusion

With respect to nutrient enrichment, the results from the 2019–20 monitoring programs in Cockburn Sound indicate a low risk that the environmental quality objective ***Maintenance of ecosystem integrity*** is not being achieved in most of Cockburn Sound.

2.9.1 Low concentrations of dissolved oxygen

From December 2019 to March 2020, the 'DO concentration' EQG was not met at 10 of the 18 water quality monitoring sites in Cockburn Sound on one or more occasions. There were no reports of deaths of marine species in Cockburn Sound during this period. It is not known if low oxygen concentrations occur at other times of the year in Cockburn Sound and adjacent marine areas. A fish kill notification was issued in May 2020 for Safety Bay, Rockingham where a number of eels and juvenile crabs were reported dead or dying. The cause of the deaths could not be determined. As the event fell outside the Cockburn Sound water monitoring period, no water quality monitoring data were available (which may have otherwise supported the investigation of the deaths).

A key recommendation in the Expert Advisory Panel's *Review of the Cockburn Sound water quality monitoring programs* (2017) was the deployment of telemetered water quality monitoring instruments to provide real-time, continuous monitoring of Cockburn Sound. DWER deployed a network of telemetered, continuous water quality monitoring instruments in Cockburn Sound in November 2020. The network will allow for the timely detection of environmental changes, such as those associated with algal blooms or pollution events that may kill marine organisms.

2.9.2 Declines in seagrass shoot densities

While there have been improvements in nutrient concentrations in the water in Cockburn Sound, seagrass shoot densities have continued to decline at some sites (Appendix D). Environmental factors other than a nutrient-enrichment-related reduction in light availability at the seafloor are likely to be contributing to the seagrass decline or lack of recovery in Cockburn Sound.

Garden Island seagrasses are highly impacted by sediment sulfides (Fraser & Kendrick 2017) and may be vulnerable to sediment stressors (Olsen *et al.* 2018). Sulfide oxidisers have been shown to potentially help seagrasses detoxify sulfides (Martin *et al*. 2019, 2020). Further research investigating interactions between seagrasses and sediment conditions, including associated microbial communities, may help to explain annual changes in shoot density.

2.9.3 Warnbro Sound reference sites

Water quality reference sites

Warnbro Sound was selected as a reference site for Cockburn Sound due to its good water quality and independence from Cockburn Sound – water mixing between the sounds is limited (EPA 2017). However, the EQG for chlorophyll *a* have been increasing over time, reflecting an increased occurrence of higher chlorophyll *a* concentrations at the reference site in the central basin of Warnbro Sound. This has had the effect of increasing the trigger for investigation of elevated chlorophyll *a* concentrations in Cockburn Sound. The causes of this change in chlorophyll *a* concentrations at the reference site are not clear and require further investigation.

Seagrass reference sites

Seagrass shoot densities have been declining at the shallow (less than 4 m) seagrass reference sites within Warnbro Sound for several years (Lavery & McMahon 2011; Mohring & Rule 2013; Rule 2015; Fraser et al. 2018, 2019; Martin *et al.* 2020). No seagrass has been recorded in any transect at Warnbro Sound site 2.0 m for the past three consecutive years and 40% of quadrats at Warnbro Sound site 3.2 m had zero counts in the 2020 survey (Martin *et al.* 2020). The declines in shoot density in Warnbro Sound are likely a result of high sediment accretion.

These continuing declines in seagrass shoot densities at the Warnbro Sound seagrass reference sites mean these sites are no longer suitable to assess Cockburn Sound seagrass health. Alternative seagrass reference sites will need to be investigated for future seagrass health surveys.

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*** and ***Maintenance of aquaculture***. The EQC for these environmental quality objectives set a level of environmental quality to ensure a low risk of any effect on human health from the consumption of seafood and the health and productivity of aquaculture species (EPA 2017).

Protecting wild seafood populations from the effects of environmental contamination is maintained through the EQC for 'maintenance of ecosystem integrity' (EPA 2017).

3.2 Water quality and seafood monitoring

For filter-feeding shellfish (excluding scallops and pearl oysters), any assessment against the environmental quality objective must use data collected from a comprehensive monitoring program consistent with the requirements of the *Western Australia Shellfish Quality Assurance Program operations manual* (WASQAP operations manual; Department of Health 2017). The WASQAP operations manual sets out the requirements for bacteriological monitoring (water and shellfish), phytoplankton and shellfish biotoxin monitoring, and the chemical analysis of shellfish in the shellfish growing areas in Cockburn Sound (Figure 11). Sampling over the 2019–20 monitoring period was undertaken by Blue Lagoon Mussels as part of the WASQAP and administered by the Department of Health (DoH).

Between July 2019 and June 2020, water samples for bacteriological monitoring were collected on six occasions from five sites (SF6, SF8, SF9, SF10, SF11) in the Southern Flats harvesting area[15] and 11 occasions from five sites (KGT1, KGT2, KGT3, KGT4, KGT5) in the Kwinana Grain Terminal harvesting area.[16] Shellfish samples were also collected for bacteriological testing on 11 occasions from two Kwinana Grain Terminal sites (North and South) and on six occasions from one Southern Flats site. Samples were analysed by PathWest Laboratory.

Depth-integrated water samples for phytoplankton identification and enumeration were collected about twice monthly on scheduled dates (during periods when shellfish were being harvested) at one of the Kwinana Grain Terminal sites (KGT3) and one of the Southern Flats sites (SF11). Samples were collected from as close to the shellfish as possible and at the location where shellfish samples for flesh testing were taken. The samples were analysed by Dalcon Environmental for specific groups of phytoplankton species known to potentially produce toxins that may be concentrated in shellfish. Composite samples of shellfish flesh were also collected for biotoxin testing in case the potentially toxic phytoplankton counts exceeded the 'alert'

[15] Harvesting area classified as 'approved' under the WASQAP operations manual.

[16] Harvesting area classified as 'conditionally approved' under the WASQAP operations manual.

level to initiate flesh testing for biotoxins for the particular species.

In addition, shellfish flesh samples were collected for routine screening for amnesic shellfish poisoning (ASP), diarrhoetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP) biotoxins following the *Marine biotoxin monitoring and management plan* (Department of Health 2016). Ten shellfish flesh samples were collected between September 2019 and June 2020 at the Kwinana Grain Terminal harvesting area. Twelve shellfish flesh samples were collected between July 2019 and June 2020 at the Southern Flats harvesting area, including an additional sample on 11 May 2020.

Source: Department of Health (2017)

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

Figure 11: Sampling locations near shellfish harvesting areas in Cockburn Sound.

Fremantle Ports undertook analysis of toxicants in mussels at three sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3; Figure 2) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3; Figure 2). A minimum of 15 mussels of uniform size (about 55–90 mm shell length) were collected on 31 March 2020 from lines with baskets suspended about 1 m below the water surface: these were deployed on 19 February 2020 for six weeks. Mussel samples were analysed for metals (inorganic arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (tributyltin [TBT], dibutyltin [DBT] and monobutyltin [MBT]) and polycyclic aromatic hydrocarbons (PAHs). Analyses for metals, organotins and PAHs were undertaken by ChemCentre.

3.3 Assessment against the 'seafood safe for human consumption' environmental quality criteria

3.3.1 Assessment of compliance with the 'faecal pathogens in water' EQC

Thermotolerant coliform concentrations (expressed as Colony Forming Units/100 millilitres [CFU/100 mL]) recorded at five sites in each of the harvesting areas in Cockburn Sound over the 2019–20 monitoring period were assessed against the 'faecal pathogens in water' EQG (EQG A, Table 4, EPA 2017):

> *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.*

See Table 28 for the results of the assessment against the EQG. Both components of the 'faecal pathogens in water' EQG were met at all sites in the Kwinana Grains Terminal and Southern Flats harvesting areas during the 2019–20 monitoring period.

Table 28: Assessment of thermotolerant (faecal) coliforms in water samples collected from five sites in each of the two shellfish harvesting areas in Cockburn Sound between July 2019 and June 2020 against the 'faecal pathogens in water' EQG.

Site	Median faecal coliform concentration (CFU/100 mL)	90th percentile faecal coliform concentration (CFU/100 mL)	Assessment
EQG	Median faecal coliform concentration ≤ 14 CFU/100 mL	90th percentile ≤ 21 CFU/100 mL	
KGT1	1.0	1.0	EQG met
KGT2	1.0	1.0	EQG met
KGT3	1.0	1.0	EQG met
KGT4	1.0	1.0	EQG met
KGT5	1.0	1.0	EQG met
SF6	1.0	1.5	EQG met
SF8	1.0	1.0	EQG met
SF9	1.0	1.0	EQG met

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	
SF10	1.0	1.0	EQG met
SF11	1.0	1.0	EQG met

3.3.2 Assessment of compliance with the ‘algal biotoxins’ EQC

Concentrations of toxic phytoplankton recorded in the two harvesting areas in Cockburn Sound over the 2019–20 monitoring period were assessed against the ‘algal biotoxins’ EQG (Table 29). The ‘algal biotoxins’ EQG are the phytoplankton ‘alert’ levels that trigger management action identified in the WASQAP *Marine biotoxin monitoring and management plan 2016* (Department of Health 2016)

Table 29: The phytoplankton levels that trigger management action.

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

Type of toxin	Phytoplankton species	Alert level (cells/litre) (notify Department of Health)	Alert level (cells/litre) (initiate flesh testing)
	Karenia/Karlodinium/Gymnodinium group	100,000	250,000

See

Table 30 for the results of the assessment against the EQG. The ‘algal biotoxins’ EQG was met on all sampling occasions in the Kwinana Grain Terminal and Southern Flats shellfish harvesting areas between July 2019 and June 2020, except for 11 and 18 May 2020.

Table 30: Assessment of phytoplankton concentrations in water samples collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2019 and June 2020 against the 'algal biotoxins' EQG.

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	**Toxic algae recorded**	**Cell density (cells/L)**	**Cell density (cells/L)**
08/07/2019	*Pseudo-nitzschia* delicatissima group	3,240	2,820
22/07/2019	*Pseudo-nitzschia* seriata group	1,010	630
12/08/2019	No toxic algae detected	-	-
26/08/2019	No toxic algae detected	-	-
9/09/2019	*Pseudo-nitzschia* seriata group	3,300	4,075
23/09/2019	No toxic algae detected	-	-
10/10/2019	No toxic algae detected	-	-
28/10/2019	No toxic algae detected	-	-
11/11/2019	No toxic algae detected	-	-
25/11/2019	*Dinophysis miles* group	10	Not detected
	Dinophysis caudata pediculata group	10	Not detected
2/12/2019	*Dinophysis rotundatum* group	10	10
	Dinophysis rhathymum group	10	Not detected
16/12/2019	*Pseudo-nitzschia* delicatissima group	3,310	2,780
6/01/2020	*Pseudo-nitzschia* delicatissima group	140	170
	Pseudo-nitzschia seriata group	30	80
	Prorocentrum rhathymum group	30	10
28/01/2020	*Pseudo-nitzschia* delicatissima group	32,700	1,240
	Alexandrium group	30	10
	Dinophysis acuminata group	30	20
	Prorocentrum rhathymum group	10	20
10/02/2020	*Pseudo-nitzschia* delicatissima group	225,600	234,400

Site		Kwinana Grain Terminal	Southern Flats
Sampling date	**Toxic algae recorded**	**Cell density (cells/L)**	**Cell density (cells/L)**
	Pseudo-nitzschia seriata group	16,400	24,800
24/02/2020	*Pseudo-nitzschia* delicatissima group	810	200
9/03/2020	*Pseudo-nitzschia* delicatissima group	1,230	1,310
	Pseudo-nitzschia seriata group	780	920
23/03/2020	*Pseudo-nitzschia* delicatissima group	431,000	398,000
	Pseudo-nitzschia seriata group	40,200	43,900
14/04/2020	*Pseudo-nitzschia* delicatissima group	220	Not detected
	Dinophysis acuminata group	10	10
28/04/2020	*Pseudo-nitzschia* delicatissima group	1,400	2,400
	Dinophysis caudata group	40	10
11/05/2020	*Dinophysis caudata* group	**1,700**	**900**
	Prorocentrum rhathymum group	100	Not detected
	Pseudo-nitzschia delicatissima group	13,900	2,800
18/05/2020	*Dinophysis caudata* pediculata group	**700**	**600**
27/05/2020	*Dinophysis caudata* group	80	170
	Pseudo-nitzschia delicatissima group	4,500	2,700
	Pseudo-nitzschia seriata group	500	Not detected
2/06/2020	*Dinophysis acuminata* group	10	Not detected
	Dinophysis caudata pediculata group	80	70
	Prorocentrum lima	10	Not detected
22/06/2020	*Pseudo-nitzschia* delicatissima group	6,900	250
	Pseudo-nitzschia seriata group	300	Not detected
Assessment	EQG was met at Kwinana Grain Terminal and Southern Flats shellfish harvesting areas on all sampling occasions except for 11 and 18 May 2020.		

Under WASQAP, routine monthly biotoxin screening was introduced in 2015 for all harvesting areas. All the samples for Cockburn Sound in the 2019–20 reporting period were negative for PSP, DSP and ASP biotoxins (Table 31).

Table 31: Results of monthly biotoxin screening in the 2019–20 reporting period.

Sampling date	Amnesic shellfish poison (ASP)		Diarrhoetic shellfish poison (DSP)		Paralytic shellfish poison (PSP)	
	EQS: < 20 mg/kg		EQS: < 0.2 mg/kg		EQS: < 0.8 mg/kg Saxitoxin equivalents	
	Kwinana Grain Terminal	Southern Flats	Kwinana Grain Terminal	Southern Flats	Kwinana Grain Terminal	Southern Flats
8/07/2019	Negative	Negative	Negative	Negative	Negative	Negative
9/09/2019	Negative	Negative	Negative	Negative	Negative	Negative
10/10/2019	Negative	Negative	Negative	Negative	Negative	Negative
11/11/2019	Negative	Negative	Negative	Negative	Negative	Negative
2/12/2019	Negative	Negative	Negative	Negative	Negative	Negative
6/01/2020	Negative	Negative	Negative	Negative	Negative	Negative
10/02/2020	Negative	Negative	Negative	Negative	Negative	Negative
9/03/2020	Negative	Negative	Negative	Negative	Negative	Negative
14/04/2020	Negative	Negative	Negative	Negative	Negative	Negative
11/05/2020	Negative	Negative	Negative	Negative	Negative	Negative
8/06/2020	Negative	Negative	Negative	Negative	Negative	Negative

3.3.3 Assessment of compliance with the '*Escherichia coli* (*E. coli*) in shellfish flesh' EQS

Escherichia coli (*E. coli*) counts (expressed as Most Probable Number per gram [MPN/g]) recorded in the flesh of mussels collected at each of the sites in the harvesting areas in Cockburn Sound over the 2019–20 monitoring period were assessed against the '*E. coli* in shellfish flesh' EQS (EQS B, Table 4, EPA 2017):

> *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.*

See

Table 32 for the results of the assessment against the EQS. Both components of the EQS were met in both harvesting areas over the 2019–20 monitoring period.

Table 32: Assessment of E. coli counts in mussel flesh collected from sites in the two shellfish harvesting areas in Cockburn Sound between July 2019 and June 2020 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			
8/07/2019	1.8	1.8	1.8	EQS met
9/09/2019	1.8	1.8	1.8	EQS met
10/10/2019	1.8	1.8	-	EQS met
11/11/2019	1.8	1.8	1.8	EQS met
18/11/2019	1.8	1.8	-	EQS met
25/11/2019	1.8	1.8	-	EQS met
2/12/2019	1.8	1.8	-	EQS met
16/12/2019	1.8	1.8	-	EQS met
6/01/2020	1.8	1.8	1.8	EQS met
9/03/2020	1.8	1.8	1.8	EQS met
11/05/2020	2.0	2.0	1.8, 2.0	EQS met

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

3.3.4 Assessment of compliance with the 'chemical concentration in seafood flesh' EQC

Concentrations of chemicals in mussel flesh were assessed against the 'chemical concentration in seafood flesh' EQG (EQG C, Table 4, EPA 2017):

> *Median chemical concentration in the flesh of seafood should not exceed the environmental quality guidelines:*
>
> *Copper 30 mg/kg (molluscs)*
>
> *Selenium 1.0 mg/kg (molluscs)*
>
> *Zinc 290 mg/kg (oysters).*

Concentrations were also assessed against the 'chemical concentration in seafood flesh' EQS (EQS D, EQS E and EQS F, Table 4, EPA 2017):

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

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

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

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

Pesticide residue concentrations in the flesh of seafood should not exceed the maximum residue limits and extraneous residue limits in Schedules 20 and 21 respectively of the Australia New Zealand Food Standards Code.[17]

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

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

Table 33: Assessment of chemicals in mussels collected at sites in Cockburn Sound against the 'chemical concentration in seafood flesh' EQC.

Chemical (mg/kg)	Environmental quality criteria (mg/kg)		Kwinana Bulk Terminal (mg/kg)				Kwinana Bulk Jetty (mg/kg)				Kwinana Grain Terminal (mg/kg)	Southern Flats (mg/kg)
	EQG	EQS	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median		
Metals												
Arsenic (total)	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (inorganic)[1]	-	1.0	0.28	0.18	0.23	0.23	0.21	0.20	0.18	0.21	<0.05	<0.05
Cadmium	-	2.0	0.09	0.1	0.1	0.1	0.1	0.1	0.11	0.1	0.18	0.19
Chromium	-	-	0.56	0.1	0.11	0.11	0.09	0.1	0.1	0.1	Not measured	
Copper	30	-	1.60	0.72	0.98	0.72	0.80	0.91	0.76	0.80	0.73	0.73
Lead	-	2.0	0.10	0.08	0.07	0.08	0.08	0.07	0.07	0.07	0.1	< 0.1
Mercury	-	0.5 (mean level)	< 0.01	0.01	< 0.01	< 0.01	0.01	< 0.01	0.01	0.01	0.009	0.008
Selenium	1.0	-	0.34	0.41	0.39	0.39	0.45	0.42	0.40	0.42	Not measured	
Zinc (EQG for oysters)	290	-	15	22	24	22	21	23	25	23	24	27

Chemical (mg/kg)	Environmental quality criteria (mg/kg)		Kwinana Bulk Terminal (mg/kg)				Kwinana Bulk Jetty (mg/kg)				Kwinana Grain Terminal (mg/kg)	Southern Flats (mg/kg)
	EQG	EQS	KBT1	KBT2	KBT3	Median	KBJ1	KBJ2	KBJ3	Median		
Tributyltin	-	-	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	Not measured	
Organics												
Polychlorinated biphenyls (PCBs) (fish)	-	0.5	Not measured				Not measured				Not measured	
Polycyclic aromatic hydrocarbons (PAHs)	-	-	All below limits of reporting				All below limits of reporting				Not measured	

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 & Turnbull 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 (DO) 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 2019–20 non river-flow period (Section 2.3; Figure 2) were assessed against the 'physical-chemical stressors' EQG (EQG A, Table 5, EPA 2017):

> *The median of the sample concentrations from the defined sampling area on each sampling occasion over the 2019–20 non river-flow period should meet the following environmental quality guideline values:*

Dissolved oxygen	≥ *5* mg/L
pH	*6–9.*

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

See tables 34 and 35 for the results. Median DO concentrations and pH of surface waters and at depth in the defined sampling area met the relevant EQG on all sampling occasions over the 2019–20 non river-flow period.

Table 34: Assessment of dissolved oxygen concentrations in surface waters and at depth, measured at four sites adjacent to the shellfish harvesting areas in Cockburn Sound over the 2019–20 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])	2/12/2019	7.1	7.0	7.5	7.3	7.2	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	9/12/2019	6.9	6.8	7.1	7.0	7.0		
	16/12/2019	7.0	6.7	7.0	7.0	7.0		
	23/12/2019	6.6	6.5	6.7	6.7	6.7		
	6/01/2020	6.9	7.0	7.2	7.0	7.1		
	13/01/2020	6.8	6.7	6.8	7.0	6.8		
	20/01/2020	6.8	6.4	6.9	6.7	6.8		
	28/01/2020	6.8	6.8	6.7	6.9	6.8		
	3/02/2020	6.6	6.4	6.8	6.7	6.7		
	10/02/2020	6.7	6.6	6.4	6.6	6.6		
	17/02/2020	6.5	6.4	6.3	6.6	6.5		
	24/02/2020	6.5	6.4	6.5	6.5	6.5		
	2/03/2020	6.5	6.4	6.6	6.6	6.6		
	9/03/2020	6.7	6.5	6.7	6.9	6.7		
	16/03/2020	6.6	6.6	6.6	6.6	6.6		
	30/03/2020	6.6	6.5	6.3	6.5	6.5		
Depth waters dissolved oxygen (mg/L)	2/12/2019	6.6	7.0	6.9	6.9	6.9	≥ 5 mg/L	EQG met on all sampling occasions and at all sites
	9/12/2019	6.8	6.8	6.5	6.7	6.8		
	16/12/2019	6.5	6.8	6.7	6.7	6.7		
	23/12/2019	6.6	6.4	5.9	6.0	6.2		
	6/01/2020	5.6	6.0	6.5	5.8	5.9		

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
	13/01/2020	6.3	6.6	6.3	6.3	6.3		
	20/01/2020	6.6	6.5	6.3	6.7	6.6		
	28/01/2020	6.1	5.9	6.2	5.7	6.0		
	3/02/2020	6.1	6.0	6.4	6.0	6.1		
	10/02/2020	6.5	6.6	6.3	6.5	6.5		
	17/02/2020	6.3	6.4	5.7	6.5	6.4		
	24/02/2020	5.7	6.0	5.9	6.1	6.0		
	2/03/2020	6.5	6.4	6.7	6.5	6.5		
	9/03/2020	6.7	6.4	6.1	6.7	6.6		
	16/03/2020	6.5	6.0	6.0	5.5	6.0		
	30/03/2020	6.4	6.4	5.8	5.2	6.1		

Table 35: Assessment of pH in surface waters and at depth, measured at four sites adjacent to the shellfish harvesting areas in Cockburn Sound over the 2019–20 non river-flow period against the 'physico-chemical stressors' EQG.

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
Surface waters pH	2/12/2019	8.2	8.2	8.2	8.2	8.2	6–9	EQG met on all sampling occasions and at all sites
	9/12/2019	8.2	8.2	8.2	8.2	8.2		
	16/12/2019	8.1	8.1	8.1	8.1	8.1		
	23/12/2019	8.2	8.1	8.2	8.2	8.2		
	6/01/2020	8.2	8.2	8.2	8.2	8.2		
	13/01/2020	-	-	-	-	-		
	20/01/2020	-	-	-	-	-		
	28/01/2020	-	-	-	-	-		
	3/02/2020	8.2	8.2	8.2	8.2	8.2		
	10/02/2020	8.2	8.2	8.2	8.2	8.2		
	17/02/2020	8.2	8.2	8.1	8.2	8.2		
	24/02/2020	8.1	8.1	8.1	8.1	8.1		
	2/03/2020	8.2	8.2	8.1	8.2	8.2		
	9/03/2020	8.2	8.2	8.2	8.2	8.2		
	16/03/2020	8.2	8.2	8.2	8.2	8.2		
	30/03/2020	8.2	8.2	8.2	8.2	8.2		
Depth waters pH	2/12/2019	8.1	8.2	8.2	8.1	8.2	6–9	EQG met on all sampling occasions and at all sites
	9/12/2019	8.1	8.2	8.2	8.2	8.2		
	16/12/2019	8.1	8.1	8.1	8.1	8.1		
	23/12/2019	8.1	8.1	8.1	8.1	8.1		
	6/01/2020	8.2	8.2	8.2	8.2	8.2		
	13/01/2020	-	-	-	-	-		

Indicator	Sampling date	Sites adjacent to shellfish harvesting areas				Assessment against EQG		
		CS9A	CS10N	CS11	CS13	Sampling occasion median	EQG	Assessment
	20/01/2020	-	-	-	-	-		
	28/01/2020	-	-	-	-	-		
	3/02/2020	8.2	8.2	8.2	8.2	8.2		
	10/02/2020	8.2	8.2	8.2	8.2	8.2		
	17/02/2020	8.2	8.2	8.1	8.2	8.2		
	24/02/2020	8.1	8.1	8.1	8.1	8.1		
	2/03/2020	8.2	8.2	8.2	8.2	8.2		
	9/03/2020	8.2	8.1	8.1	8.2	8.2		
	16/03/2020	8.2	8.1	8.1	8.1	8.1		
	30/03/2020	8.2	8.2	8.1	8.2	8.2		

3.4.2 Assessment of compliance with the 'toxicants' EQG

Concentrations of ammonia and nitrate–nitrite measured at four water quality monitoring sites close to the shellfish harvesting areas in Cockburn Sound (CS9A, CS10N, CS11 and CS13) over the 2019–20 non river-flow period (Section 2.3; Figure 2) were assessed against the 'toxicants' EQG for the maintenance of aquaculture production (EQG B, Table 5, EPA 2017). 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) on one occasion on 29 January 2020 (Section 2.3; Figure 2) were also assessed against the 'toxicants' EQG for the maintenance of aquaculture production.

The reference document (EPA 2017) (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, ammonia and nitrate–nitrite in water samples collected at each of the Kwinana Bulk Terminal and Kwinana Bulk Jetty sites were assessed against the relevant 'toxicants' EQG values.

The toxicant concentrations recorded at all the sites were below the relevant EQG values (

Table 36).

Table 36: Assessment of concentrations of ammonia, nitrate–nitrite and copper at sites near the shellfish harvesting areas in Cockburn Sound against the 'toxicants' EQG.

<table>
<tr><th rowspan="2">Site</th><th colspan="3">Ammonia (µg N/L)</th><th colspan="3">Nitrate–Nitrite (µg N/L)</th><th colspan="2">Copper (µg/L)</th></tr>
<tr><th>EQG</th><th>Surface</th><th>Bottom</th><th>EQG</th><th>Surface</th><th>Bottom</th><th>EQG</th><th>Surface</th></tr>
<tr><td>KBT1</td><td rowspan="12">≤1,000</td><td>8</td><td>< 3</td><td rowspan="12">Nitrite-N ≤100
Nitrate-N ≤100,000</td><td>4</td><td>< 2</td><td rowspan="12">≤5</td><td>0.4</td></tr>
<tr><td>KBT2</td><td>< 3</td><td>12</td><td>< 2</td><td>< 2</td><td>0.4</td></tr>
<tr><td>KBT3</td><td>4</td><td>< 3</td><td>3</td><td>< 2</td><td>0.4</td></tr>
<tr><td>KBJ1</td><td>< 3</td><td>8</td><td>< 2</td><td>< 2</td><td>0.3</td></tr>
<tr><td>KBJ2</td><td>< 3</td><td>6</td><td>< 2</td><td>< 2</td><td>0.3</td></tr>
<tr><td>KBJ3</td><td>< 3</td><td>< 3</td><td>< 2</td><td>< 2</td><td>0.3</td></tr>
<tr><td>CS13</td><td>2.0</td><td>13.0</td><td>1</td><td>13</td><td>Not measured</td></tr>
<tr><td>CS9A</td><td colspan="2">95th percentile = 3.2</td><td colspan="2">95th percentile = 2</td><td>Not measured</td></tr>
<tr><td>CS10N</td><td colspan="2">95th percentile = 9.4</td><td colspan="2">95th percentile = 3</td><td>Not measured</td></tr>
<tr><td>CS11</td><td colspan="2">95th percentile = 3.1</td><td colspan="2">95th percentile = 2</td><td>Not measured</td></tr>
</table>

3.5 Conclusions

Based on the results from the 2019–20 monitoring programs in Cockburn Sound, there is a high degree of certainty that the environmental quality objectives ***Maintenance of seafood safe for human consumption*** and ***Maintenance of aquaculture*** have been achieved in the 'approved' and 'conditionally approved' shellfish harvesting areas in southern Cockburn Sound. There is no information available from other areas in Cockburn Sound or for wild shellfish or fish.

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

4. Environmental value: Recreation and Aesthetics

4.1 Environmental quality objectives

The environmental quality objectives for the environmental value **Recreation and Aesthetics** are:

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

The EQC for these environmental quality objectives set a level of environmental quality that will ensure:

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

4.2 Water quality monitoring

The cities of Cockburn, Kwinana and Rockingham undertook bacterial water sampling at several popular recreational beaches (program sites) around Cockburn Sound during the 2019–20 monitoring period (Figure 12). DoH administered the program and encouraged the minimum collection of 65 samples between November and early May (the time of year when most people participate in recreational activities) over five consecutive years. This was based on its revised approach to the National Health and Medical Research Council's (2008) recommendation of 100 samples collected over five consecutive years. The minimum of 65 samples is equivalent to 13 samples per season (equivalent to about one sample collected each fortnight). This minimum number of samples maintains statistical confidence when assigning a site classification (beach grades) following the National Health and Medical Research Council (2008) guidelines.[18]

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

[18] For more information on beach grades go to DoH's website: ww2.health.wa.gov.au/Articles/A_E/Beach-grades-for-Western-Australia

less samples per season).

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

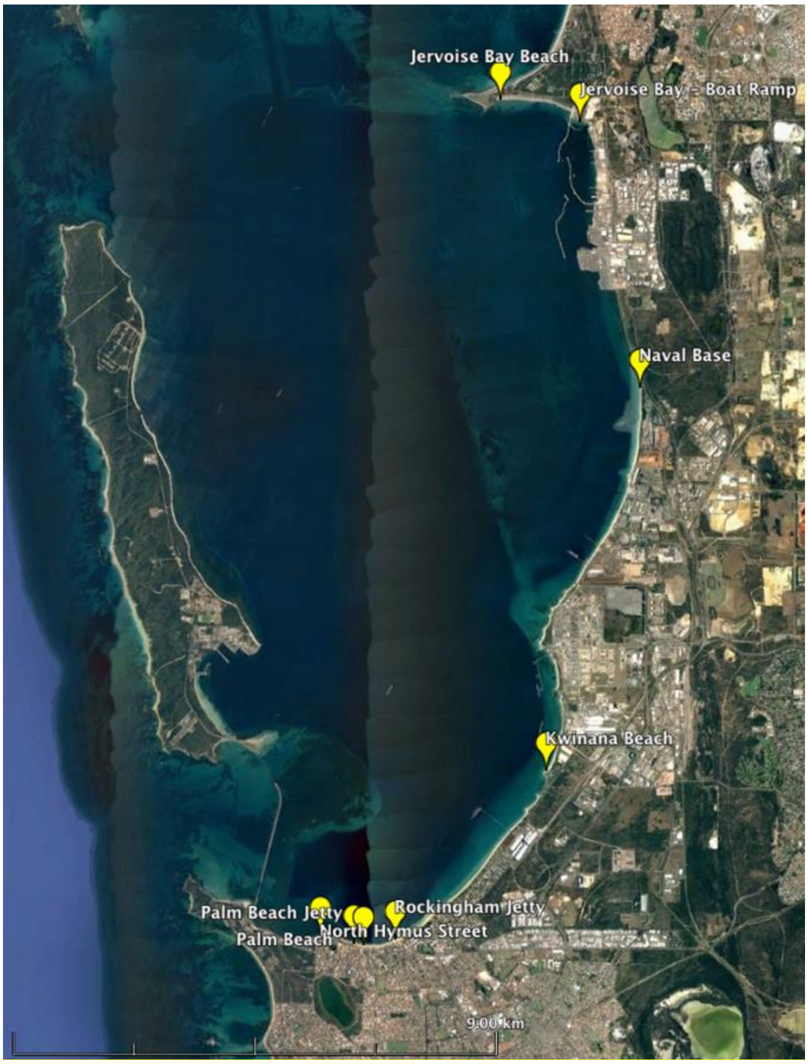


Figure 12: Sampling locations near recreational beaches in Cockburn Sound.

4.3 Assessment against the 'maintenance of primary and secondary contact recreation' environmental quality criteria

4.3.1 Assessment of compliance with the 'faecal pathogens' EQG

Enterococci counts (expressed as Most Probable Number per 100 millilitres [MPN/100 mL]) recorded at each of eight locations around Cockburn Sound over the 2019–20 monitoring period were assessed against the 'faecal pathogens' EQG for primary-contact recreation (EQG A, Table 6, EPA 2017):

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

Enterococci counts were also assessed against the 'faecal pathogens' EQG for secondary-contact recreation (EQG A, Table 7, EPA 2017):

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

The 'faecal pathogens' EQG for both primary- and secondary-contact recreation were met at all of the sites monitored over the 2019–20 monitoring period (see Table 37 for the results).

Table 37: Assessment of the 95th percentile of enterococci counts (samples collected between 2015–16 and 2019–20) at eight locations around Cockburn Sound against the 'faecal pathogens' EQG.

Location	Type of site	No. of measurements	EQG		Rolling 5-year 95th percentile of enterococci counts (MPN/100 ml)
			Primary contact	Secondary contact	
North Hymus Street[1]	Program	54	200	2,000	70
Jervoise Bay Beach[1]	Program	59			32
Rockingham Beach + Jetty[1]	Program	42			34
Palm Beach Jetty[1]	Program	50			6
Naval Base[1]	Program	22			2
Kwinana Beach[1]	Program	22			30
Jervoise Bay Boat Ramp[1]	Non-core	61			20
Palm Beach[1]	Non-core	39			135
Assessment		Primary-contact and secondary-contact recreation EQG met at all sites			

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

Note: The 95th percentiles were calculated using DoH's Enterotester V200. The Enterotester is a Microsoft® Excel template predicated on a risk management approach to recreational water surveillance (Lugg et al. 2012).

4.3.2. Assessment of compliance with the 'physical' EQG

Water clarity and pH were recorded at each of the 18 water quality monitoring sites over the 2019–20 non river-flow period (Section 2.3; Figure 2) and assessed against the 'physical' EQC for primary-contact recreation (EQG D and EQS E, Table 6, EPA 2017):

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.*[19]

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.*

The pH was also assessed against the ‘physical’ EQG for secondary contact recreation (EQG E, Table 7, EPA 2017):

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.*

Water clarity and pH met the relevant ‘physical’ EQC for primary and secondary contact recreation at all the sites (see Table 38 for the results).

Table 38: Assessment of pH and water clarity (Secchi disc) at 18 water quality monitoring sites in Cockburn Sound over the 2019–20 non river-flow period against the ‘physical’ EQC for primary and secondary contact recreation.

Site	pH EQC	Median pH (surface)	Median pH (bottom)	Water clarity EGG	Range of Secchi disc measurements (m ± 0.1 m)	Assessment
CS4	Not to exceed the range of 5–9 pH units	8.2	8.2	>1.6 m	4.5–14.0	EQC met at all sites
CS5		8.2	8.2		3.9–14.0	
CS6A		8.1	8.1		4.8–10.0	
CS7		8.1	8.1		2.9–10.5	
CS8		8.2	8.2		4.2–12.7	
CS9		8.2	8.1		3.9–9.4	
CS10N		8.2	8.1		4.3–10.5	
CS11		8.2	8.1		4.2–12.1	
CS12		8.2	8.1		4.0–10.2	
CS13		8.2	8.2		4.0–11.2	
CS9A		8.2	8.2		2.5–10.4	

[19] The former Office of the Environmental Protection Authority (now DWER) advised that it is reasonable to use vertical Secchi disc measurements in marine waters.

Site	pH EQC	Median pH (surface)	Median pH (bottom)	Water clarity EGG	Range of Secchi disc measurements (m ± 0.1 m)	Assessment
CB		8.2	8.1		4.0–9.6	
G1		8.2	8.2		3.4–9.8	
G2		8.2	8.2		4.6–9.6	
G3		8.2	8.2		5.5–12.4	
SF		8.2	8.2		5.1–10.3	
MB		8.2	8.2		3.4–10.1	
NH3		8.2	8.1		2.9–5.8	

4.3.3. Assessment of compliance with the ‘toxic chemicals’ EQC

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

4.4 Indicators of aesthetic quality

The community highly values the ecological, recreational and aesthetic attributes of Cockburn Sound and thus EQC have been developed to protect its aesthetic values (EPA 2017). Many of the guidelines for aesthetic quality are subjective and relate to the general appreciation and enjoyment of Cockburn Sound by the community as a whole. Additional factors are taken into account, such as whether the observations are of an intensity or in a location likely to trigger community concern and whether the impacts are transient, persistent or regular events.

Near each of the 18 water quality monitoring sites on each of the 16 sampling occasions during the December 2019 to March 2020 non river-flow period (Section 2.3; Figure 2), MAFRL made qualitative observations of the following indicators of aesthetic quality:

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

- odours.

See tables 39 (a) and (b) for the results.

Grain was observed on the water surface on six of the 16 water quality sampling days at several sites (i.e. sites MB, CB, CS9, CS9A, CS10N). A large plume of grain was observed at site CS9A on 16 December 2019.

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

Algal blooms were observed on 13 of the 16 water quality sampling days. The algal blooms were often visible down to the south-eastern parts of Cockburn Sound (Cossington & Wienczugow 2020). Phytoplankton scum was noted throughout the water quality sampling period. However, the scum was not associated with any significant algal blooms.

The pattern of persistent algal blooms within the Northern Harbour (site NH3) continued as observed in previous years (Cossington & Wienczugow 2020). The warmer water, reduced flushing and assimilation of nutrients in the Northern Harbour in the summer provide ideal conditions for algal blooms.

In response to the persistent and frequent algal blooms throughout Cockburn Sound, weekly phytoplankton samples were collected from integrated water samples at sites CS5, CS7, CS9, CS9A, CS13, CB, MB, G1 and G3 (Cossington & Wienczugow 2020). The phytoplankton samples were analysed by the Phytoplankton Ecology Unit (PEU) at DWER. The PEU analysis found very low counts of phytoplankton in the water samples.

These localised impacts to aesthetic quality require further studies to determine the extent to which they occur, both spatially and temporally.

Table 39 (a): Qualitative observations of indicators of aesthetic quality at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound over the 2019–20 non river-flow period.

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour variation	Surface films or oils	Surface or submerged debris	Odours
2/12/2019	CS9A, CS10N, NH3 (surface phytoplankton scum)	-	-	NH3	NH3	-	MB (grain, algae, seagrass)	CS12 (industrial odours)
9/12/2019	CS6A, CS7, CB, CS12, CS9, CS9A, CS13, CS11, G1, CS8 CS5, NH3 (surface phytoplankton scum)	CB, CS9A, NH3	-	CB, CS9A, NH3 (algal blooms)	CB, NH3 (very green)	CS9A	CB (grain, algae, seagrass)	-
16/12/2019	CS7, CB (surface phytoplankton scum)	-	-	-	-	-	CS9A (large grain plume); WSSB, WSS4 (seagrass)	-
23/12/2019	CS6A, CS7, CB, CS12, CS9, CS9A, CS13, CS11, G2, CS8, CS4, CS5, NH3 (surface phytoplankton scum)	CS9, CS9A, CS8, G2, CS4, CS5, NH3	-	CS9, CS9A, CS8, G2, CS4, CS5, NH3	CS9, CS9A, CS8, G2, CS4, CS5, NH3 (very green)	CS10 (floating foam)	CS10 (debris)	-
6/01/2020	CS9, CS9A,	CS9, CS9A,	-	CS9, CS9A,	CS9, CS9A,	-	-	-

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour variation	Surface films or oils	Surface or submerged debris	Odours
	NH3 (algal blooms)	NH3		NH3	NH3 (algal blooms)			
13/01/2020	CS7, CS9, CS9A, CS13, MB (surface phytoplankton scum); G1, NH3 (algal bloom)	G1, NH3	-	CS7, CS9, CS9A, CS13, MB (surface phytoplankton scum); G1, NH3 (algal bloom)	CS9, CS9A, CS13, MB, G1, NH3 (very green)	-	CB, WSSB (seagrass)	-
20/01/2020	CS6A, CS7, CB, CS12,CS9, CS9A, CS10N, CS13, CS11, MB,G1, CS8, CS5, NH3 (surface phytoplankton scum)	CS9, CS9A, CS10N, CS13, CS11, MB,G1, CS8, CS5, NH3	-	CS6A, CS7, CB, CS12,CS9, CS9A, CS10N, CS13, CS11, MB,G1, CS8, CS5, NH3 (algal blooms)	CS6A, CS7, CB, CS12,CS9, CS9A, CS10N, CS13, CS11, MB,G1, CS8, CS5, NH3 (very green)	-	CS9, CS10N (grain); G3, CS4 (seagrass)	-
28/01/2020	CS7, CS9A (surface phytoplankton scum); NH3 (algal bloom)	NH3	-	NH3	NH3 (very green)	CS7,CS9A	CS6A, CS11, WSSB, WSS4 (seagrass); CB (grain)	CS7 (fish odour)

Table 39 (b): Qualitative observations of indicators of aesthetic quality at each of the 18 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound over the 2019–20 non river-flow period.

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour variation	Surface films or oils	Surface or submerged debris	Odours
3/02/2020	CS12, CS9A, NH3 (algal bloom)	CS12, CS9A, NH3	-	CS12, CS9A, NH3	CS12, CS9A, NH3 (very green)	CS10N	CS10N (grain)	CS12 (industrial odours)
10/02/2020	-	CS6A, CS7, CB, CS12,CS9, CS9A, CS10N, CS13, CS11, MB,G1, CS5, NH3	-	CS6A, CS7, CB, CS12,CS9, CS9A, CS10N, CS13, CS11, MB,G1, CS5, NH3	CS6A, CS7, CB, CS12,CS9, CS9A, CS10N, CS13, CS11, MB,G1, CS5, NH3 (green)	-	WSSB, WSS4 (seagrass)	CS6A, CS7, CB, CS12 (industrial odours)
17/02/2020	-	CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, CS8, CS5, NH3	-	CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, CS8, CS5, NH3	CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF, G1, CS8, CS5, NH3 (green)	-	-	-
24/02/2020	-	CS7, CS9A, CS10N, NH3	-	CS7, CS9A, CS10N, NH3	CS7, CS9A, CS10N, NH3 (algal bloom)	-	-	CS12 (industrial odours)
2/03/2020	-	CS9, CS9A, CS11, MB, G1, NH3	-	CS9, CS9A, CS11, MB, G1, NH3	CS9, CS9A, CS11, MB, G1, NH3	CS11, MB	CS11, MB (seagrass leaves)	CS12 (industrial odours)
9/03/2020	-	-	-	CS7, CB, CS12, CS9, CS9A, CS10N,	-	-	CS7, CB, CS12, CS9, CS9A, CS10N,	-

Sampling date	Nuisance organisms	Algal blooms	Faunal deaths	Water clarity	Water colour variation	Surface films or oils	Surface or submerged debris	Odours
				CS13, CS11 (phytoplankton scum)			CS13, CS11 (phytoplankton scum); SF (seagrass)	
16/03/2020	CS9A (surface phytoplankton scum), NH3 (algal bloom)	NH3	-	NH3	NH3 (green)	-	CS6A, CS7, CB (seagrass)	-
30/03/2020	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, CS8, G2, CS4, NH3, WSSB, WSS4 (surface phytoplankton scum)	CS11, MB, SF,G1, CS8,CS4, NH3, WSSB, WSS4	-	NH3	CS6A, CS7, CB, CS12, CS9, CS9A, CS10N, CS13, CS11, MB, SF,G1, CS8, CS4, NH3, WSSB, WSS4 (green)	-	G2 G3, WSSB, WSS4 (seagrass, macro algae)	-

4.5 Conclusions

Based on the results from the 2019–20 monitoring programs in Cockburn Sound, there were no recorded exceedences of the EQC for the environmental quality objectives ***Maintenance of primary contact recreation values*** and ***Maintenance of secondary contact recreation values***. As such, there is a high degree of certainty that the environmental quality objectives have been achieved and the waters are safe for recreational activities.

5. Environmental value: Industrial Water Supply

5.1 Environmental quality objective

The environmental quality objective for the environmental value **Industrial Water Supply** is:

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

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

A reduction in the quality of the incoming seawater would have a significant impact on the pre-treatment requirements, and potentially the efficiency of the reverse osmosis membranes, resulting in additional costs to produce 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, EPA 2017).

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

5.2 Perth Seawater Desalination Plant intake water quality monitoring

The Water Corporation undertakes real-time continuous monitoring of a suite of parameters including temperature, pH, dissolved oxygen and hydrocarbons in the intake seawater. All equipment at the desalination plant is routinely recalibrated to ensure accuracy and reliability.

The Water Corporation also monitors other parameters in the intake seawater via a routine sampling program. Parameters relevant to the water quality criteria include total suspended solids (TSS) and bacterial indicators, which were monitored weekly during the reporting period; and boron and bromide, which were monitored three times. Sampling for the bacterial indicator *Escherichia coli* (*E. coli*) was replaced with sampling for enterococci in May 2017, as this gives a more robust pathogen indicator in salt water. For water quality parameters, water samples were collected by an in-house process chemist and analysed by accredited laboratories.

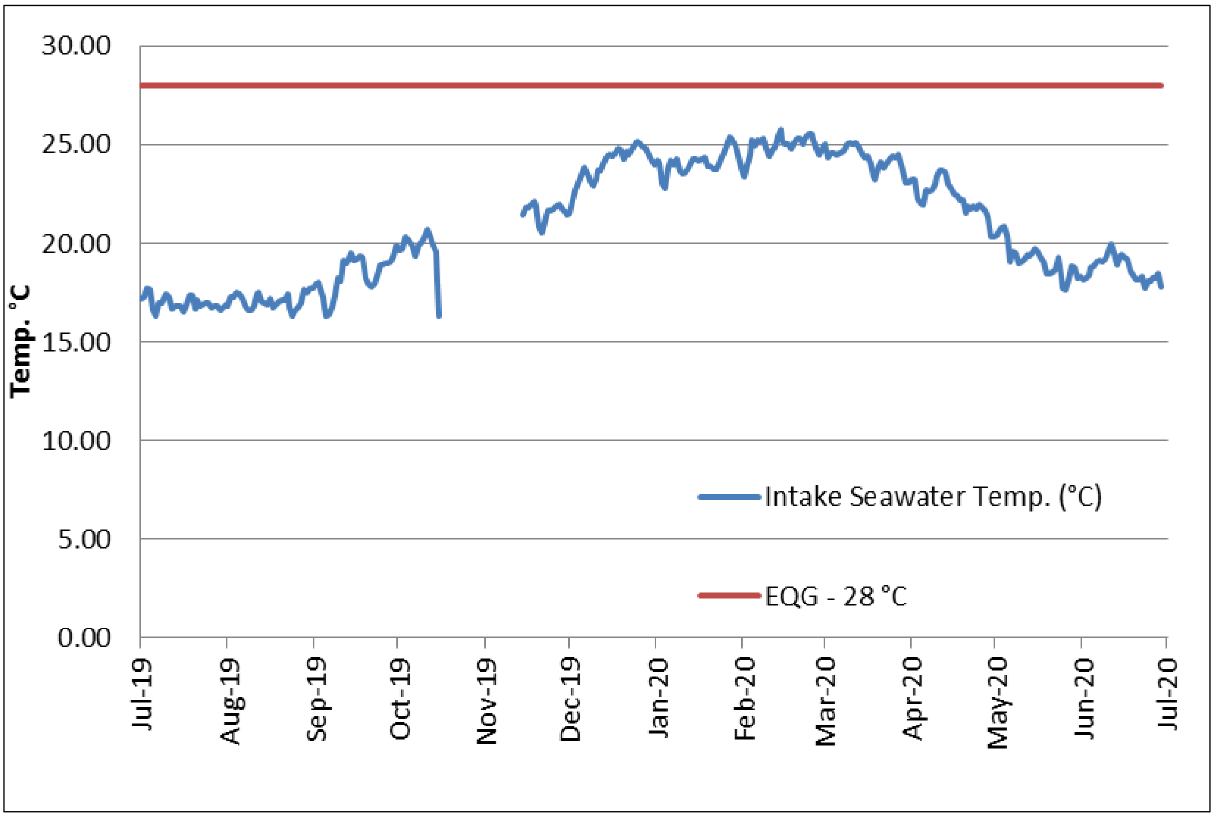
5.3 Assessment against the environmental quality criteria for 'maintenance of water quality for desalination plant intake water'

5.3.1 Biological indicators

Enterococci did not exceed the EQG of 32 Colony Forming Units per 100 millilitres (CFU/100 mL) on any sampling occasion over the July 2019 to June 2020 monitoring period. Enterococci was generally under the limit of reporting of <10 MPN/100 mL. The highest recording during the reporting period was 10 MPN/100 mL, which was recorded on three occasions.

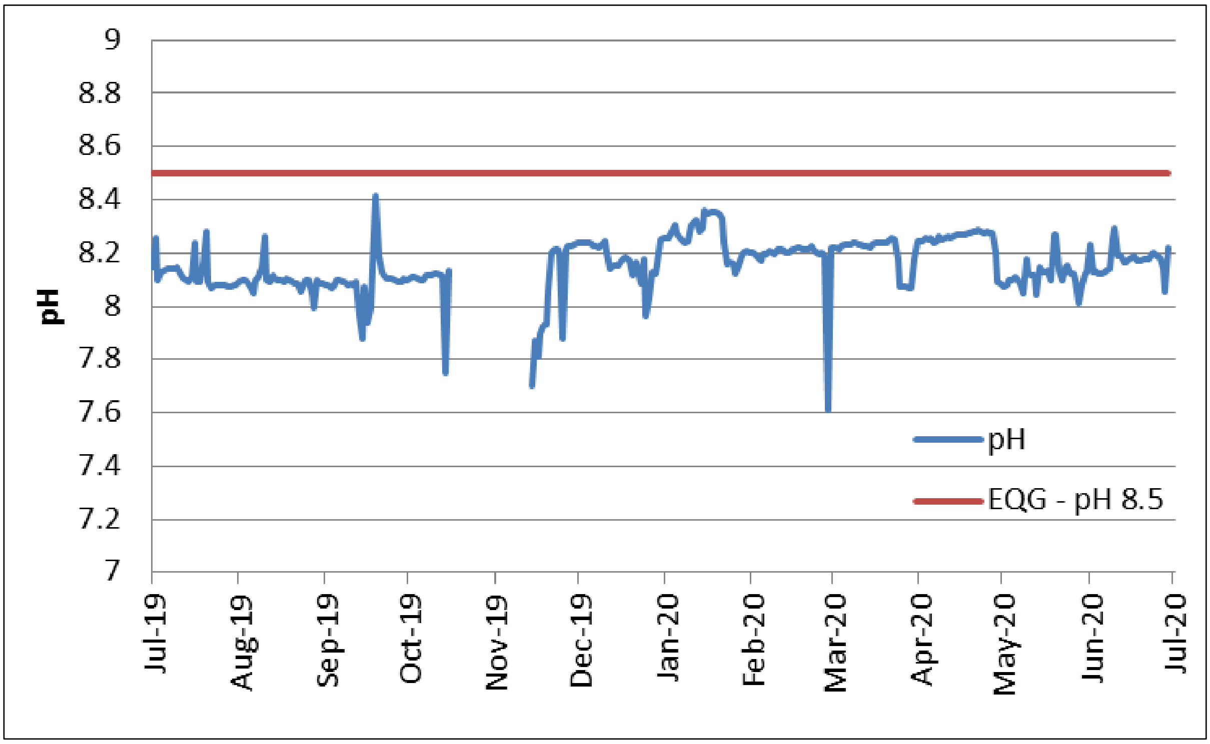
5.3.2 Physical and chemical indicators

Over the 2019–20 monitoring period, the temperature of the intake seawater was below the EQG of 28°C (Figure 13) and pH was below the EQG of 8.5 (Figure 14). Dissolved oxygen concentrations were above the EQG of 2 milligrams per litre (mg/L) over the monitoring period (**Error! Reference source not found.**).



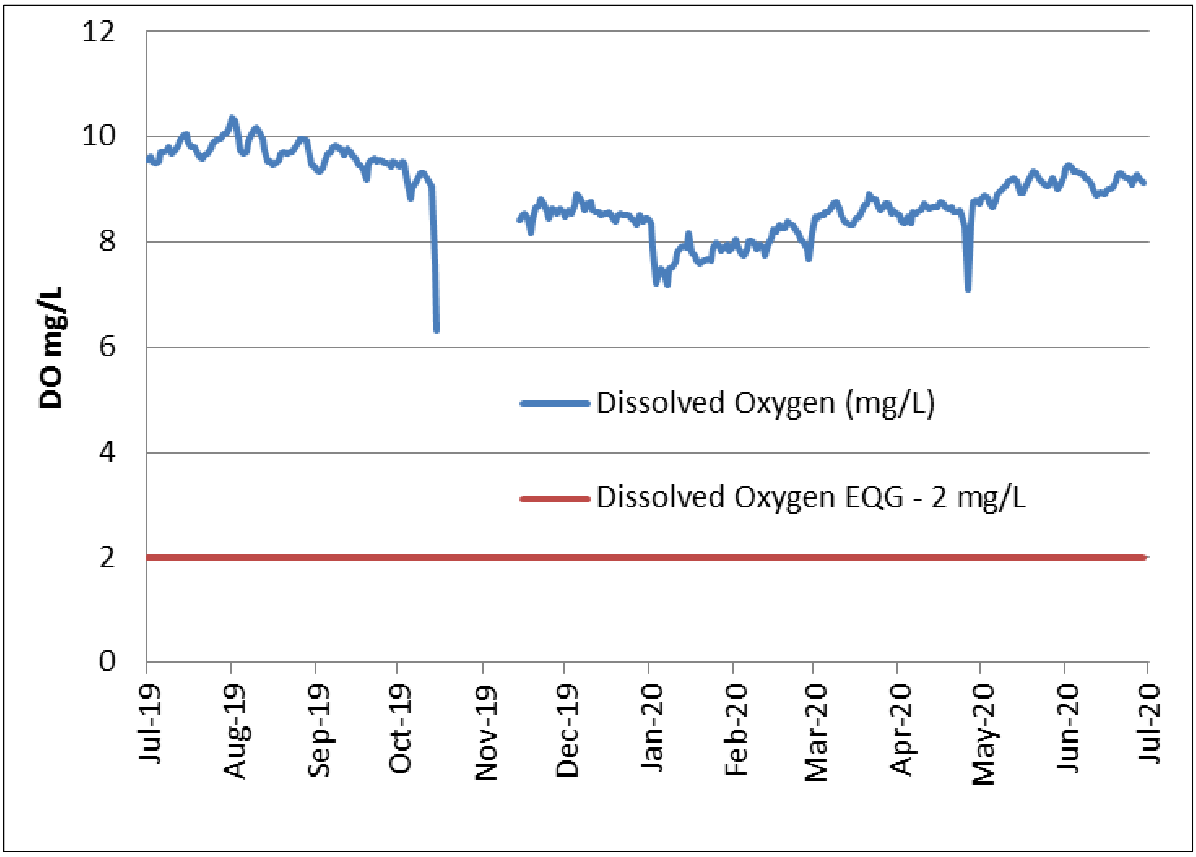
Note: Data recorded during the scheduled plant shutdown have been removed, as the data are not representative of seawater quality (data removed from 15/10/19 – 13/11/19).

Figure 13: Daily average temperature of the intake seawater over the 2019–20 monitoring period.



Note: Data recorded during the scheduled plant shutdown have been removed, as the data are not representative of seawater quality (data removed from 15/10/19 – 13/11/19). Single point decreases in pH, such as what occurred on 28/02/20, are also associated with short-term plant shutdowns and the data are not representative of seawater quality.

Figure 14: Daily average pH of the intake seawater over the 2019–20 monitoring period.



Note: Data recorded during the scheduled plant shutdown have been removed, as the data are not representative of seawater quality (data removed from 15/10/19 – 13/11/19).

Figure 15: Daily average dissolved oxygen concentration of the intake seawater over the 2019–20 monitoring period.

The ‘rolling’ four-week median concentration of TSS exceeded the EQG of 4.5 mg/L from mid-September 2019 to mid-February 2019 (Figure 16). There were no exceedences of the PSDP limit (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.

Over the 2019–20 monitoring period, hydrocarbon concentrations in the intake seawater did not exceed the Water Corporation’s limit. The boron concentration recorded in May 2020 (5.4 mg/L) slightly exceeded the EQG of 5.2 mg/L. The recorded bromide concentrations were all less than the EQG of 77 mg/L (Table 40). The Water Corporation advised that boron is removed by the reverse osmosis process.

The Water Corporation did not find a significant reduction in the 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 2019–20 monitoring period. It did observe natural variation in the quality of the intake seawater over the 2019–20 monitoring period, as in previous years. However, these variances had a minimal effect on the operation of the desalination plant.

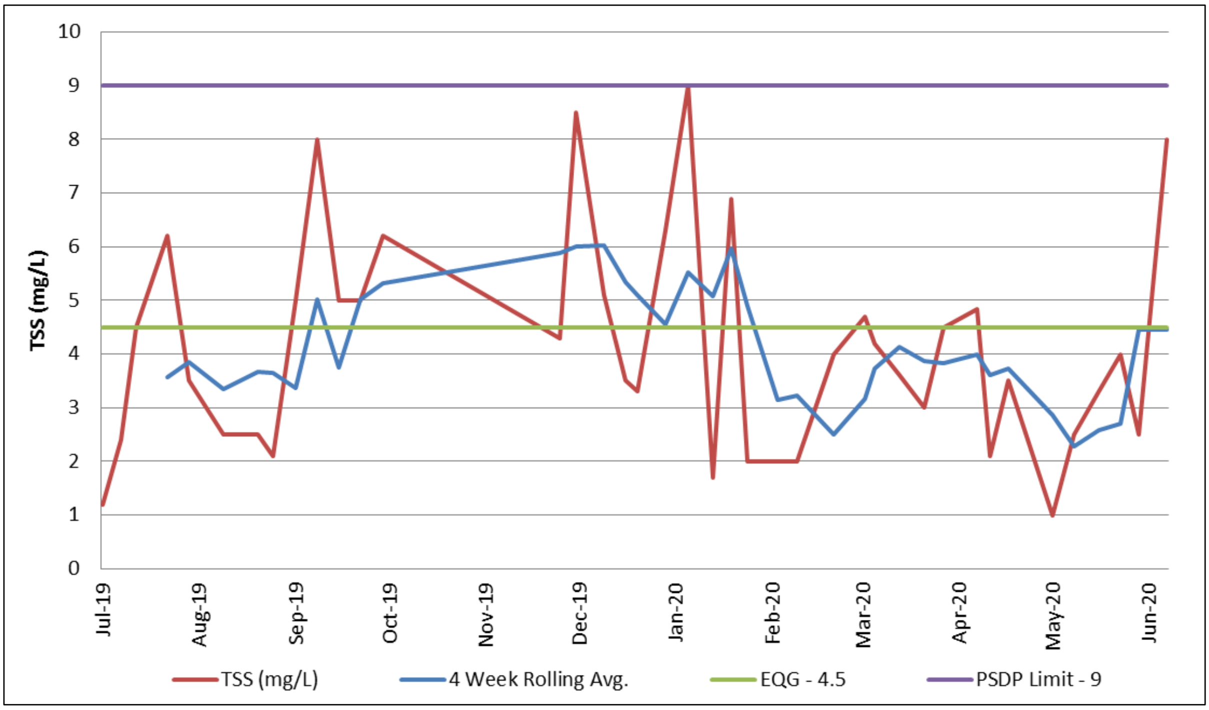


Figure 16: Weekly and 'rolling' four-weekly median total suspended solids (TSS) concentration in the intake seawater over the 2019–20 monitoring period.

Table 40: Quarterly concentrations of boron and bromide in the intake seawater over the 2019–20 monitoring period.

Sampling occasion	Boron (mg/L)		Bromide (mg/L)	
	EQG	Concentration	EQG	Concentration
July 2019	5.2	4.8	77	70
October 2019		4.5		71
January 2020		5		68
May 2020		5.4		62

5.4 Conclusions

The results from the 2019–20 monitoring of the intake seawater from Cockburn Sound into the Perth Seawater Desalination Plant indicated minor exceedences of the EQG for total suspended solids (TSS). The quality of the intake seawater for the desalination process was not considered to have been compromised. Hence there is a high degree of certainty that the environmental quality objective has been achieved during the reporting period.

Glossary

Absolute minimum criteria	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 before 2005.
Anthropogenic	Resulting from, or relating to, the influence of human beings on nature.
Approved shellfish harvesting area	A shellfish harvesting area classified as 'approved' for harvesting or collecting shellfish for direct marketing.
Baseline lower depth limit (LDL)	Mean of the lower depth limit measurements from 2000–02 (three years) at each seagrass 'depth limit' site.
Butyltin Degradation Index (BDI)	The relationship between tributyltin (TBT) and its breakdown products dibutyltin (DBT) and monobutyltin (MBT) provides an indication of how recently contamination occurred. BDI = (DBT + MBT)/TBT (Garg *et al*. 2009). A BDI of 1.0 indicates that half the TBT has broken down into DBT and MBT (in other words TBT in the sediment has reached its half-life).
Chlorophyll *a*	A complex molecule that is able to capture sunlight and convert it into a form that can be used for photosynthesis (a process which uses solar energy to convert carbon dioxide and water into carbohydrate). The concentration of chlorophyll *a* in water is used as a measure of phytoplankton biomass.
Conditionally approved shellfish harvesting area	The classification of a shellfish harvesting area which meets 'approved' harvesting area criteria for a predictable period. The period depends upon established performance standards specific in a management plan. A 'conditionally approved' area is closed when it does not meet the 'approved' harvesting area criteria.
Contaminant	Any physical, chemical or biological substance or property which is introduced into the environment. Does not imply any effect.
$\delta^{34}S$ (delta 34 S)	Standardised method for reporting measurements of the ratio of the two most common stable isotopes of sulfur, ^{34}S:^{32}S, as measured in a sample against the equivalent ratio in a known reference standard. Deviation from the international standard, which is set at δ0.00, is expressed as the $\delta^{34}S$ (a ratio in per million [$^{o}/_{oo}$]). Positive values indicate greater levels of ^{34}S and negative values greater levels of ^{32}S in a sample.
Dissolved inorganic nutrients	Dissolved inorganic nutrient concentrations in seawater are made up of soluble inorganic nitrogen compounds consisting of dissolved nitrite, nitrate and ammonia in solution.

	Dissolved phosphorus in seawater is made up of both soluble organic phosphorus and inorganic ortho-phosphate ions. Most soluble forms of nitrogen and phosphorus are readily available for uptake by phytoplankton and in high concentrations can give rise to phytoplankton blooms.
Environmental quality criteria (EQC)	The numerical values (e.g. cadmium 0.7 µg/L) or narrative statements (e.g. the 95th percentile of the bioavailable contaminant concentration in the test samples should not exceed the EQG value) that serve as benchmarks to determine whether a more detailed assessment of environmental quality is required (EQG), or whether a management response is required (EQS).
Environmental quality guideline (EQG)	A numerical value or narrative statement which, if met, indicates there is a high probability that the associated environmental quality objective has been achieved.
Environmental quality management framework	Provides the context within which management of existing activities and decisions about future activities occurs. The management framework does this by confirming the environmental objectives and establishing ambient environmental limits and triggers.
Environmental quality objective	A specific management goal for a part of the environment, which is either ecologically based (by describing the desired level of health of the ecosystem) or socially based (by describing the environmental quality required to maintain specific human uses).
Environmental quality standard (EQS)	A numerical value or narrative statement which, if not met, indicates a high probability that the associated environmental quality objective has not been achieved and a management response is triggered.
Environmental value	A particular value or use of the marine environment that is important for a healthy ecosystem or for public benefit, welfare, safety or health and which requires protection from the effects of pollution, environmental harm, waste discharge and deposits. There are two types of environmental value: ecological and social.
Extraneous residue limit	The maximum concentration of a pesticide residue or contaminant arising from environmental sources (including former agricultural use) other than the direct or indirect use of a pesticide or contaminant substance that is legally permitted or accepted in a food.
High level of ecological protection	Allows for small changes in the quality of water, sediment or biota (e.g. small changes in contaminant concentrations with no resultant detectable changes beyond natural variation in the diversity of species and biological communities, eco-system processes and abundance/biomass of marine life).

Light attenuation in water	The exponential decay of light intensity with increasing depth because of absorption and scattering. A large light attenuation coefficient means that light is quickly ‘attenuated’ (i.e. weakened) as it passes through the water column; a small light attenuation coefficient means that the water is relatively transparent to light.
Low level of 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 nearby high ecological protection areas).
Low reliability value (LRV)	For a number of toxicants where there are insufficient toxicological data to develop reliable guideline trigger levels, low reliability values have been derived to give guidance in the absence of any higher reliability guidelines being available. LRVs should not be used as default guideline trigger values. However, it is assumed that if ambient concentrations fall below the LRV then there is low risk of ecological impact. If concentrations are above a LRV, it does not necessarily mean an impact is likely. Exceedance of a LRV does not trigger mandatory assessment against the EQS, but does signal that the possibility of ecological impact should be considered, particularly if further increases beyond the LRV are likely.
Lower depth limit (LDL)	The maximum depth and distance at which seagrass shoots are observed within a 1 m belt either side of the transect line. The objective of this measure is to identify the position of the boundary of a seagrass bed and, by reference to the baseline and/or reference conditions, to establish the magnitude and direction of change (in other words, gain or loss) of seagrass meadow.
Mann-Kendall trend analysis	The Mann-Kendall trend analysis is a non-parametric statistical test to detect a monotonic upward or downward trend in the variable of interest over time.
Marine biotoxins	Toxic compounds produced by some species of phytoplankton.
Maximum residue limit	The highest concentration of a chemical residue that is legally permitted or accepted in a food.
Mean shoot height	The 80th percentile of shoot heights within quadrats. The tallest 20% of shoots inside a quadrat were excluded and the height of the tallest remaining shoots measured. Mean shoot height is measured as long leaves are often necrotic for much of their length and maximum height may not be an

	accurate measure of canopy height within each quadrat.
Median	A measure used in statistics representing the ‘middle’ number in a sequence of numbers that has been arranged from the smallest value to the largest value. The main advantage of the median compared with the average or mean of a dataset, is that is it not influenced so much by very large or very small values and is therefore considered to be more representative of the majority of values in a dataset.
Moderate level of ecological protection	Allows for moderate changes in the quality of water, sediment or biota (such as moderate changes in contaminant concentrations that could cause small changes beyond natural variation in ecosystem processes and abundance/biomass of marine life, but no detectable changes from the natural diversity of species and biological communities).
Non river-flow period	The main period for nutrient-related monitoring in Cockburn Sound. This is over summer when river flow is minimal and nutrient concentrations are most stable.
Normalisation	A procedure to adjust concentrations of contaminants in sediments for the influence of natural variability in sediment composition, in particular for grain size, organic matter content and mineralogy.
Nutrients	Elements or compounds, such as nitrogen and phosphorus, that are essential for organic growth and development.
Percentile	A measure used in statistics whereby the p^{th} percentile of a distribution of data is the value that is greater than or equal to *p*% of all the values in the distribution. For example the 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.
Perfluoroalkyl and polyfluoroalkyl substances (PFAS)	A group of synthetic fluorine-containing chemicals used in heat, stain and water resistant products (such as non-stick cookware, specialised textiles, Scotchgard™) and were used in firefighting foams. PFAS are highly persistent in the environment, moderately soluble, can be transported long distances and transfer between soil, sediment, surface water and groundwater. They have been shown to be toxic to some animals and, because they break down very slowly, can bioaccumulate and biomagnify in some wildlife, including fish. This means that fish and animals higher in the food chain may accumulate higher concentrations of PFAS in their bodies. Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are two of the best-known PFAS and are contaminants of emerging concern in Australia and

	internationally. They have been identified in the environment at a number of known and suspected contaminated sites in Western Australia.
Phytoplankton	Single-celled plants and other photosynthetic organisms (including cyanobacteria, diatoms and dinoflagellates) that live in the water column.
Public authority	A Minister of the Crown acting in their official capacity, department of the government, state agency or instrumentality, local government or other person, whether corporate or not, who or which under the authority of a written law administers or carries on for the benefit of the State, or any district or other part thereof, a social service or public utility.
Re-sampling trigger	Where the total concentration of a contaminant in individual sediment sample sites exceeds the EQG re-sampling trigger, additional sampling of that potentially contaminated site will generally be required to better define the area of high concentration.
Seagrass	Submerged flowering plants that mainly occur in shallow marine areas and estuaries.
Shellfish	Under the *Western Australia Shellfish Quality Assurance Program (WASQAP) operations manual 2017* (Department of Health 2017) shellfish means all edible species of molluscan bivalves such as oysters, clams, scallops, pipis and mussels, either shucked or in the shell, fresh or frozen, whole or in part or processed. The definition does not include spat, scallops or *Pinctada* spp. where the consumed product is only the adductor mussel.
Social value	A particular value or use of the marine environment that is important for public benefit, welfare, safety or health and which requires protection from the effects of pollution, environmental harm, waste discharges and deposits.
State Environmental Policy (SEP)	A State Environmental Policy is a non-statutory instrument developed by the EPA under the *Environmental Protection Act 1986*. It is a flexible policy instrument which is developed through public consultation and adopted on a whole-of-government basis.
Total nutrients	In seawater the total nitrogen and total phosphorus concentrations are made up of a combination of soluble and insoluble organic and inorganic compounds. The organic nutrients incorporate all organic particulate matter, including phytoplankton, zooplankton, bacteria and organic surface films on re-suspended sediments, detrital matter and some soluble organic compounds. The inorganic nitrogen compounds consist of dissolved nitrite, nitrate and ammonia

	in solution. Inorganic phosphorus is made up of dissolved inorganic ortho-phosphates.
Total toxicity of the mixture (TTM)	An interpretive tool used for estimating the potential toxicity of mixtures of up to five toxicants, where the interactions are simple and predictable. If the total toxicity of the mixture exceeds one, the mixture has exceeded the water quality guideline. $TTM = \sum(C_i)/EQG_i)$, where C_i is the concentration of the 'i'th component in the mixture and EQG_i is the guideline for that component.

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Appendix A: 2019–20 Nutrient concentrations

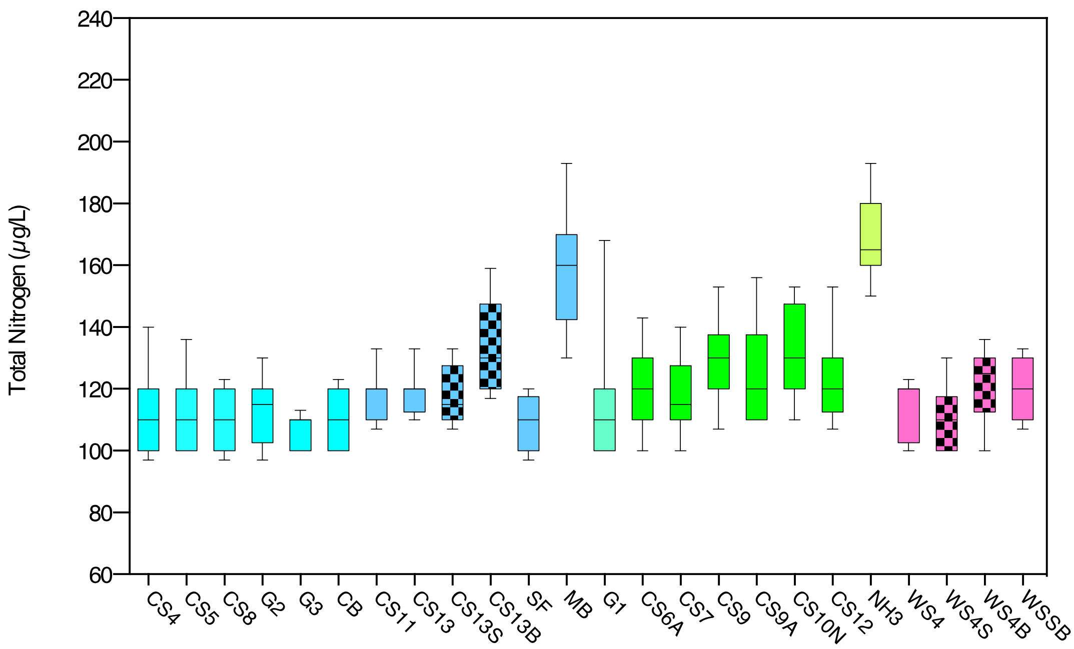
Total nitrogen

Total nitrogen concentrations over the 2019–20 non river-flow period ranged from 90 micrograms per litre (µg/L) measured at four sites in Cockburn Sound (CS4, CS8, G2 and SF) to 200 µg/L measured at sites MB and NH3 on 20 and 28 January 2020 respectively (Cossington & Wienczugow 2020).

The median total nitrogen concentration at site MB (160 µg/L) was significantly higher than most of the other sites except for sites CS9, CS9A, CS10N, CS12 and NH3 (Figure A1; Cossington & Wienczugow 2020).

The total nitrogen at site CS13 showed median total nitrogen concentrations in the integrated and bottom water samples were significantly higher than in the surface water samples (Cossington & Wienczugow 2020). At the Warnbro Sound reference site WS4, the integrated and the bottom water samples showed that the bottom water had significantly higher total nitrogen concentrations than the surface water, but there was no significant difference between the integrated and bottom water sample medians.

Comparisons of median total nitrogen concentrations between ecological protection areas showed that MPA-NH was significantly higher than all other areas in Cockburn and Warnbro Sound (Figure A2; Cossington & Wienczugow 2020).



Notes:

1) The ‘box’ represents the 25th and 75th percentiles and the ‘whiskers’ the 10th and 90th percentiles.
2) Light blue bar = HPA-N sites; dark blue bar = HPA-S sites; blue/green bar = MPA-CB site; bright green bar = MPA-ES sites; pale green bar = MPA-NH site; pink bars = Warnbro Sound reference sites. For site locations, see Figure 2. Hatched bars = concentrations in discrete surface (S) and bottom (B) waters.

Figure A1: Median total nitrogen concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound from December 2019 to March 2020.

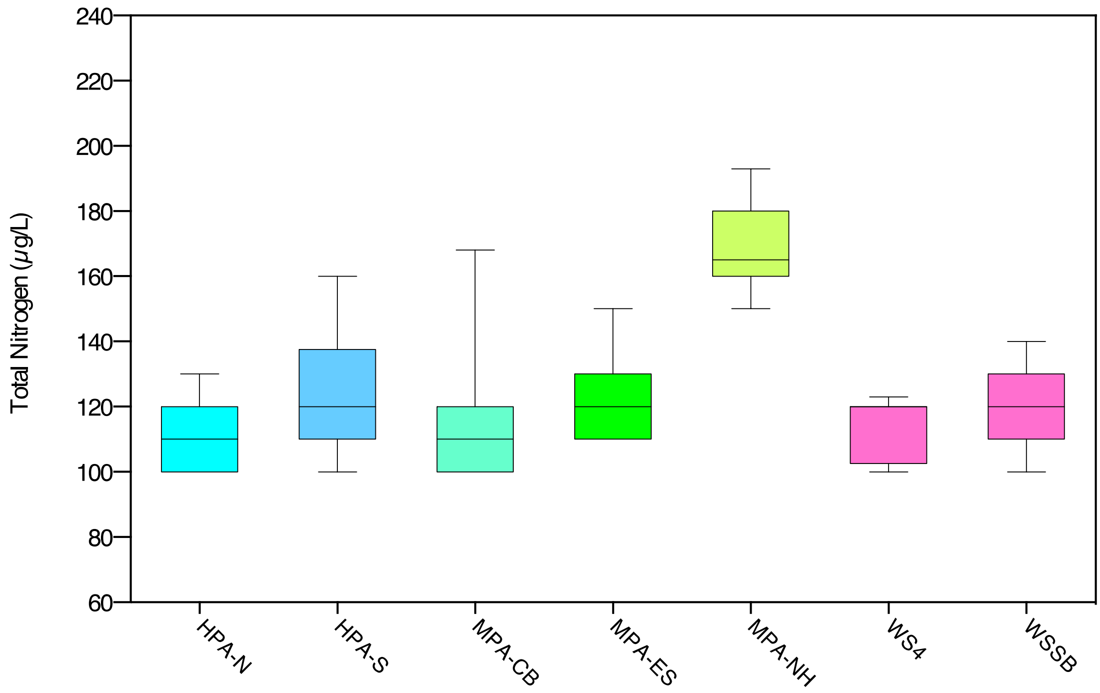


Figure A2: Median total nitrogen concentrations at the ecological protection areas in Cockburn Sound and Warnbro Sound reference sites from December 2019 to March 2020.

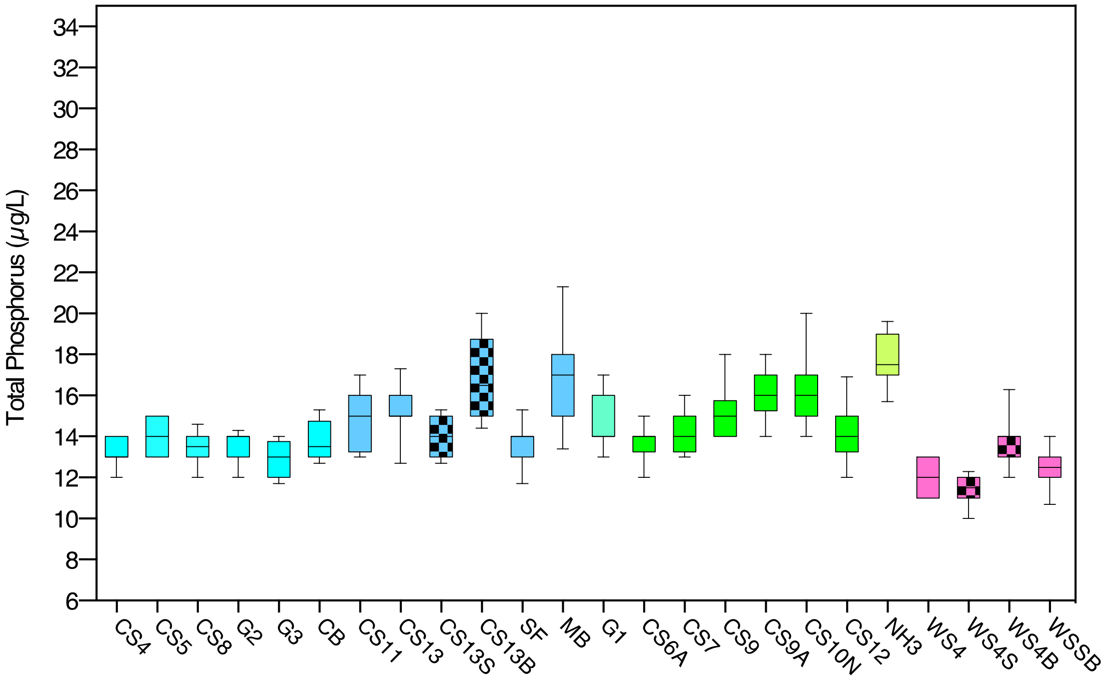
Total phosphorus

Total phosphorus concentrations ranged from 10 µg/L at the Warnbro Sound reference site WSSB to 22 µg/L at site MB, which was measured on 20 January 2020 (Cossington & Wienczugow 2020).

The highest median total phosphorus concentration was measured at site NH3, with a median of 17.5 µg/L (Figure A3; Cossington & Wienczugow 2020). The median total phosphorus concentration at site NH3 was significantly higher than the other sites, except for sites CS9, CS9A, CS10N, CS11, CS13, G1 and MB.

The median total phosphorus concentrations were significantly higher in the bottom waters sampled at Warnbro Sound reference site WS4 and site CS13 than in the surface waters sampled at these sites (Cossington & Wienczugow 2020). The bottom water at site WS4 also had a significantly higher median total phosphorus concentration than the integrated water median at the same site.

Comparisons of the median total phosphorus concentrations between ecological protection areas showed that MPA-NH had the highest total phosphorus concentrations during 2020 (Figure A4; Cossington & Wienczugow 2020). The Warnbro Sound reference sites WSSB and WS4 had significantly lower median total phosphorus concentrations than the ecological protection areas in Cockburn Sound, except for HPA-N where no significant difference was found when compared with WSSB.



Notes:

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

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

Figure A3: Median total phosphorus concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound from December 2019 to March 2020.

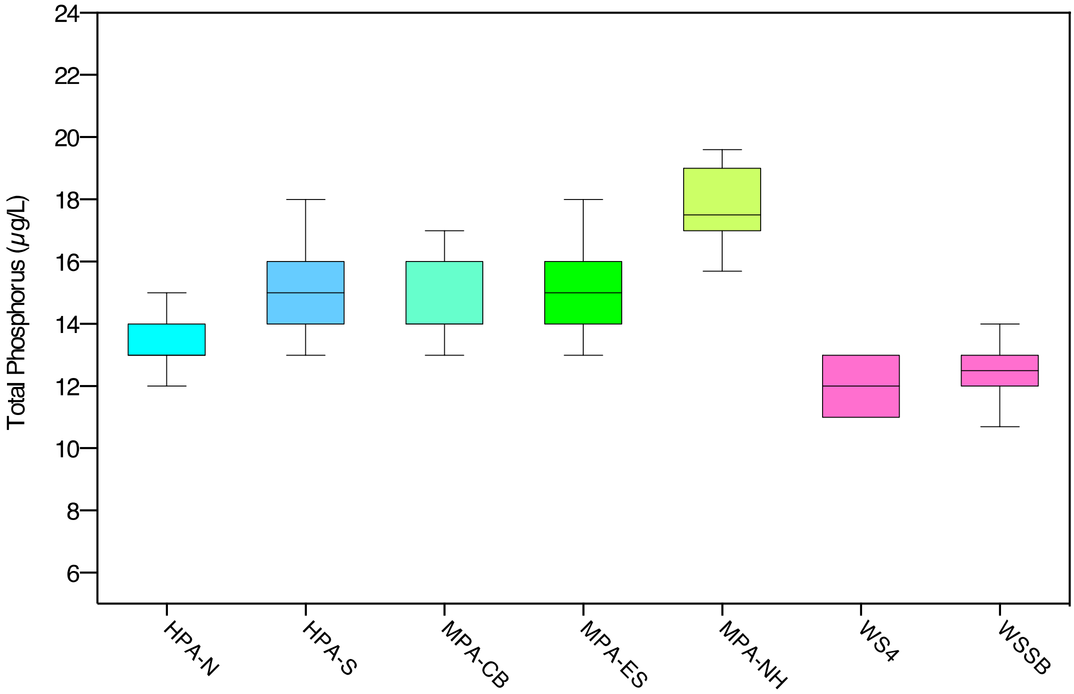


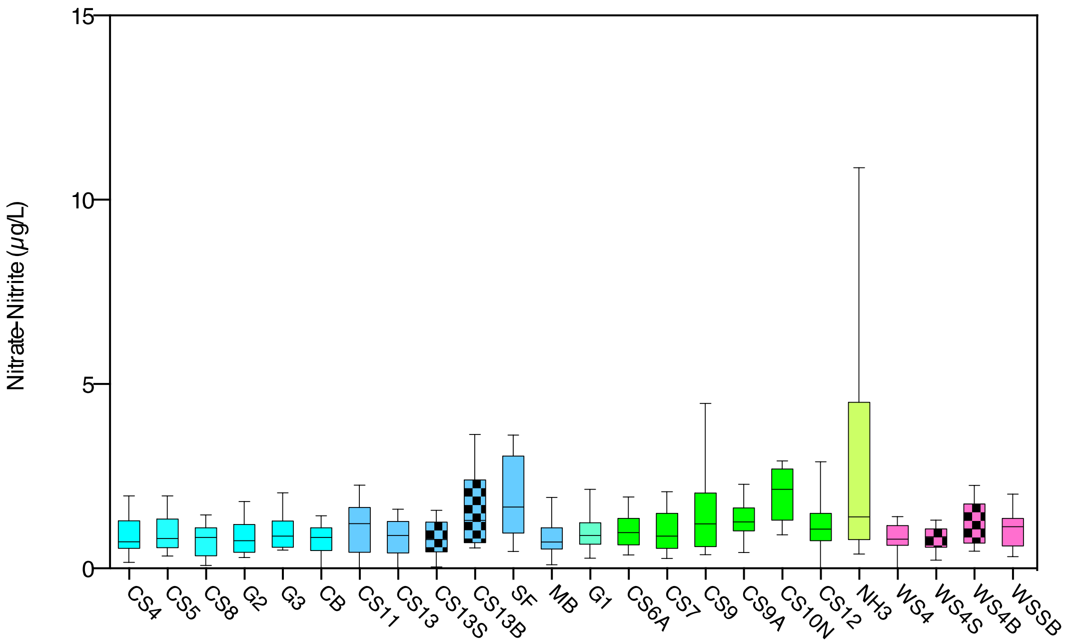
Figure A4: Median total phosphorus concentrations at the ecological protection areas in Cockburn Sound and Warnbro Sound reference sites from December 2019 to March 2020.

Nitrate–nitrite

Nitrate–nitrite concentrations ranged from less than the analytical reporting limit (< 2 µg/L), which was measured at all sites on numerous occasions, to 20 µg/L at site NH3 in MPA-NH on 9 March 2020. Median nitrate–nitrite concentrations were below the analytical reporting limit at all sites except for site CS10N in MPA-ES (Figure A5; Cossington & Wienczugow 2020).

Median nitrate–nitrite concentrations at CS10N were significantly higher than four of the northern high protection area HPA-N sites (CS4, CS8, CB, and G2), two HPA-S sites (CS13, MB) and the Warnbro Sound reference site WS4 (Figure A5; Cossington & Wienczugow 2020). The median nitrate–nitrite concentrations in the discrete surface, bottom and integrated water samples were not found to be significantly different at sites CS13 or WS4.

Comparisons of the median nitrate–nitrite concentrations between ecological protection areas showed no significant differences between different ecological areas (Figure A6; Cossington & Wienczugow 2020).



Notes:

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

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

Figure A5: Median nitrate–nitrite concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound over the period December 2018 to March 2019.

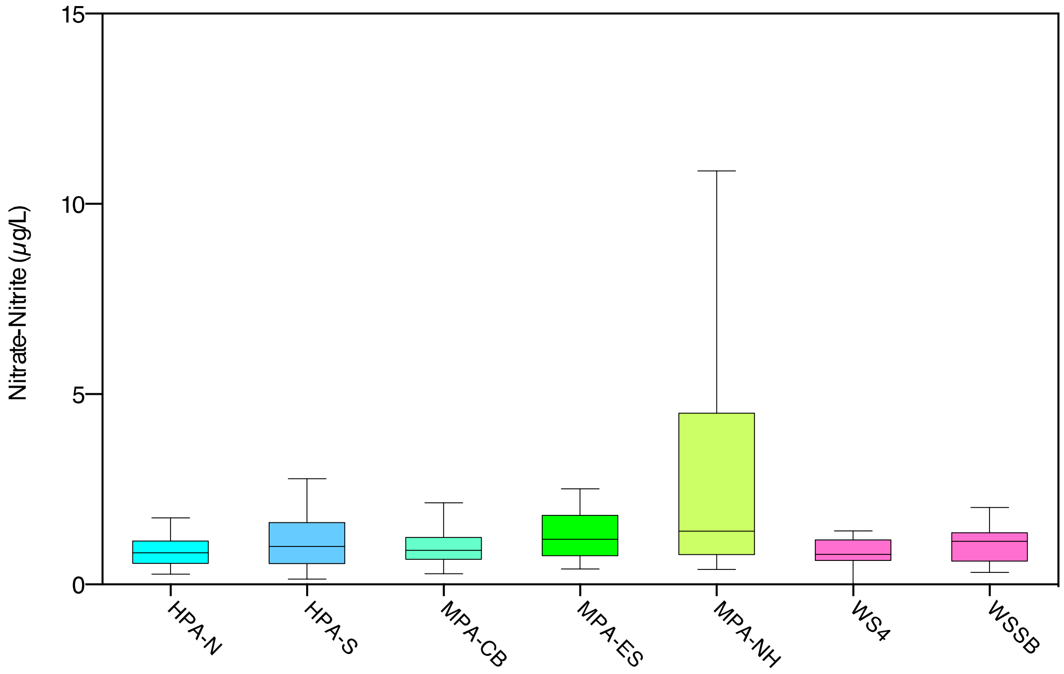


Figure A6: Median nitrate–nitrite concentrations at the ecological protection areas in Cockburn Sound and Warnbro Sound reference sites from December 2019 to March 2020.

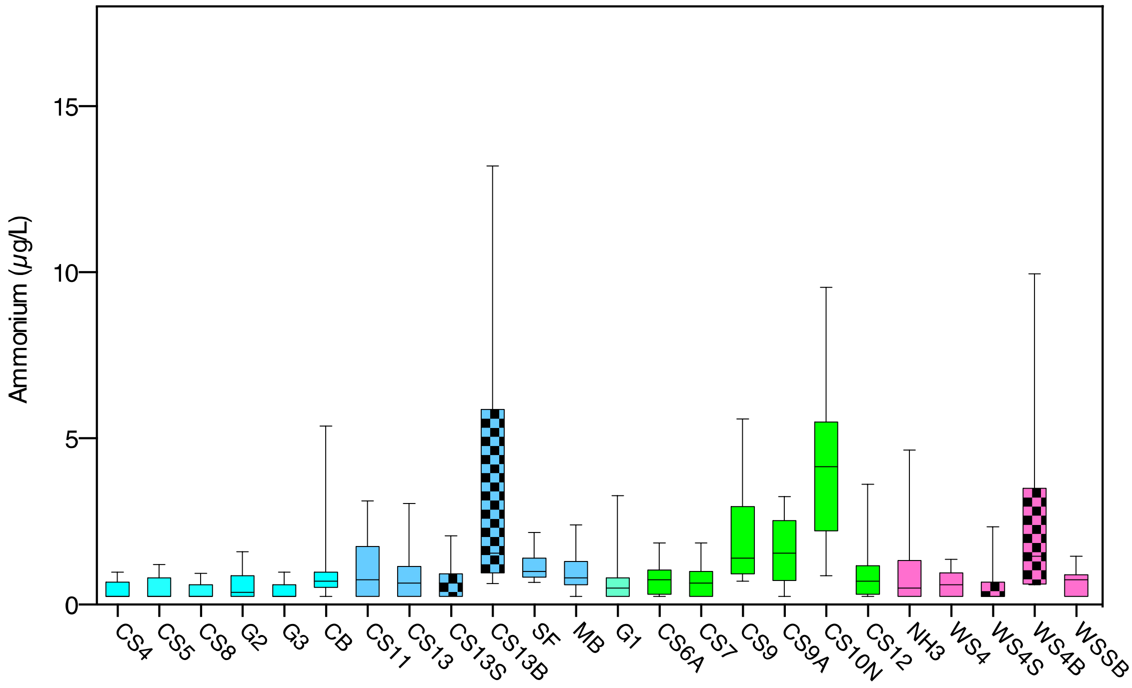
Ammonium

Ammonium concentrations ranged from less than the analytical reporting limit (< 0.5 µg/L), which was recorded at most sites on one or more occasions, to 11 µg/L recorded at sites CS9 and CS10N on 2 March and 16 March 2020 respectively (Figure A7; Cossington & Wienczugow 2020).

The highest median ammonium concentration was 4.15 µg/L at site CS10N in MPA-ES (Figure A7; Cossington & Wienczugow 2020). The median ammonium concentration at CS10N was significantly higher than all other sites, except sites CS9 and CS9A in MPA-ES and sites MB and SF in HPA-S (Cossington & Wienczugow 2020).

The median ammonium concentrations of the discrete bottom water samples at Cockburn Sound site CS13 and Warnbro Sound site WS4 were elevated and significantly higher than both the surface and integrated water samples (Figure A7; Cossington & Wienczugow 2020).

Comparisons of the median ammonium concentrations between ecological protection areas showed that HPA-N had significantly lower median ammonium concentrations than HPA-S and MPA-ES (Figure A8; Cossington & Wienczugow 2020).



Notes:

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

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

Figure A7: Median ammonium concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound from December 2019 to March 2020.

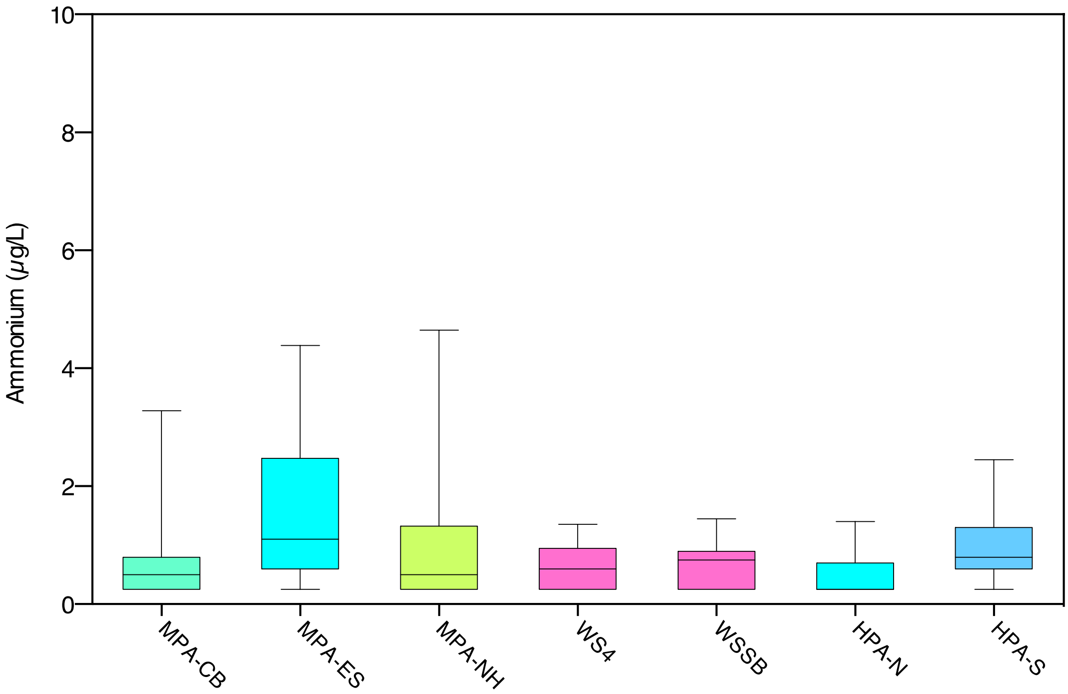


Figure A8: Median ammonium concentrations at the ecological protection areas in Cockburn Sound and Warnbro Sound reference sites from December 2019 to March 2020.

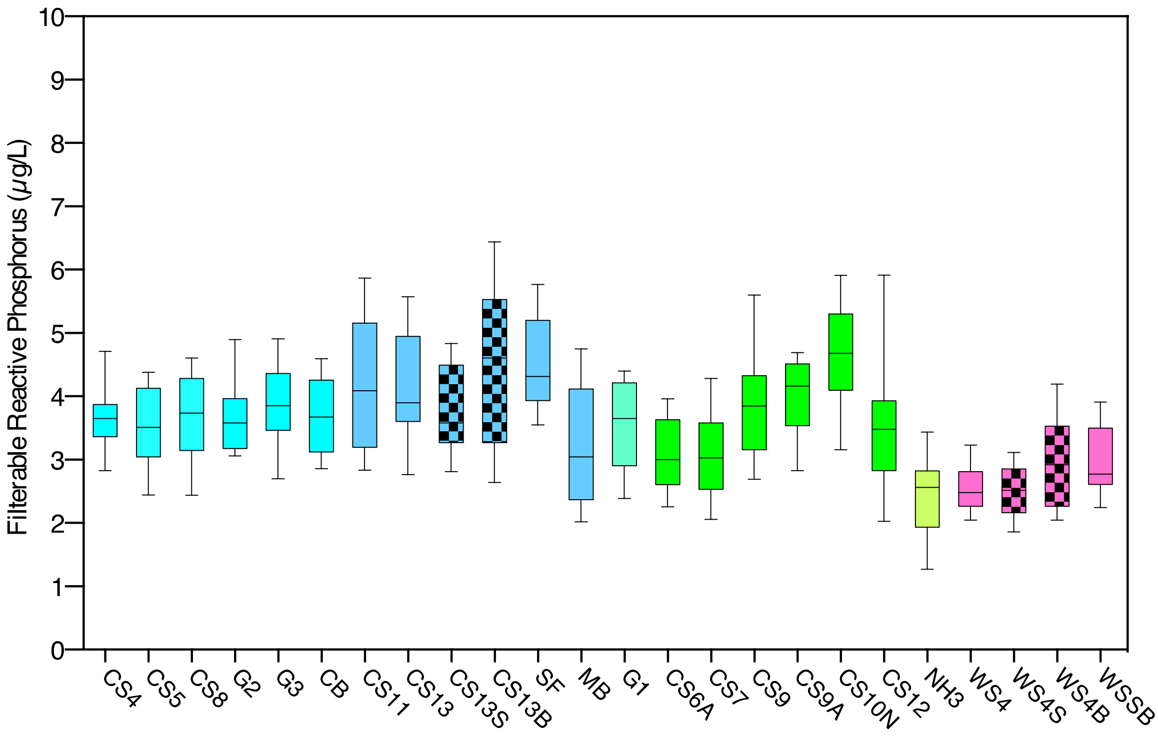
Filterable reactive phosphorus

Filterable reactive phosphorus (FRP) concentrations ranged from less than the analytical reporting limit (< 2 µg/L) at sites CS5, MB, NH3, WSS4 and WSSB, to 7 µg/L at site CS12 on 9 December 2019 (Figure A9; Cossington & Wienczugow 2020).

The highest median FRP concentration was 4.7 µg/L at site CS10N (Figure A9; Cossington & Wienczugow 2020). Sites CS10N and SF had significantly higher median FRP concentrations than sites CS6A and CS7 in MPA-ES, NH3 in MPA-NH, MB in HPA-S and Warnbro Sound reference sites WS4 and WSSB.

There were no significant differences between the median FRP concentrations in the discrete surface and bottom water samples at WS4 and CS13 (Figure A9; Cossington & Wienczugow 2020).

The Cockburn Sound ecological protection areas were found to have higher median FRP concentrations than Warnbro Sound (Figure A10; Cossington & Wienczugow 2020). Site G1 at Careening Bay in Cockburn Sound also had significantly higher median FRP concentration than Warnbro Sound site WS4 (Cossington & Wienczugow 2020).



Notes:

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

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

Figure A9: Median filterable reactive phosphorus concentration at 18 water quality monitoring sites in Cockburn Sound and two reference sites in Warnbro Sound from December 2019 to March 2020.

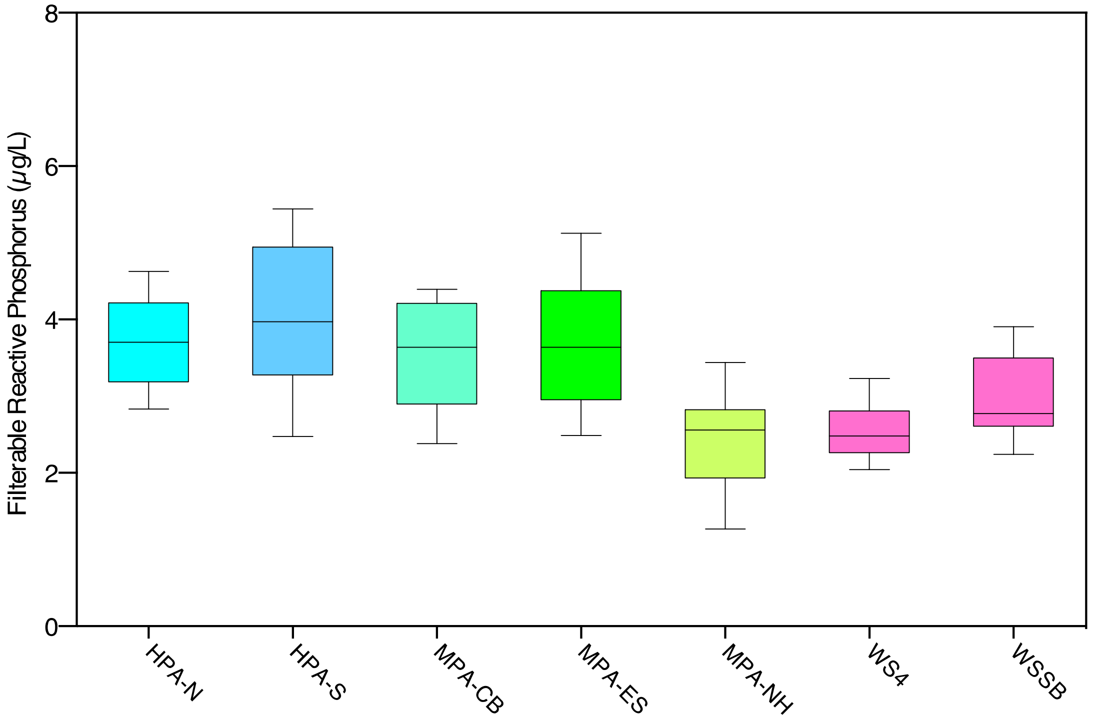
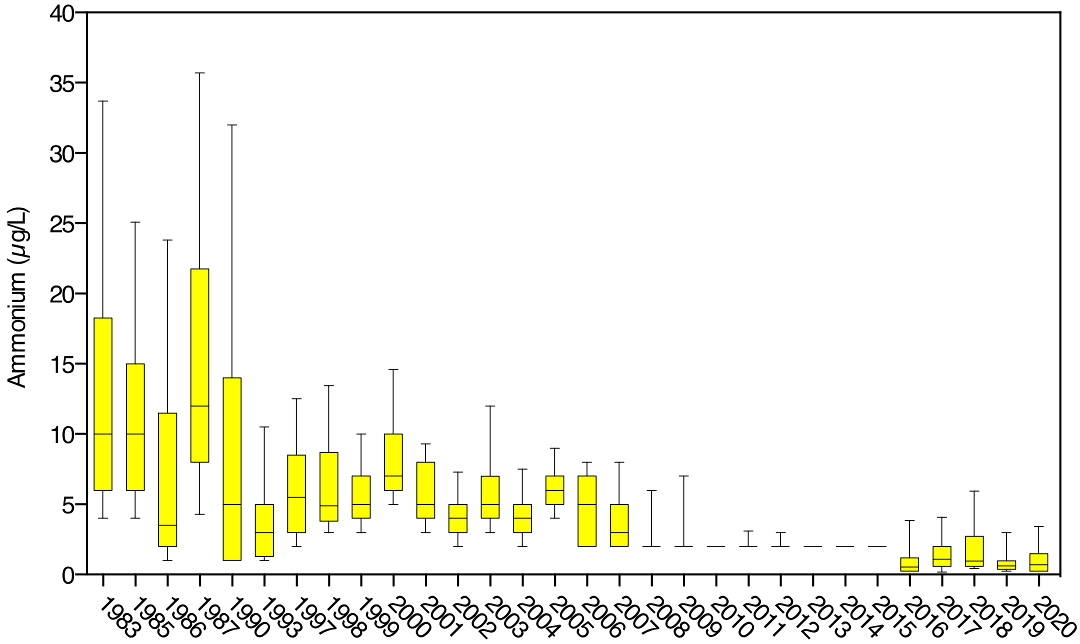


Figure A10: Median filterable reactive phosphorus concentrations at the ecological protection areas in Cockburn Sound and Warnbro Sound reference sites from December 2019 to March 2020.

Appendix B: Variations and trends over time in nutrient concentrations

Ammonium

Median non river-flow period ammonium concentrations in Cockburn Sound declined from the 1980s to 2000s, and again from around 2008 onwards (Figure B1; Cossington & Wienczugow 2020). The variability between sites within years has also decreased over that time. The median ammonium concentrations at historical Cockburn Sound sites (i.e. CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11) in 2020 were not significantly different from the median concentrations recorded in 2016–19, but were significantly lower than earlier years (Cossington & Wienczugow 2020).



Notes:

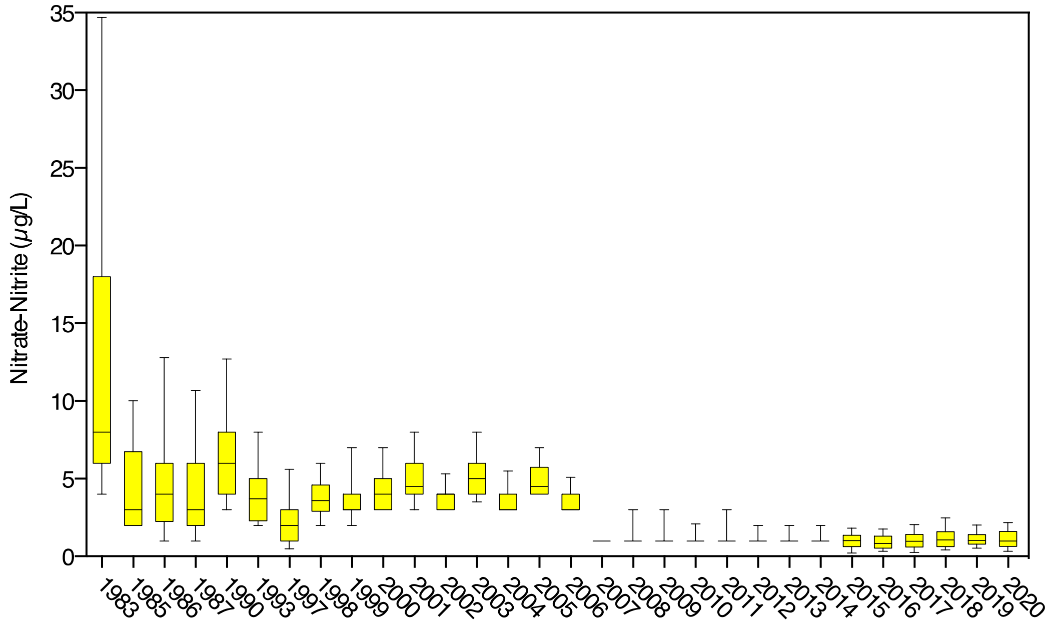
(1) The ‘box’ represents the 25th and 75th percentiles and the ‘whiskers’ the 10th and 90th percentiles.

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

Figure B1: Median ammonium concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 from 1983 to 2020.

Nitrate–nitrite

The median nitrate–nitrite concentrations at the historical Cockburn Sound sites in the 2019–20 non river-flow season were not significantly different from the concentrations recorded from seasons 2006–19, but were significantly lower than nitrate–nitrite concentrations recorded in those years (Figure B2; Cossington & Wienczugow 2020). The median nitrate–nitrite concentrations for the historical Cockburn Sound have fluctuated very little since 2007, however site NH3 has experienced more fluctuations during the same period (Figure B3; Cossington & Wienczugow 2020).



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

Figure B2: Median nitrate–nitrite concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 from 1983 to 2020.

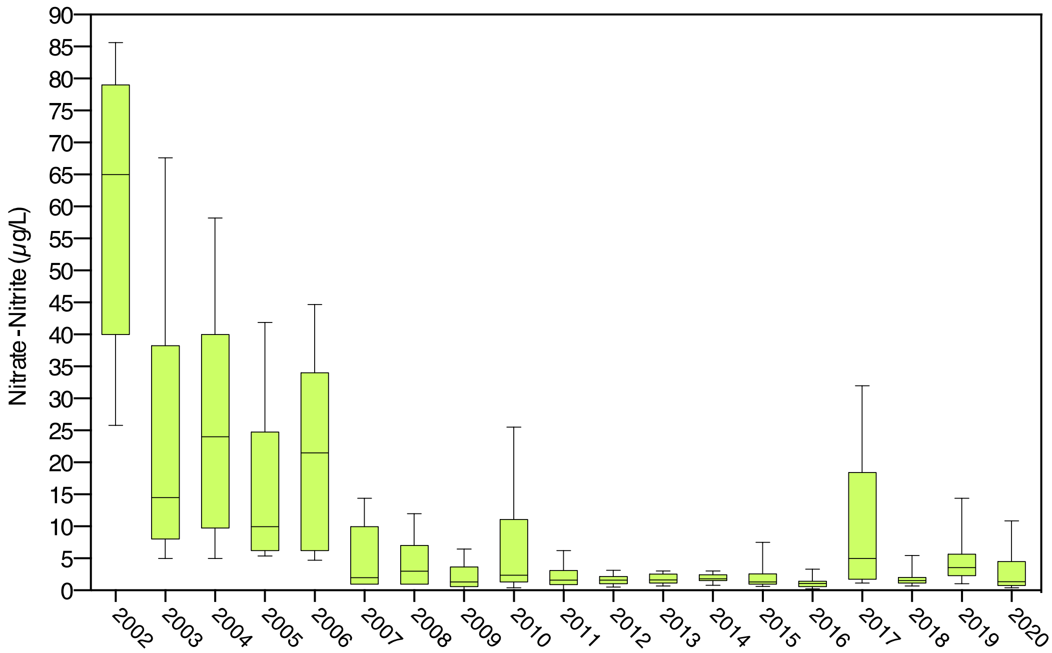
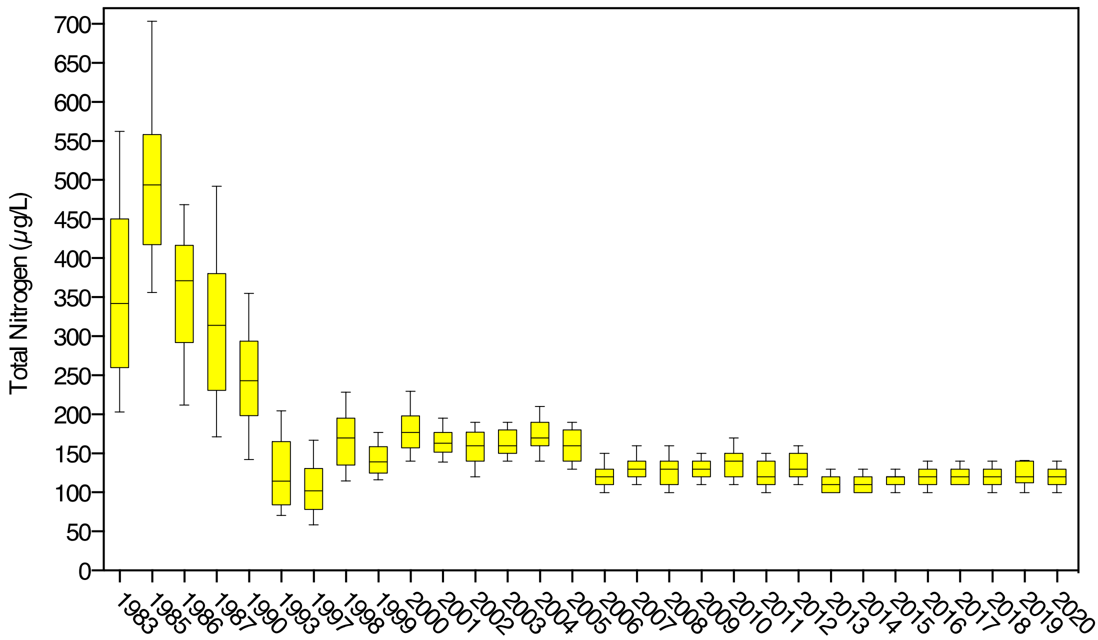


Figure B3: Median nitrate–nitrite concentrations at site NH3 in the Northern Harbour from 1983 to 2020.

Total nitrogen

The median total nitrogen concentrations at the Cockburn Sound historical sites in 2019–20 were not significantly different to the median total nitrogen concentrations for seasons 1993–94, 1998–2005, 2007, 2009–10 and 2012 (Figure B4; Cossington & Wienczugow 2020).

Median concentrations in 2019–20 were significantly lower than all other years when total nitrogen was measured (Cossington & Wienczugow 2020).



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

Figure B.4. Median total nitrogen concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 from 1983 to 2020.

Filterable reactive phosphorus

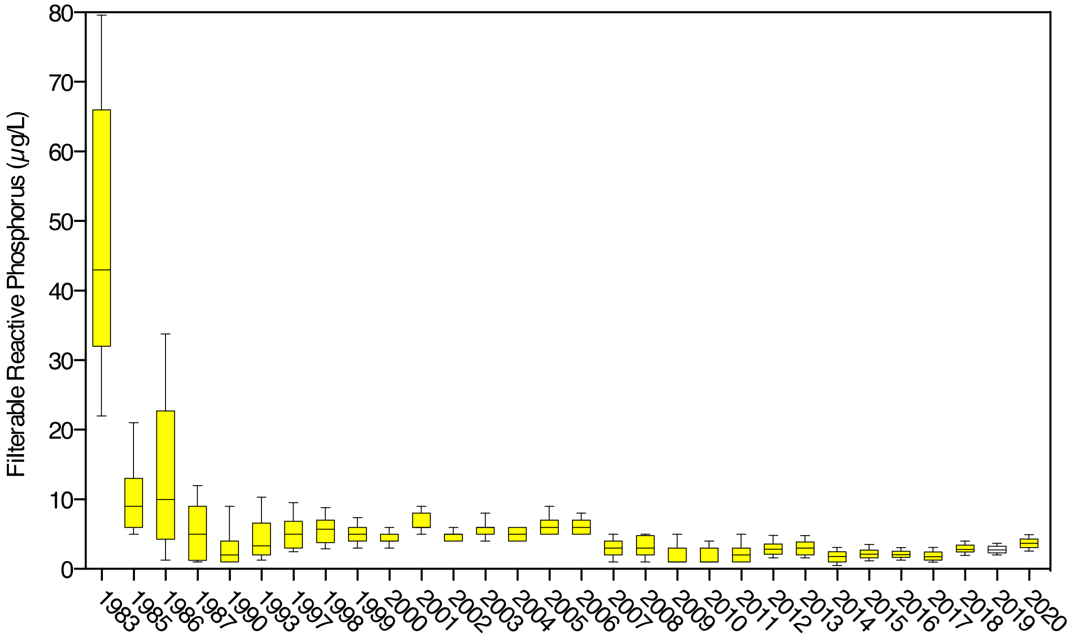
Median non river-flow period filterable reactive phosphorus (FRP) concentrations at historic Cockburn Sound sites have decreased during the past 35 years and generally remained stable in the past 12 years (Figure B5; Cossington & Wienczugow 2020).

The median FRP concentrations at the historical sites were significantly higher in 2019–20 than 1990, 2009–11 and 2014–17 (Cossington & Wienczugow 2020).

Total phosphorus

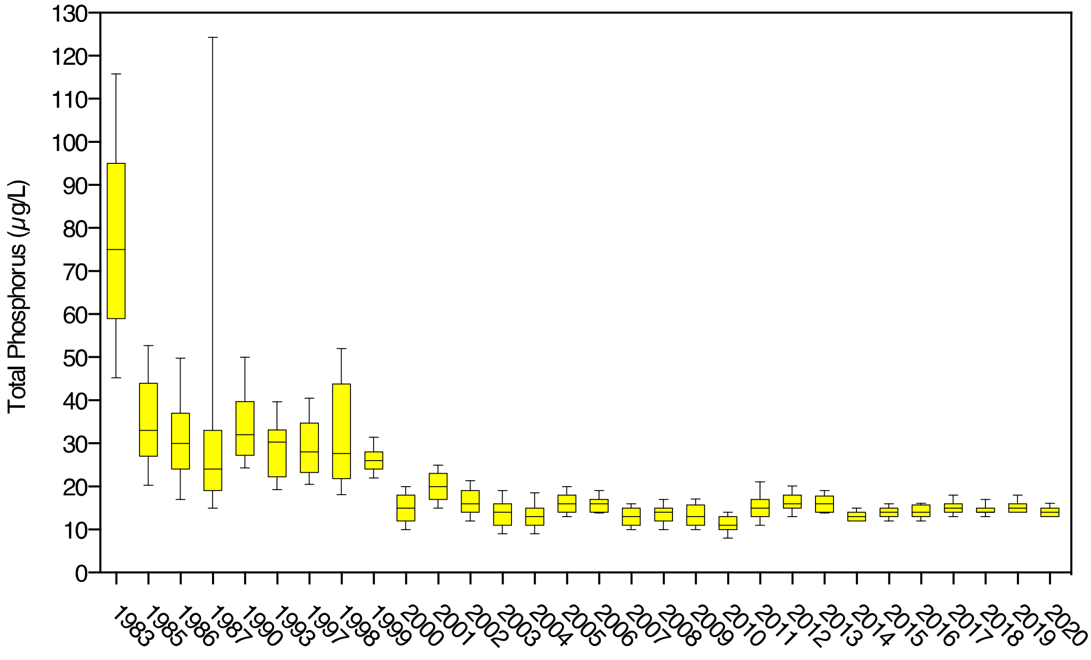
Median total phosphorus concentrations at the historical Cockburn Sound sites have slowly decreased over the years (Figure B6; Cossington & Wienczugow 2020).

The median total phosphorus concentrations at the historical Cockburn Sound sites in 2019–20 were significantly lower than in the 1980s and 1990s when total phosphorus was measured (Cossington & Wienczugow 2020).



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

Figure B5: Median filterable reactive phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 from 1983 to 2020.



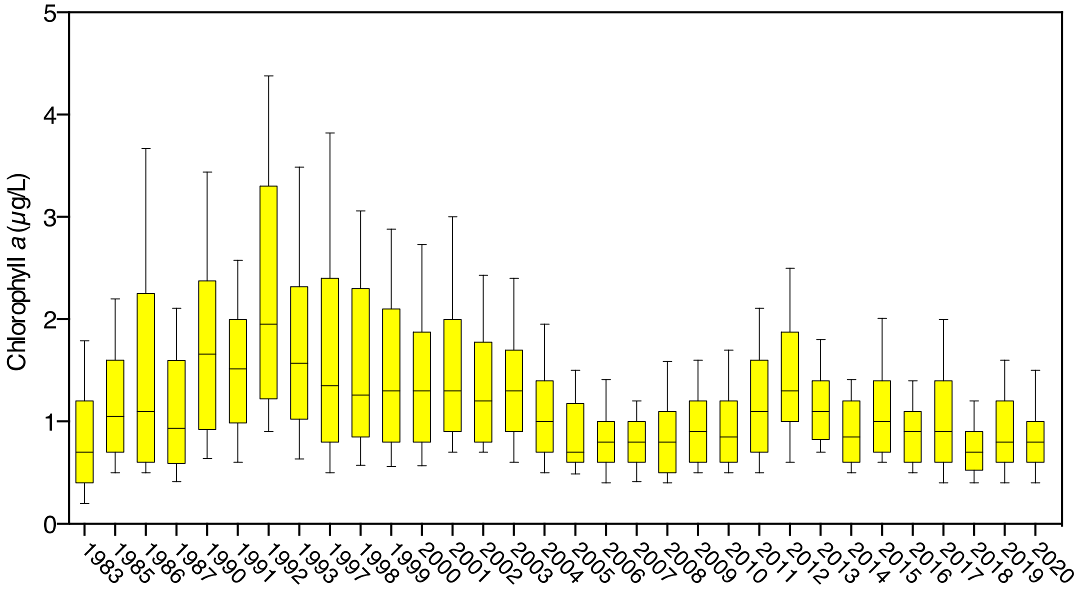
Note: The ‘box’ represents the 25th and 75th percentiles and the ‘whiskers’ the 10th and 90th percentiles.

Figure B6: Median total phosphorus concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 from 1983 to 2020.

Appendix C: Variations and trends over time in chlorophyll *a* concentrations and light attenuation

Chlorophyll a

Median chlorophyll *a* concentrations in Cockburn Sound generally increased from the early 1980s to mid-1990s, remained high in the early 2000s, and then decreased in the mid-2000s (Figure C1; Cossington & Wienczugow 2020). There was an additional increase in median chlorophyll *a* concentrations in 2011–13.



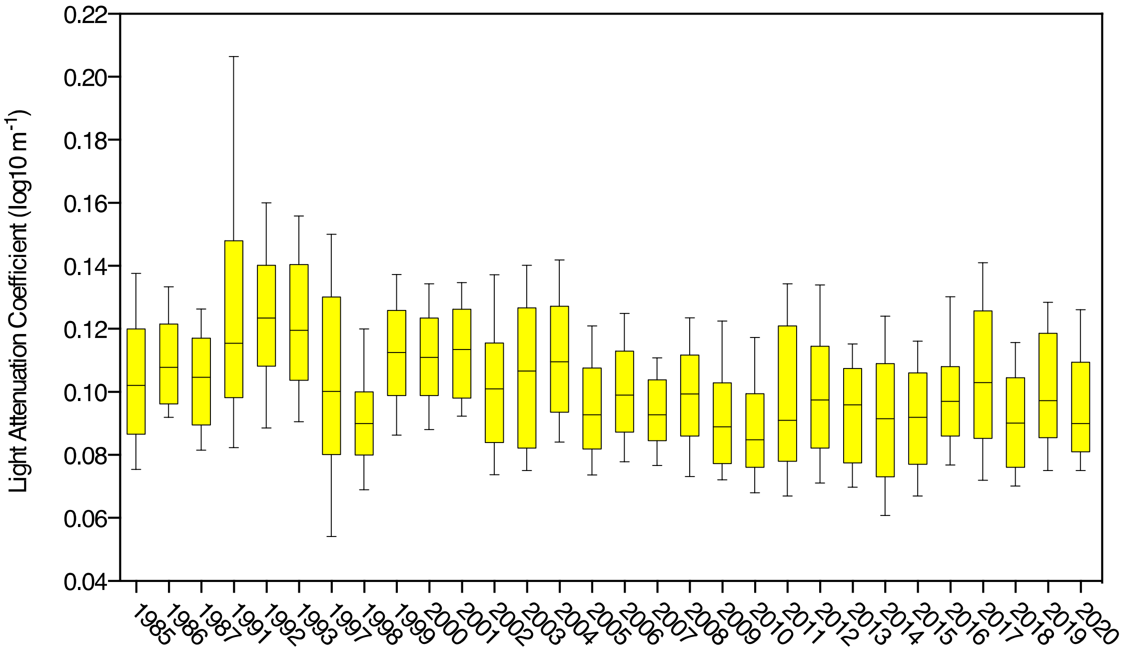
Note: The 'box' represents the 25th and 75th percentiles and the 'whiskers' the 10th and 90th percentiles.

Figure C1: Median chlorophyll a concentrations at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 from 1983 to 2020.

The median chlorophyll *a* concentration at the eight historic Cockburn Sound sites in 2019–20 was significantly lower than in 1985, 1990–2003 and 2011–13 (Cossington & Wienczugow 2020). There was no significant difference in median chlorophyll *a* concentrations in any other year recorded.

Light attenuation coefficient

Median light attenuation coefficients (LAC) at the eight historic Cockburn Sound sites in 2019–20 (2020) were significantly lower than in 1991–93, 1999–2001 and 2003–04, but significantly higher than in 2009–10 (2010) (Figure C2; Cossington & Wienczugow 2020). There was no significant difference between 2019–20 and all other years.



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

Figure C2: Median light attenuation coefficients at CS4, CS5, CS6/CS6A, CS7, CS8, CS9, CS10/CS10N and CS11 from 1985 to 2020.

Appendix D: Temporal trends in seagrass shoot density and lower depth limits of seagrass distribution

See Table D1 for the results of the Mann-Kendall trend analyses of mean and median *Posidonia sinuosa* shoot densities at each of the 11 seagrass monitoring sites in Cockburn Sound, the five sites outside Cockburn Sound and the five reference sites in Warnbro Sound (Martin et al. 2020). See figures D1–D4 for plots of mean and median shoot density at each site over time (Martin et al. 2020).

Table D1: Results of Mann-Kendall trend analyses of mean and median Posidonia sinuosa shoot densities at the seagrass monitoring sites in and around Cockburn Sound and the reference sites in Warnbro Sound.

Ecological protection area	Site	Seagrass shoot density (shoots/m^2)			
		Mean shoot density		Median shoot density	
		Mann-Kendall Statistic	p-value (two-tailed test)	Mann-Kendall Statistic	p-value (two-tailed test)
HPA-N	Garden Island 2.0 m	-0.03	0.90	-0.03	0.90
	Garden Island 2.5 m	-0.05	0.82	-0.02	0.94
	Garden Island 3.2 m	-0.37	**0.04**	-0.39	**0.03**
	Garden Island 5.5 m	-0.56	**<0.01**	-0.51	**<0.01**
	Garden Island 7.0 m	-0.29	*0.10*	-0.32	*0.07*
	Luscombe Bay	-0.01	0.99	-0.10	0.66
	Garden Island Settlement	-0.37	*0.06*	-0.30	*0.14*
	Kwinana	-0.10	0.62	-0.18	0.37
HPA-S	Southern Flats	-0.33	*0.06*	-0.31	*0.08*
	Mangles Bay	-0.25	*0.19*	-0.10	0.65
MPA-ES	Jervoise Bay	-0.47	**0.01**	-0.51	**<0.01**
Sites Outside Cockburn Sound	Carnac Island	-0.16	0.43	-0.14	0.49
	Coogee	-0.19	0.38	-0.18	0.41
	Woodman Point	-0.52	**<0.01**	-0.35	*0.08*
	Bird Island	-0.11	0.62	-0.15	0.49
	Mersey Point	-0.01	0.99	0.00	0.99

Ecological protection area	Site	Seagrass shoot density ($shoots/m^2$)			
		Mean shoot density		Median shoot density	
		Mann-Kendall Statistic	p-value (two-tailed test)	Mann-Kendall Statistic	p-value (two-tailed test)
Reference sites	Warnbro Sound 2.0 m	-0.54	**<0.01**	-0.50	**0.01**
	Warnbro Sound 2.5 m	-0.26	*0.15*	-0.23	*0.20*
	Warnbro Sound 3.2 m	-0.56	**<0.01**	-0.58	**<0.001**
	Warnbro Sound 5.2 m	-0.31	*0.08*	-0.30	*0.09*
	Warnbro Sound 7.0 m	0.12	0.56	0.06	0.78

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

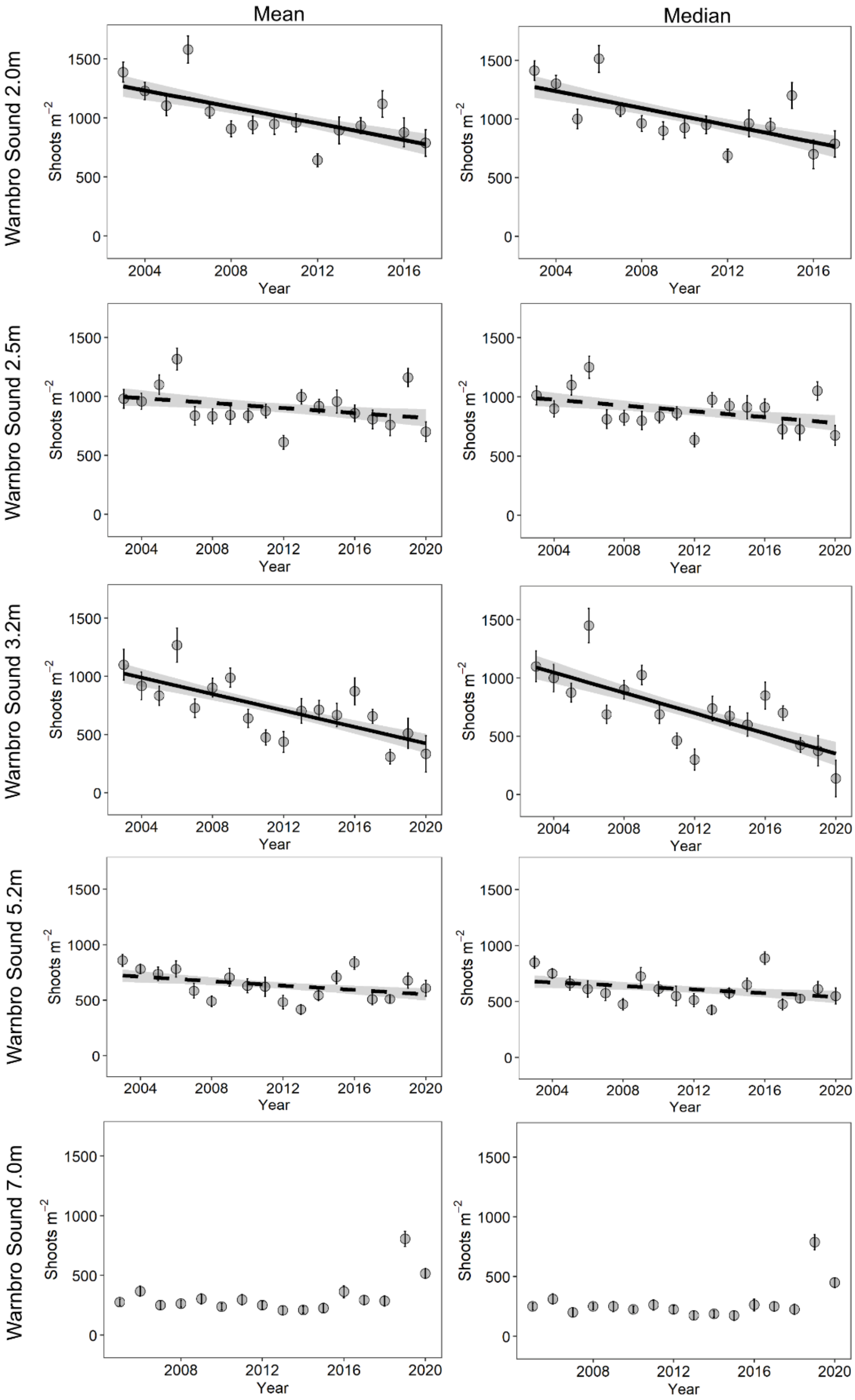
Trends were assessed as 'significant trends' at α = 0.05 and 'potential trends' at α = 0.2.

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

There was a significant (α = 0.05) downward trend in mean shoot density and a potential downward (α = 0.2) trend in median shoot density at Woodman Point.

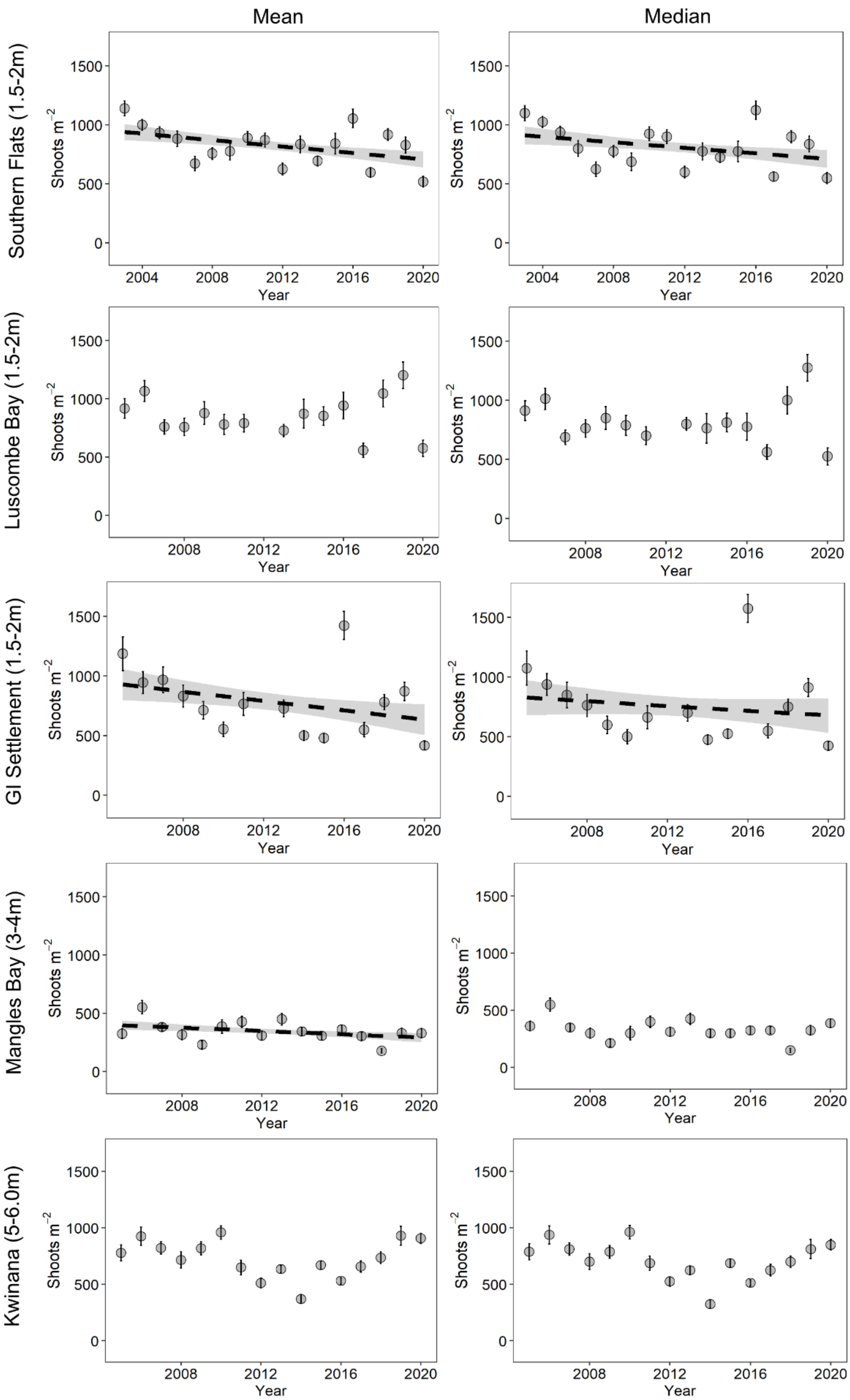
There were no significant trends in mean or median shoot densities at any of the other monitoring sites outside Cockburn Sound (Coogee, Carnac Island, Mersey Point, and Bird Island).

Significant (α = 0.05) downward trends in mean and median shoot densities were recorded at the reference sites Warnbro Sound 2.0 m and 3.2 m. There were potential downward (α = 0.2) trends in mean and median shoot densities recorded at Warnbro Sound 2.5 m and 5.2 m. There were no significant trends in mean or median shoot densities at Warnbro Sound 7.0 m.



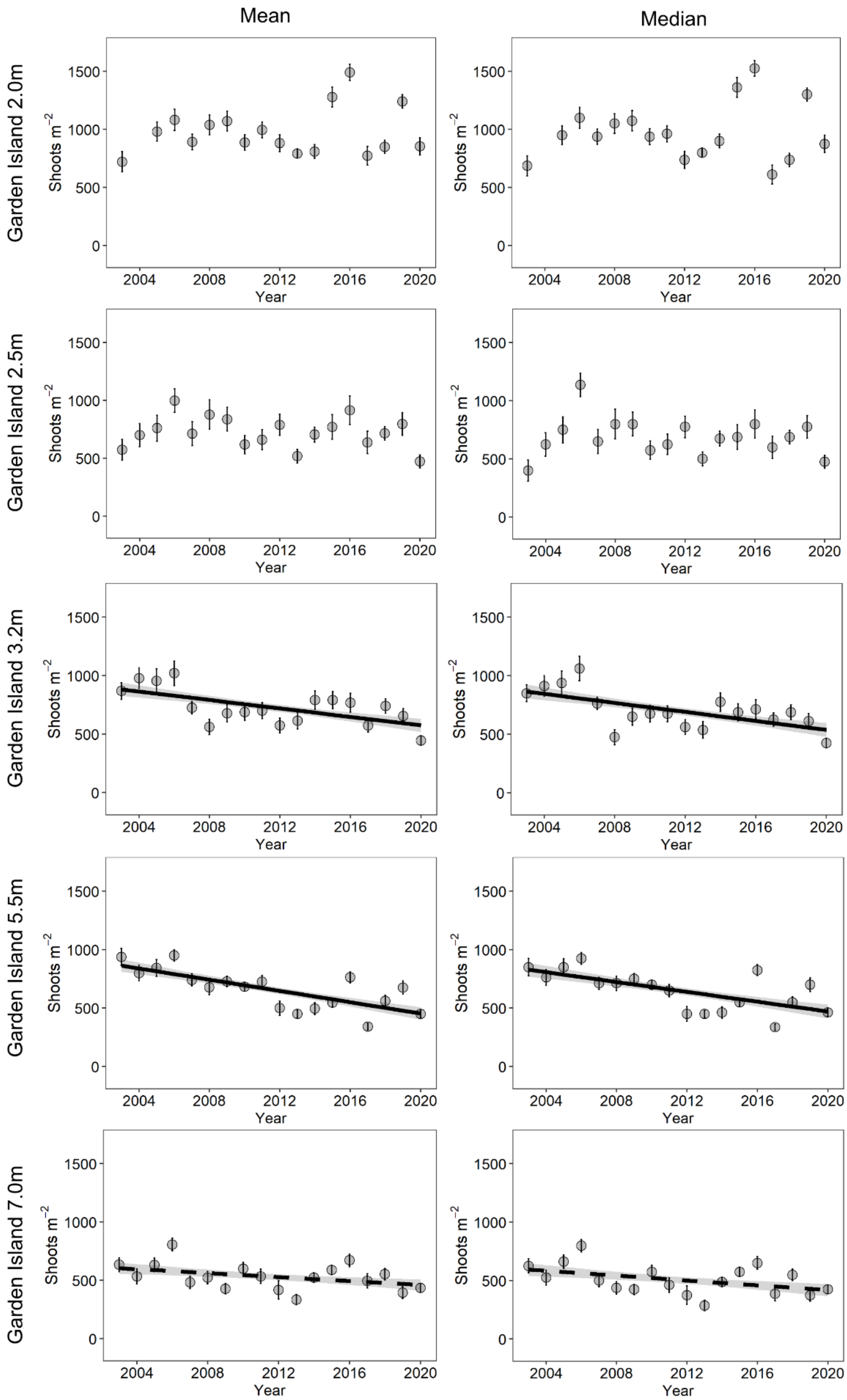
Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.

Figure D1: Trends in mean (± standard error) and median shoot densities at five reference sites in Warnbro Sound. Note that there was no seagrass present in and around Warnbro Sound 2.0 m.



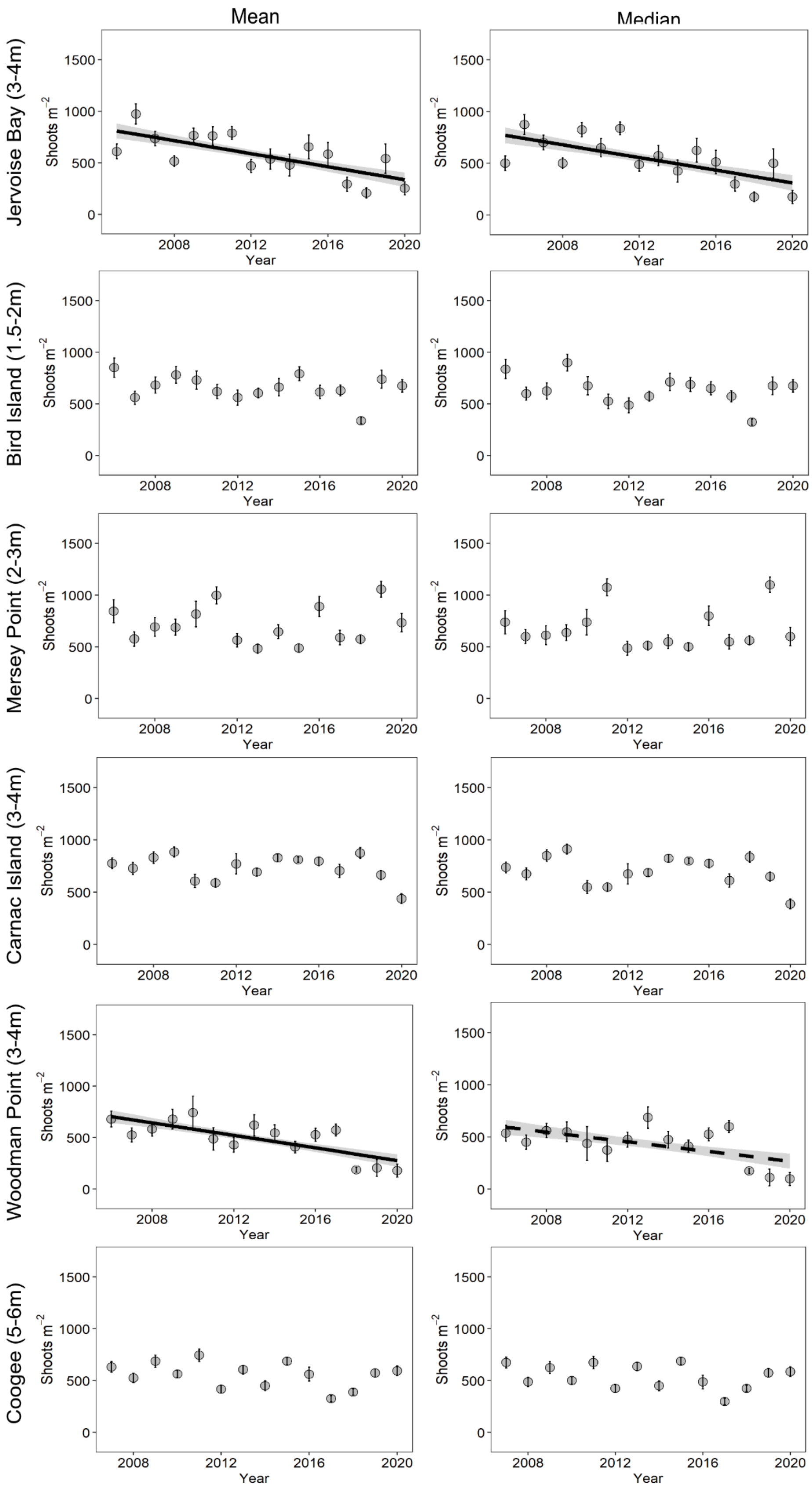
Note: Solid lines show significant trends (α = 0.05), dotted lines show trends where α = 0.2, and dashed lines shown the 95% confidence bands.

Figure D2: Trends in mean (± standard error) and median shoot densities at five potential impact sites in the Cockburn Sound high ecological protection area.



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

Figure D3: Trends in mean (± standard error) and median shoot densities at five potential impact sites on eastern shore of Garden Island in the Cockburn Sound high ecological protection area.



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

Figure D4: Trends in mean (± standard error) and median shoot densities at Jervoise Bay and five potential impact sites outside Cockburn Sound.

See Table D2 for the results of the Mann-Kendall trend analyses of the mean lower depth limit (LDL) at the four ‘depth limit’ sites (Martin et al. 2020). There were no significant trends in LDL over time for any of the sites, however Garden Island South and Warnbro Sound showed potential downward ($\alpha = 0.2$) trends in LDL. These results should be treated with caution due to the absence of data for the period from 2009 to 2012. The depth transects sites at Southern Flats and Mangles Bay were excluded from the trend analyses as these sites were established in 2017.

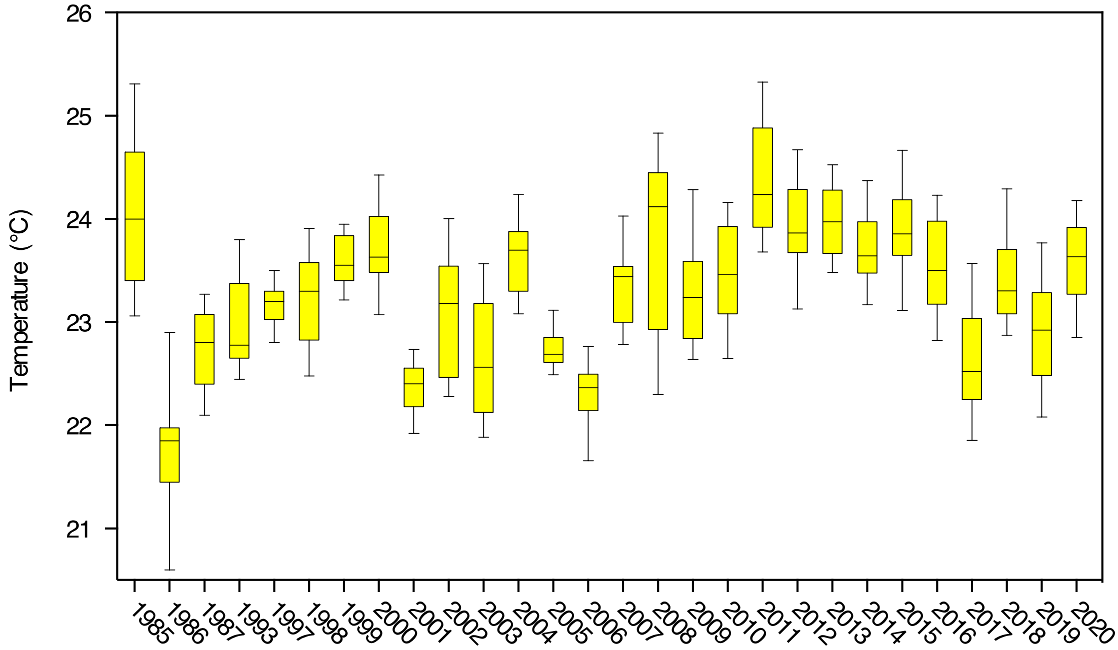
Table D2: Results of Mann-Kendall trend analyses of the mean lower depth limit at the three ‘depth limit’ sites in and around Cockburn Sound and one ‘depth limit’ reference site in Warnbro Sound.

Site	Mann-Kendall statistic	p-value
Garden Island North	0.33	0.45
Garden Island South	0.62	0.07*
Woodman Point	0.20	0.65
Warnbro Sound	0.59	0.09*

Note: * denotes p-values < 0.2 which is indicative of a potential downward trend

Appendix E: Variations and trends over time in water temperature in Cockburn Sound

See Figure E1 for the trends in median February bottom water temperatures measured at the eight Cockburn Sound sites for which there are long-term data available (CS4, CS5, CS8, CS6/CS6A, CS7, CS9, CS10/10N and CS11) (Cossington & Wienczugow 2020). Bottom water temperatures are used for analysis as they better represent the average temperature of the water column at any one time (Cossington & Wienczugow 2020). The 2020 median February bottom water temperature was 23.64° celsius.



Notes:

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

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

Figure E1: Median February bottom water temperatures in Cockburn Sound over the period 1985 to 2020.

The temperatures observed during February 2020 correlate with the Australian Bureau of Meteorology’s El Niño-Southern Oscillation indicator of neutral, although the Bureau predicted a 50% probability that a La Niña event would occur in late 2020 that might cause elevated sea temperatures in 2021 (Cossington & Wienczugow 2020). As sea temperature and water quality are closely related, any future increases in sea temperature may impact on water quality in Cockburn Sound.