GOVERNMENT OF
WESTERN AUSTRALIA

Cockburn Sound Environmental Monitoring Report 2022

Assessment against the environmental quality objectives and criteria as set out in the *State Environmental (Cockburn Sound) Policy 2015*

Cockburn Sound Management Council

Produced and published by
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National Relay Service 13 36 77

January 2025

FIRST 116043

Acknowledgments

The Cockburn Sound Management Council would like to thank the public authorities that have provided environmental monitoring data and information for inclusion in this report. The Council would like to especially thank Mrs Rebecca James, Mr Denis Doak and Ms Melissa Manns (Fremantle Port Authority), Dr Julia Phillips and Ms Karis Tingey (Water Corporation), Ms Tracey Stamp and Mr Jared Koutsoukos (Environmental Health Directorate, Department of Health) and Mr Kyle Hodson (Harvest Road Group) for their assistance.

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

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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) (SEP). An essential component of the framework is environmental quality monitoring. The monitoring 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).

The Cockburn Sound Management Council collates the monitoring results from its own water quality and seagrass health monitoring programs and the monitoring programs managed by other public authorities. It reports annually to the Western Australian 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 programs undertaken in Cockburn Sound for the reporting period 1 December 2021 to 30 November 2022.

Environmental value: Ecosystem Health

The 2022 monitoring data highlighted some localised, albeit persistent, water quality issues, but indicated water quality generally meets ecosystem health criteria across Cockburn Sound. There is no evidence of a recovery in seagrass health with shoot densities stable at most sites but at levels well below baseline. The results of the assessments suggest that the environmental quality objective of *maintenance of ecosystem integrity* was achieved during the 2022 monitoring period. More detail is provided below.

Nutrient enrichment

Over recent years, the water quality nutrient status of Cockburn Sound has become relatively stable. The areas with consistently higher concentrations of nutrients, chlorophyll-a and elevated light attenuation are those situated in the south and south-eastern shoreline areas of Cockburn Sound and areas with less flushing and exchange of water, including Jervoise Bay Northern Harbour and Mangles Bay. Elevated chlorophyll-a concentrations observed along the eastern shore met guideline values.

Seagrass is particularly susceptible to the effects of nutrient enrichment, which results in a decrease in available light at the seabed and an increase in the epiphyte load. Seagrasses are slow to recover from disturbance and this has been evident in Cockburn Sound. Despite nutrient levels and light attenuation in the water column generally meeting the relevant EQC, there is no evidence of any substantial recovery in seagrass health since monitoring began in the 1990s. The 2022 assessment suggest that seagrass health at most sites is stable, but at a level that is below baseline, and that seagrass health continues to decline at some sites. It is plausible that pressures other than nutrient enrichment are in part responsible for the state of seagrass health in this system.

The outcome of the 2022 assessment was that environmental quality guidelines and standards for nutrient enrichment are generally being met, except in Northern Harbour which consistently fails to meet EQC. Less flushed areas in the southern part of the Sound (e.g. Mangles Bay) also display some signs of nutrient enrichment but tend to meet environmental standards.

Other physical and chemical stressors

Bottom water dissolved oxygen concentrations generally met guideline values in the northern half of Cockburn Sound but exceeded these values repeatedly in the southern section and at one site along the Kwinana coast. All sites met the less conservative environmental quality standard on all occasions.

A lack of available data meant that an assessment against the temperature, salinity and pH criteria could not be completed. However, except for occasionally elevated salinity levels near the Perth Seawater Desalination Plant, no notable observations were made.

Considering these results and the results of previous monitoring reports, there is a reasonable degree of confidence that the established criteria are generally met and that these parameters in Cockburn Sound are not significantly affected by anthropogenic activity at an ecosystem scale.

Toxicants in marine waters

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). The 2022 monitoring data suggest that established criteria were met at all stations and sampling occasions, except for TRHs at a single site near the Kwinana Bulk Terminal. The results suggest relevant water quality objectives are generally being achieved.

Toxicants in sediments

The 2022 monitoring data suggest that conservative guideline values are generally met. Slightly elevated concentrations for cadmium and tributyltin (TBT) exceeded guideline values at a single site near the Kwinana Bulk Jetty while slightly elevated levels of three organotoxins (acenaphthene, acenaphthylene and fluorene) were reported from multiple sites around the commercial jetties. However, all reported elevated concentrations remained below the re-sampling trigger, indicating relevant water quality objectives are generally being achieved.

Environmental value: Fishing and Aquaculture

All assessments of algal biotoxins (in water), toxins (in seafood) and toxicants in water met the relevant criteria, except for the alert levels for two potentially toxic phytoplankton species (out of 68 reported species) that were exceeded on two occasions in January 2022 in the water at Southern Flats. Given the low incidence of alert level exceedances in water, the 2022 monitoring data suggests the environmental quality objectives of *maintenance of seafood safe for human consumption and maintenance of aquaculture production* were 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.

Environmental value: Recreation and Aesthetics

All assessments of 2022 monitoring data against primary and secondary contact recreation criteria met guideline values. Based on these results, there is a high level of confidence that the environmental quality objectives of *maintenance of primary contact recreation values* and *maintenance of secondary contact recreation values* are being achieved in Cockburn Sound and that waters in the Sound are safe for swimming.

Observations of nuisance organisms and phytoplankton blooms, reduced water clarity, water colour issues and floating debris were relatively common in several locations. This may suggest that while the environmental quality objective of *maintenance of aesthetic values* is generally being achieved, this objective is being compromised locally.

Environmental value: Cultural and Spiritual

The environmental quality objective for the environmental value of Cultural and Spiritual is that *cultural and spiritual values of the marine environment are protected*.

Currently, no criteria specific to this environmental value have been developed. The existing criteria that are implemented to ensure ecosystem integrity, seafood quality and recreational and aesthetic values are protected, may reasonably be expected to contribute to protecting cultural and spiritual values in Cockburn Sound. However, engagement with Traditional Owners is required to identify the cultural and spiritual values in Cockburn Sound and to test whether additional objectives and/or criteria need to be developed to ensure these values are protected. This will be completed as part of the SEP Review Project which will be undertaken over 2024–27.

Environmental value: Industrial Water Supply

Data collected at the Perth Seawater Desalination Plant intake over the 2022 monitoring period indicate that water quality of intake water generally meets the relevant criteria. Total suspended solids (TSS) is the only parameter for which criteria were commonly exceeded. Variation in intake water quality is expected and the 2022 results are generally in line with previous years.

No adverse impact on the operation of the plant nor a need for mitigation measures were reported by Water Corporation, indicating that the environmental quality objective *maintenance of water quality for industrial use* was achieved during the reporting period.

1. Introduction

1.1 The State Environmental (Cockburn Sound) Policy 2015

The Environmental Protection Authority (EPA) has established an environmental quality management framework for Cockburn Sound through the *State Environmental (Cockburn Sound) Policy* (SEP), first established in 2005 and revised in 2015.

The SEP provides an important mechanism to ensure that the values and uses of Cockburn Sound are protected. The overall objective of the policy is to ensure that the environmental quality of the Sound is maintained or improved in seagrass areas and the quality of other values.

The environmental quality management framework established through the SEP is based on that recommended by the National Water Quality Management Strategy, representing an agreed, Australia-wide approach to protecting water quality and associated environmental values. The management framework and associated monitoring provide a strong basis for an adaptive management approach that is effective in protecting the integrity and biodiversity of the marine ecosystem, and current and projected future societal uses of these waters, from the effects of pollution, waste discharges and deposits.

1.2 The environmental quality management framework

The environmental quality management framework is underpinned by environmental values, environmental quality objectives (EQOs) 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.

For most environmental health parameters/indicators, two quantitative EQC have been established, forming a two-tiered framework with:

- environmental quality guidelines (EQG) being threshold numerical values or narrative statements which, if met, indicate a high degree of certainty that the associated EQO has been achieved and the environmental values protected
- environmental quality standards (EQS) being threshold numerical values or narrative statements that indicate a level beyond which there is a significant risk that the associated EQO has not been achieved and that the environmental values are at risk.

This allows a ‘traffic light’ reporting system to be adopted, which can be used to communicate the results of the monitoring:

- Green: EQG is met – no action required
- Orange: EQG is not met but EQS is met – may require further investigation
- Red: EQS is not met – investigation and management action may be required

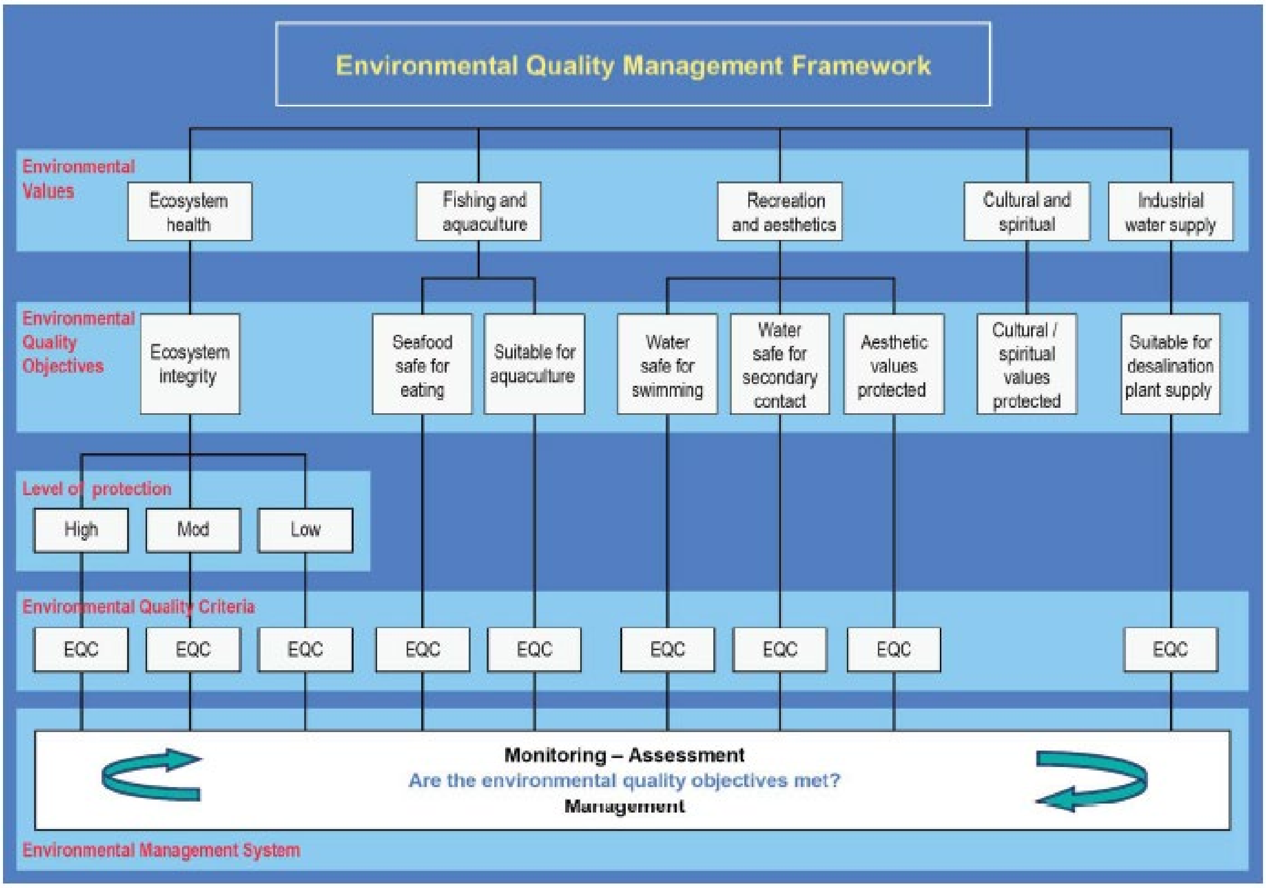


Figure 1: Environmental quality management framework for Cockburn Sound (EPA 2017)

The SEP describes three levels of ecological protection (high protection, moderate protection and low protection) and where they apply spatially in Cockburn Sound (Figure 2).

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 established zones of ecological protection convey the minimum acceptable level of environmental quality to be achieved in each area and are consistent with protecting ecosystem integrity in Cockburn Sound.

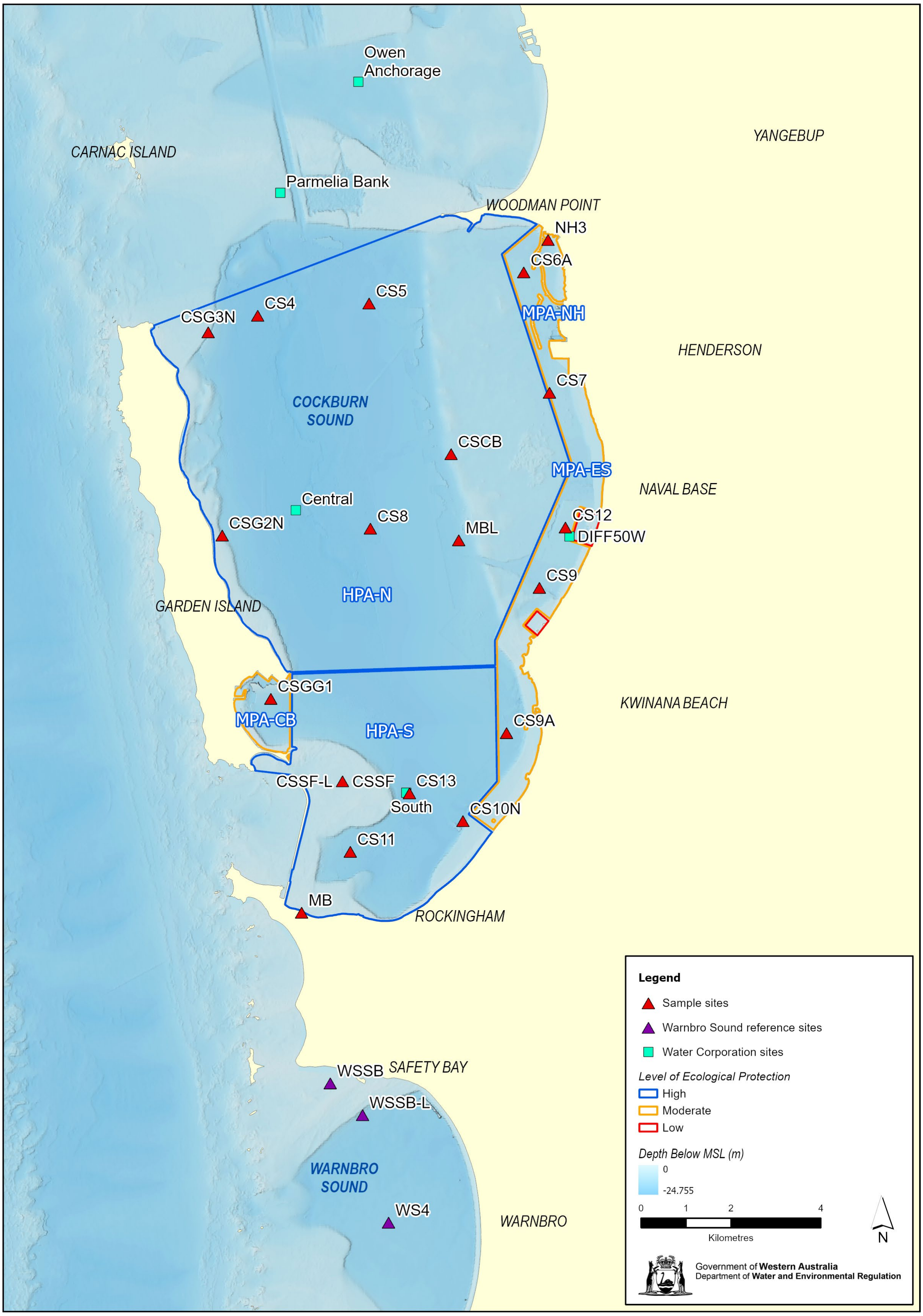


Figure 2: The ecological protection areas in Cockburn Sound and the location of water and sediment quality monitoring sites within Cockburn Sound and reference sites in Warnbro Sound (Flukes 2024)

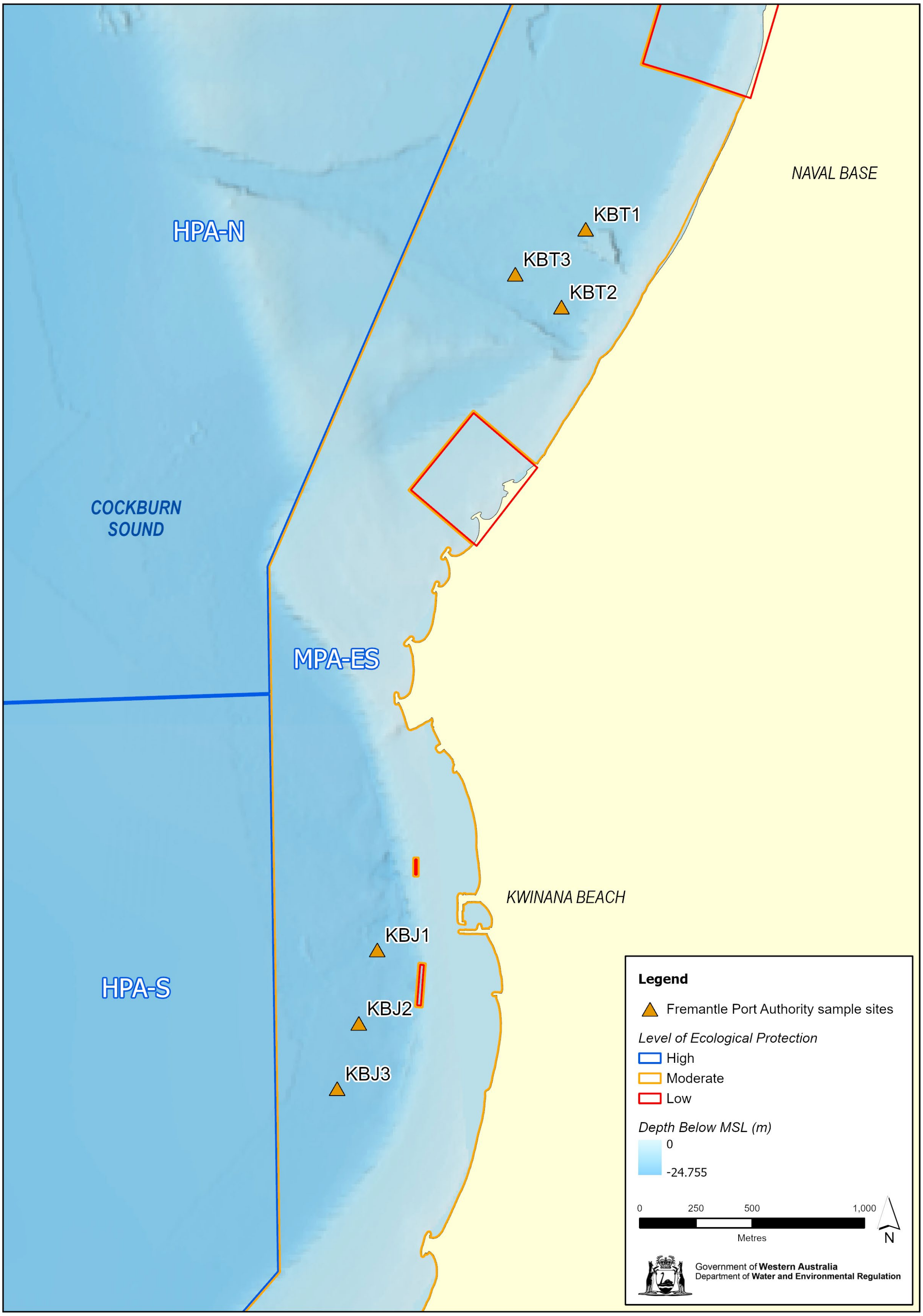


Figure 3: Fremantle Port Authority's marine water and sediment quality monitoring sites in Cockburn Sound (Flukes 2024)

Most of Cockburn Sound is designated as having a high level of ecological protection, except for Careening Bay and a coastal strip in the eastern part of the Sound, where waste disposal and other societal uses preclude a high level of ecological protection, and a moderate level of protection has been established. These zones are further subdivided into the following spatially defined areas[1]:

- High Protection Area – North (HPA-N)
- High Protection Area – South (HPA-S)
- Moderate Protection Area – Eastern Sound (MPA-ES)
- Moderate Protection Area – Careening Bay (MPA-CB)
- Moderate Protection Area – Southern Harbour (MPA-SH) – not currently monitored
- Moderate Protection Area – Northern Harbour (MPA-NH)

A few small areas around outfalls in Cockburn Sound (less than 1% of the protected area) have been designated as having a low level of ecological protection. For these areas compliance monitoring and reporting is completed by the proponent and provided to the Department of Water and Environmental Regulation. Cockburn Sound Management Council (CSMC) does not report on environmental performance within low ecological protection zones.

1.3 Monitoring programs for measuring environmental performance

1.3.1 Overview

An essential component of the environmental quality management framework is the implementation of appropriate environmental 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* (EPA 2005) specifies how samples should be collected and analysed, as well as how the results should be assessed against the EQC.

Under the SEP, responsibility for monitoring against the EQC is shared across several public authorities, based on their roles and responsibilities. Not all parameters for all EQC are, or need to be, monitored on a regular basis. The relevant public authorities determine what monitoring should be undertaken based on an assessment of risks and impacts.

1.3.2 CSMC and Department of Water and Environmental Regulation monitoring programs and recent changes

The EQC for Cockburn Sound were originally developed specifically for the assessment of environmental quality during the non river-flow period in the summer months. During these months the conditions in the Sound are relatively stable (e.g. low frequency of storm and rainfall events and limited input of freshwater from the Swan River), which allows useful comparisons to be made between years. This period is also critical for seagrass growth

[1] For some parameters, the data from all monitoring sites within a defined area are grouped prior to comparison against the EQC. In those cases, reporting is done for each area as opposed to for each site.

and recreational activity and covers the seasonal occurrence of phytoplankton blooms and stratification events. By concentrating monitoring effort during this season, the monitoring programs were able to collect sufficient datapoints for statistically robust analyses. The CSMC-managed water quality monitoring program was aligned accordingly and based around weekly monitoring on 16 occasions over the non river-flow period (December to March) at 18 sites across Cockburn Sound and two sites in Warnbro Sound (reference sites) each year.

The Cockburn Sound water quality monitoring programs were reviewed by an expert advisory panel in 2017 (known as the Hatton Review), resulting in a series of recommendations that have, in part, been implemented since 2017.

The State Government also recognised the need for robust environmental baseline datasets to support environmental impact assessment of several planned large infrastructure projects, including Westport (the State Government’s proposed future container port in Kwinana), an expansion of Water Corporation’s Perth Seawater Desalination Plant and the potential expansion of the Australian Marine Complex for Commonwealth Defence purposes.

The CSMC/Department of Water and Environmental Regulation environmental monitoring programs currently include:

CSMC

- CSMC: monthly field sampling (vessel based, year-round) and measurement of nutrient-related and physical-chemical water quality parameters at 18 impact sites plus two reference sites
- CSMC: an annual field program to monitor seagrass shoot density at 11 sites in Cockburn Sound, five reference sites and two additional nearby sites
- CSMC: an annual field program to monitor seagrass lower depth limit at four sites in Cockburn Sound and two reference sites
- CSMC: periodic mapping of seagrass distribution and extent in Cockburn Sound, based on airborne multi-spectral imagery and field validation

Department of Water and Environmental Regulation

- continuous sampling of physical-chemical water quality parameters by water quality buoys at eight sites across Cockburn Sound.

Recent changes to the environmental monitoring programs conducted in the Sound – in response to the Hatton Review and the expected increase in pressure from planned infrastructure development – are explained in Table 1.

These changes and associated challenges have impacted the capacity to compare the results against established EQC and are intended to be resolved as part of the SEP Review Project over the 2024–27 period.

Table 1: Recent changes to Cockburn Sound environmental monitoring programs

Change	Rationale	Consequence for CSMC reporting & recommendations
Jan 2021 – Department of Water and Environmental Regulation established eight telemetered water quality stations in Cockburn Sound	Multiple new large-scale infrastructure proposals are being developed for Cockburn Sound, requiring 24/7 detailed environmental baselines captured over several full years. Deploying telemetered water quality stations in Cockburn Sound also delivered on one of the Hatton Review (of the environmental monitoring program in Cockburn Sound) recommendations.	Implementation of the telemetered water quality stations have generated a much-improved environmental baseline for Cockburn Sound but have not improved the baseline of the reference sites in Warnbro Sound. Also, technical issues have resulted in lost and inaccurate data collected in 2021 and 2022. Several water quality EQC are based on a rolling percentile value calculated from reference site data. As no telemetered station was deployed in Warnbro Sound, reference site data are not available for calculation of rolling percentiles. Thus, telemetered data from Cockburn Sound cannot be tested against the EQC. Quality assurance/control of the monitoring data captured by the buoys over 2022–24 is required and will be completed by the Department of Water and Environmental Regulation in Q1 2025. **Addition of one additional telemetered buoy for the reference site is recommended.**
Jan 2021 – CSMC adopted year-round monthly water quality monitoring in favour of weekly monitoring over the summer period (Dec–Mar)	Extending the manual water quality monitoring program over the full year was recommended by the Hatton Review. Frequency of monitoring was limited by the budget available.	The change reduced the available data points from 16 for the original non river-flow period to three for a typical season, which is insufficient for deriving medians or percentiles and compromising the comparisons against several established EQC. **It is recommended that the monitoring methodology is reviewed with the aim of ensuring adequate data is collected to assess environmental performance in accordance with the established environmental quality management framework. The addition of a telemetered water quality station at a suitable reference site may address this issue.**
Jan–Feb 2022 – CSMC stopped monitoring of three shallow Warnbro Sound reference sites for seagrass – 2.0 m, 2.5 m and 3.2 m	Seagrass shoot density had been seriously affected by sand accretion/erosion at these sites. In response, two shallow seagrass sites in Shoalwater Islands Marine Park and one site in Owen Anchorage were selected from the existing monitoring program to replace the Warnbro Sound reference sites that had been impacted.	The new reference sites are active and comparisons against the EQC derived from Warnbro Sound reference sites and new reference sites are both presented in this report to provide all relevant information and to complete the comparisons against the EQC. The 2023 Cockburn Sound Monitoring Report will contain an assessment of the first two years of using the new reference sites for assessing environmental performance and developing recommendations going forward.

1.3.3 Data sources 2022

Table 2 summarises the environmental quality indicators measured by the various 2022 monitoring programs for comparison against the EQC for Cockburn Sound, as well as the sources of these data.

More detail for each monitoring program considered in this report is provided under the relevant sections.

It should be noted that because of several technical issues (Table 1), the data from the Department of Water and Environmental Regulation's telemetered stations deployed in Cockburn Sound have not been used in the preparation of this report. The available datasets are being analysed for quality assurance and control and it is expected that several datasets will be available for inclusion in the 2023 report.

Table 2: Environmental quality indicators and data sources for the 2022 reporting period, against the EQOs

EQOs		Indicator	Data source
Ecosystem Health – Maintenance of ecosystem integrity			
Physical and chemical stressors	Nutrient enrichment	Chlorophyll-a concentration, light attenuation coefficient and seagrass shoot density	CSMC
	Phytoplankton biomass	Phytoplankton biomass (measured as chlorophyll-a)	
	Other physical and chemical stressors	Dissolved oxygen concentration, water temperature, salinity and pH	CSMC, Water Corporation and Fremantle Port Authority
Toxicants (marine waters)	Metals and metalloids	Copper	CSMC and Fremantle Port Authority
	Non-metallic inorganics	Ammonia	
	Organics	BTEX	
	Oils and petroleum hydrocarbons	Total recoverable hydrocarbons (TRHs)	
Toxicants (sediments)	Metals and metalloids	Arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc	Fremantle Port Authority
	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)	
Fishing and aquaculture			
Maintenance of	Biological contaminants	*Faecal coliform, total coliform,*	WASQAP* –

EQOs			Indicator	Data source
seafood safe for human consumption			*Escherichia coli (E. coli)* in fish flesh and algal biotoxins	Department of Health
	Chemicals	Metals	Arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc	WASQAP* – Harvest Road Group, Fremantle Port Authority
		Organic chemicals	Polychlorinated biphenyls and PAHs	
		Organometallics	TBT, DBT, MBT	
Maintenance of aquaculture	Physical and chemical stressors		Dissolved oxygen, pH	CSMC
	Toxicants	Non-metallic inorganic chemicals	Ammonia, nitrate–nitrite	CSMC and Fremantle Port Authority
		Metals and metalloids	Copper	
Recreation and aesthetics				
Maintenance of primary contact recreation values	Biological		*Enterococci*	Department of Health
	Physical		pH, water clarity	CSMC
	Toxic chemicals	Inorganic chemicals	Copper, nitrate–nitrite	CSMC and Fremantle Port Authority
		Organic chemicals	BTEX	
Maintenance of secondary contact recreation values	Biological		*Enterococci*	Department of Health
	Physical and chemical		pH	CSMC
			Toxic chemicals	CSMC and Fremantle Port Authority
Maintenance of Aesthetic Quality	Visual indicators		Nuisance organisms, faunal deaths, water clarity, colour variation, surface films, debris and odour	CSMC
Industrial Water Supply				
Maintenance of water quality for industrial use	Biological		*E. coli/enterococci*	Water Corporation
	Physical and chemical		Temperature, pH, dissolved oxygen, total suspended solids, hydrocarbons, boron and bromide	

WASQAP = Western Australia Shellfish Quality Assurance Program

1.4 This report

The CSMC collates the monitoring results from its own water quality and seagrass health monitoring programs and the monitoring programs managed by other public authorities. It reports annually to the Minister for Environment on the extent to which the results meet EQC and objectives as set out in the *Environmental quality criteria reference document for Cockburn Sound* (EPA 2017), a supporting document to the SEP.

This report presents the findings of the environmental quality monitoring programs undertaken in Cockburn Sound for the reporting period 1 December 2021 to 30 November 2022.

Findings are summarised and discussed in the context of meeting the EQC and achieving the objectives established for Cockburn Sound. The structure of the report is aligned with the environmental value and EQO as follows:

- **Environmental value: Ecosystem Health (Section 2)**
  - EQO: Maintenance of ecosystem integrity
- **Environmental value: Fishing and Aquaculture (Section 3)**
  - EQO: Maintenance of seafood safe for human consumption
  - EQO: Maintenance of aquaculture
- **Environmental value: Recreation and Aesthetics (Section 4)**
  - EQO: Maintenance of primary contact recreation values
  - EQO: Maintenance of secondary contact recreation values
  - EQO: Maintenance of aesthetic values
- **Environmental value: Cultural and Spiritual Values (Section 5)**
  - EQO: Cultural and spiritual values of the marine environment are protected
- **Environmental value: Industrial Water Supply (Section 6)**
  - EQO: Maintenance of water quality for industrial use

2. Environmental value: Ecosystem Health

2.1 EQO

The EPA recommends ecosystem integrity to be considered in terms of structure (e.g. biodiversity, biomass and abundance of biota) and function (e.g. food chains and nutrient cycles) (EPA 2017). Ecosystem structure and function may be affected by a suite of anthropogenic and natural pressures that include waste discharge, pollution, seabed modification, commercial/recreational fishing and climate change.

The environmental quality management framework established in Cockburn Sound by the SEP is aimed at ensuring the environmental value established for Cockburn Sound are protected from the effects of pollution, environmental harm, waste discharges and deposits. Hence, with respect to the environmental value of Ecosystem Health, the SEP focuses on ensuring the 'environmental conditions' –that is, water and sediment quality (and, by extension, seagrass health) – are maintained and continue to support ecosystem integrity.

Monitoring and management of other pressures (e.g. harvesting of biota, shipment-related underwater noise, climate change) and parameters of ecosystem integrity and biodiversity (such as fish and iconic species populations) are delivered by regulatory agencies with responsibilities under other relevant legislation.

Under the framework, the EQO *maintenance of ecosystem integrity* is considered to be achieved when the environmental quality EQC are met in each of the spatially defined ecological protection areas. See Figure 2 and Table 3 for details of the water quality and seagrass monitoring sites in each ecological protection area.

2.2 Monitoring programs

2.2.1 CSMC water quality monitoring program

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 (Figure 2). Depth-integrated water quality samples were collected monthly (as of January 2021) from all monitoring sites with the addition of two discrete surface and bottom samples collected at sites CS13 and WS4.

The depth-integrated water samples were analysed for nutrients (i.e. 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 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 for reporting purposes.

In addition to these analyses, physical and chemical parameters (i.e. water depth, water temperature, salinity, pH, turbidity, dissolved oxygen (DO) and chlorophyll-a by fluorescence) were measured in situ at each site.

Table 3: High and moderate ecological protection areas for Cockburn Sound and the associated water quality and toxicants monitoring sites.

Ecological protection area	Water quality monitoring sites	Toxicants in sediment / water monitoring sites
High Protection Area North (HPA-N)	CS4, CS5, CS8, G2, G3 and CB; Central	-
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	-
Moderate Protection Area Careening Bay (MPA-CB)	G1	-
Moderate Protection Area Eastern Sound (MPA-ES)	CS6A, CS7, CS9, CS9A, CS10N and CS12; DIFF50W	Sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) are 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	-

2.2.2 Port Authority water quality monitoring

Fremantle Port Authority undertook monitoring of toxicants in marine waters at three sites around the Kwinana Bulk Terminal (KBT1, KBT2 and KBT3) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2 and KBJ3) (Figure 3). Water quality samples were collected in January 2022, along with measurements of the physical-chemical parameters of DO, 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, phaeophytin-a and filtered copper. Samples were analysed by ChemCentre for TRHs and BTEX.

2.2.3 Port Authority marine sediment monitoring

Fremantle Port Authority undertook monitoring of toxicants in marine sediments at three sites around the Kwinana Bulk Terminal (KBT1, KBT2 and KBT3) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2 and KBJ3) (Figure 3).

Sediment samples were collected in February 2022 at all six sites. Five 100 mm diameter sediment cores were collected within 1 mP2P 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 (i.e. arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (i.e. TBT, DBT and MBT), PAHs, PFAS and TRHs.

Methods used throughout the analyses followed those outlined in the standard operating procedures and standard laboratory analytical procedures. Laboratories with methods accredited by the National Association of Testing Authorities, Australia (or laboratories with demonstrated quality assurance/quality control procedures in place) undertook the analyses.

2.3 Assessment against the nutrient enrichment criteria

The extent to which nutrient enrichment has affected water quality and seagrass health is assessed by measuring and/or calculating:

1. median chlorophyll-a concentration over the full non river-flow period, which is a measure of phytoplankton standing crop or chronic phytoplankton concentration
2. light attenuation coefficient, which is a measure of the extent to which the amount of light is reduced as it travels through the water column, and, hence, an inverted measure of water clarity
3. seagrass shoot density and lower depth limit, which are measures of plant health within existing seagrass meadows and meadow depth, respectively
4. chlorophyll-a concentration at the time of sampling, which is a snapshot measure of phytoplankton biomass at the time of each sampling event.

The first two water quality indicators measure water column properties relevant to seagrass health. The seagrass indicators directly measure plant health within the existing meadows and meadow depth. The fourth indicator is not immediately related to seagrass health and is used to assess the comparative frequency of algal blooms.

The 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 may enable seagrass meadows to re-establish along the eastern side of Cockburn Sound, including the Kwinana Shelf, to depths of up to 10 m
- minimise the occurrence and extent of phytoplankton blooms in Cockburn Sound.

2.3.1 Chlorophyll-a and light attenuation coefficient

Calculation of EQG

Yearly updates to the EQC for chlorophyll-a and light attenuation coefficient are based on rolling percentiles calculated using weekly monitoring measurements collected at Warnbro Sound reference site WS4 summer (non river-flow) monitoring period over several years. However, since January 2021, the monitoring frequency was changed from weekly sampling during the non river-flow period to monthly monitoring throughout the year, reducing the weighting of, and contribution by, the current year in percentile calculations.

The 2022 EQC were calculated using data from the 2022 non river-flow period and sampling undertaken over the same period during previous years (n=103). The updated EQC are presented in Table 4 below.

Table 4: The 2022 high and moderate protection EQG for chlorophyll-a concentration and light attenuation coefficient (LAC)

Indicator	High protection (Rolling 80th percentile)	Moderate protection (Rolling 95th percentile)
Chlorophyll-a (µg/L)	0.96	1.49
LAC (log_{10} m^{-1})	0.095	0.115

Assessment against the EQG

The chlorophyll-a concentrations and light attenuation coefficients recorded from December 2021 to March 2022 from each of the 18 water quality monitoring sites were assessed against the nutrient enrichment EQG.

High protection: The median chlorophyll-a concentration/light attenuation coefficient during the non river-flow period is not to exceed a chlorophyll-a concentration of 1.0 µg/L or a light attenuation coefficient of 0.095 log_{10} m^{-1}.

Moderate protection: The median chlorophyll-a concentration/light attenuation coefficient during the non river-flow period is not to exceed a chlorophyll-a concentration of 1.5 µg/L or a light attenuation coefficient of 0.115 log_{10} m^{-1}.

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. However, it was noted that median chlorophyll-a and light attenuation coefficient values far exceeded MPA criteria.

The 2022 assessment indicated that the nutrient enrichment EQG for chlorophyll-a and light attenuation coefficient were met in all relevant ecological protection areas (Table 5).

Reviewing the data in more detail, it was noted that individual monthly chlorophyll-a and/or light attenuation coefficient measurements were above the EQG value on one or two occasions at several sites. The only site median that was above the EQG value was for chlorophyll-a at Mangles Bay.

Table 5: Assessment of chlorophyll-a concentrations and light attenuation coefficients (LAC) against the nutrient enrichment EQG for each ecological protection area and the individual monitored sites

Ecological protection areas	Sites	Chlorophyll-a (µg/L) 2022 EQG	Chlorophyll-a (µg/L) 2022 Site Median	Chlorophyll-a (µg/L) 2022 Ecological Protection Area Median	LAC (log10 m-1) 2022 EQG	LAC (log10 m-1) 2022 Site Median	LAC (log10 m-1) 2022 Ecological Protection Area Median	Assessment
HPA-N	CS4	1.0	0.6	**0.6**	0.095	0.076	**0.079**	**EQG met**
	CS5		0.8			0.078		
	CS8		0.9			0.084		
	CB		0.7			0.085		
	G2		0.6			0.085		
	G3		0.5			0.074		
HPA-S	CS11	1.0	0.9	**0.9**	0.095	0.084	**0.082**	**EQG met**
	CS13		0.9			0.081		
	SF		0.6			0.076		
	MB/MB-L		1.3			0.091		
MPA-CB	G1	1.5	0.9	**0.9**	0.115	0.088	**0.088**	**EQG met**
MPA-ES	CS10N	1.5	0.9	**0.8**	0.115	0.093	**0.098**	**EQG met**
	CS12		0.9			0.096		
	CS6A		0.6			0.104		
	CS7		0.7			0.100		
	CS9		1.1			0.100		
	CS9A		0.9			0.099		
MPA-NH	NH3	N/A	3.3	3.3	N/A	0.147	0.147	N/A

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

See Appendix B for additional information on ammonium, total nitrogen and total phosphorus concentrations.

2.3.2 Seagrass health

The impact of nutrient enrichment on seagrass health in Cockburn Sound is focused on the historically dominant species *Posidonia sinuosa* and is based on three EQS:

- EQS (i) and (ii) requires comparisons of shoot densities at Cockburn Sound sites against those at reference sites of similar depth and against baseline values. The assessment involves the calculation of rolling percentiles calculated over several years.

- EQS (iii) involves an assessment to determine whether the edge of existing seagrass meadows (lower depth level) is maintained at the same depth since the commencement of monitoring. A statistically significant result indicating that meadows are retreating into shallower waters indicates that the EQS has not been met.

In addition to the above comparisons, trend analyses of seagrass shoot density and lower depth level at all sites are conducted to provide an additional line of evidence.

Seagrass health monitoring was not undertaken in 2021 because of covid restrictions. Therefore, the calculation of rolling percentiles was done for the years 2020 and 2022.

Notes relevant to EQS (i) and (ii) – shoot density

The assessment of EQS (i) and (ii) involved comparisons against shoot densities at (Figure 4):

- historical Warnbro Sound reference sites
- new reference sites, used for the first time in this report.

The calculation of the EQS (i) and (ii) has historically been based on shoot densities at five Warnbro Sound reference sites. However, natural and localised erosion processes have resulted in significant seagrass declines at all three shallow (<5 m) Warnbro Sound reference sites. Monitoring of these three sites was aborted after 2020 but given that one of the criteria (i.e. EQS (i)) involves a comparison over two years, an assessment against these sites is included in this report for completeness (Appendix C).

The seagrass monitoring program has included five sites outside of Cockburn Sound since 2007: two in Shoalwater Islands Marine Park (SIMP) and three in Owen Anchorage (OA). It had been suggested that these sites could replace the historical reference sites in Warnbro Sound where significant seagrass loss has occurred. Three of these sites have now been included as new reference sites in shallow water for the first time: Carnac Island (OA), Mersey Point (SIMP) and Bird Island (SIMP). Woodman Point (OA) was not included as it is near an ocean outlet for Woodman Point Wastewater Treatment Plant (used in emergencies) and, additionally, experiences pressure from erosion and recreational anchoring. Coogee (OA) was not included because a statistically significant decline in seagrass health was recorded at this site and because it was of similar depth to the established Warnbro Sound (5.5 m) reference site, where seagrass health has not shown signs of decline.

Notes relevant to EQS (iii) – lower depth limit

The assessment of EQS (iii) is based on changes in the lower depth distribution of seagrass meadows compared with baseline at selected monitoring sites. Six seagrass sites are monitored for lower depth limit, but only four have 2000–02 baselines against which the 2022 monitoring results can be compared.

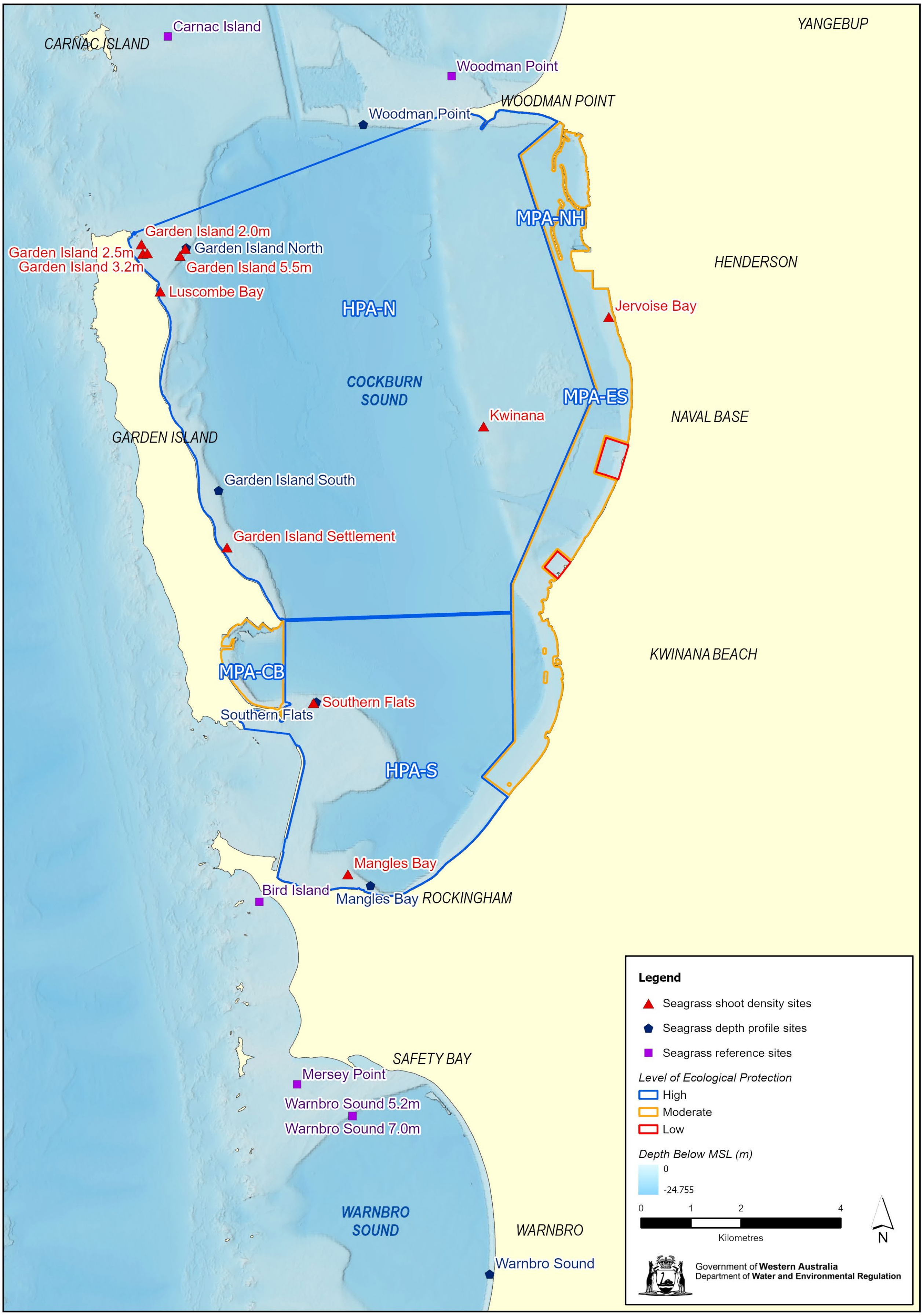


Figure 4: Seagrass monitoring sites (Flukes 2024)

Summary of outcomes – seagrass health assessments EQS (i), (ii) and (iii)

Seagrass health is assessed for the high and moderate protection areas defined for Cockburn Sound. The established seagrass monitoring sites allow this assessment to be made for the reference site at Warnbro Sound and three protection areas in Cockburn Sound:

- High Protection Area North: HPA-N
- High Protection Area South: HPA-S
- Moderate Protection Area Eastern Shelf: MPA-ES.

Comparisons against the seagrass health criteria are undertaken for each site, but the assessment of whether the criteria are met is done at the level of a protection area. The criteria specify that if EQS (i) and (ii) and (iii) are each achieved for at least one site within a defined area, the seagrass health assessment for that area is positive (Table 6).

Table 6: Scorecard of EQG and EQS achievements using the traditional Warnbro Sound reference sites and new reference sites

Where a dash (-) is present, it indicates that there were no data recorded in 2022. Not all EQS are recorded at each monitoring site; therefore, if an EQS is not relevant at a stated monitored site n/a is used.

Ecological protection area	EQG met	Monitoring site	Traditional reference sites				New reference sites			
			EQS (i)	EQS (ii)	EQS (iii)	Overall result	EQS (i)	EQS (ii)	EQS (iii)	Overall result
HPA-N	✓	Luscombe Bay	✓	-	n/a	✓	✓	✓	n/a	✓
		Garden Island Settlement	✓	-	n/a		✓	✓	n/a	
		Garden Is. (2.0 m)	✓	-	n/a		✓	✓	n/a	
		Garden Is. (2.5 m)	✓	-	n/a		✓	✓	n/a	
		Garden Is. (3.2 m)	✓	-	n/a		✓	✓	n/a	
		Kwinana	✓	✓	n/a		✓	✓	n/a	
		Garden Is. (5.5 m)	✓	✓	n/a		✓	✓	n/a	
		Garden Is. (7.0 m)	✓	✓	n/a		✓	✓	n/a	
		Garden Is. North (depth)	n/a	n/a	✓		n/a	n/a	✓	
		Garden Is. South (depth)	n/a	n/a	✓		n/a	n/a	✓	
HPA-S	✓	[1]Southern Flats	✓	-	n/a	?	✓	✓	n/a	✓
		[1]Mangles Bay	✓	-	n/a		✗	✓	n/a	
MPA-CB	✓	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MPA-ES	✓	Jervoise Bay	✓	-	n/a	?	✓	✓	n/a	✓
MPA-NH	✓	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Ecological protection area	EQG met	Monitoring site	Traditional reference sites				New reference sites			
			EQS (i)	EQS (ii)	EQS (iii)	Overall result	EQS (i)	EQS (ii)	EQS (iii)	Overall result
Reference site	n/a	Warnbro Sound (depth)	n/a	n/a	✓	✓	n/a	n/a	✓	✓

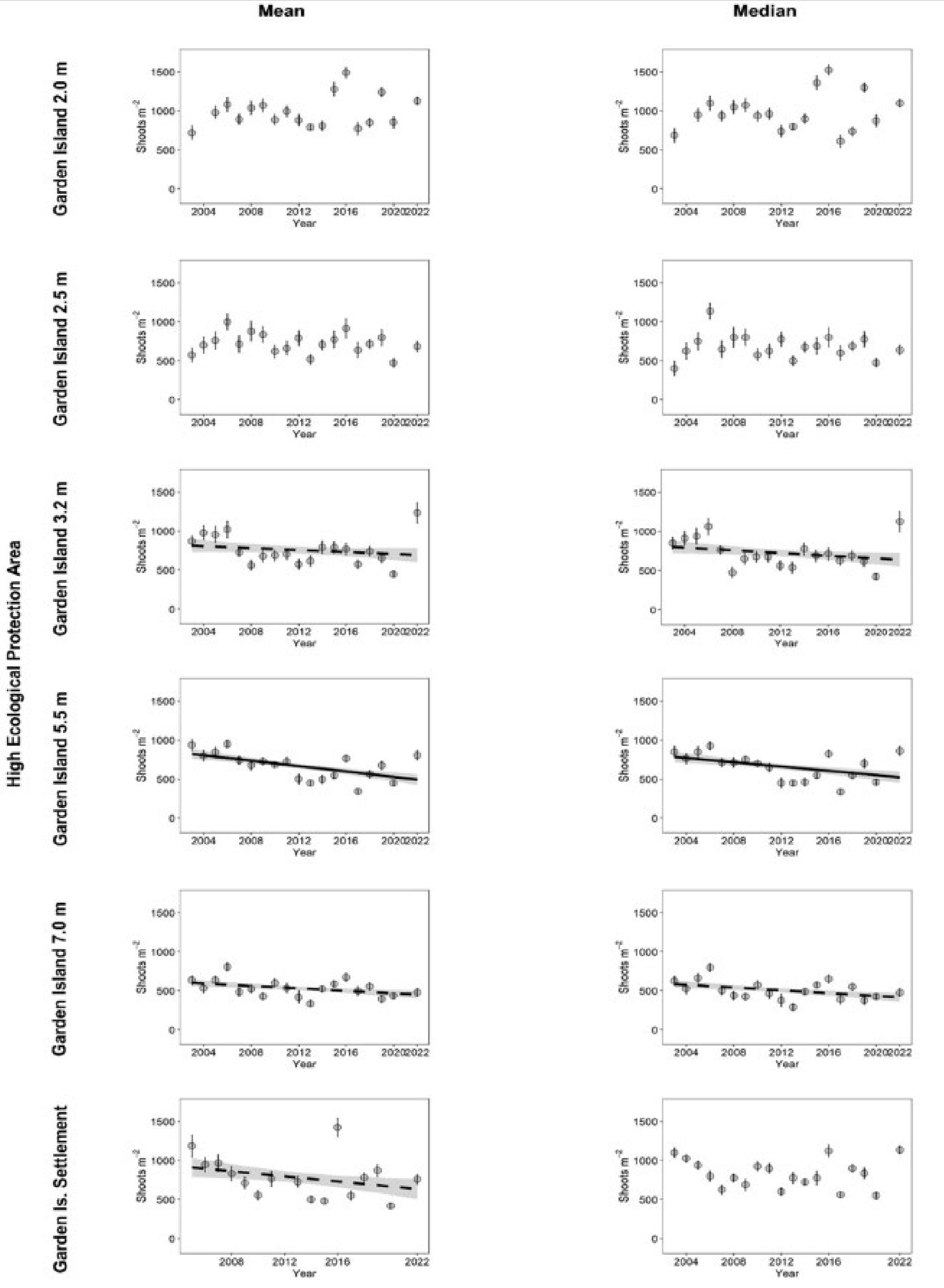
[1]Assessment of EQS (iii) not possible at Southern Fats and Mangles Bay because of a lack of baseline depth data.

The 2022 seagrass health assessment suggests that seagrass health in Cockburn Sound generally meets the criteria.

The full assessment of the 2022 monitoring results against the established seagrass health criteria is provided in Appendix C.

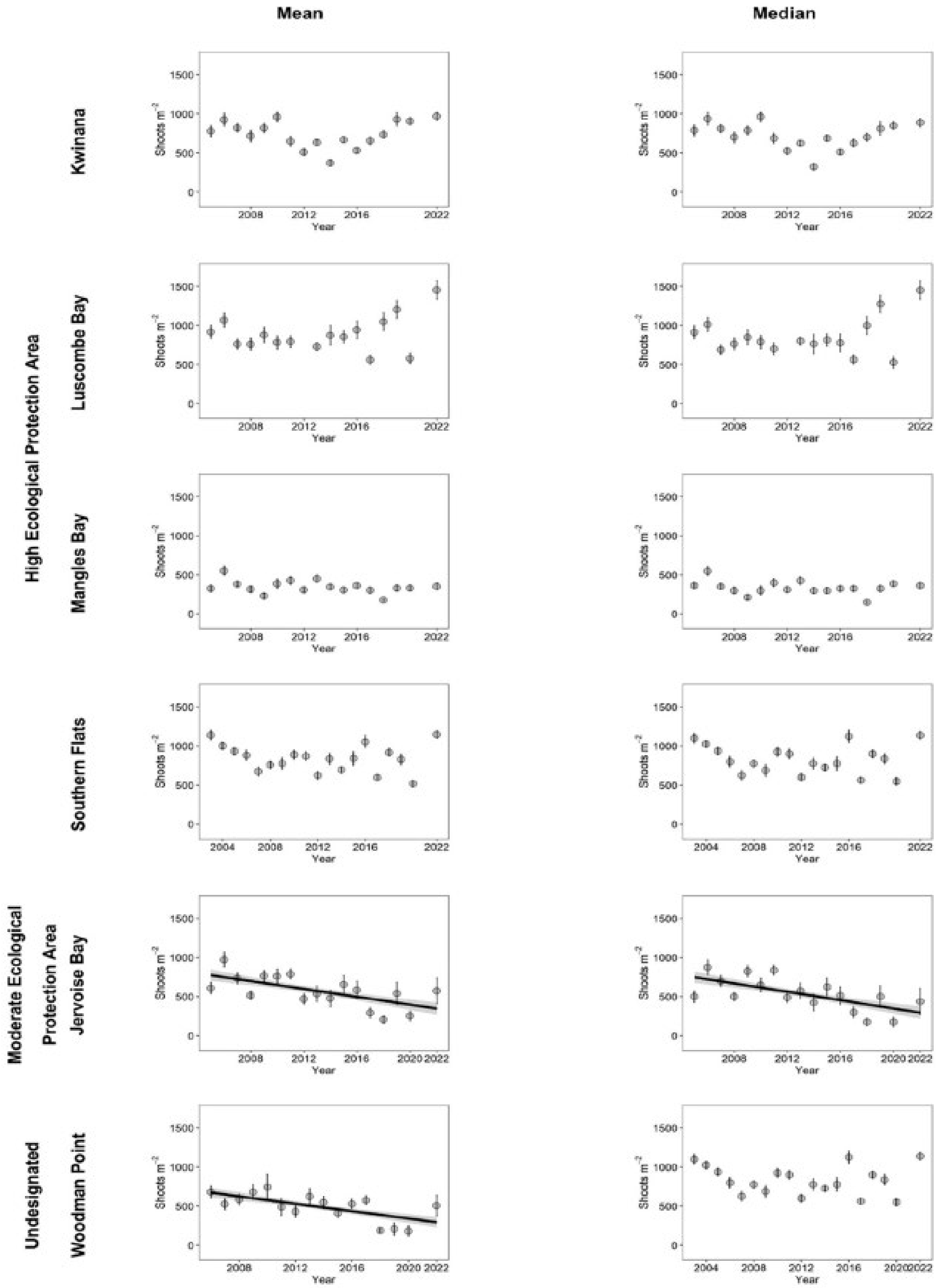
Summary of outcomes – trend analyses

No criteria have been established for trends in seagrass shoot densities, but trends are analysed at each site as an additional line of evidence (Figure 5 and Figure 6).



Solid black lines indicate significant trends (α = 0.05), and dashed lines indicate potential trends (α = 0.2)
Shaded grey areas indicate 95% confidence bands

Figure 5: Mann-Kendall trend analysis results for mean and median (+SE) Posidonia sinuosa shoot densities at Garden Island 'potential impact' sites in the Cockburn Sound High Ecological Protection Area



Solid black lines indicate significant trends (α = 0.05), and dashed lines indicate potential trends (α = 0.2)
Shaded grey areas indicate 95% confidence bands

Figure 6: Mann-Kendall trend analysis results for mean and median (+SE) Posidonia sinuosa shoot densities at 'potential impact' sites in the Cockburn Sound High Ecological

Protection Area, Moderate Protection Area and undesignated

The results of the seagrass shoot density trend analyses suggest:

- neutral trends at Garden Island sites 2.0 m and 2.5 m (HPA-N), Kwinana (HPA-N), Luscombe Bay (HPA-N), Mangles Bay (HPA-S) and Southern Flats (HPA-S)
- declining (but not statistically significant) trends at Garden Island 3.2 m (HPA-N), Garden Island 7.0 m (HPA-N) and Garden Island Settlement (HPA-N)
- statistically significant declining trends at Garden Island 5.5 m (HPA-N), Jervoise Bay (MPA-ES) and Woodman Point (undesignated zone)

There were no significant trends reported for lower depth limit.

Conclusion – seagrass health assessment

Similar to previous years, trends in seagrass mean and median shoot densities were either declining or stable throughout Cockburn Sound and surrounding areas, with seagrass at a number of sites showing potential or significant declining trends in shoot densities. Trends in reference site mean and median shoot densities were all stable, but variable in rolling percentiles (Appendix C).

Across the 20 years of sampling there has not been a significant increasing trend in mean or median shoot densities in Cockburn Sound that might indicate widespread recovery of the seagrass meadows at ecosystem level. Two of the 11 Cockburn Sound sites (Jervoise Bay and Garden Island 5.5 m) and Woodman Point (undesignated zone) displayed significant ($\alpha = 0.05$) declining trends in mean and/or median shoot density. Of the six Cockburn Sound sites that displayed potential declining trends in 2020, only the three sites at Garden Island (Garden Island 3.2 m, Garden Island 7.0 m and Garden Island Settlement) are still displaying potential declining trends.

Mangles Bay is the only Cockburn Sound site where seagrass shoot density did not meet the minimum criteria. Seagrass shoot densities at all other sites appeared to have increased from 2020, with the majority of these having shoot densities more than double those recorded in 2020. Woodman Point had the most drastic increase in shoot density increasing by more than five times since 2020. These results are unexpected and coincided with a new consultant conducting the monitoring. This will require further investigation in following years.

With respect to the reference sites, seagrass shoot densities at the historical sites Warnbro Sound 5.2 m and Warnbro Sound 7.0 m and at the new sites Carnac Island and Bird Island remained stable, displaying no trends. Rolling percentiles for Mersey Point displayed a significant positive trend.

The lower depth limit of seagrass meadows (i.e. typically the maximum depth where light intensity allows photosynthesis to exceed respiration) ranged from 6.5 m at Mangles Bay to 11.3 m at Woodman Point. While three of the four depth transects with a 2000–02 baseline had lower depth level values that were potentially shallower than previous measurements, no significant trends were observed.

2.3.3 Phytoplankton biomass

The effect of nutrient enrichment on the frequency and severity of phytoplankton blooms is assessed by comparisons of monitoring data against two EQG and, where these are not met, against two EQS:

- EQG (i) and (ii) assess the spatial extent of any observed elevated chlorophyll-a concentrations on each sampling occasion **and** the frequency of elevated concentrations at each site over the non river-flow period.
- EQS (i) and (ii) are essentially the same assessments but against more forgiving number of occurrences and conducted over two years.

Summary of outcomes

A summary of the outcomes of the phytoplankton biomass assessment are provided in Table 7.

Table 7: Assessment of phytoplankton biomass (chlorophyll-a concentrations) at Cockburn Sound sites from December 2021 to March 2022 against the phytoplankton biomass EQS (ii)

<table>
<tr><th rowspan="2">Ecological protection area</th><th rowspan="2">Monitoring site</th><th rowspan="2">EQG (i)</th><th rowspan="2">EQG (ii)</th><th rowspan="2">EQS (i)</th><th colspan="3">EQS (ii)</th><th colspan="2">Overall result</th></tr>
<tr><th>2020</th><th>2022</th><th>Result</th><th>Area</th><th>Site</th></tr>
<tr><td rowspan="6">HPA-N</td><td>CS4</td><td rowspan="6">✓</td><td>✓</td><td rowspan="6">n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td rowspan="6">✓</td><td>✓</td></tr>
<tr><td>CS5</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>CS8</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>CB</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>G2</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>G3</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td rowspan="4">HPA-S</td><td>CS11</td><td rowspan="4">✓</td><td>✓</td><td rowspan="4">n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td rowspan="4">✓</td><td>✓</td></tr>
<tr><td>CS13</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>SF</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>MB/MB-L</td><td>×</td><td>✓</td><td>×</td><td>✓</td><td>✓</td></tr>
<tr><td>MPA-CB</td><td>G1</td><td>-</td><td>✓</td><td>-</td><td>n/a</td><td>n/a</td><td>n/a</td><td>-</td><td>✓</td></tr>
<tr><td rowspan="6">MPA-ES</td><td>CS10N</td><td rowspan="6">✓</td><td>✓</td><td rowspan="6">n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td rowspan="6">✓</td><td>✓</td></tr>
<tr><td>CS12</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>CS6A</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>CS7</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>CS9</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>CS9A</td><td>✓</td><td>n/a</td><td>n/a</td><td>n/a</td><td>✓</td></tr>
<tr><td>MPA-NH</td><td>NH3</td><td>-</td><td>×</td><td>-</td><td>×</td><td>×</td><td>×</td><td>-</td><td>×</td></tr>
</table>

Conclusion – phytoplankton biomass assessment

The 2022 phytoplankton biomass assessment suggests that the frequency and severity of phytoplankton biomass in Cockburn Sound is generally within guideline values, except in Mangles Bay (MB) and Northern Harbour (NH3).

In Mangles Bay elevated chlorophyll-a concentrations were recorded more than 25% of the time in 2022, but the site had met the EQG in 2020 and hence met the EQS. Northern Harbour (NH3), in contrast, is known to have a persistent nutrient enrichment problem, and monitoring data demonstrate that chlorophyll-a concentrations commonly exceed (80+%) the environmental criteria. **At NH3 the EQS was exceeded, and water quality objectives are not being achieved.**

The full assessment of the 2022 monitoring results against phytoplankton criteria is provided in Appendix D.

2.4 Assessment against the EQC for other physical and chemical stressors

2.4.1 DO concentration

Monthly measurements of DO concentrations (% saturation) were collected in the bottom waters[2] at 18 water quality monitoring sites in Cockburn Sound (Figure 2) from 1 December 2021 to 31 November 2022 and were assessed against DO concentration criteria (EPA 2017:35):

High protection:

EQG: Median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than or equal to 90% saturation.

EQS (i): Median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than or equal to 60% saturation.

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

EQS (iii): No deaths of marine organisms resulting from deoxygenation.

Moderate protection:

EQG: Median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than or equal to 80% saturation.

EQS (i): Median DO concentration in bottom waters at a site, calculated over a period of no more than one week, is greater than or equal to 60% saturation.

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

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

EQS (iii): No deaths of marine organisms resulting from deoxygenation.

The DO concentration recorded at each site was compared with the relevant EQG (Table 8). Sites at which the EQG were exceeded were subsequently assessed against the EQS.

The EQG were exceeded at one site in HPA-N (CS4), three sites in HPA-S (CS11, CS13 and MB/MB-L) and one site in MPA-ES (CS9). For all these sites the EQS was met.

Table 8: Assessment of DO concentrations (% saturation) in bottom waters at Cockburn Sound sites against the DO EQC

Ecological protection area	Site (depth)	No. of occasions EQG was not met (n=12)	EQG met	EQS met	Overall result
HPA-N	CS4 (21 m)	1	×	✓	✓
	CS5 (19 m)	0	✓	n/a	✓
	CS8 (20 m)	0	✓	n/a	✓
	CB (9.5 m)	0	✓	n/a	✓
	G2 (11 m)	0	✓	n/a	✓
	G3 (17 m)	0	✓	n/a	✓
HPA-S	CS11 (18 m)	3	×	✓	✓
	CS13 (20 m)	3	×	✓	✓
	SF (3.5 m)	0	✓	n/a	✓
	MB/MB-L (1.5 m)	1	×	✓	✓
MPA-CB	G1 (15 m)	0	✓	n/a	✓
MPA-ES	CS10N (16 m)	0	✓	n/a	✓
	CS12 (10 m)	0	✓	n/a	✓
	CS6A (10 m)	0	✓	n/a	✓
	CS7 (10.5 m)	0	✓	n/a	✓
	CS9 (13 m)	2	×	✓	✓
	CS9A (16 m)	0	✓	n/a	✓
MPA-NH	NH3 (10 m)	0	✓	n/a	✓

DO concentrations at Fremantle Port Authority monitoring sites

DO concentrations, measured as percentage saturation, were also recorded at three sites surrounding the Kwinana Bulk Jetty (KBJ1, KBJ2 and KBJ3) and three sites around the Kwinana Bulk Terminal (KBT1, KBT2 and KBT3) – surveyed by Fremantle Port Authority during a single sampling event on 25 January 2022.

All sites met the relevant EQG.

DO concentrations at Water Corporation monitoring sites

DO concentrations, measured as percentage saturation were collected quarterly (on 13 December 2021, 14 February 2022, 19 May 2022 and 24 August 2022) in bottom waters at three Water Corporation sites in Cockburn Sound and two sites outside Cockburn Sound during the 2022 monitoring period (Table 9). Additional DO measurements were taken at Cockburn Sound water quality monitoring sites CS9 and CS12 in MPA-ES on each sampling occasion. All the monitored sites (i.e. Central, South, DIFF50W, CS9, CS12, Parmelia Bank. Owen Anchorage) met the EQG for DO.

Table 9: Assessment of DO (% saturation) in the bottom waters at Water Corporation monitoring sites in and outside Cockburn Sound

Ecological protection area	Site (depth)	Dec 2021	Feb 2022	May 2022	Aug 2022
		EQG met			
HPA-N	Central (21 m)	✓	✓	✓	✓
HPA-S	South (20 m)	✓	✓	✓	✓
MPA-ES	DIFF50W (10 m)	✓	✓	✓	✓
	CS9 (13 m)	✓	✓	✓	✓
	CS12 (10 m)	✓	✓	✓	✓
Sites outside Cockburn Sound	Parmelia Bank (7 m)	✓	✓	✓	✓
	Owen Anchorage (14 m)	✓	✓	✓	✓

Conclusion – DO assessment

Bottom water DO concentrations generally met guideline values in HPA-N but exceeded these values for one to three occasions (out of a total 12) at three sites (out of four) in HPA-S and on two occasions at CS9 in MPA-ES. The less conservative environmental quality standard (EQS) values were met at all sites and on all occasions, suggesting that relevant water quality objectives are generally being achieved.

2.4.2 Water temperature

Monthly measurements of surface[3] and bottom[4] water temperature were collected at 18 water quality monitoring sites[5] (Figure 2) from 1 December 2021 to 31 November 2022.

Median water temperature calculated over a season for individual sites are compared against the 80th High Ecological Protection Area (HEPA) or 90th percentile Moderate Ecological Protection Area (MEPA) values derived from measurements at reference sites. However, only three (monthly) measurements of water temperature per season were available for the 2022 reporting period, which does not allow statistically robust median and percentile values to be calculated.

For the purpose of this report, the available surface and bottom temperature data for all individual Cockburn Sound and reference sites for each season were plotted for visual analysis. Note that these are grouped according to depth with reference site WS4 accompanying deeper sites and reference site WSSB accompanying shallower sites (Figures E1 – E4 in Appendix E).

No notable observations were made.

[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).

Conclusion – Water temperature assessment

A lack of available data meant that an assessment against the temperature criteria could not be completed. However, considering the results of previous monitoring reports, there is a reasonable degree of confidence that the established criteria are generally met and that water temperature in Cockburn Sound is not significantly adversely affected by anthropogenic activity at an ecosystem scale.

2.4.3 Salinity

Monthly measurements of surface[6] and bottom[7] water salinities were collected at 18 water quality monitoring sites[8] (Figure 2) from 1 December to 31 November 2022.

Median salinity calculated over a season for individual sites are compared against the 80th (HEPA) or 90th percentile (MEPA) values derived from measurements at reference sites. However, only three (monthly) measurements of water temperature per season were available for the 2022 reporting period, which does not allow statistically robust median and percentile values to be calculated.

For the purpose of this report, the available surface and bottom salinity data for all individual Cockburn Sound and reference sites for each season were plotted for visual analysis (Figures E5 – E8 in Appendix E). Note that these are grouped according to depth with reference site WS4 accompanying deeper sites and reference site WSSB accompanying shallower sites.

One notable observation was made. Bottom water salinity measurements at sites CS12 and CS9 were higher than those measured at other sites, particularly in autumn and winter (Figure 7 and Figure 8).

[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).

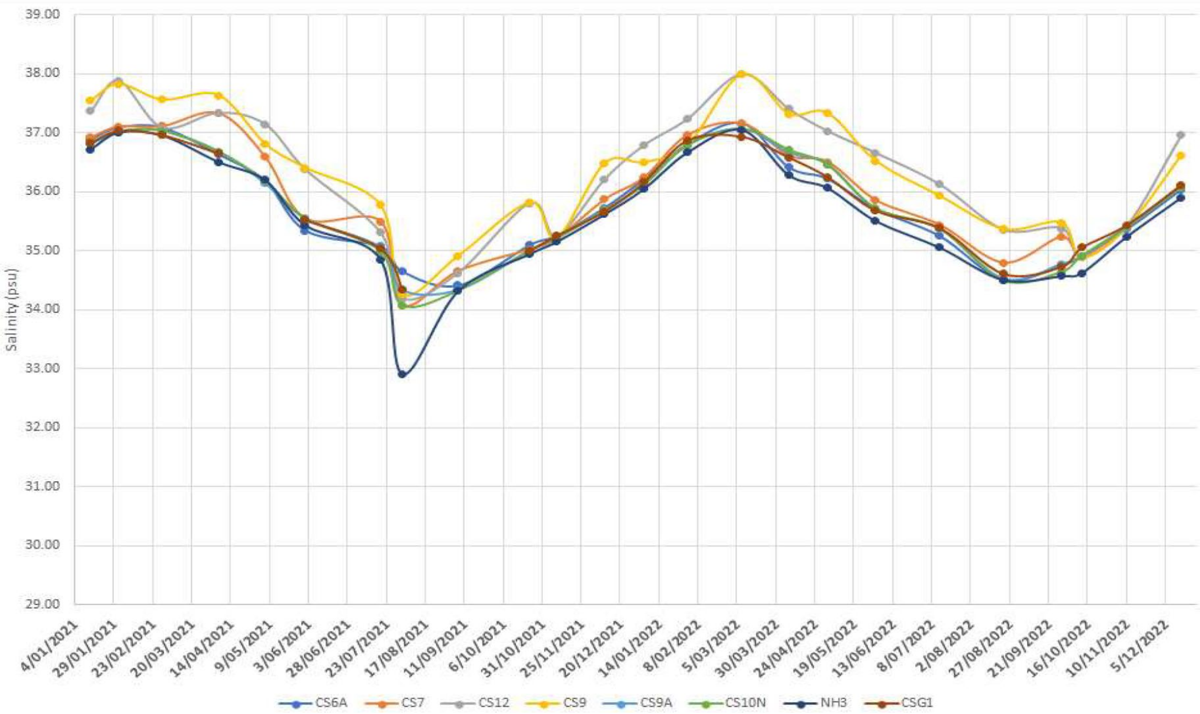


Figure 7: Bottom water salinity measures at sites in the moderate protection areas (Jan 2021 – Dec 2022)

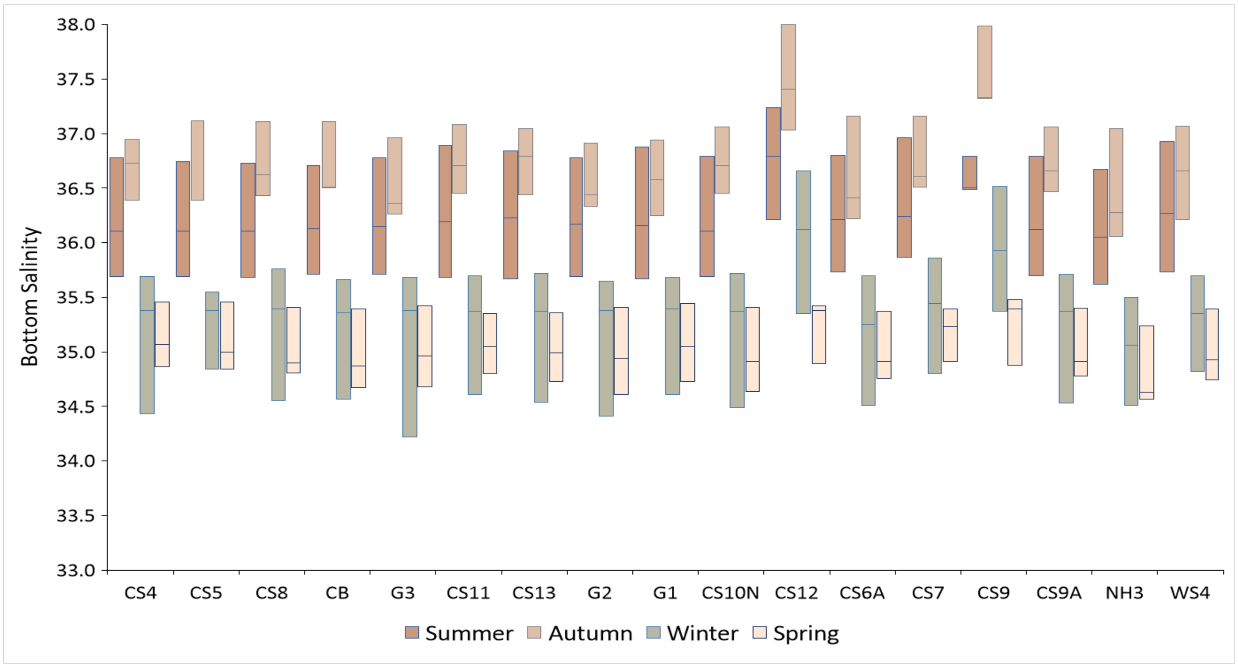


Figure 8: Bottom water salinity at 16 deep water sites compared with WS4 (deep water reference site)

Salinity concentrations at Water Corporation monitoring sites

Salinity concentrations were measured collected quarterly (on 13 December 2021, 14 February 2022, 19 May 2022 and 24 August 2022) in the bottom waters at three Water Corporation sites in Cockburn Sound and two sites located outside Cockburn Sound during the 2022 monitoring period (Figure 2). Additional salinity measurements were taken at Cockburn Sound water quality monitoring sites CS9 and CS12 in MPA-ES on each sampling occasion. No notable observations were made at these monitoring sites (i.e. Central, South, DIFF50W, CS9, CS12, Parmelia Bank. Owen Anchorage).

Conclusion – Salinity assessment

A lack of available data meant that an assessment against the salinity criteria could not be completed. Elevated bottom water salinity was observed at sites CS9 and CS12 in MPA-ES. These results can be explained by the proximity of the Perth Seawater Desalination Plant diffuser outfall to site CS12 (10 m depth), which is close to the Calista Channel, and to site CS9 (13 m depth), a small distance 'downstream' in the Calista Channel. Brine, originating from the desalination plant, follows along the deepest contours of the seabed, which direct it into the Calista Channel and then it usually flows in a southern direction towards CS9 and into the Stirling Channel where it is directed into the deeper central basin of the Sound.

Considering that previous monitoring reports have indicated salinity criteria are regularly exceeded at these two sites, additional monitoring may be required to understand the spatial and temporal extent of the observed elevated salinity levels within the water column and whether other water quality parameters remain unaffected. At this stage, there is no evidence that salinity in Cockburn Sound is significantly affected by anthropogenic activity at an ecosystem scale.

2.4.4 pH

Monthly measurements of surface[9] and bottom[10] water pH were collected at 18 water quality monitoring sites[11] (Figure 2) from 1 December 2021 to 31 November 2022.

Median pH calculated over a season for individual sites is required to not deviate beyond the 20th and 80th percentile (HPA) and 5th to 95th percentile (MPA) values derived from measurements at reference sites. However, only three (monthly) measurements of pH per season were available for the 2022 reporting period, which does not allow statistically robust median and percentile values to be calculated.

For the purpose of this report, the available surface and bottom pH data for all individual Cockburn Sound and reference sites for each season were plotted for visual analysis. Note that these are grouped according to depth with reference site WS4 accompanying deeper sites and reference site WSSB accompanying shallower sites (Figures E9 – 12 in Appendix E).

No notable observations were made. The pH measurements recorded for all surface and bottom waters across all sites monitored in Cockburn and Warnbro Sounds ranged between 8.00 to 8.35 pH units. There were no significant differences of pH in both the surface and bottom waters between any of the sites monitored during the survey.

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

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

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

Conclusion – pH assessment

A lack of available data meant that an assessment against the pH criteria could not be completed. However, considering the results of previous monitoring reports, there is a reasonable degree of confidence that the established criteria are generally met and that pH in Cockburn Sound is not significantly adversely affected by anthropogenic activity.

2.5 Assessment against the EQC for toxicants in marine waters

2.5.1 Non-metallic inorganics (ammonia) in marine waters

Monthly measurements of depth-integrated ammonium concentrations were collected at 18 water quality monitoring sites (Figure 2) in Cockburn Sound from December 2021 to November 2022.

For ammonia measured in water, 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) should not exceed the EQG values of 500 µg/L for high protection areas and 1,200 µg/L for moderate protection areas.

Since no individual monthly ammonia concentration exceeded the high protection EQG value of 500 µg/L nor the moderate protection EQG value of 1,500 µg/L, the EQG for ammonia were considered to have been met at all sites and for all sampling occasions. However, because of the limited dataset for this reporting period, statistical analysis (such as calculation of 95th percentiles) could not be undertaken.

2.5.2 Toxicants in marine waters around the bulk jetties

Surface marine water samples were collected in January 2022 at six sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3), in the MPA-ES (Figure 3). The samples were analysed for ammonia, filtered copper, TRHs and BTEX. Bottom marine water samples were also collected at the six sites and analysed for nutrients (i.e. ammonia, ortho-phosphate, nitrate-nitrate, total phosphorus and total nitrogen).

The EQC reference document (EPA 2017) recommends a minimum of five samples are used to calculate a median value 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 limited sample size for this reporting period, concentrations of toxicants in individual 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 Jetty (Table 10). 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 for all sites except KBT1, where the LRV for high protection was exceeded (noting that there is not currently an EQG value for moderate protection).

At all sites, the total toxicity of the mixture (TTM),[12] based on the effects of ammonia, copper and benzene, was below 1.0 µg/L (Table 10). 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 10: Assessment of toxicants in marine waters sampled at three sites around Kwinana Bulk Terminal and three sites around Kwinana Bulk Jetty against the moderation protection EQG or LRV for toxicants in marine waters

Toxicant (µg/L)	EQG/LRV (µg/L)	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Ammonia	EQG: 1,200	$<3^{S}$	$<3^{S}$	$<3^{S}$	6^{S}	9^{S}	6^{S}
		6^{B}	1.5^{B}	7^{B}	8^{B}	30^{B}	4^{B}
Copper (filtered)	EQG: 3.0	0.3	0.3	0.9	0.3	0.4	0.4
Benzene	EQG: 900	<1	<1	<1	<1	<1	<1
Toluene	LRV: 230	<1	<1	<1	<1	<1	<1
Ethylbenzene	LRV: 5.0P1	<1	<1	<1	<1	<1	<1
Xylene	m-xylene LRV: 75P1 p-xylene LRV: 200P1	<1	<1	<1	<1	<1	<1
TRHs (C6–C40)	LRV: 71, 2	285	<250	<250	<250	<250	<250
TTM	If TTM>1, mixture exceeded WQ guideline	<1	<1	<1	<1	<1	<1

'<' 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.

2.5.3 Conclusion – toxicants in marine waters assessment

A lack of available data meant that robust 95th percentiles could not be determined. However, the data suggests that established criteria are met at all stations and sampling occasions, except for TRHs at a single site near the Kwinana Bulk Terminal, and that relevant water quality objectives are generally being achieved.

2.6 Assessment against the EQC for toxicants in sediments

2.6.1 Toxicants in sediments at Fremantle Port Authority monitoring sites

Surface (top 2 cm) sediment samples were collected at six sites in February 2022 around the Kwinana Bulk Terminal – KBT1, KBT2, KBT3 – and the Kwinana Bulk Jetty – KBJ1, KBJ2, KBJ3 in MPA-ES (Figure 3). The samples were analysed for total organic carbon, metals (i.e. arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), inorganics (i.e. nitrogen and phosphorus), organotins (i.e. TBT, DBT and MBT), PAHs, TRHs, PFOS and PFOA.

[12] TTM = Σ (Ci/EQGi), where C is the concentration of the 'i'th component in the mixture and EQG is the guideline for that component.

The concentrations of contaminants in sediments were compared against the EQG (EPA 2017:56–57):

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 nor PFAS in sediment.

The 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 11). An elevated cadmium concentration was reported in the sediment at KBJ1; however, the concentration measured was below the re-sampling trigger.

After normalisation to 1% total organic carbon,[13] median concentrations of TBT in the Kwinana Bulk Terminal samples were below the EQG value (Table 12). An elevated concentration of TBT was found in one of the Kwinana Bulk Jetty samples (KBJ1); however, the concentration was below the re-sampling trigger.

There are no EQG values for the TBT breakdown products DBT or MBT. One of the three Kwinana Bulk Terminal samples (KBT1) had a butyltin degradation index (BDI) greater than 1.0 (Table 12), suggesting that the TBT originally deposited in this area had been degraded into DBT and MBT.

Concentrations of acenaphthene, acenaphthylene and fluorene were observed to be exceed the respective EQG values but were below the re-sampling trigger concentrations (Table 13).

The concentrations of total TRHs, PFOS and PFOA reported in the Kwinana Bulk Terminal and Kwinana Bulk Jetty sites are shown in Table 14. There are no EQG values for TRHs (Table 14). The concentrations of PFOS and PFOA were below the analytical limit of reporting at all reported sites.

Table 11: Assessment of toxicants (metals) in sediment collected from sites around Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling triggers for toxicants in sediments

Chemical (milligrams per kilogram [mg/kg])	EQC		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Metals								
Arsenic	20	70	3.3	2.9	4.0	2.6	1.8	1.6
Cadmium	1.5	10	<0.05	<0.05	0.1	**1.9**	0.2	0.2
Chromium	80	370	16.5	15.3	10.7	17.1	10.8	9.8
Copper	65	270	12.6	15.7	14.5	13.1	2.2	6.1

[13] 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.

Chemical (milligrams per kilogram [mg/kg])	EQC		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Lead	50	220	6.4	5.7	5.0	5.7	1.6	2.2
Mercury	0.15	1	0.06	0.05	0.02	0.13	0.02	0.03
Selenium	-	-	0.3	0.3	0.2	0.4	0.3	0.3
Zinc	200	410	26.2	21.8	29.5	33.1	5.3	9.7

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

Table 12: Assessment of toxicants (organotins) in sediment collected from sites around the Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling trigger for toxicants in sediments

Chemical (milligrams per kilogram [mg/kg])	EQC		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Organotins (µg Sn/kg normalised to 1% total organic carbon [TOC])								
TBT	5	70	0.31	1.00	1.72	**6.51**	1.40	4.25
Dibutyltin	-	-	0.26	0.31	0.21	0.23	0.58	0.57
MBT	-	-	0.26	0.31	0.21	0.23	0.58	0.57
BDI	-	-	1.70	0.60	0.20	0.10	0.80	0.30

Table 13: Assessment of toxicants (organics) in sediment collected from sites around Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling trigger for toxicants in sediments

Chemical (milligrams per kilogram [mg/kg])	EQC		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Organics (mg/kg normalised to 1% TOC)								
Acenaphthene	0.016	0.5	**0.026**	**0.031**	**0.021**	**0.023**	**0.058**	**0.057**
Acenaphthylene	0.044	0.64	0.026	0.031	0.021	0.023	**0.058**	**0.057**
Anthracene	0.085	1.1	0.026	0.031	0.021	0.023	0.058	0.057
Benzo(a)anthracene	0.261	1.6	0.026	0.031	0.021	0.023	0.058	0.057
Benzo(a)pyrene	0.43	1.6	0.026	0.031	0.021	0.023	0.058	0.057
Chrysene	0.384	2.8	0.026	0.031	0.021	0.055	0.058	0.057
Dibenzo(a,h)anthracene	0.063	0.26	0.026	0.031	0.021	0.023	0.058	0.057
Fluoranthene	0.6	5.1	0.026	0.031	0.021	0.078	0.058	0.057
Fluorene	0.019	0.54	**0.026**	**0.031**	**0.021**	**0.023**	**0.058**	**0.057**
Naphthalene	0.16	2.1	0.026	0.031	0.021	0.023	0.058	0.057
Phenathrene	0.24	1.5	0.026	0.031	0.021	0.023	0.058	0.057
Pyrene	0.665	2.6	0.026	0.031	0.021	0.083	0.058	0.057

Table 14: Assessment of toxicants (organics) in sediment collected from sites around Kwinana Bulk Terminal and the Kwinana Bulk Jetty against the EQG and the re-sampling trigger for toxicants in sediments

Chemical (milligrams per kilogram [mg/kg])	EQC		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Organics (mg/kg normalised to 1% TOC)								
TRH (C6–C40)	-	-	63.78	78.13	53.65	57.34	145.35	143.68
Total PFOS	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Total PFOA	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002

2.6.2 Conclusion – Toxicants in sediments assessment

The 2022 monitoring data suggest that conservative guideline values are generally met. Slightly elevated concentrations for cadmium and TBT exceeded guideline values at a single site near the Kwinana Bulk Jetty while slightly elevated levels of three organotoxins (acenaphthene, acenaphthylene and fluorene) were reported from multiple sites around the commercial jetties. However, all reported elevated concentrations remained below the re-sampling trigger, indicating relevant water quality objectives are generally being achieved.

2.8 Conclusion – Environmental value: Ecosystem Health

The 2022 monitoring data highlighted some localised, albeit persistent, water quality issues, but indicated water quality generally meets ecosystem health criteria across Cockburn Sound. There is no evidence of a recovery in seagrass health, with shoot densities stable at most sites but at levels well below baseline. The results of the assessments suggest that the EQO of *maintenance of ecosystem integrity* was achieved during the 2022 monitoring period. A breakdown of the results for each component is presented in Table 15.

Table 15: Summarised assessment of ecosystem health criteria

Group	Subgroup	Variable	Assessment
Physical and chemical stressors	Nutrients	Chlorophyll-a	Criteria met
		Light attenuation coefficient	Criteria met
		Seagrass shoot density	Criteria met but remaining concerns
		Leaf and lead cluster	N/A
		Lower depth limit	Criteria met
		Phytoplankton biomass	Localised/temporary issues noted (NH3)
	Other	DO	Localised/temporary issues noted
		Water temperature	No evidence of issues
		Salinity	Localised/temporary issues noted
		pH	No evidence of issues
Toxicants (water)	Metals and metalloids	Copper	Criteria met
	Non-metallic inorganics	Ammonia	Criteria met
	Organics	BTEX	Criteria met
	Oils and petroleum hydrocarbons	TRHs	Criteria met (single exception)
Toxicants (sediment)	Metals and metalloids	Arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc	Criteria met (single exception)
	Organometallics	TBT, DBT, monobutyltin (MBT)	Criteria met (single exception)
	Organics	PAHs	Slightly elevated concentrations below re-sampling trigger
	Oils and petroleum hydrocarbons	TRHs	No criteria available
	PFAS	PFOA, PFOS, and perfluorohexane sulfonate (PFHxS)	No criteria available

3. Environmental value: Fishing and Aquaculture

3.1 EQOs

The EQOs for the environmental value of Fishing and Aquaculture are:

- maintenance of seafood safe for human consumption
- maintenance of aquaculture production.

The EQC for these EQOs 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 programs

For filter-feeding shellfish (excluding scallops and pearl oysters), any assessment against the EQO must use data collected from a comprehensive monitoring program consistent with the requirements of the *Western Australia Shellfish Quality Assurance Program operations manual version 7* (WASQAP operations manual; Department of Health 2020). The WASQAP operations manual sets out the requirements for bacteriological monitoring (of water and shellfish), phytoplankton and shellfish biotoxin monitoring, and the chemical analysis of shellfish in the shellfish growing areas in Cockburn Sound (Figure 9). Phytoplankton sampling was undertaken at the Southern Flats harvesting area from January to August 2022 by Harvest Road as part of the WASQAP, which is administered by the Department of Health. Sampling at the Southern Flats harvesting area ceased in August 2022. The Kwinana Grain Terminal harvesting area in Cockburn Sound has been in commercial closure since 23 February 2021.

Depth-integrated water samples for phytoplankton identification and enumeration were collected about monthly from January to August 2022 at one Southern Flats site. Samples were collected as close to the shellfish as possible. The samples were analysed by Dalcon Environmental for specific groups of phytoplankton species known to potentially produce toxins that may be concentrated in shellfish.

In addition, Fremantle Port Authority undertook analysis of toxicants in mussels at three sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) (Figure 3). A minimum of 15 mussels of uniform size (about 55–90 mm shell length) were collected in March and April 2022 from lines with baskets suspended about 1 m below the water surface. These were deployed for six weeks prior to collection. Mussel samples were analysed for metals (i.e. inorganic arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc), organotins (TBT, DBT and MBT) and PAHs. Analyses for metals, organotins and PAHs were undertaken by ChemCentre.

Figure 9: Sampling locations near the shellfish harvesting areas in Cockburn Sound (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.

3.3 Assessment against the seafood safe for human consumption EQC

3.3.1 Assessment against algal biotoxins EQC

Concentrations of toxic phytoplankton recorded in the Southern Flats harvesting area in Cockburn Sound between January and August 2022 (n=9) were assessed against the algal biotoxins EQG (Table 16). The algal biotoxins EQG are the phytoplankton alert levels that trigger management action identified in the WASQAP *Marine biotoxin monitoring and management plan version 2 2020* (Department of Health 2020).

Table 16: Phytoplankton levels that trigger management actions

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

Table 17 below presents the results of the assessment against the EQG. The algal biotoxins EQG was met in the Southern Flats shellfish harvesting area on all sampling occasions except for two occasions in January 2022. On 10 January 2022, the *Pseudo-nitzschia seriata* group exceeded the alert levels for initiating flesh testing, and on 17 January 2022, both the *Pseudo-nitzschia delicatissima* and *Pseudo-nitzschia seriata* groups of toxic algae exceeded the alert levels for initiating flesh testing.

An exceedance of the EQG is intended to trigger an assessment of toxins in seafood tissue against the EQS. The *Environmental Quality Criteria Reference Document for Cockburn Sound* (EPA 2017) also strongly recommends that the monitoring results are referred to the Department of Health for advice before undertaking further assessment against the EQS. There is no indication a response was actioned.

Table 17: Phytoplankton concentrations in water samples collected from one site in the Southern Flats harvesting area within Cockburn Sound between January and August 2022, compared against the algal biotoxins EQG

Toxic algae recorded	10/01/2022	17/01/2022	24/02/2022	21/03/2022	26/04/2022	07/07/2022	05/07/2022	02/08/2022	17/02/2022
Bacillariophyceae (cells/L)									
Amphora spp	1,200	3,800	200	-	-	5,600	200	600	1,000
Asterionellopsis glacialis	-	2,200	1,400	18,000	-	-	-	1,400	46,600
Bacteriastrum spp	-	-	-	-	-	-	1,200	-	-
Chaetoceros	-	-	41,800	-	-	-	-	-	-

Toxic algae recorded	10/01/2022	17/01/2022	24/02/2022	21/03/2022	26/04/2022	07/07/2022	05/07/2022	02/08/2022	17/02/2022
curvisetus									
Chaetoceros spp	10,600	6,200	15,400	-	5,160,000	775,000	23,000	2,800	248,000
Chaetoceros tenuissimus	-	-	-	-	-	-	-	200	-
Climacodium frauenfeldianum	-	-	600	-	-	-	-	-	-
Climacodium spp	600	-	-	1,000	-	-	-	-	-
Cocconeis spp	-	-	600	-	-	400	-	400	-
Corethron spp	-	-	-	-	-	-	200	-	400
Coscinodiscus spp	-	-	-	200	-	-	400	800	-
Cylindrotheca closterium	6600	5,200	200	6,600	12,000	10,000	5,000	1,000	16,000
Dactyliosolen spp	-	200	200	200	-	-	-	-	8,000
Detonula spp	-	-	1,400	-	-	-	-	-	-
Diponeis chersonensis	-	-	200	-	-	-	-	-	-
Diploneis spp	-	600	400	-	-	200	-	-	-
Entomoneis tenuistriata	-	-	200	-	-	-	-	-	-
Entomoneis spp	400	800	-	-	-	-	-	-	-
Eucampia spp	-	-	-	-	-	-	-	-	1,800
Grammatophora spp	-	-	-	200	-	400	-	800	-
Guinardia spp	10,000	3,600	-	6,000	400	2,800	-	600	1,800
Hemialus spp	-	-	-	400	400	-	-	-	-
Leptocylindrus spp	36,000	21,000	-	29,000	400	1,200	-	1,000	800
Licmophora spp	200	200	-	-	1,200	1,200	-	400	800
Lioloma spp	400	-	-	-	200	-	-	-	-
Microtabella spp	600	-	-	400	-	-	-	-	-
Navicula spp	1,000	600	200	200	304,000	54,000	8,000	1,200	22,000
Nitzschia longissima	800	400	1,800	10,000	10,000	410,000	1,200	1,200	2,000
Nitzschia spp	200	1,000	1,000	-	-	-	-	-	-
Paralia marina	-	-	-	-	-	1,000	-	-	400
Pinnularia spp	-	-	-	-	200	-	-	-	-
Plagiotropis spp	-	-	-	-	-	-	-	400	4,600

Toxic algae recorded	10/01/ 2022	17/01/ 2022	24/02/ 2022	21/03/ 2022	26/04/ 2022	07/07/ 2022	05/07/ 2022	02/08/ 2022	17/02/ 2022
Pleurosigma spp	3,800	3,000	200	-	200	600	200	800	-
Proboscia alata	600	400	9,800	6,400	-	-	-	-	-
Pseudo-nitzschia delicatissima group	462,000	850,000	-	10,800	-	-	-	600	19,400
Pseudo-nitzschia seriata group	1,770,000	2,558,000	-	2,800	-	-	-	-	-
Rhizosolenia spp	-	200	-	200	-	200	400	-	400
Skeletonema spp	-	-	-	400	-	-	3,400	-	850,000
Striatella unipunctata	-	-	-	-	-	600	-	-	-
Surirella spp	-	-	-	-	-	-	-	200	200
Thalassionema spp	-	-	-	-	200	1,400	-	400	12,400
Thalassiosira spp	-	400	400	-	-	-	-	1,000	-
Cryptophyceae (cells/L)									
Cryptomonas spp	-	200	-	-	-	-	-	-	-
Cyanobacteria (cells/L)									
Oscillatoria spp	-	-	-	15,400	-	-	-	-	-
Trichodesmium spp	-	2,800	-	-	-	-	-	-	-
Dictyochophyceae (cells/L)									
Dictyocha fibula var. rhombica	-	-	-	-	-	-	200	-	-
Octatis octonaria	-	-	-	-	-	-	-	-	200
Dinophyceae (cells/L)									
Dinophysis caudata	-	-	-	-	-	10	30	-	-
Ebria tripartita	-	-	200	-	-	-	800	-	-
Heterocapsa spp	1,400	1,600	-	200	200	-	-	200	-
Karenia/ Karlodinium/ Gymnodinium group	4,000	-	-	-	200	-	200	-	-
Oxytoxum spp	-	-	-	-	-	-	-	-	-
Peridinioid dinoflagellates	-	-	-	-	-	-	-	-	600
Phalochroma rotundatum	-	200	-	-	-	-	-	-	-
Prorocentrum cordatum	600	200	-	-	-	-	-	-	-

Toxic algae recorded	10/01/ 2022	17/01/ 2022	24/02/ 2022	21/03/ 2022	26/04/ 2022	07/07/ 2022	05/07/ 2022	02/08/ 2022	17/02/ 2022
Prorocentrum dentatum	-	-	-	-	-	-	-	-	400
Prorocentrum micans	200	-	-	-	-	200	-	400	200
Prorocentrum rhathymum	200	-	-	-	-	-	-	-	-
Prorocentrum triestinum	-	-	-	-	-	-	-	-	600
Prorocentrum spp	-	200	-	-	-	-	-	400	-
Protoperidinium spp	8,000	1,000	-	-	-	-	200	-	600
Tripos furca	-	-	-	-	-	-	200	-	-
Tripos intermedius	-	-	-	-	-	-	400	-	200
Tripos lineatus	-	-	-	-	-	200	-	-	600
Prasinophyceae (cells/L)									
Prasinophytes	14,000	1,800	-	-	-	-	-	-	-
Tetraselmis spp	-	200	-	-	-	-	-	-	-
Pyramimonadophyceae (cells/L)									
Pyramimonas spp	-	-	-	-	-	-	-	200	-
Raphidophyceae (cells/L)									
Heterosigma akashiwo	200	-	-	-	-	-	-	-	-

3.3.2 Assessment against chemicals in seafood flesh EQC

Concentrations of chemicals in the flesh of mussels collected at three sites around the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and three sites around the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) were assessed against the chemical concentration in seafood flesh EQG (EPA 2017:67–68).

> Median chemical concentration in the flesh of seafood should not exceed the EQG:
>
> Copper 0 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 (EPA 2017:67–68).

> 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.[14]

See Table 18 for the results of the assessment against the EQC. For parameters for which EQC are available, the concentrations of metals in mussel flesh at sites in Cockburn Sound were below the relevant EQG or EQS at the Kwinana Bulk Terminal and Kwinana Bulk Jetty sites. The concentrations of PAHs in mussel flesh sampled from mussels at these sites were all below the analytical limits of reporting.

Table 18: Assessment of chemicals in mussels collected at sites in Cockburn Sound against the chemical concentration in seafood flesh EQC

Chemical	EQC (mg/kg)		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	EQS	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Metals (mg/kg)								
Arsenic (inorganic)	-	1.0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cadmium	-	2.0	0.15	0.11	0.11	0.13	0.11	0.09
Chromium	-	-	0.20	0.19	0.24	0.23	0.21	0.38
Copper	30	-	1.0	0.99	0.83	1.4	1.1	1.1
Lead	-	2.0	0.19	0.16	0.15	0.18	0.18	0.17
Mercury	-	0.5 (mean)	0.010	0.010	0.012	0.012	0.010	0.011
Selenium	1.0	-	0.54	0.51	0.56	0.60	0.49	0.35
Zinc (oysters)	290	-	32	26	22	31	27	27
TBT	-	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DBT	-	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MBT	-	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics (mg/kg)								
PAHs	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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

[14] 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).

3.4 Assessment against the maintenance of aquaculture production EQC

3.4.1 Assessment against the physical-chemical stressors EQG

DO and pH were measured at four water quality monitoring sites close to the shellfish harvesting areas in Cockburn Sound – CS9A, CS10N, CS11 and CS13 – between 1 December 2021 to 30 November 2022. Based on the EQC document, the following EQGs were defined for both DO and pH (EPA 2017:73):

> The median of the sample concentrations from the defined sampling area (either from one sampling run or all samples over an agreed period of time) should meet the following environmental quality guideline value detailed below.

DO	≥ 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 Southern Flats harvesting area.

Median concentration could not be robustly calculated, but all individual measurements of DO concentration were less than 5 mg/L (Figure 10) and all pH values in surface and depth readings were between 6 and 9 (refer to Figure 11). All EQG were met.

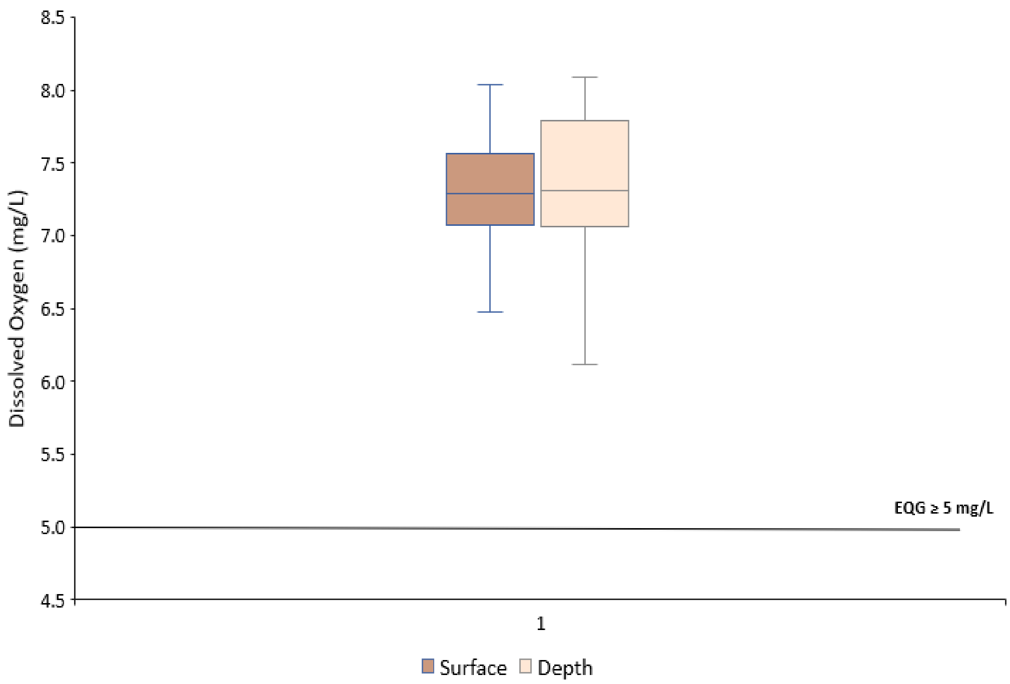

Figure 10: DO levels at the surface and at depth

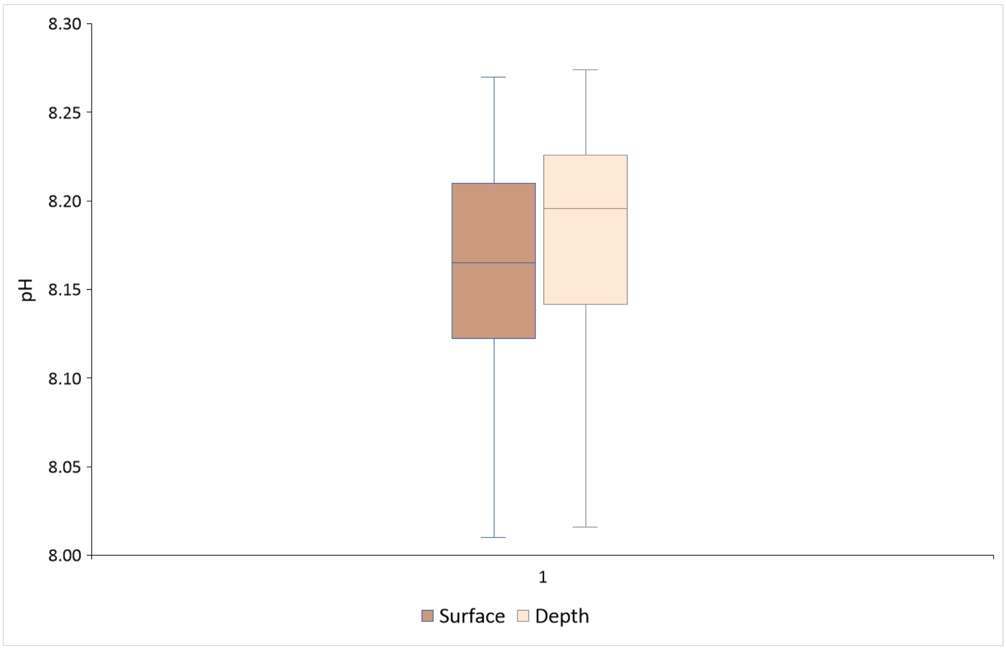

Figure 11: pH levels at surface and at depth

3.4.2 Assessment against the toxicants EQG

Depth-integrated samples collected from December 2021 to November 2022 at four water quality monitoring sites relatively close to the shellfish harvesting areas in Cockburn Sound (CS9A, CS10N, CS11 and CS13) were analysed for ammonia and nitrate–nitrite. In addition, surface water samples collected on a single occasion in January 2022 at three sites adjacent to the Kwinana Bulk Terminal (KBT1, KBT2, KBT3) and three sites adjacent to the Kwinana Bulk Jetty (KBJ1, KBJ2, KBJ3) were analysed for ammonia, nitrate-nitrite and copper levels.

Table 5 in the EPA reference document (2017:73) specifies the toxicant EQG as:

> 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 environmental quality guideline value.

For each contaminant, 95th percentiles were calculated from the 48 samples collected at CS9A, CS10N, CS11 and CS13 and compared against the EQG (Table 19). All met the EQG.

As 95th percentiles could not be robustly calculated for the KBT/KBJ sites, all measurements of copper, ammonia and nitrate–nitrite concentrations collected at these sites were individually assessed against the relevant toxicants EQG values (Table 19). All measurements were below the EQG.

Table 19: Assessment of concentrations of ammonia, nitrate-nitrite and copper at sites near the shellfish harvesting areas in Cockburn Sound against the toxicant 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="10">≤1,000</td><td><3</td><td>6</td><td rowspan="10">Nitrite-N ≤100
Nitrate-N ≤100,000</td><td><2</td><td>2</td><td rowspan="10">≤5</td><td>0.3</td></tr>
<tr><td>KBT2</td><td><3</td><td><3</td><td><2</td><td>2</td><td>0.3</td></tr>
<tr><td>KBT3</td><td><3</td><td>7</td><td><2</td><td>4</td><td>0.9</td></tr>
<tr><td>KBJ1</td><td>6</td><td>8</td><td><2</td><td><2</td><td>0.3</td></tr>
<tr><td>KBJ2</td><td>9</td><td>30</td><td><2</td><td>6</td><td>0.4</td></tr>
<tr><td>KBJ3</td><td>6</td><td>4</td><td><2</td><td><2</td><td>0.4</td></tr>
<tr><td>CS13</td><td>95th per. = 3.2</td><td>95th per. = 11.9</td><td>95th per. = 1.9</td><td>95th per. = 5.5</td><td>Not measured</td></tr>
<tr><td>CS9A</td><td colspan="2">95th percentile = 16.9</td><td colspan="2">95th percentile = 4.5</td><td>Not measured</td></tr>
<tr><td>CS10N</td><td colspan="2">95th percentile = 5.3</td><td colspan="2">95th percentile = 2.9</td><td>Not measured</td></tr>
<tr><td>CS11</td><td colspan="2">95th percentile = 4.0</td><td colspan="2">95th percentile = 4.8</td><td>Not measured</td></tr>
</table>

3.4 Conclusion – Environmental value: Fishing and Aquaculture

All assessments of algal biotoxins (in water), toxins (in seafood) and toxicants in water met the relevant criteria, except for the alert levels for two potentially toxic phytoplankton species (out of 68 reported species) that were exceeded on two occasions in January 2022 in the water at Southern Flats. Given the low incidence of alert level exceedances in water, the 2022 monitoring data suggests the EQOs of *maintenance of seafood safe for human consumption* and *maintenance of aquaculture production* were 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 recommends only eating shellfish harvested commercially under strict quality assurance monitoring programs.

4. Environmental value: Recreation and Aesthetics

4.1 EQOs

The EQOs for the environmental value of 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 (aesthetic values are protected).

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

- people undertaking primary contact recreational activities where a 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.

4.2 Water quality monitoring

The cities of Cockburn, Kwinana and Rockingham undertook bacterial water sampling at several popular recreational beaches (program sites) in Cockburn Sound during the peak recreational season between November 2021 and May 2022 (Figure 12). The Department of Health administered the program and encouraged the minimum collection of 65 samples 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.[15]

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 fewer sampling events 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).

[15] For more information on beach grades, visit the Department of Health's website: www.health.wa.gov.au/Articles/A_E/Beach-grades-for-Western-Australia

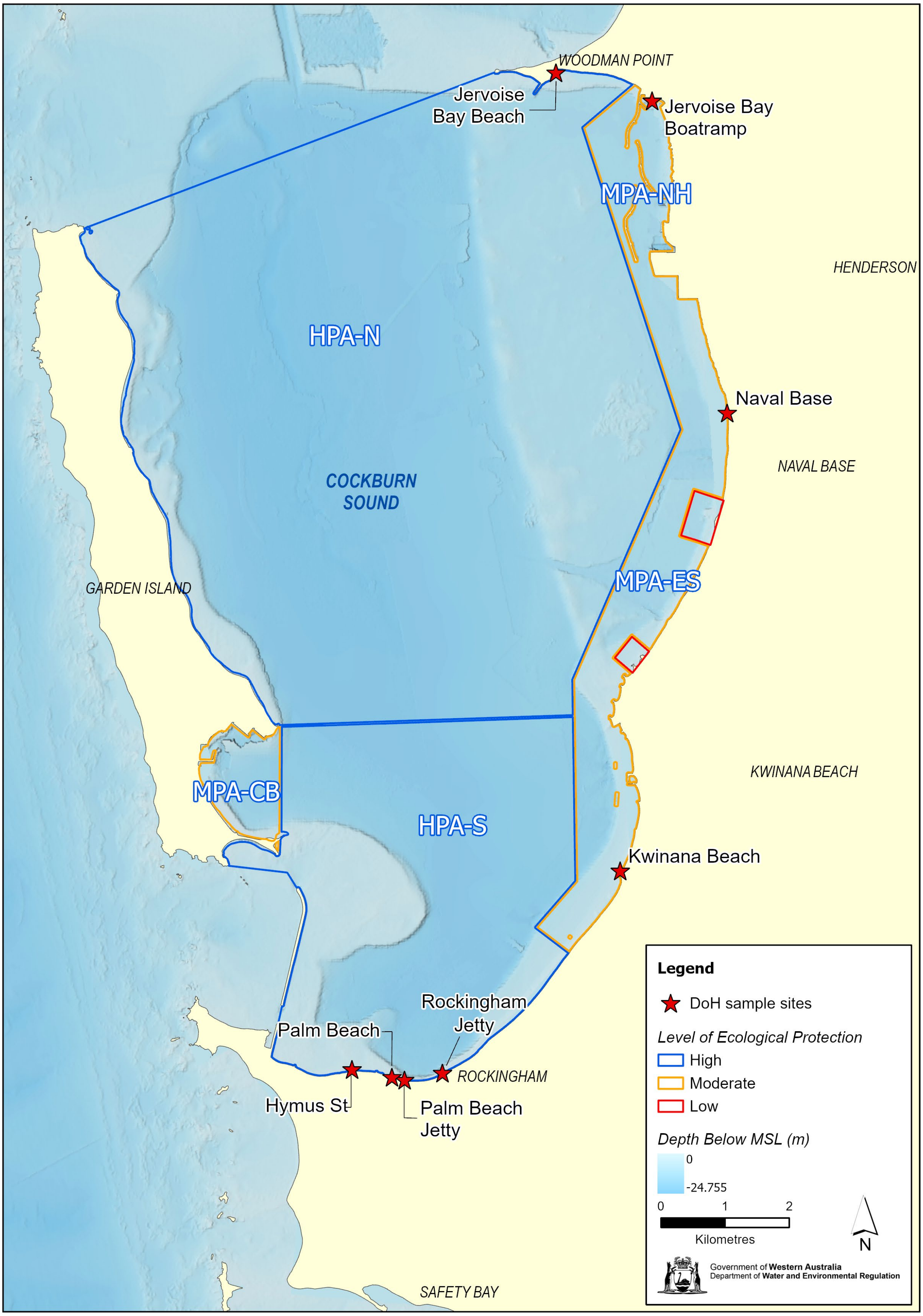

Figure 12: Sampling locations near recreational beaches in Cockburn Sound (Flukes 2024)

4.3 Assessment against primary and secondary contact EQC

4.3.1 Assessment against the EQG for faecal pathogens

Enterococci counts (expressed as most probable number per 100 millilitres [MPN/100 mL]) recorded at each of eight locations around Cockburn Sound between November 2021 and March 2022 were assessed against the faecal pathogens EQG for primary contact recreation (EPA 2017:80):

> 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 (EPA 2017:92):

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

Table 20 below presents the measured Enterococci counts reported by the Department of Health. The faecal pathogens EQG for both primary and secondary contact recreation were met at all the sites monitored.

Table 20: Assessment of the 95th percentile of Enterococci counts (samples collected from November to May between 2017–18 and 2021–22) at eight locations in Cockburn Sound against the faecal pathogen 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	40	200	2,000	55
Jervoise Bay Beach[1]	Program	56			70
Rockingham Beach and Jetty[1]	Program	45			14
Palm Beach Jetty[1]	Program	43			16
Naval Base[1]	Program	19			12
Kwinana Beach[1]	Program	19			12
Jervoise Bay Boat Ramp[1]	Non-core	56			22
Palm Beach[1]	Non-core	29			2
Assessment		Primary contact and secondary contact recreation EQG met at all sites			

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

Note: The 95th percentiles were calculated using the Department of Health's Enterotester V200v2. 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 against the EQG for physical parameters

Water clarity and pH were recorded at each of the 18 water quality monitoring sites during the non river-flow period between November 2021 and May 2022 (Figure 2) and assessed against the physical EQC for primary contact recreation (EPA 2017:80):

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.[16]

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 (EPA 2017:92):

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 EQC for primary and secondary contact recreation at all sites (Table 21).

Table 21: Assessment of pH and water clarity (based on Secchi disc depth readings) at 18 water quality monitoring sites in Cockburn Sound between November 2021 and May 2022, against the physical EQC for primary and secondary contact recreation

Site	pH EQC	Median pH (surface)	Median pH (bottom)	Water clarity EQG	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	6.0 – 10.0	EQC met at all sites
CS5		8.2	8.2		5.0 – 11.0	
CS6A		8.2	8.2		5.3 – 6.8	
CS7		8.2	8.2		4.8 – 7.5	
CS8		8.2	8.2		4.5 – 7.8	
CS9		8.2	8.1		5.3 – 7.1	
CS10N		8.2	8.2		3.5 – 9.5	
CS11		8.2	8.2		4.1 – 9.0	
CS12		8.2	8.2		4.1 – 8.0	
CS13		8.2	8.2		3.6 - 10.5	
CS9A		8.2	8.2		2.9 – 7.4	
CB		8.2	8.2		4.7 – 7.5	

[16] The former Office of the Environmental Protection Authority (now the Department of Water and Environmental Regulation) 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 EQG	Range of Secchi disc measurements (m ± 0.1 m)	Assessment
G1		8.2	8.2		3.9 – 8.2	
G2		8.2	8.2		3.8 – 8.2	
G3		8.2	8.2		6.8 – 10.0	
SF		8.2	8.2		3.1 – 4.1	
MB		8.2	8.2		1.1* – 2.4	
NH3		8.2	8.2		3.9 – 5.5	

* Maximum depth at site at time of monitoring

4.3.3. Assessment against the EQC for toxic chemicals

Section 2.5 describes the results of comparisons of measured concentrations of toxic chemicals against the criteria established for ecosystem health. These criteria were met at all stations and sampling occasions. As the criteria for toxic chemicals to protect ecosystem health are more stringent than those to protect primary and secondary contact recreation, it can be deducted that all EQC were met and this assessment was not required to be completed.

4.4 Assessment against aesthetic quality EQC

The community highly values the ecological, recreational and aesthetic attributes of Cockburn Sound, which resulted in the development of a set of qualitative EQC to protect its aesthetic values (EPA 2017). Guidelines for aesthetic quality relate to the general appreciation and enjoyment of Cockburn Sound by the community as a whole. Additional factors considered are 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.

MAFRL made qualitative observations of the following indicators of aesthetic quality near each of the 18 water quality monitoring sites between 1 December 2021 and 30 November 2022:

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

Observations indicate that localised and temporary issues occur from time to time at several sites across Cockburn Sound, but more frequently in the southern part of the Sound and along the eastern shore. These issues include nuisance organisms (sometimes present in adequate number to form algal blooms), decreased water clarity, water colour issues and, less frequently, floating debris (e.g. wheat dust).

Occasionally, odour was reported at sites adjacent to the industrial area on the eastern shore of Cockburn Sound (e.g. CS9 and CS12). Odour associated with dredging was reported in Warnbro Sound at reference site WSSB.

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

See Table F1 in Appendix F for detailed results.

4.5 Conclusions – Environmental value: Recreation and aesthetics

All assessments of monitoring data against primary and secondary contact recreation criteria met guideline values. On the basis of these results, there is a high level of confidence that the EQOs of *maintenance of primary contact recreation values* and *maintenance of secondary contact recreation values* are being achieved in Cockburn Sound.

Observations of nuisance organisms and phytoplankton blooms, reduced water clarity, water colour issues and floating debris were relatively common in several locations. This may suggest that while the EQO of *maintenance of aesthetic values* is generally being achieved, this objective is being compromised locally.

5. Environmental value: Cultural and Spiritual

5.1 EQO

The EQO for the environmental value of Cultural and Spiritual is *cultural and spiritual values of the marine environment are protected*.

Currently, no EQC specific to this environmental value have been developed. The existing EQC that are implemented to ensure ecosystem integrity, seafood quality and recreational and aesthetic values are protected, may reasonably be expected to contribute to protecting cultural and spiritual values in Cockburn Sound. However, engagement with Traditional Owners is required to identify the cultural and spiritual values in Cockburn Sound and to test whether additional EQO and/or EQC need to be developed to ensure these values are protected. This will be completed as part of the SEP Review Project which will be undertaken over 2024–27.

6. Environmental value: Industrial Water Supply

6.1 EQO

The EQO for the environmental value of Industrial Water Supply is *maintenance of water quality for industrial use* (water is of suitable quality for industrial use).

The Perth Seawater Desalination Plant (desalination plant), in the industrial zone along the eastern shore of Cockburn Sound, takes seawater from Cockburn 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 has the potential to significantly impact 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).

6.2 Perth Seawater Desalination Plant intake water quality monitoring

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

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 *Enterococci* (which replaced *E. coli* as of May 2017, a more robust pathogen indicator for salt water), boron and bromide. For water quality parameters, water samples were collected by an in-house process chemist and analysed by accredited laboratories.

Water Corporation provided intake monitoring data for two calendar years. However, for the purpose of this report only the data collected during the 2022 reporting period (1 December 2021 – 30 November 2022) were considered.

6.3 Assessment against industrial water supply EQC

6.3.1 Biological indicators

During the 2022 monitoring period, *Enterococci* numbers were below the limit of reporting (<10 colony-forming units/mL). No spikes above the EQG or EQS were reported for this period.

6.3.2 Physical and chemical indicators

Temperature

Over the 2022 monitoring period, temperature of the intake seawater remained below the EQG of 28°C (Figure G1 and G2 in Appendix G).

pH and DO

Over the 2022 monitoring period, pH remained below the EQG of 8.5 and DO concentrations remained above the EQG of 2 mg/L (Figures G3 – G6 in Appendix G).

Total suspended solids

Over the 2022 monitoring period, the rolling four-week median concentration of TSS (Figure G7 and G8 in Appendix G) exceeded the EQG of 4.5 mg/L more than 50% of the time and exceeded the desalination plant limit of 9 mg/L three times. Dosing of coagulant in the desalination plant's pre-treatment process is automated to adjust the variance in TSS up to the desalination plant's operational limit of 9 mg/L (i.e. the EQS).

Boron and bromide concentrations

Over the 2022 monitoring period, boron concentrations remained relatively stable and met the EQG consistently (Table 22). Boron and bromide are removed from the water by the reverse osmosis process; however, higher concentrations reduce the efficiency of this process which may impact on the production rate.

Table 22: Quarterly boron and bromide concentrations of intake seawater for the monitoring period between 1 December 2021 and 30 November 2022

Sampling month	Boron (mg/L)		Bromide (mg/L)	
	EQG	Concentration	EQG	Concentration
Jan-22	5.2	4.8	77	71
Apr-22		4.7		72
Jul-22		4.8		71
Nov-22		4.7		72

6.4 Conclusions – Environmental value: Industrial Water Supply

Data collected at the Perth Seawater Desalination Plant intake over the 2022 monitoring period indicate that water quality of intake water generally meets the relevant criteria. TSS was the only parameter for which criteria were commonly exceeded. Variation in intake water quality is expected, and the 2022 results are generally in line with previous years. No adverse impact on the operation of the plant nor a need for mitigation measures were reported by Water Corporation, indicating that the EQO was achieved during the reporting period.

List of shortened forms

AMC	absolute minimum criteria
BDI	butyltin degradation index
BTEX	benzene, toluene, ethylbenzene and xylene
CSMC	Cockburn Sound Management Council
DBT	dibutyltin
DO	dissolved oxygen
EPA	Environmental Protection Authority
EQC	environmental quality criteria
EQG	environmental quality guideline(s)
EQS	environmental quality standard(s)
HPA-N	High Protection Area North
HPA-S	High Protection Area South
KBJ	Kwinana Bulk Jetty
KBT	Kwinana Bulk Terminal
LAC	light attenuation coefficient
LDL	lower depth limit
LRV	low reliability value
MAFRL	Marine and Freshwater Research Laboratory
MBT	monobutyltin
MPA-CB	Moderate Protection Area Careening Bay
MPA-ES	Moderate Protection Area Eastern Sound
MPA-NH	Moderate Protection Area Northern Harbour
MPA-SH	Moderate Protection Area Southern Harbour
MPN	most probable number
PAH	polycyclic aromatic hydrocarbon
PFAS	perfluoroalkyl and polyfluoroalkyl substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
pH	potential of hydrogen
SEP	State Environmental (Cockburn Sound) Policy 2015
TBT	tributyltin
TOC	total organic carbon
TRH	total recoverable hydrocarbons
TSS	total suspended solids
TTM	total toxicity of the mixture
WASQAP	Western Australia Shellfish Quality Assurance Program

Glossary

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.
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 (i.e. TBT in the sediment has reached its half-life).
Chlorophyll-a	A complex molecule that can 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 on established performance standards specified 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.
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 (environmental quality guideline), or whether a management response is required (environmental quality standard).
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 (EQO)	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, ecosystem processes and abundance/biomass of marine life).
Light attenuation in water	The exponential decay of light intensity with increasing depth because of absorption and scattering. A large light attenuation coefficient means that light is quickly 'attenuated' (i.e. weakened) as it passes through the water column. A small light attenuation coefficient means that the water is relatively transparent to light.
Low level of 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 several 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, there is low risk of ecological impact. If concentrations are above an LRV, it does not necessarily mean an impact is likely. Exceedance of an LRV does not trigger mandatory assessment against the EQS but does signal that the possibility of ecological impact should be considered, particularly if further increases beyond the LRV are likely.
Maximum residue limit	The highest concentration of a chemical residue that is legally permitted or accepted in a food.
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 most 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, particularly for grain size, organic matter content and mineralogy.
Nutrients	Elements or compounds, such as nitrogen and phosphorus, which 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. E.g. 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 that were used in firefighting foams. PFAS are highly persistent in the environment, are moderately soluble, and 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 several 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.
Re-sampling trigger	Where the total concentration of a contaminant in individual sediment sample sites exceeds the environmental quality guideline re-sampling trigger, additional sampling of that potentially contaminated site will generally be required to better define the area of high concentration.
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 (Cockburn Sound) Policy 2015 (SEP)	The *State Environmental (Cockburn Sound) Policy 2015* which is a non-statutory instrument developed by the Environmental Protection Authority under the *Environmental Protection Act 1986* that provides an important mechanism for the environmental management of Cockburn Sound. It is a flexible policy instrument which was developed through public consultation and adopted on a whole-of-government basis.
Total nitrogren; total phosphorus	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 = $\sum(CR_iR)/EQGR_iR)$, where CR_iR is the concentration of the 'i'th component in the mixture and $EQGR_iR$ is the guideline for that component.

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Appendix A: Chlorophyll-a concentrations and light attenuation coefficient

Chlorophyll-a

The monthly chlorophyll-a concentration measured at water quality monitoring sites between January 2021 and December 2022 are shown in Figures A1–A3 below (Wilson 2023). For the purpose of this report, only data collected between 1 December 2021 and 30 November 2022 will be discussed.

Chlorophyll-a concentrations for the monitoring sites in HPA-N were less variable than those measured at sites in HPA-S, MPA-ES or MPA-CB (Figure A1).

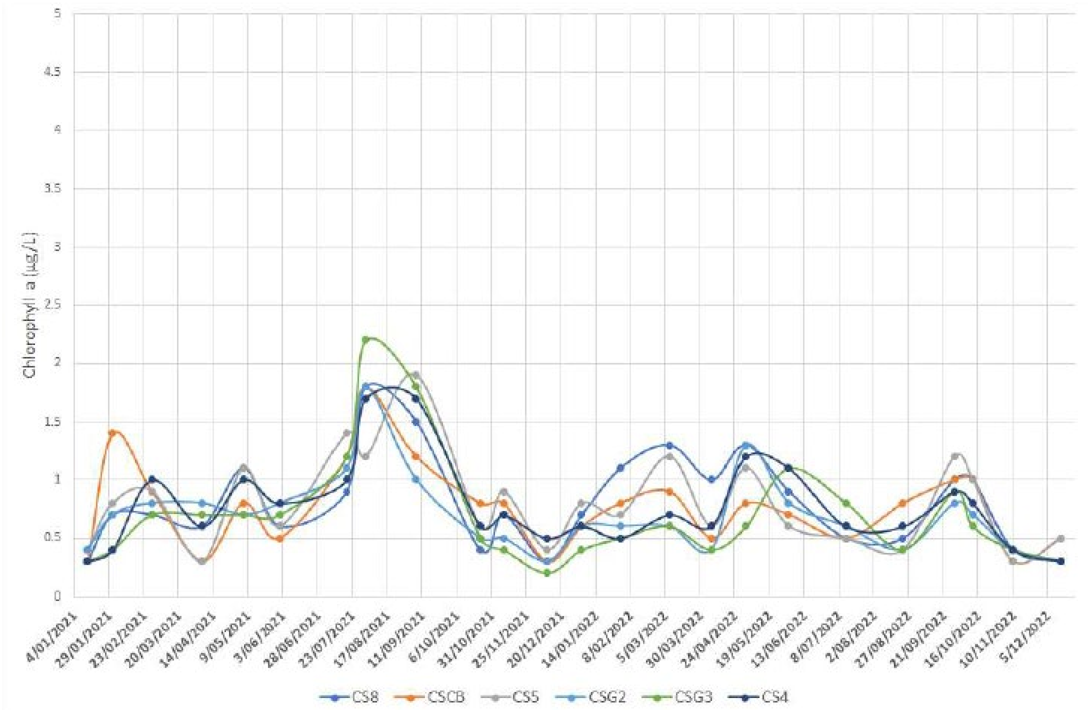

Figure A1: Monthly chlorophyll-a concentrations measured at water quality monitoring sites in HPA-N from January 2021 to December 2022 (Wilson 2023)

For the sites in the HPA-S, chlorophyll-a concentrations were more variable, particularly in Mangles Bay (site MB), where the highest chlorophyll-a concentration (4.5 µg/L) was recorded in the high protection areas (Figure A2).

For the sites in the moderate protection areas, chlorophyll-a concentrations were variable but generally followed the same pattern (Figure A3). Site NH3 (Northern Harbour) typically had higher chlorophyll-a concentrations than any other site.

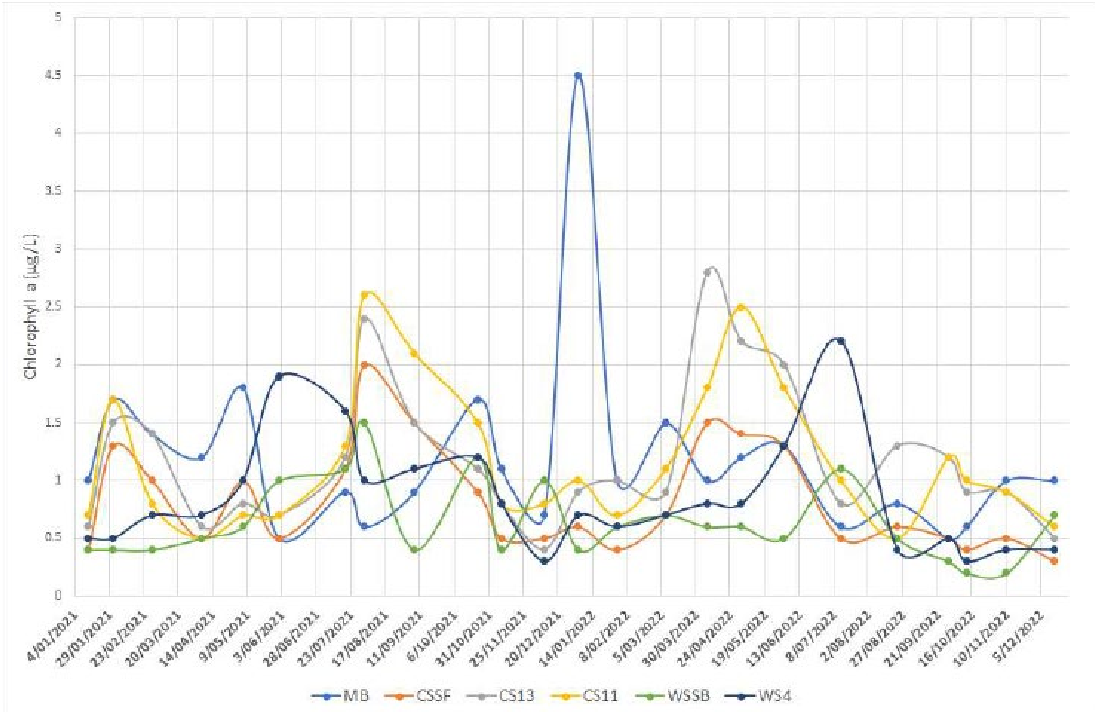

Figure A2: Monthly chlorophyll-a concentration measured at water quality monitoring sites HPA-S and Warnbro Sound from January 2021 to December 2022 (Wilson 2023)

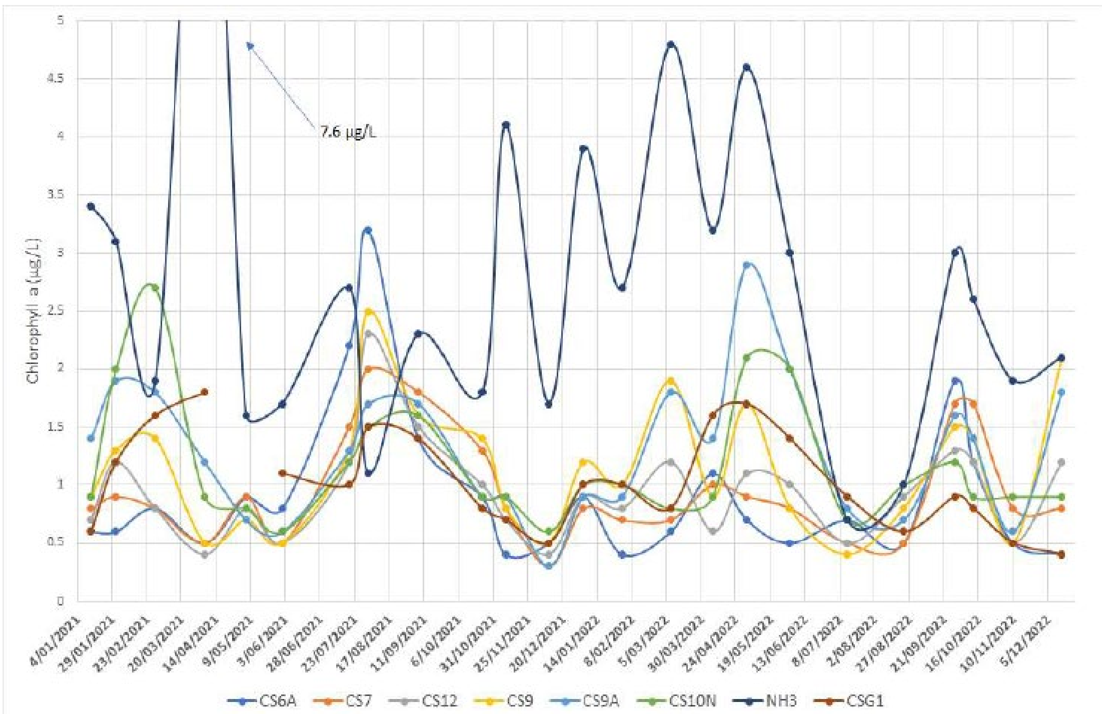

Figure A3: Monthly chlorophyll-a concentration measured at water quality monitoring sites MPA-ES, MPA-CB and MPA-NH from January 2021 to December 2022

Light attenuation coefficient

Light attenuation measured monthly at water quality monitoring sites between January 2021 and December 2022 are shown in Figures A6–A8 (Wilson 2023). For the purpose of this report, only data collected between 1 December 2021 and 30 November 2022 will be further discussed.

Monitoring sites in HPA-N (Figure A6) appeared to be less variable than other areas, with peaks in majority of the sites occurring in April 2022 and between August and October 2022. There was no repeat occurrence during the 2022 monitoring period of the large spike in light attenuation recorded in 2021.

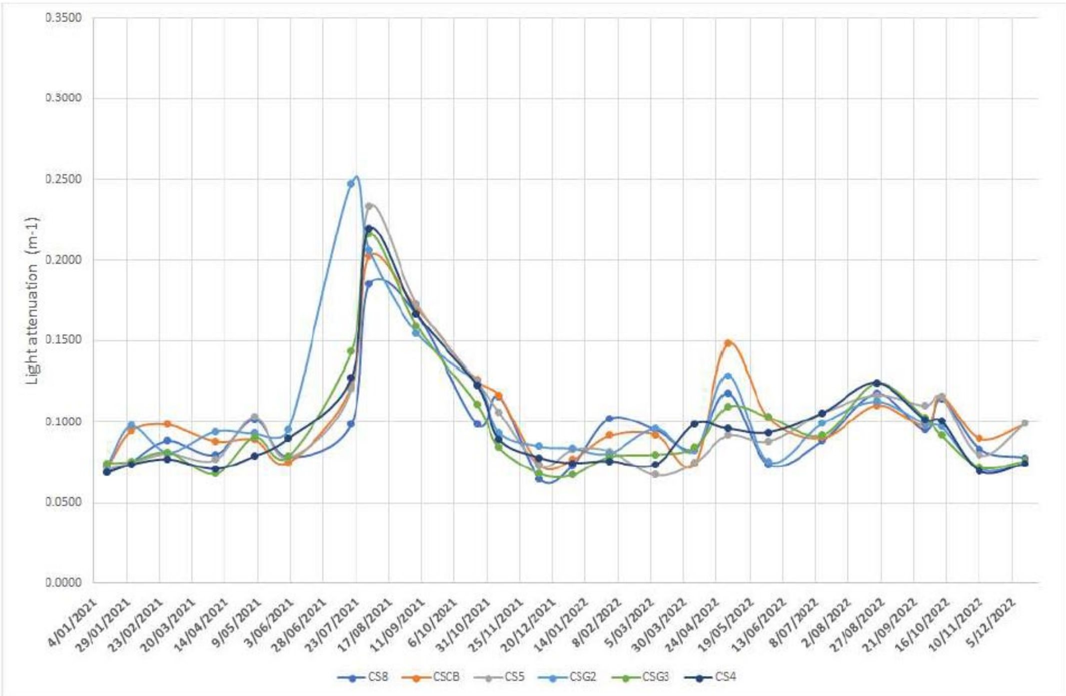

Figure A6: Monthly light attenuation at water quality monitoring sites in HPA-N from January 2021 to December 2022 (Wilson 2023)

Monitoring sites in HPA-S showed relatively mild elevated levels in light attenuation at sites MB and SF in April and at various sites within this ecological protection area in August 2022 (Figure A7).

Light attenuation recorded at sites in moderate protection areas largely followed a similar pattern with elevated levels recorded at CS9A and CS10N in some months. In site NH3 (Northern Harbour) elevated levels were recorded consistently (Figure A8).

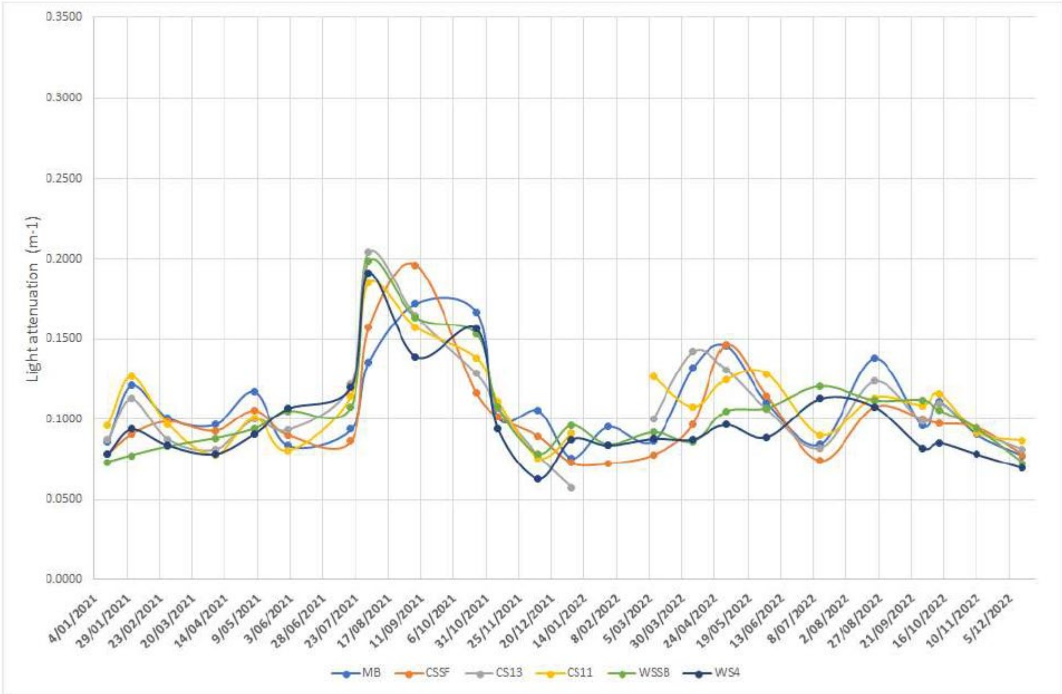

Figure A7: Monthly light attenuation at water quality monitoring sites in HPA-S from January 2021 to December 2022 (Wilson 2023)

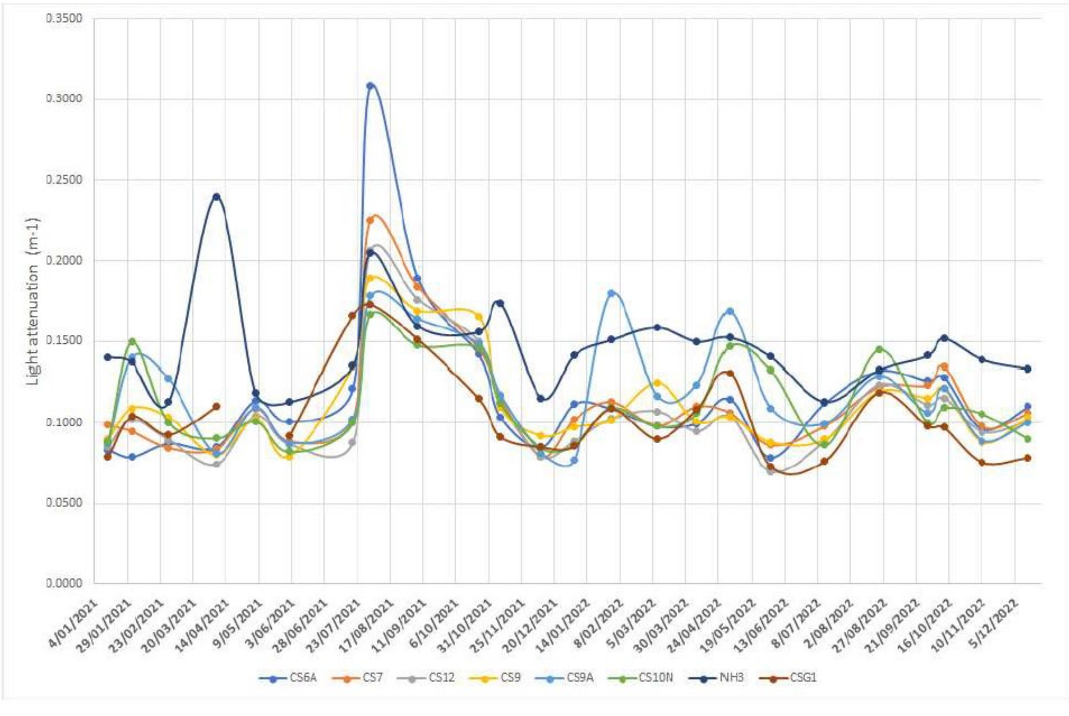

Figure A8: Monthly light attenuation at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January 2021 to December 2022 (Wilson 2023)

Appendix B: Monthly nutrient concentrations

Ammonium

Ammonium concentrations measured monthly at water quality monitoring sites between January 2021 and December 2022 are shown in Figures B1–B3 (Wilson 2023). For the purpose of this report, only data collected between 1 December 2021 and 30 November 2022 will be further discussed.

Ammonium concentrations were less variable in sites within HPA-N compared with the other ecological protection areas (Figure B1). At some sites within this area, mildly elevated nutrient concentrations were observed in June and August 2022. There was no repeat occurrence during the 2022 monitoring period of the spike in nutrients recorded in 2021.

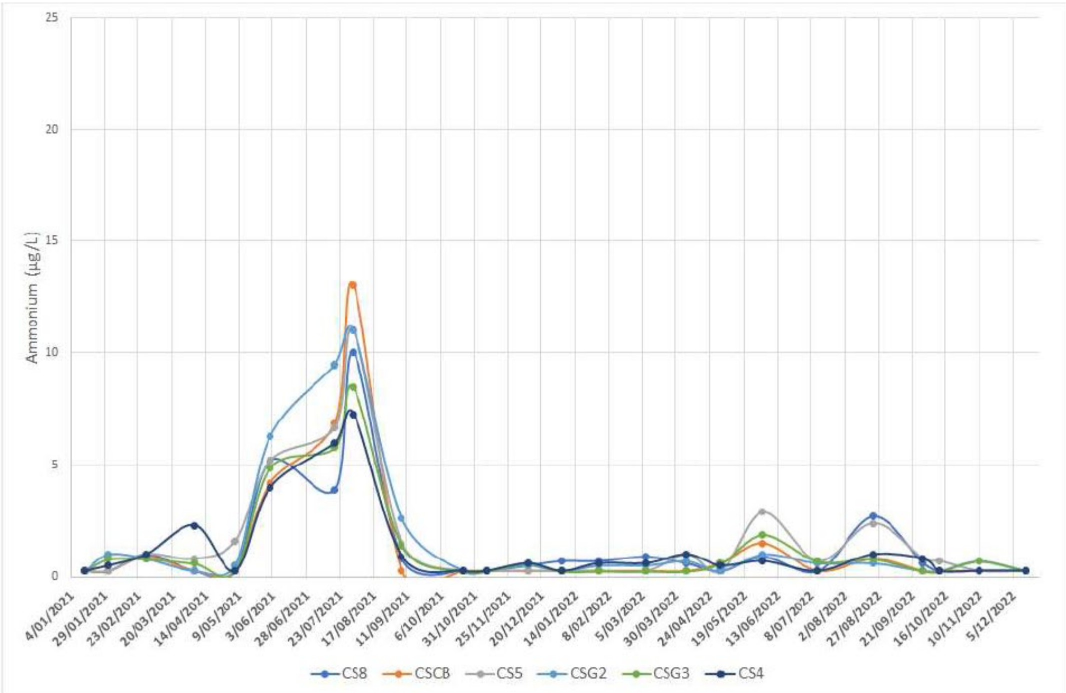

Figure B1: Monthly ammonium concentrations at water quality monitoring sites HPA-N from January 2021 to December 2022 (Wilson 2023)

Ammonium concentrations were more variable at sites in HPA-S, with elevated levels observed at CS11, CS13 and reference site WS4 in March 2022 (Figure B2).

As for the monitored sites within the MPA, significantly elevated levels were recorded at CS9A and NH3 over winter 2022, with mildly elevated levels recorded at CS10N in several months throughout the year (Figure B3).

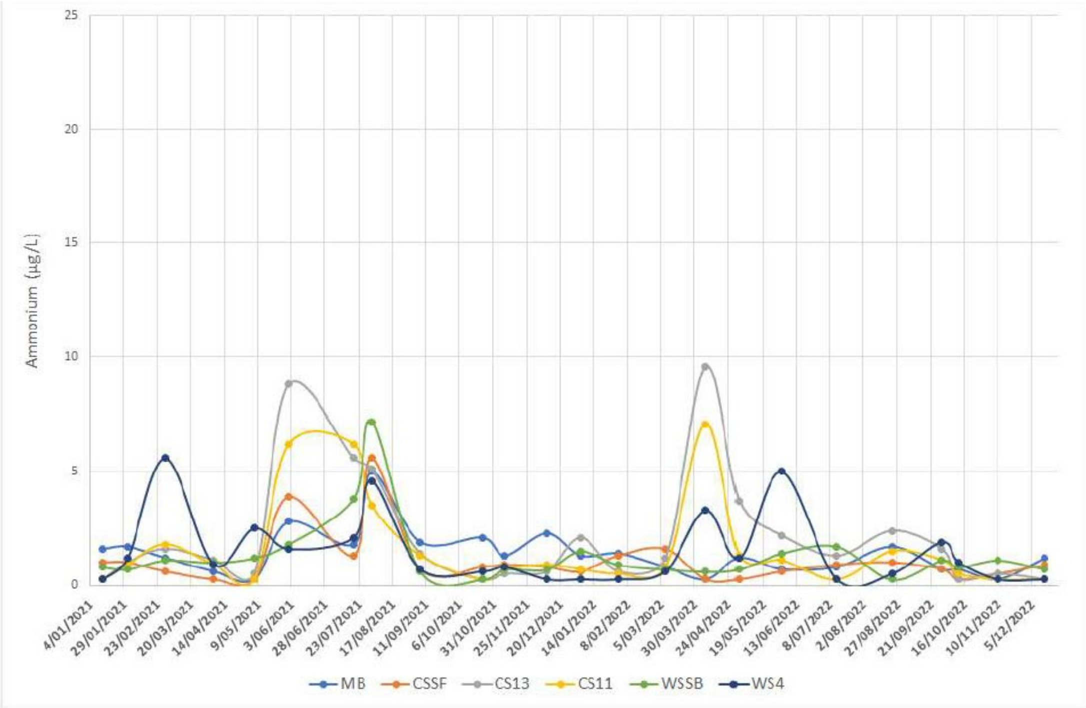

Figure B2: Monthly ammonium concentrations at water quality monitoring sites HPA-S from January 2021 to December 2022 (Wilson 2023)

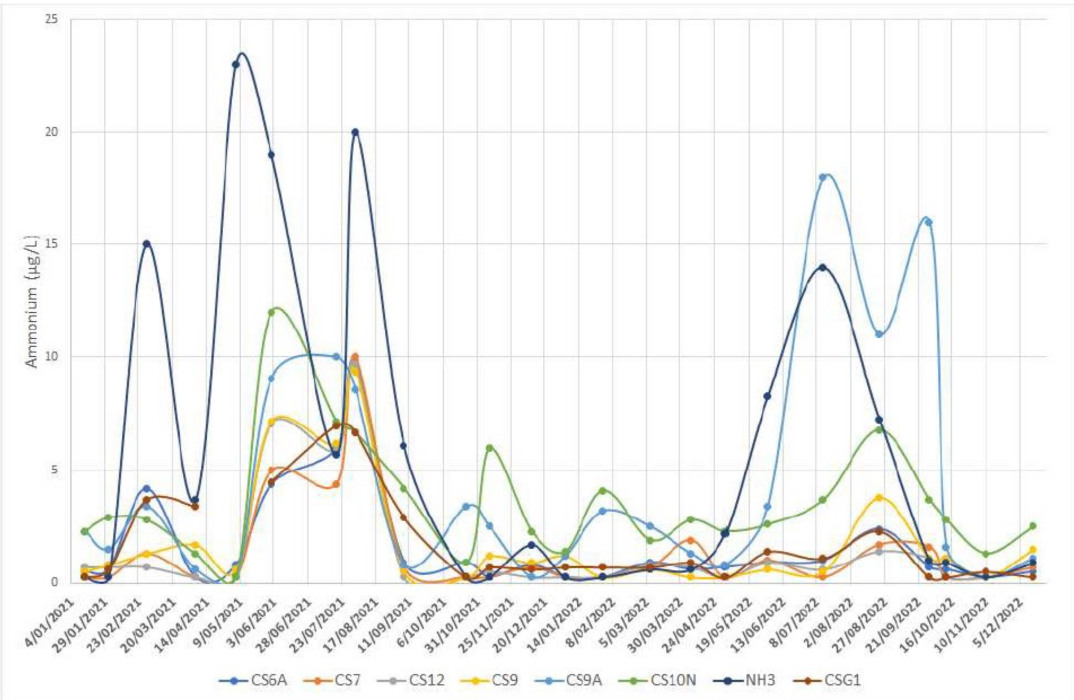

Figure B3: Monthly ammonium concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January 2021 to December 2022 (Wilson 2023)

Total nitrogen

Total nitrogen concentrations measured monthly at water quality monitoring sites between January 2021 and December 2022 are shown in Figures B4–B6 (Wilson 2023). For the purpose of this report, only data collected between 1 December 2021 and 30 November 2022 will be further discussed.

Total nitrogen concentrations measured at the monitoring sites in HPA-N remained relatively stable throughout the 2022 reporting period (Figure B4). There was no repeat occurrence during the 2022 monitoring period of the spike in total nitrogen recorded in 2021.

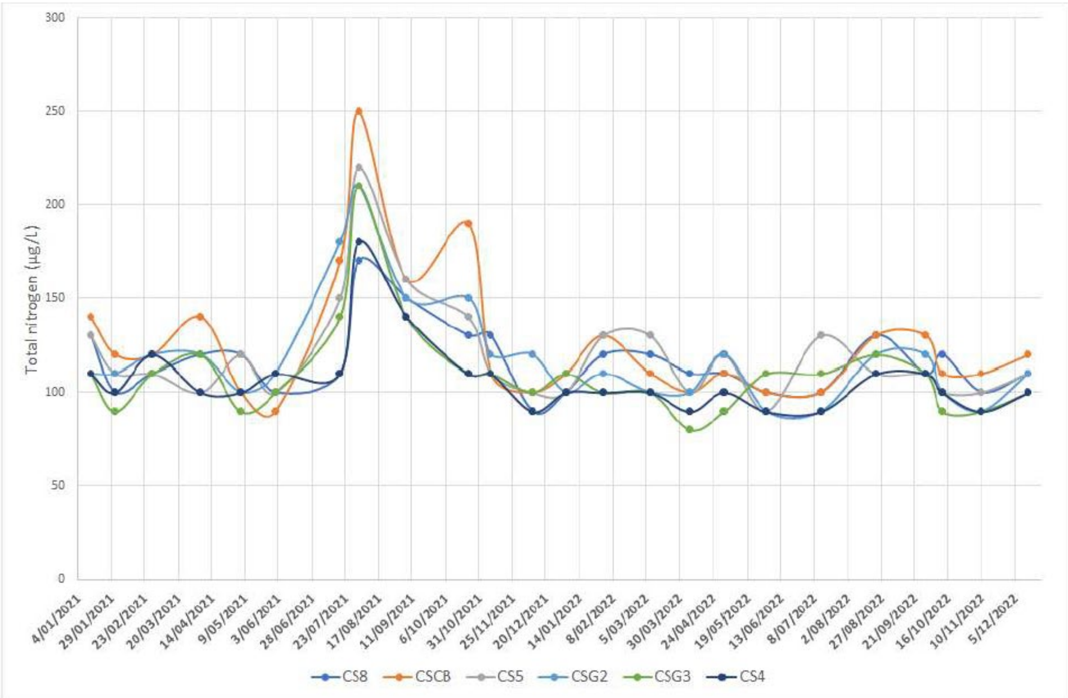

Figure B4: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-N from January 2021 to December 2022 (Wilson 2023)

For the sites in the southern HPA, site MB (range 120 to 240 µg/L) had higher total nitrogen concentrations than the other sites (Figure B5). Total nitrogen concentrations displayed some variation throughout the year.

Total nitrogen concentrations also displayed a level of variation at monitoring sites within the moderate protection areas. Elevated total nitrogen concentrations were observed at different sites for different months but were consistently reported at NH3 in Northern Harbour (Figure B6).

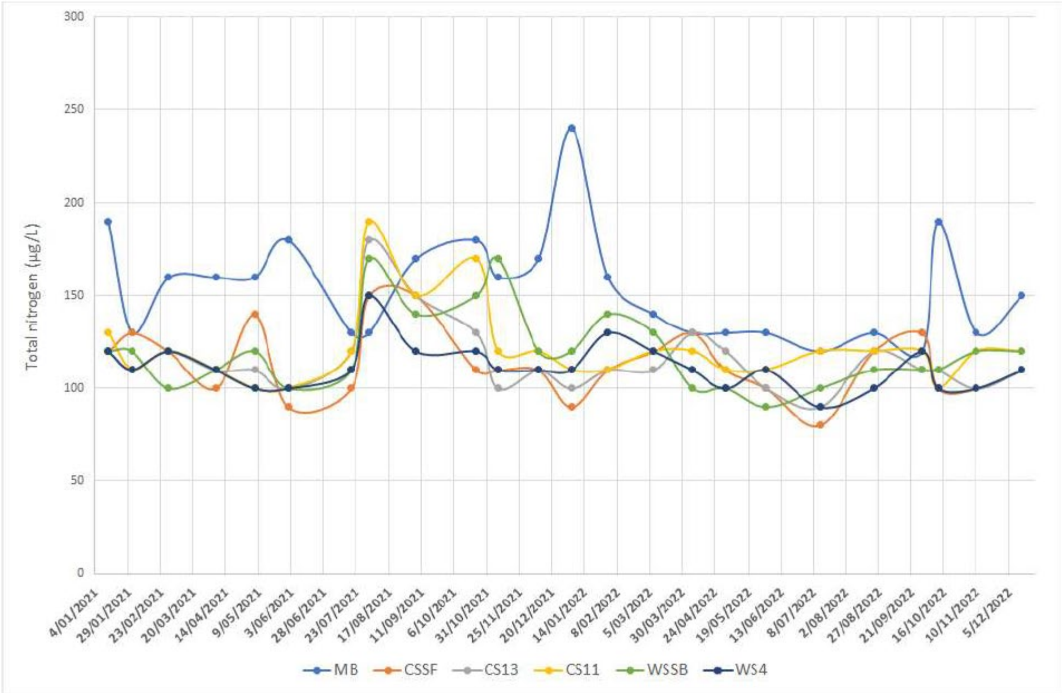

Figure B5: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-S from January 2021 to December 2022 (Wilson 2023)

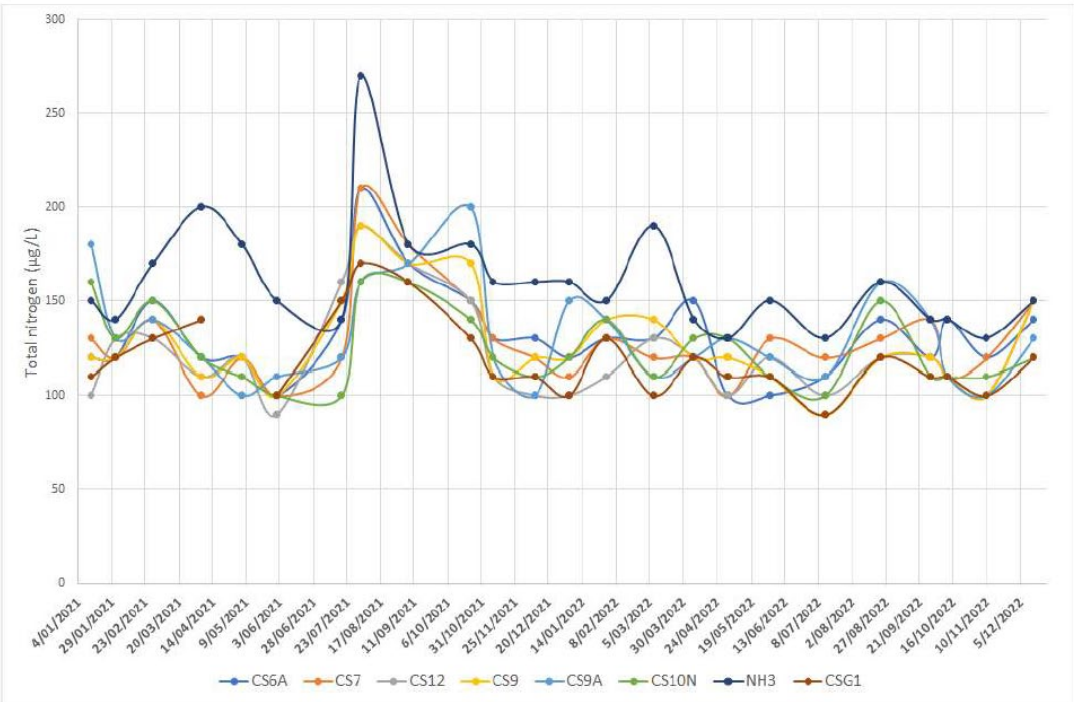

Figure B6: Monthly total nitrogen concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January 2021 to December 2022 (Wilson 2023)

Total phosphorus

Total phosphorus concentrations measured monthly at water quality monitoring sites between January 2021 and December 2022 are shown in Figures B7–B9 (Wilson 2023). For the purpose of this report, only data collected between 1 December 2021 and 30 November 2022 will be further discussed.

Total phophorus concentrations measured at the monitoring sites in HPA-N remained relatively stable throughout the 2022 reporting period (Figure B7). Mildly elevated levels were observed at some stations in May 2022, with lower concentrations measured in April and November 2022.

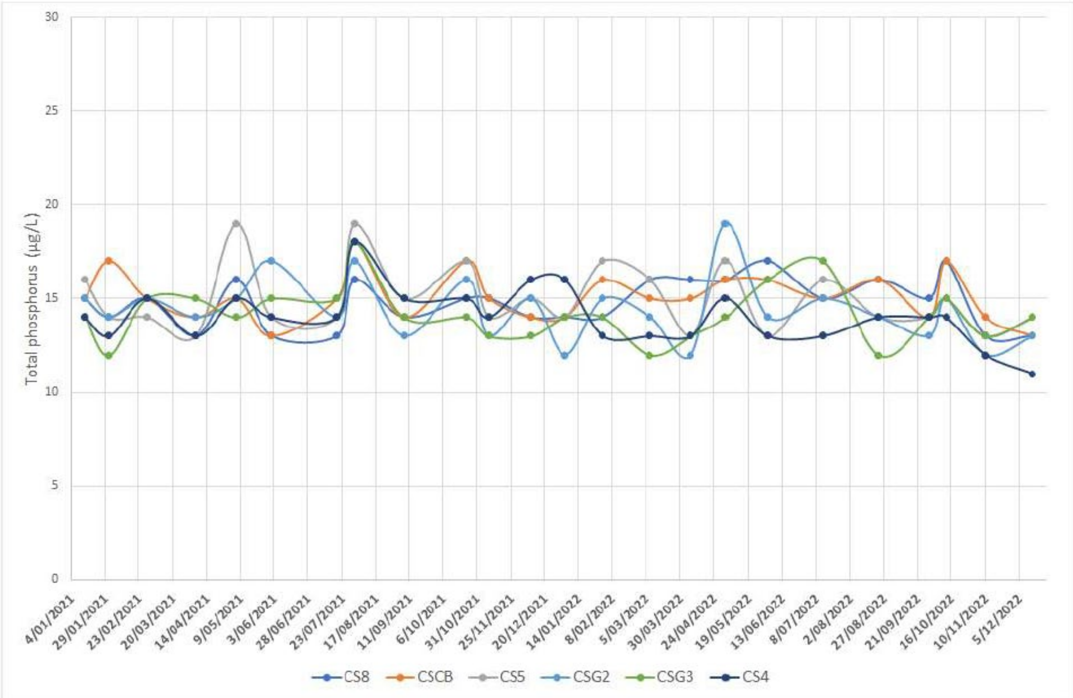

Figure B7: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-N from January 2021 to December 2022 (Wilson 2023)

Total phosphorus concentrations were more variable at sites in HPA-S, with elevated levels observed at Site MB in January 2022. Deeper sites within HPA-S such CS13 showed peaks in total phosphorus concentrations in April and August 2022 (Figure B8).

Within the moderate protection areas, elevated total phosphorus concentrations were observed at different sites for different months but were consistently reported at NH3 in Northern Harbour (Figure B9).

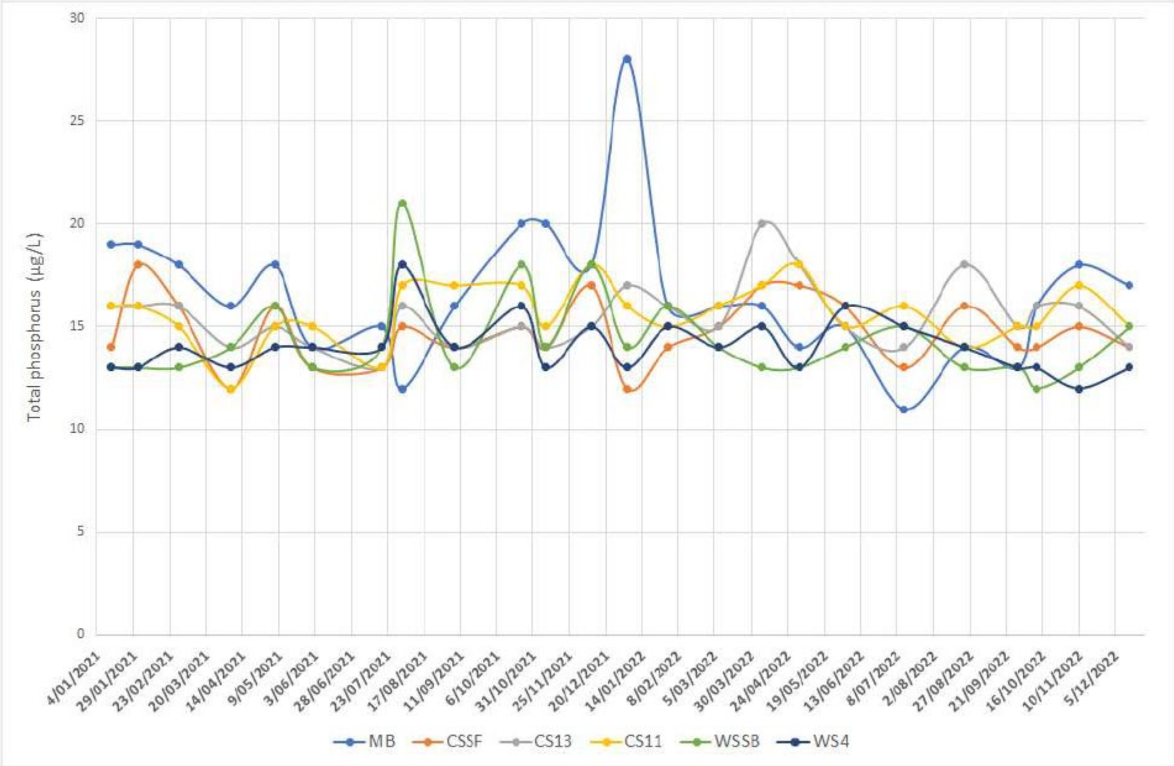

Figure B8: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-S from January 2021 to December 2022 (Wilson 2023)

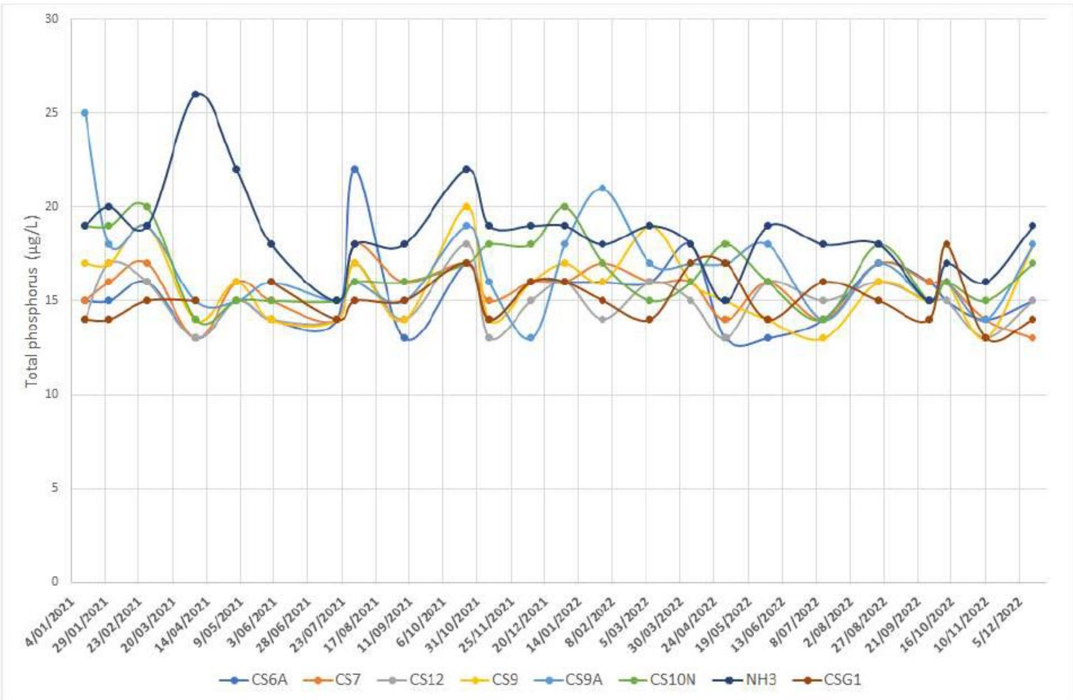

Figure B9: Monthly total phosphorus concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January 2021 to December 2022 (Wilson 2023)

Appendix C: Seagrass health

Assessment using Warnbro Sound reference sites

Calculation of EQS (i) and (ii) – seagrass shoot density

The calculated rolling percentiles for EQS (i) and (ii) for seagrass shoot density are presented in Table C1. In 2020, shoot density data was available for the shallow Warnbro Sound reference sites, but monitoring of these sites was abandoned for 2022 because of almost complete seagrass loss from sediment accretion/erosion.

For the calculation of EQS (i) the absolute minimum criteria (AMC) were used in most instances, as seagrass shoot density at most sites has declined over time. The values used in the assessment against EQS (i) are denoted in bold. Values for EQS (ii) at the shallow three reference sites could not be determined as they were not monitored in 2022.

Table C1: The 2020 and 2022 rolling 20th, 5th and 1st percentiles of seagrass shoot density for the Warnbro Sound reference sites for each depth category

If the rolling 20th and 5th percentiles are below the AMC, the AMC values are used instead. All percentiles are based on data from 2017–2020/2022. The numbers used for the EQS assessment are denoted in bold.

Warnbro Sound reference sites 2020							Warnbro Sound reference sites 2022					
Site name	Depth category (m)	N	20th	5th	AMC 5th	AMC 1st	N	20th	5th	1st	AMC 5th	AMC 1st
Warnbro Sound (2.0 m)	1.5–2.0	2	**720**	**686**	666	412	0	-	-	-	**666**	**412**
Warnbro Sound (2.5 m)	2.0–3.0	92	480	183	**500**	**275**	0	-	-	-	**500**	**275**
Warnbro Sound (3.2 m)	3.0–4.0	49	165	25	**171**	**100**	0	-	-	-	**171**	**100**
Warnbro Sound (5.5 m)	5.0–6.0	96	350	225	**419**	**324**	96	375	244	11.2	**419**	**324**
Warnbro Sound (7.0 m)	7.0	92	**200**	**89**	59	25	92	**200**	**50**	1.2	59	25

Assessment against EQS (i) and (ii) – seagrass shoot density

EQS (i)

The assessment of EQS (i) is based on data from two consecutive years. As seagrass monitoring was not undertaken in 2021, the years 2020 and 2022 are used in this assessment.

Within Cockburn Sound, seagrass health at four sites failed to meet the 2020 value but all sites met the 2022 value, such that EQS (i) was successfully met at all monitoring sites (Table C2). Seagrass health at Woodman Point also failed to meet the 2020 value but met the 2022 value.

It was noted that Bird Island, one of the new reference sites, failed to meet both the 2020 and 2022 values based on the Warnbro Sound (2.0 m) site and, hence, exceeded EQS (i).

Table C2: Assessment of EQS (i) for each potential impact site in 2022 and 2022, and EQS (ii) for 2022 only

Median shoot densities (shoots/m^2) at each potential impact site are compared against the Warnbro Sound reference site trigger values. Note that the relevant EQS (i) for comparison against the median is highlighted in bold. Where a cell has a dash (-), there is no data available because the shallow Warnbro Sound reference sites are no longer being monitored as there is an absence of seagrass.

Ecological protection area	Site name	Depth 2022 (m)	Ref. site depth (m)	2022 (no. of non-0 quadrants)	Median (shoots.m^{-2})		EQS (i)			EQS (ii)	Results			
					2020	2022	2020 20th	2022 20th	AMC 5th	2022 5th	2020 EQS (i)	2022 EQS (i)	2022 EQS (ii)	Overall result
HPA-N	Luscombe Bay	1.2	1.5–2.0	23	520	1450	**720**	-	**666**	-	✗	✓	-	?
	Garden Is. Settlement	0.9	1.5–2.0	24	425	838	**720**	-	**666**	-	✗	✓	-	?
	Garden Is. 2.0 m	1.6	1.5–2.0	24	875	1110	**720**	-	**666**	-	✓	✓	-	?
	Garden Is. 2.5 m	2.3	2.0–3.0	24	475	638	480	-	**500**	-	✗	✓	-	?
	Garden Is. 3.2 m	3.3	3.0–4.0	24	425	1125	165	-	**171**	-	✓	✓	-	?
	Kwinana*	3.5	5.0–6.0	24	850	888	350	425	**419**	244	✓	✓	✓	✓
	Garden Is. 5.5 m	4.8	5.0–6.0	24	463	863	350	375	**419**	244	✓	✓	✓	✓
	Garden Is. 7.0 m	6.0	6.0–7.0	23	425	475	**200**	**200**	59	50	✓	✓	✓	✓
HPA-S	Southern Flats	2.0	1.5–2.0	20	550	1138	**720**	-	**666**	-	✗	✓	-	?
	Mangles Bay	2.6	3.0–4.0	24	388	363	165	-	**171**	-	✓	✓	-	?
High - Undesignated	Woodman point	3.5	3.0–4.0	9	100	650	165	-	**171**	-	✗	✓	-	?

Ecological protection area	Site name	Depth 2022 (m)	Ref. site depth (m)	2022 (no. of non-0 quadrants)	Median (shoots.m^{-2})		EQS (i)			EQS (ii)	Results			
					2020	2022	2020 20th	2022 20th	AMC 5th	2022 5th	2020 EQS (i)	2022 EQS (i)	2022 EQS (ii)	Overall result
	Bird Island	1.6	1.5–2.0	23	675	675	**720**	-	**666**	-	✗	✗	-	✗
	Mersey Point	2.5	2.0–3.0	24	600	1525	480	-	**500**	-	✓	✓	-	?
	Carnac Island	2.3	3.0–4.0	24	388	813	165	-	**171**	-	✓	✓	-	?
	Coogee	3.2	5.0–6.0	24	588	537	350	375	**419**	244	✓	✓	✓	✓
Protection level	**Site name**	**Site depth 2022 survey**	**Ref. site depth (m)**	**2022 n**	**Median (shoots/m^{-2})**		**EQS (i)**			**EQS (ii)**	**Interpretation of EQS (i) and (ii)**			
					2020	**2022**	**2020 5th**	**2022 5th**	**AMC 1st**	**2022 1st**	**2020 EQS (i)***	**2020 EQS (i)**	**2022 EQS (ii)**	**Overall result**
MPA-NH	Jervoise Bay	2.6 m	3.0–4.0	8	175	438	165	-	**171**	-	✓	✓	-	?

EQS (ii)

The assessment of EQS (ii) for all shallow sites was confounded by a lack of data at the reference sites and could not be completed. Seagrass health at the three deeper sites in the High Protection Area and the Coogee monitoring site (undesignated zone) met EQS (ii) (Table C2).

Assessment using new reference sites

Calculation of EQS (i) and (ii) – seagrass shoot density

The assessment of shoot density against EQS (i) and (ii) was also completed using an assemblage of three new shallow reference sites and deeper Warnbro Sound reference sites, which remain suitable. Cockburn Sound sites were matched to reference sites on the basis of depth (Table C3). Some sites have become shallower over time (e.g. Garden Island 7.0 m site), in which case they were matched with a shallower reference site.

The calculated rolling percentiles of seagrass shoot density for EQS (i) and (ii) are presented in Table C3. For EQS (i) the AMC was used in many of the assessments because the new reference sites were still below this value. The values used in the assessment against EQS (i) and EQS (ii) are denoted in bold.

Table C3: Matchings of Cockburn Sound monitoring sites with new and historical reference sites, with comments and justifications

<table>
<tr><th>Ecological protection area</th><th>Potential impact sites</th><th>Site depth 2022</th><th>New reference sites</th><th>Justification</th></tr>
<tr><td rowspan="8">HPA-N</td><td>Luscombe Bay</td><td>1.2 m</td><td>Bird Is. 1.5–2.0 m</td><td rowspan="5">Monitoring of the three shallow (<5.0 m) Warnbro Sound reference sites was abandoned after 2020, because of significant seagrass loss from natural accretion/erosion processes.</td></tr>
<tr><td>Garden Is. Settlement</td><td>0.9 m</td><td>Bird Is. 1.5–2.0 m</td></tr>
<tr><td>Garden Is. 2.0 m</td><td>1.6 m</td><td>Bird Is. 1.5–2.0 m</td></tr>
<tr><td>Garden Is. 2.5 m</td><td>2.3 m</td><td>Mersey Pt. 2.0-3.0 m</td></tr>
<tr><td>Garden Is. 3.2 m</td><td>3.3 m</td><td>Carnac Is. 3.0–4.0 m</td></tr>
<tr><td>Garden Is. 5.5m</td><td>4.8 m</td><td>Warnbro Sound 5.5 m</td><td>The Warnbro Sound 5.5 m reference site is unaffected by sediment movement and remains valid.</td></tr>
<tr><td>Garden Is. 7.0 m</td><td>6.0 m</td><td>Warnbro Sound 5.5 m</td><td>Garden Island 7.0 m impact site has become shallower and is in this report compared against the Warnbro Sound 5.5 m reference site.</td></tr>
<tr><td>Kwinana</td><td>3.5 m</td><td>Carnac Is. 3.0–4.0 m</td><td>Kwinana Impact site has become shallower and is now compared against Carnac Is. 3–4 m.</td></tr>
</table>

Ecological protection area	Potential impact sites	Site depth 2022	New reference sites	Justification
HPA-S	Southern Flats	2.0 m	Bird Is. 1.5–2.0 m	Historical Warnbro Sound reference site has now been replaced by Bird Island.
	Mangles Bay	2.6 m	Mersey Pt. 2.0–3.0 m	Mangles Bay has become shallower and is now compared with Mersey Point.
High - undesignated	Woodman Point	3.5 m	Carnac Is. 3.0–4.0 m	Historical Warnbro Sound reference site has now been replaced by Carnac Island.
MPA-NH	Jervoise Bay	2.6 m	Mersey Pt. 2.0–3.0 m	Jervoise Bay has become shallower and is now compared with Mersey Point.

Table C4: The 2020 and 2022 rolling 20^{th}, 5^{th} and 1^{st} percentiles for new and suitable historic reference sites for each depth category

If the rolling 20^{th} and 5^{th} percentiles are below the AMC, AMC values are used instead. The values used in the assessment against EQS (i) and EQS (ii) are denoted in bold.

Sites	Depth (m)	Reference sites 2020					Reference sites 2022					
		N	20^{th}	5^{th}	AMC 5^{th}	AMC 1^{st}	N	20^{th}	5^{th}	1^{st}	AMC 5^{th}	AMC 1^{st}
Bird Island	1.5–2.0	92	330	189	**666**	**412**	89	290	175	2.6	**666**	**412**
Mersey Point	2.0–3.0	93	410	225	**500**	**275**	94	490	241	13.5	**500**	**275**
Carnac Island	3.0–4.0	96	**425**	**250**	171	100	96	**425**	**250**	15.2	171	100
Warnbro Sound (5.5 m)	5.0–6.0	96	350	225	**419**	**324**	**96**	375	244	11.2	**419**	**324**
Warnbro Sound (7.0 m)	7.0	92	**200**	**89**	59	25	90	**200**	**50**	1.2	59	25

Assessment against EQS (i) and (ii) – seagrass shoot density

EQS (i)

The assessment of EQS (i) is based on data from two consecutive years.

Within Cockburn Sound, seagrass health at seven sites failed to meet the 2020 value but only one site failed to meet both the 2020 and 2022 values, such that EQS (i) was successfully met at all monitoring sites apart from Mangles Bay (Table C5). Seagrass health at Woodman Point (undesignated zone) also failed to meet the 2020 value but met the 2022 value.

EQS (ii)

The assessment of EQS (ii) was possible for all sites using the new reference sites in shallow water. All Cockburn Sound sites met EQS (ii).

Table C5: Assessment of EQS (i) for each potential impact sites in 2020 and 2022, and EQS (ii) for 2022 only

Median shoot densities (shoots/m^2) at each potential impact site are compared against the applicable reference site trigger values. Note that the relevant EQS (i) for comparison against the median is highlighted in bold.

Ecological protection area	Site name	Depth (m)	Ref. site and depth (m)	2022 n	Median (shoots/m^{-2})		EQS (i)			EQS (ii)	Results			
					2020	2022	2020 20th	2022 20th	AMC 5th	2022 5th	2020 EQS (i)	2022 EQS (i)	2022 EQS (ii)	Overall result
HPA-N	Luscombe Bay	1.2	Bird Is. (1.5–2.0)	23	520	1450	330	290	**666**	175	×	✓	✓	✓
	Garden Island Settlement	0.9	Bird Is. (1.5–2.0)	24	425	838	330	290	**666**	175	×	✓	✓	✓
	Garden Island (2.0 m)	1.6	Bird Is. (1.5–2.0)	24	875	1110	330	290	**666**	175	✓	✓	✓	✓
	Garden Island (2.5 m)	2.3	Mersey Pt. (2.0–3.0)	24	475	638	410	490	**500**	241	×	✓	✓	✓
	Garden Island (3.2 m)	3.3	Carnac Is. (3.0–4.0)	24	425	1125	**425**	**425**	171	250	✓	✓	✓	✓
	Kwinana	3.5	Carnac Is. (3.0–4.0)	24	850	888	**425**	**425**	171	250	×	✓	✓	✓
	Garden Is. (5.5 m)	4.8	Warnbro (5.0–6.0)	24	463	863	350	375	**419**	244	✓	✓	✓	✓
	Garden Is. (7.0 m)	6.0	Warnbro (5.0–6.0)	23	425	475	350	200	**419**	244	✓	✓	✓	✓
HPA-S	Southern Flats	2.0	Bird Is. (1.5–2.0)	20	550	1138	330	290	**666**	175	×	✓	✓	✓
	Mangles Bay	2.6	Mersey Pt.	24	388	363	410	490	**500**	241	×	×	✓	×

Ecological protection area	Site name	Depth (m)	Ref. site and depth (m)	2022 n	Median (shoots/m^{-2})		EQS (i)			EQS (ii)	Results			
					2020	2022	2020 20th	2022 20th	AMC 5th	2022 5th	2020 EQS (i)	2022 EQS (i)	2022 EQS (ii)	Overall result
			(2.0–3.0)											
High - Undesignated	Woodman point	3.5	Carnac Is. (3.0–4.0)	9	100	650	**425**	**425**	171	250	×	✓	✓	✓
Protection level	**Site name**	**Depth (m)**	**Ref site and depth (m)**	**2022 n**	**Median (shoots/m^{-2})**		**EQS (i)**			**EQS (ii)**	**Interpretation of EQS (i) and (ii)**			
					2020	**2022**	**2020 5th**	**2022 5th**	**AMC 1st**	**2022 1st**	**2020 EQS (i)**	**2022 EQS (i)**	**2022 EQS (ii)**	**Overall result**
MPA-NH	Jervoise Bay	2.6	Mersey Pt. (2.0-3.0)	8	175	438	225	241	**275**	13.5	×	✓	✓	✓

Assessment against EQS (iii) – lower depth limit

EQS (iii) was achieved at all four sites for which a 2000–02 baseline was available (Table C6). Lower depth limit ranged from 6.5 m at Mangles Bay to 11.3 m at Woodman Point. While the results provided some evidence that seagrasses may have retreated into shallower waters at Garden Island and Warnbro Sound, no significant trends were observed (Table C7).

Table C6: Mean lower depth limit (LDL) ± standard error in 2020 and 2022, with 2022 compared with the baseline LDL

Note: Southern Flats and Mangles Bay have no baseline recorded.

Ecological protection area	Site	Mean LDL 2020 (m)	Mean LDL 2022 (m)	Baseline	Assessment
				Mean LDL 2000–02 (m)	EQS (iii)
High	Garden Island North (depth)	10.2 ± 0.5	9.4 ± 0.4	9.8 ±0.2	✓
	Garden Island South (depth)	12.9 ± 0.2	6.9 ± 0.3	7.6 ±0.4	✓
	Southern Flats (depth)	8.6 ± 0.5	8.6 ± 0.2	n/a	n/a
	Mangles Bay (depth)	6.3 ± 0.4	6.5 ± 0.4	n/a	n/a
Undesignated	Warnbro Sound (depth)	12.7 ± 0.1	8.2 ± 0.4	8.4 ±0.5	✓
	Woodman Point (depth)	9.8 ± 0.1	11.3 ± 0.5	8.7 ±0.8	✓

Table C7: Trend analyses of LDL at 'depth transect'. Significant trends (i.e., $p<0.05$) are donated in bold

Ecological protection area	Site	LDL	P value	Significant trends
High	Garden Island North (depth)	0.05	1	-
	Garden Island South (depth)	0.21	0.54	-
	Southern Flats (depth)	0.60	0.22	-
	Mangles Bay (depth)	0.32	0.61	-
Undesignated	Warnbro Sound (depth)	0.18	0.62	-

Trend analysis of shoot density (additional line of evidence)

Warnbro Sound reference sites

Table C8 presents the Mann-Kendall trend analyses for changes in shoot density for each reference site in Warnbro Sound. Statistically significant decreases in shoot density were recorded for most of the shallow sites and a potential trend was observed for Warnbro Sound reference site 5.5 m.

Table C8: Summary of Mann-Kendall trend analysis for Warnbro Sound reference sites based on the mean, median and the 20th, 5th and 1st percentiles since the inception of monitoring

Significant trends are identified in bold (p<0.05) and potential trends denoted by italic and '*' (p<0.2)

Site name	Mean		Median		20th percentile		5th percentile		1st percentile	
	Trend statistic	p-value	Trend statistic	p-value	Trend statistic	p-value	Trend statistic	p-value	Trend statistic	p-value
[1]Warnbro Sound (2.0 m)	-0.54	**<0.01**	-0.5	**0.01**	-0.65	**<0.001**	-0.51	**0.01**	-0.43	**0.03**
[1]Warnbro Sound (2.5 m)	-0.26	*0.15**	-0.23	*0.20**	-0.48	**0.02**	-0.72	**<0.001**	-0.93	**<0.001**
[1]Warnbro Sound (3.2 m)	-0.56	**<0.01**	-0.58	**<0.001**	-0.52	**<0.01**	-0.49	**0.01**	-0.81	**<0.001**
[2]Warnbro Sound (5.5 m)	-0.31	*0.08**	-0.30	*0.09**	-0.15	0.46	0	1	-0.01	1
Warnbro Sound (7.0 m)	0.05	0.8	0.02	0.97	-0.13	0.52	-0.24	0.23	-0.12	0.59

[1] Warnbro Sound 2.0, 2.5 and 3.2 m, sites were not surveyed in 2022, because of an absence of seagrass. The trend reported is up until the last seagrass survey in 2020.

[2] Warnbro Sound 5.5 m trend data for mean and median were not reported in the consultant's report. Therefore, results from 2020 are reported here.

New reference sites (and Coogee)

The three new reference sites Bird Island, Mersey Point and Carnac Island showed no significant downward trends in seagrass shoot density since the commencement of monitoring. Shoot density at Coogee, which was not selected as a new reference site, showed a significant declining trend for 20th, 5th and 1st percentiles (Table C9).

Table C9: Summary of trend analysis for new reference sites based on the mean, median and 20th, 5th and 1st percentiles since the inception of monitoring.

Significant trends are identified in bold (p<0.05) and potential trends are detonated by italics and '*' (p<0.2). Significant negative trends are identified by red, and significant positive trends by green.

Site name	Mean		Median		20th percentile		5th percentile		1st percentile	
	Statistic	P value	Statistic	P value	Statistic	P value	Statistic	P value	Statistic	P value
Bird Island	-0.1	0.62	-0.09	0.65	0.06	0.78	*-0.303*	*0.12**	0.11	0.59
Mersey Point	0.117	0.56	0.13	0.53	**0.472**	**0.01**	**0.713**	**<0.01**	**0.45**	**0.02**
Carnac Island	-0.15	0.44	-0.07	0.75	-0.16	0.44	-0.05	0.82	-0.456	1
Coogee	-0.14	0.49	-0.16	0.46	**-0.55**	**0.01**	**-0.684**	**<0.01**	**-0.456**	**0.02**

[1]Warnbro Sound 5.5 m trend data for mean and median were not reported in the consultant's report. Therefore, results from 2020 are reported here.

Cockburn Sound sites

In Cockburn Sound, shoot density at most sites followed a neutral trend, except at Garden Island 5.5 m (MPA-N), Woodman Point (undesignated) and Jervoise Bay (MPA-ES), for which significant declines were reported. In 2020, seagrass at these sites also followed a statistically significant negative trend. The negative trend reported for Garden Island – 3.2 m (HPA-N) in 2020 – was not significant in 2022 (Table C10).

Table C10: Summary of trend analysis on the mean and median shoot densities at potential impact sites[1]

Significant trends ($p<0.05$) are denoted in bold text with declining ($p<0.2$) are denoted by '*'.

Ecological protection area	Site	Mean	P value	Median	P value	Significant trends
HPA-N	Luscombe Bay	0.12	0.56	0.04	0.86	-
	Garden Is. Settlement	-0.33	0.08	-0.22	0.26	-
	Garden Is. (2.0 m)	0.05	0.82	0.04	0.85	-
	Garden Is. (2.5 m)	-0.08	0.68	-0.04	0.83	-
	Garden Is. (3.2 m)	-0.22	0.19*	-0.24	0.16*	-
	Garden Is. (5.5m)	**-0.43**	**0.01**	**-0.36**	**0.04**	↓
	Kwinana	0.03	0.9	-0.07	0.74	-
	Garden Is. (7.0 m)	0.31	0.07*	-0.3	0.09*	-
HPA-S	Southern Flats	-0.19	0.26	-0.17	0.33	-
	Mangles Bay	-0.19	0.3	-0.03	0.9	-
Undesignated	Woodman point	**-0.48**	**0.01**	-0.19	0.32	↓
MPA-ES	Jervoise Bay	**-0.41**	**0.02**	**-0.51**	**0.01**	↓

[1]Designated as an 'impact' site when using the traditional Warnbro Sound Reference sites; designated as a reference site when using new reference sites.

Appendix D: Phytoplankton biomass

Calculation of EQG (i) and (ii) values

Yearly updates to the EQC for chlorophyll-a and light attenuation coefficient are based on rolling percentiles calculated using data collected at the Warnbro Sound reference site WS4 during the non river-flow monitoring period over recent years. While this methodology is maintained, it should be noted that because of changes to the CSMC monitoring program implemented in 2021, the number of data points during the non river-flow period has decreased from 16 to four, which requires data from more years to be considered.

The 2022 EQC were calculated using data from the 2022 non river-flow period and sampling undertaken over the same period during previous years, 2015 to 2022 inclusive (n=103). The updated EQC are presented in Table D1 below.

Table D1: The 2022 high and moderate protection EQG for phytoplankton biomass

Indicator	High protection Median (WS4)	Moderate protection 80th percentile (WS4)
Phytoplankton biomass (µg/L)	2.1	2.9

Phytoplankton biomass (measured as chlorophyll-a) was recorded at 18 water quality monitoring sites in the five ecological protection areas in Cockburn Sound (Figure 2). The monthly phytoplankton biomass measurement for each monitoring site recorded from 1 December 2021 to 31 March 2022 were assessed against the 2022 phytoplankton biomass EQG:

High protection: **i)** Median phytoplankton biomass in high protection areas is not to exceed 2.1 µg/L on any occasion during the non river-flow period.
ii) Phytoplankton biomass at any site is not to exceed 2.1 µg/L on 25% or more occasions during the non river-flow period.

Moderate protection: **i)** Median phytoplankton biomass in moderate protection areas is not to exceed 2.9 µg/L on more than one occasion during the non river-flow period.
ii) Phytoplankton biomass at any site is not to exceed 2.9 µg/L on 50% or more occasions during the non river-flow period.

Where phytoplankton biomass exceeded the EQG the monitoring data was compared against the EQS:

High protection: **i)** Median phytoplankton biomass in high protection areas is not to exceed 2.1 µg/L on more than one occasion during the non river-flow period and in two consecutive years.

ii) Phytoplankton biomass at any site is not to exceed 2.1 µg/L on 25% or more occasions during the non river-flow period and in two consecutive years.

Moderate protection: **i)** Median phytoplankton biomass in moderate protection areas is not to exceed 2.9 µg/L on more than one occasion during the non river-flow period and in two consecutive years.

ii) Phytoplankton biomass at any site is not to exceed 2.9 µg/L on 50% or more occasions during the non river-flow period and in two consecutive years.

Assessment against EQG (i) and (ii)

The results of the assessment against the phytoplankton biomass EQG are presented in Table D2 and Table D3 below.

EQG (i) were met in all ecological protection areas. However, EQG (ii) was not met in Mangles Bay (site MB) and Northern Harbour (site NH3).

Table D2: Assessment of phytoplankton biomass against EQG (i) for each sampling occasion and for each of the ecological protection areas

Note that MPA-CB and MPA-NH were not presented as there was only one data point per sampling occasion.

Ecological protection area	Dec 2021	Jan 2022	Feb 2022	Mar 2022	Results EQG (i)
HPA-N **Median chlorophyll-a concentration (µg/L)** EQG (i): 2.1 µg/L	0.3	0.6	0.7	0.8	✓
HPA-S **Median chlorophyll-a concentration (µg/L)** EQG (i): 2.1 µg/L	0.6	1.0	0.9	1.0	✓
MPA-ES **Median chlorophyll-a concentration (µg/L)** EQG (i): 2.9 µg/L	0.5	0.9	0.9	1.0	✓

Table D3: Assessment of phytoplankton biomass against EQG (ii) for each sampling occasion and each monitoring site (December 2021 to March 2022)

Ecological protection area	Sites	2022 EQG (ii) value and fail percentage	Proportion of occasions EQG (ii) value was exceeded	Results EQG (ii)
HPA-N	CS4	2.1µg/L exceeded on ≥25% occasions	0%	✓
	CS5		0%	✓
	CS8		0%	✓
	CB		0%	✓
	G2		0%	✓
	G3		0%	✓
HPA-S	CS11	2.1µg/L exceeded on ≥25% occasions	0%	✓
	CS13		0%	✓
	SF		0%	✓
	MB/MB-L		25%	×
MPA-CB	G1	2.9µg/L exceeded on ≥50%	0%	✓

Ecological protection area	Sites	2022 EQG (ii) value and fail percentage	Proportion of occasions EQG (ii) value was exceeded	Results EQG (ii)
		occasions		
MPA-ES	CS10N	2.9µg/L exceeded on ≥50% occasions	0%	✓
	CS12		0%	✓
	CS6A		0%	✓
	CS7		0%	✓
	CS9		0%	✓
	CS9A		0%	✓
MPA-NH	NH3	2.9µg/L exceeded on ≥50% occasions	50%	×

Assessment against EQS (i) and (ii)

As EQG (i) was met for all ecological protection areas, an assessment against EQS (i) was not required.

The assessment against EQS (ii) for MB and NH3 required the preceding year's data (Dec 2019 – Mar 2020) to be assessed. The results are provided in Table D4. Phytoplankton biomass criteria for the preceding year were met in Mangles Bay (19%) but again exceeded in Northern Harbour (88%) (Table D5).

Table D4: Chlorophyll-a concentrations of sites MB and NH for the preceding period (December 2019 to March 2020)

Ecological protection area	Sites	Date of sampling	Chlorophyll-a (µg/L)	Results EQS (ii)
HPA-S EQS (ii): 2.1 µg/L	MB	2/12/2019	0.4	✓
		9/12/2019	0.5	✓
		16/12/2019	1.2	✓
		23/12/2019	1.7	✓
		6/01/2020	1.1	✓
		13/01/2020	1.6	✓
		20/01/2020	2.6	×
		28/01/2020	0.8	✓
		3/02/2020	1.2	✓
		10/02/2020	1.0	✓
		17/02/2020	0.8	✓
		24/02/2020	0.9	✓
		2/03/2020	2.2	×
		9/03/2020	3.6	×
		16/03/2020	1.0	✓
MPA-NH	NH3	2/12/2019	2.7	✓

Ecological protection area	Sites	Date of sampling	Chlorophyll-a (µg/L)	Results EQS (ii)
EQS (ii): 2.9 µg/L		9/12/2019	4.6	×
		16/12/2019	4.4	×
		23/12/2019	4.3	×
		6/01/2020	3.1	×
		13/01/2020	3.3	×
		20/01/2020	4.7	×
		28/01/2020	4.3	×
		3/02/2020	3.0	×
		10/02/2020	3.8	×
		17/02/2020	3.9	×
		24/02/2020	4.9	×
		2/03/2020	4.5	×
		9/03/2020	2.1	✓
		16/03/2020	5.6	×
		30/03/2020	4.2	×

Table D5: Assessment of phytoplankton biomass against EQS (ii) for sites MB and NH3

Ecological protection area	Sites	2020 EQS (ii) value and fail percentage	Proportion of occasions EQS (ii) value was exceeded	Results EQS (ii)
HPA-S	MB/MB-L	2.1µg/L exceeded on ≥25% occasions	**19%**	✓
MPA-NH	NH3	2.9µg/L exceeded on ≥50% occasions	**88%**	×

Appendix E: Physical and chemical parameters – data plots

Temperature

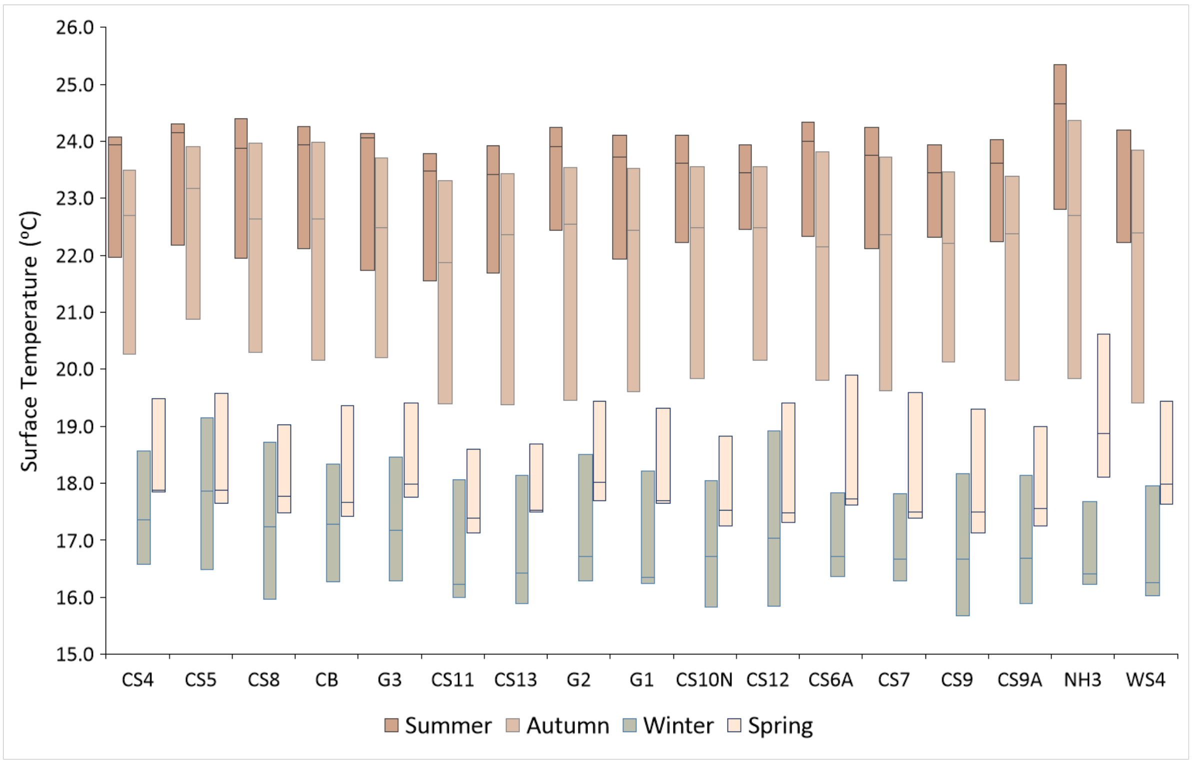

Figure E1. Surface water temperature at 16 deep water sites compared with WS4 (deep water reference site)

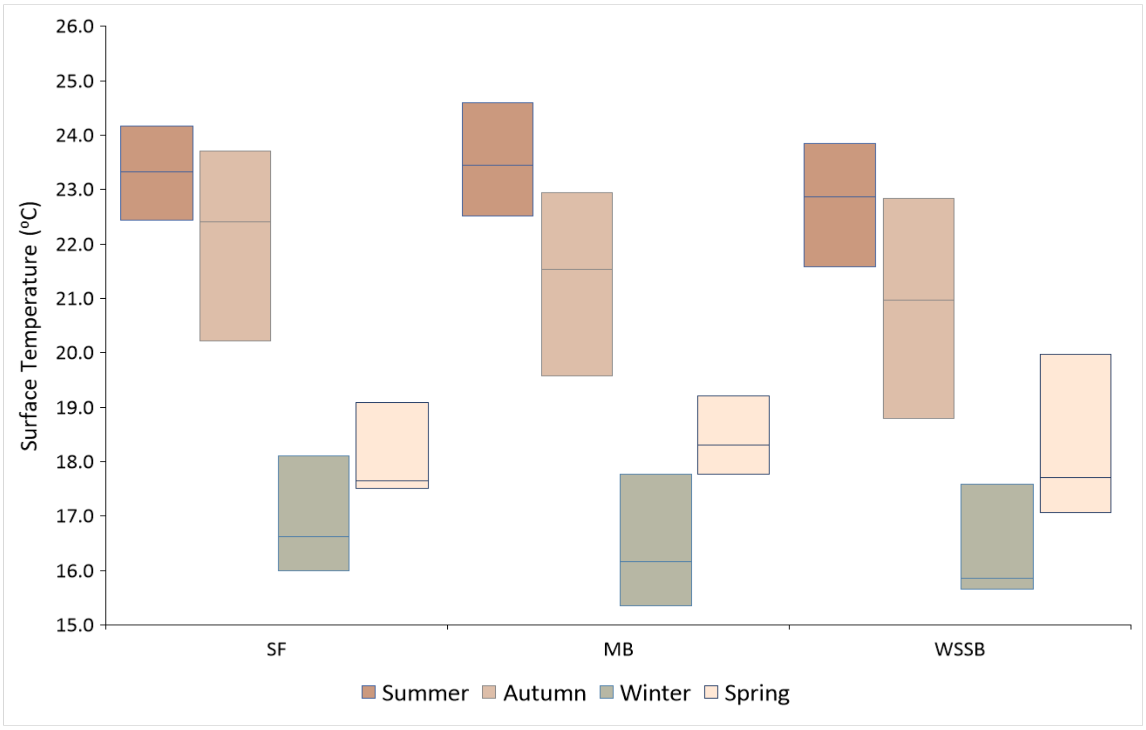

Figure E2. Surface water temperature at two shallow water sites compared with WSSB (shallow water reference site.

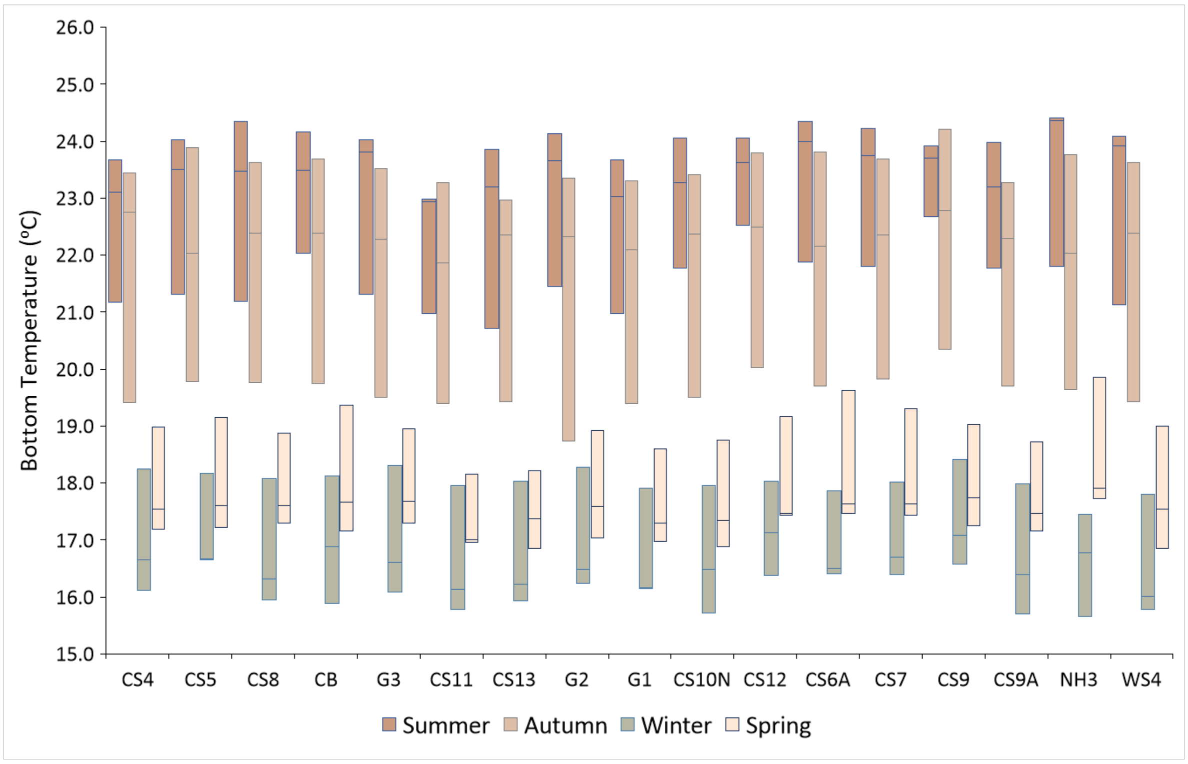

Figure E3. Bottom water temperature at 16 deep water sites compared with WS4 (deep water reference site)

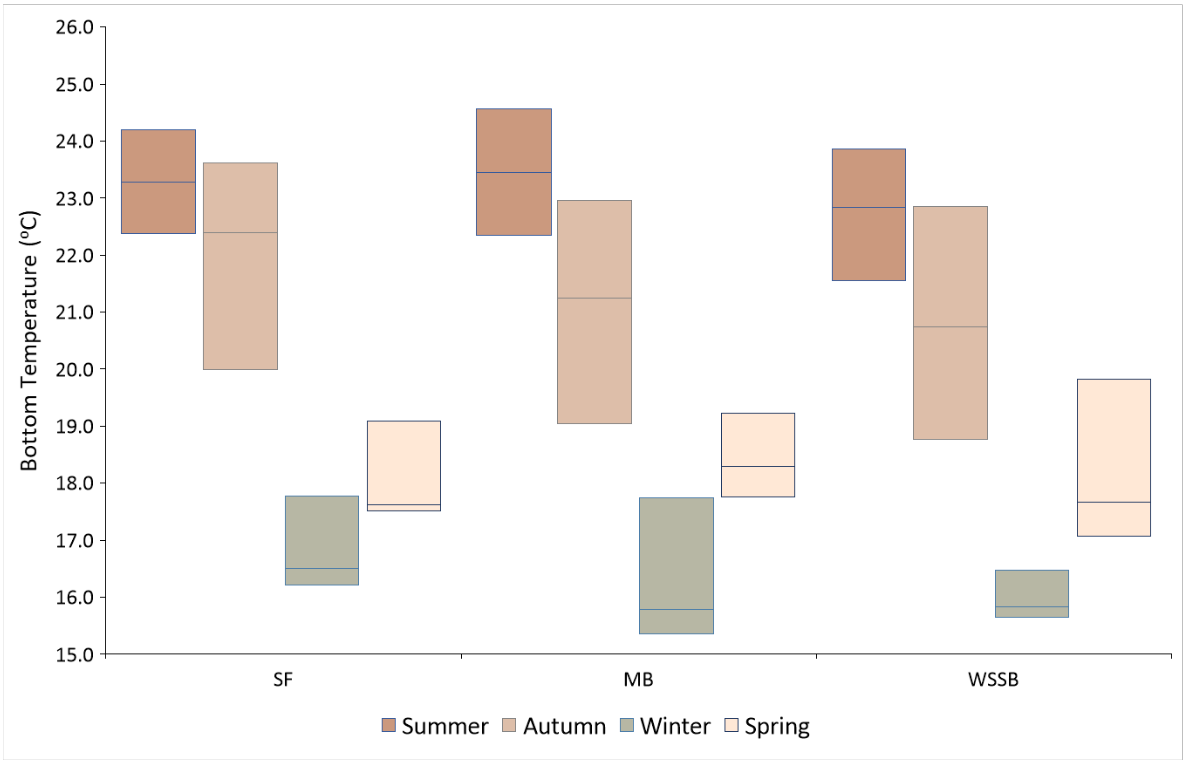

Figure E4. Bottom water temperature at two shallow water sites compared with WSSB (shallow water reference site)

Salinity

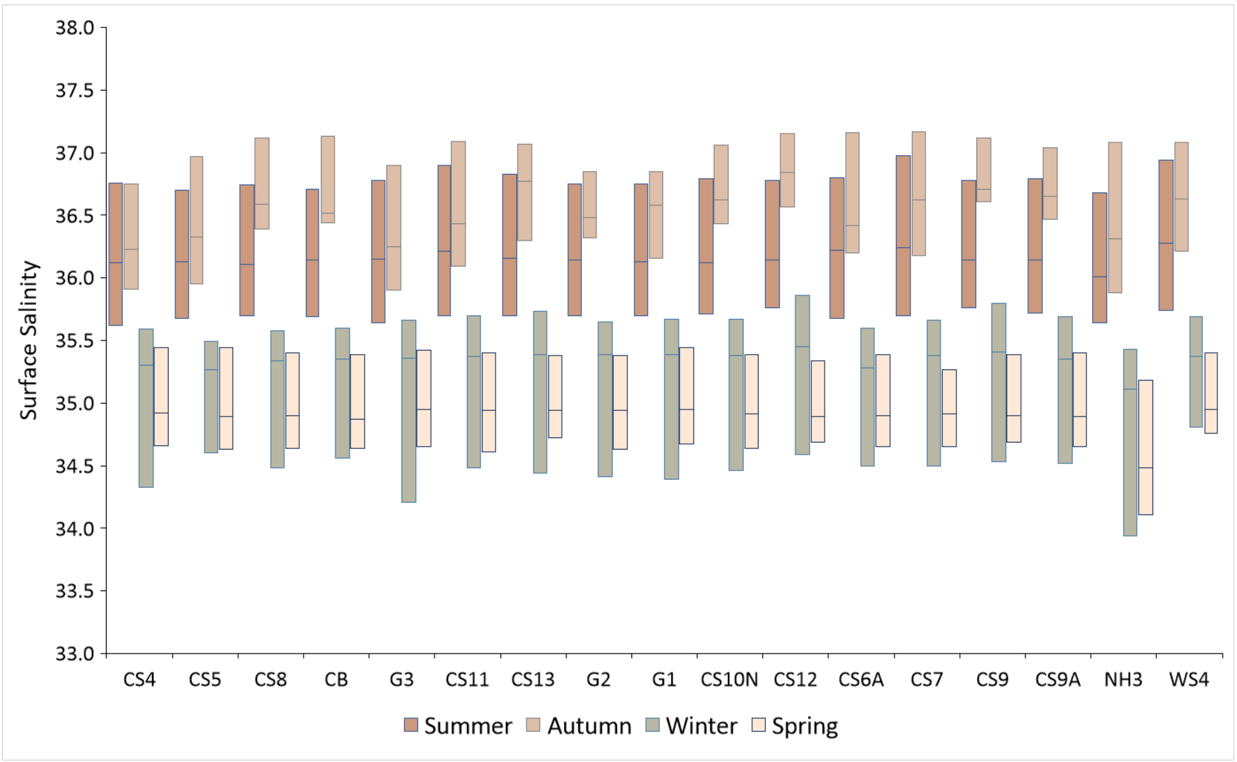

Figure E5. Surface water salinity at 16 deep water sites compared with WS4 (deep water reference site)

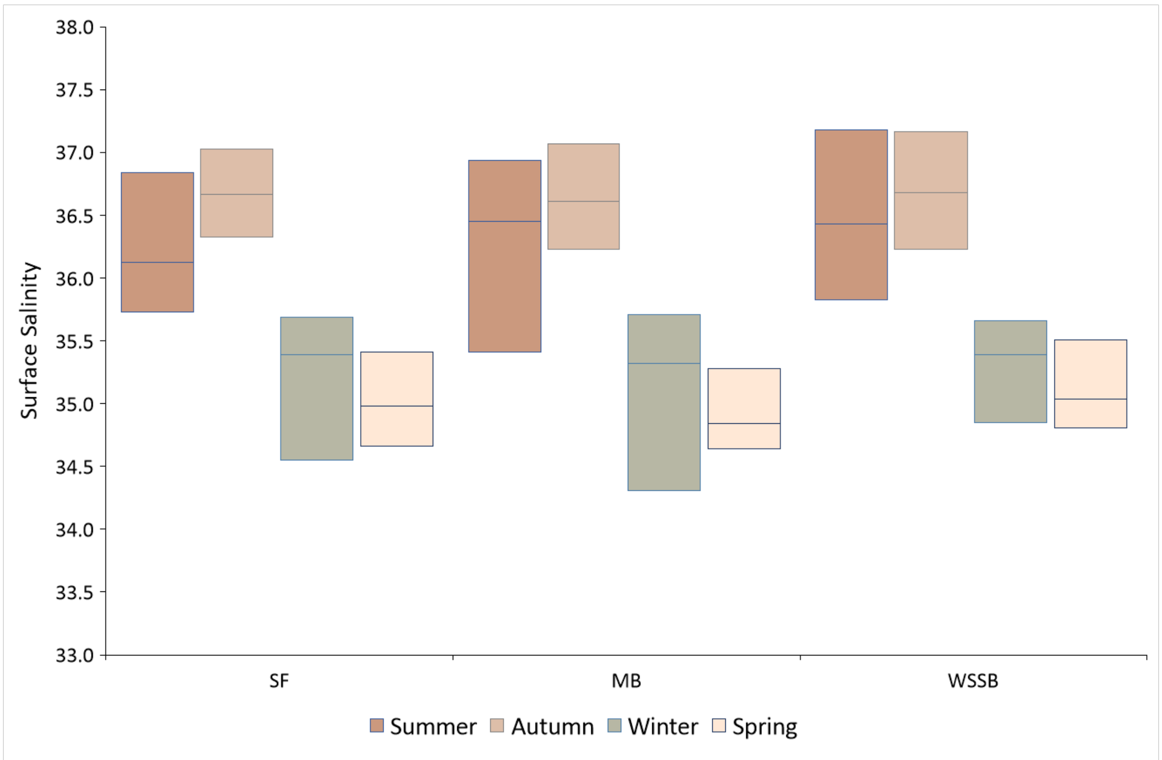

Figure E6. Surface water salinity at two shallow water sites compared with WSSB (shallow water reference site)

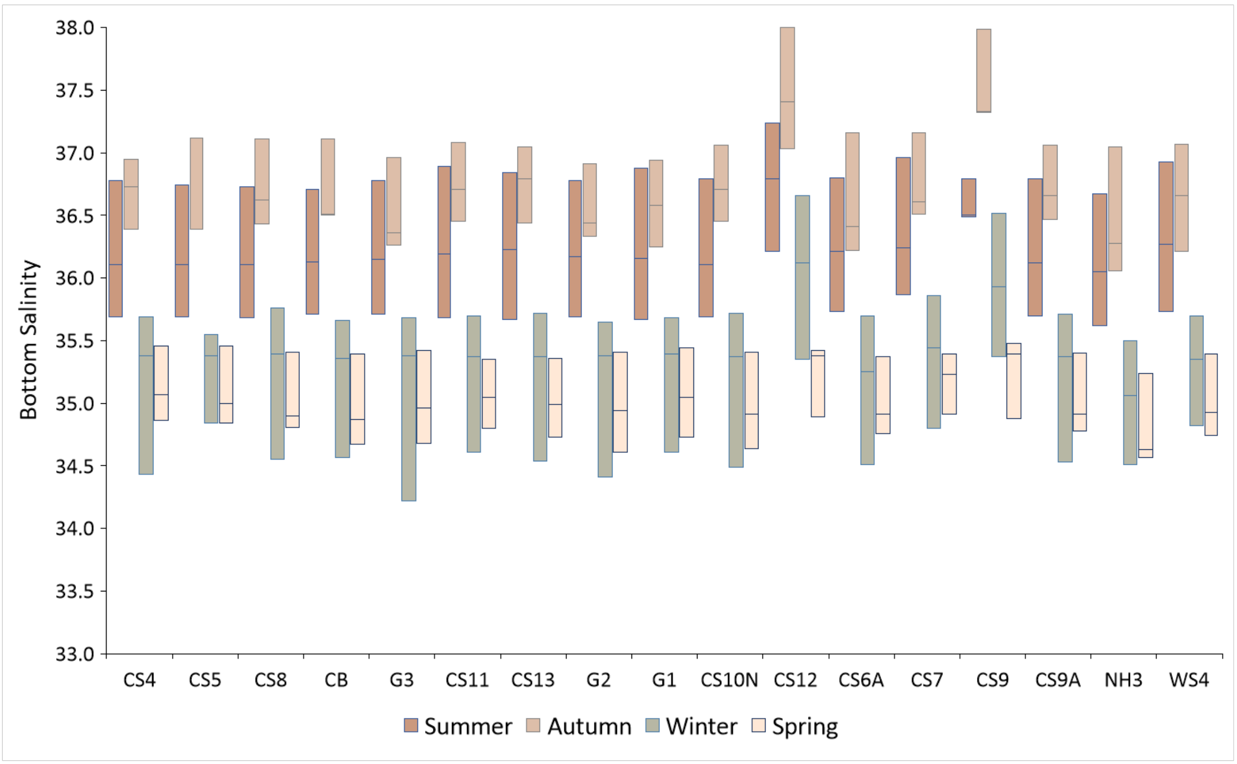

Figure E7. Bottom water salinity at 16 deep water sites compared with WS4 (deep water reference site)

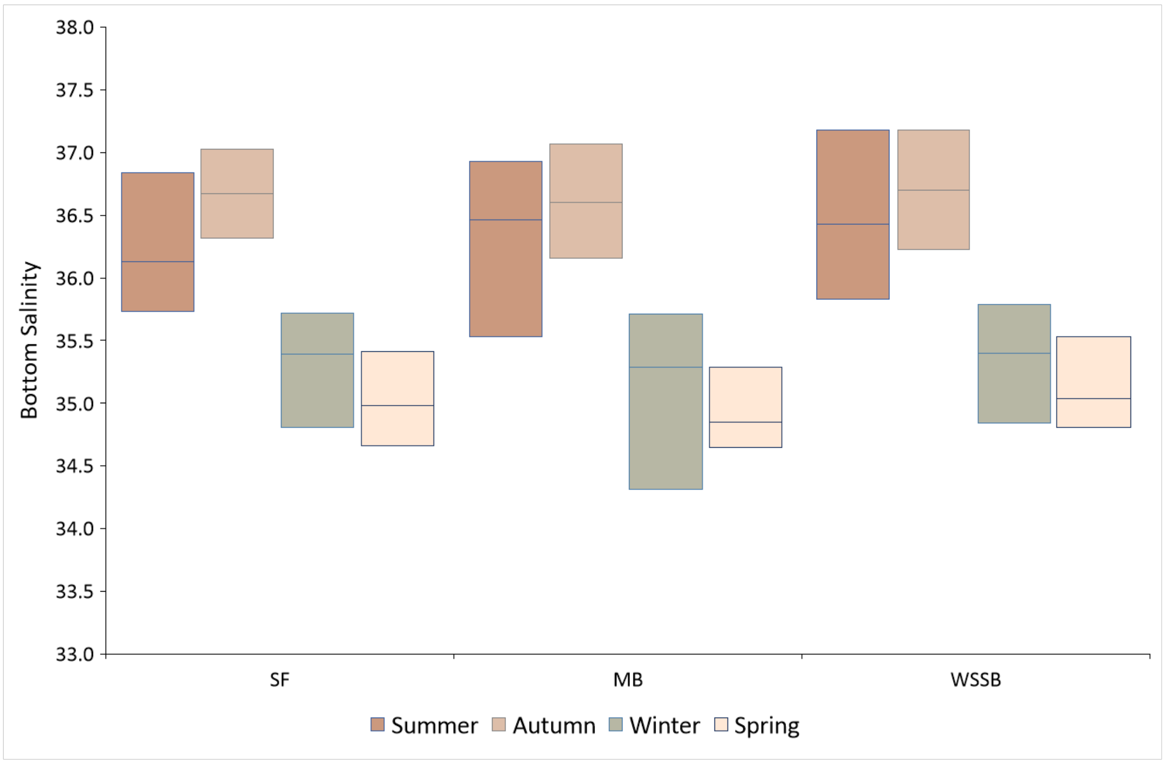

Figure E8. Bottom water salinity at two shallow water sites compared with WSSB (shallow water reference site)

pH

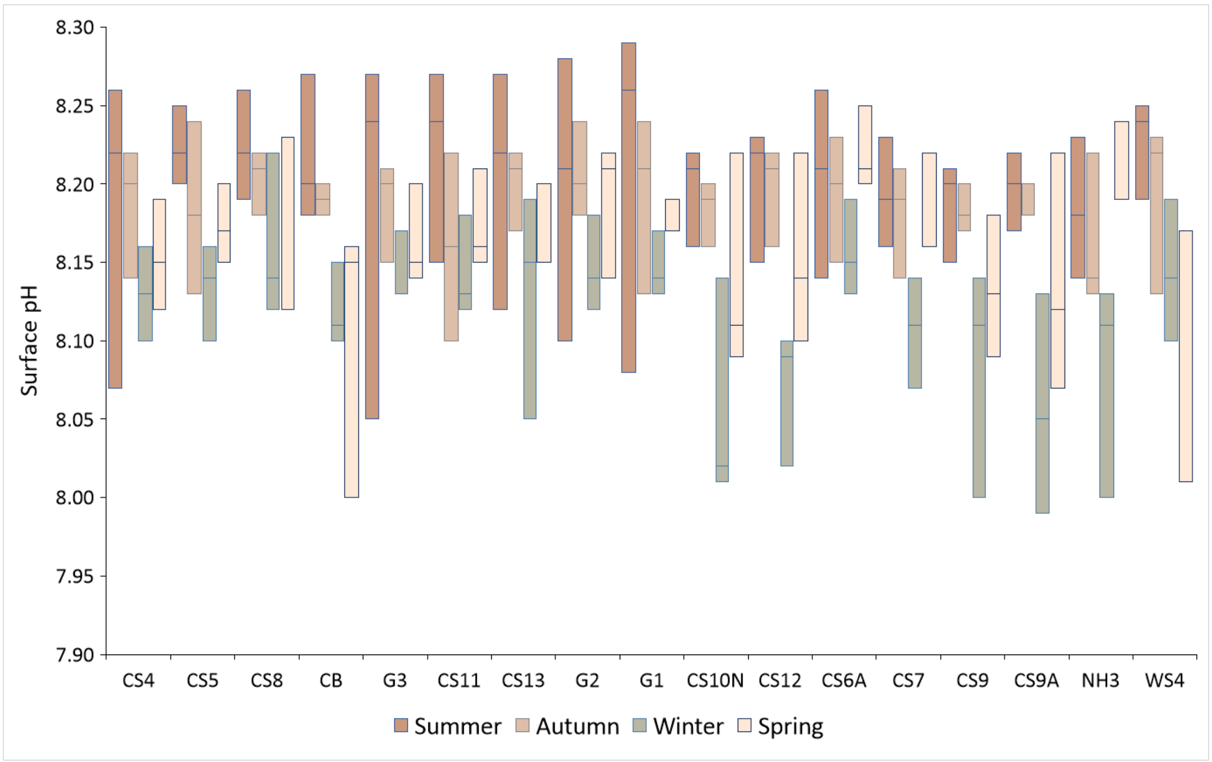

Figure E9. Surface water pH at 16 deep water sites compared with WS4 (deep water reference site)

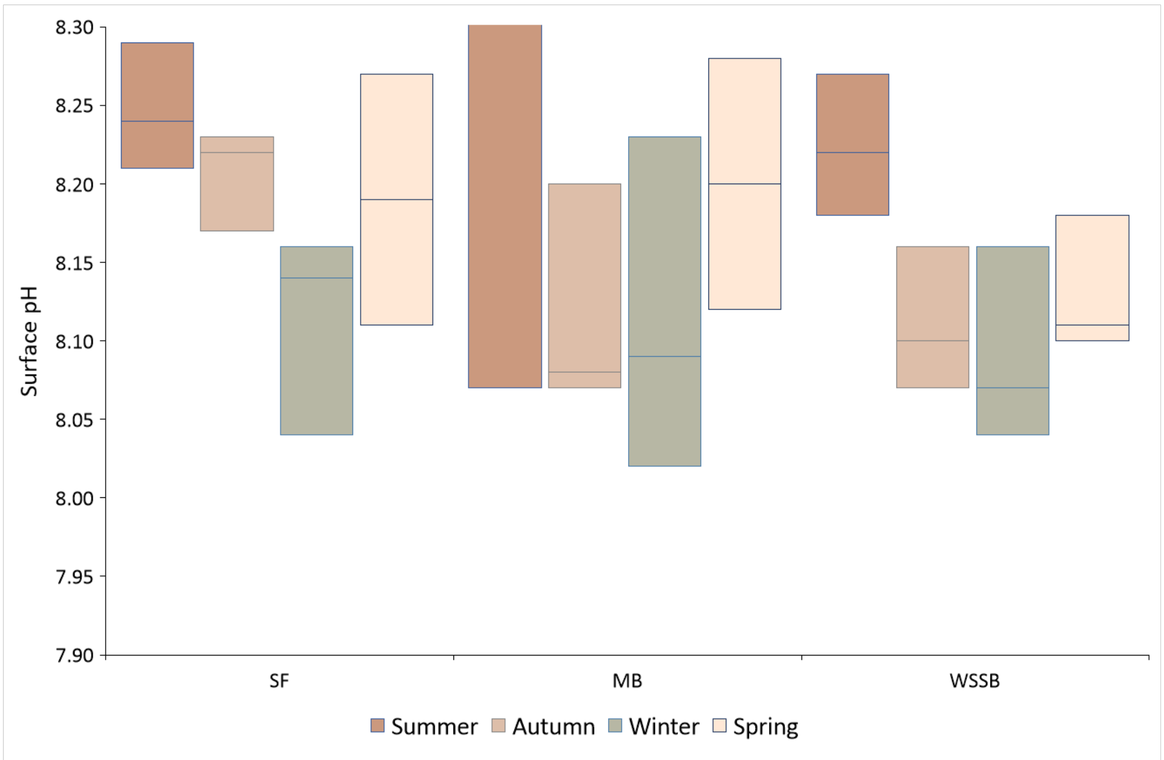

Figure E10. Surface water pH at two shallow water sites compared with WSSB (shallow water reference site)

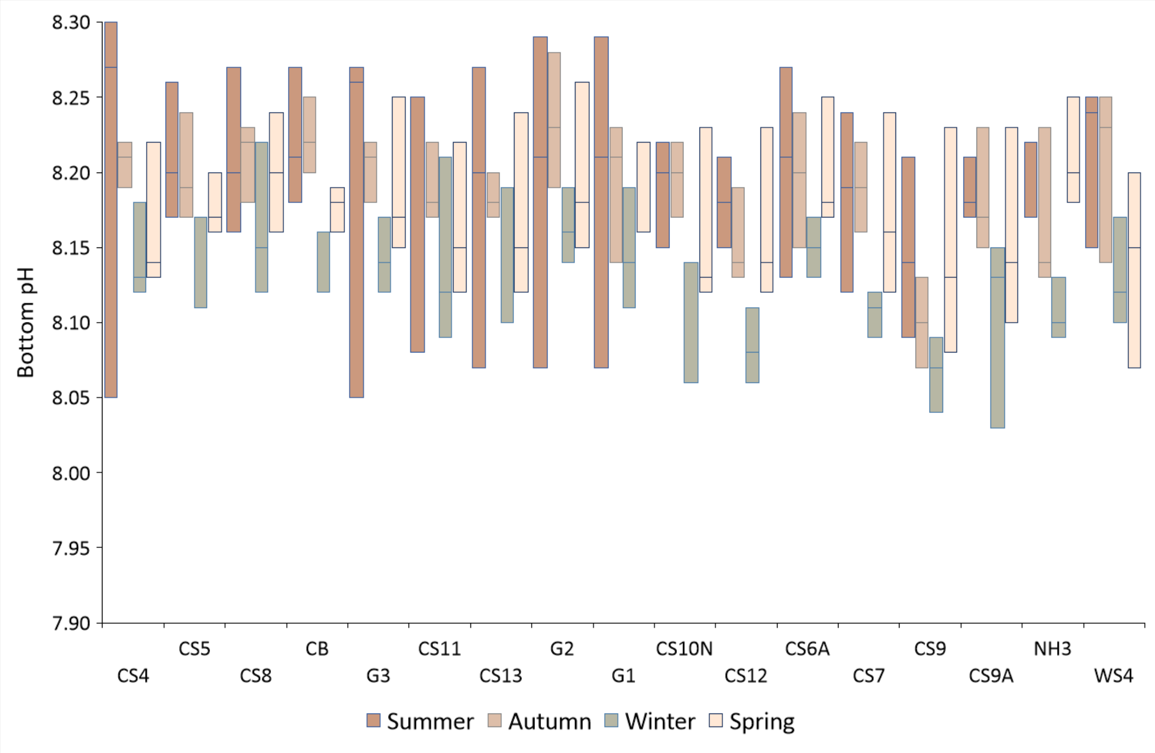

Figure E11. Bottom water pH at 16 deep water sites compared with WS4 (deep water reference site)

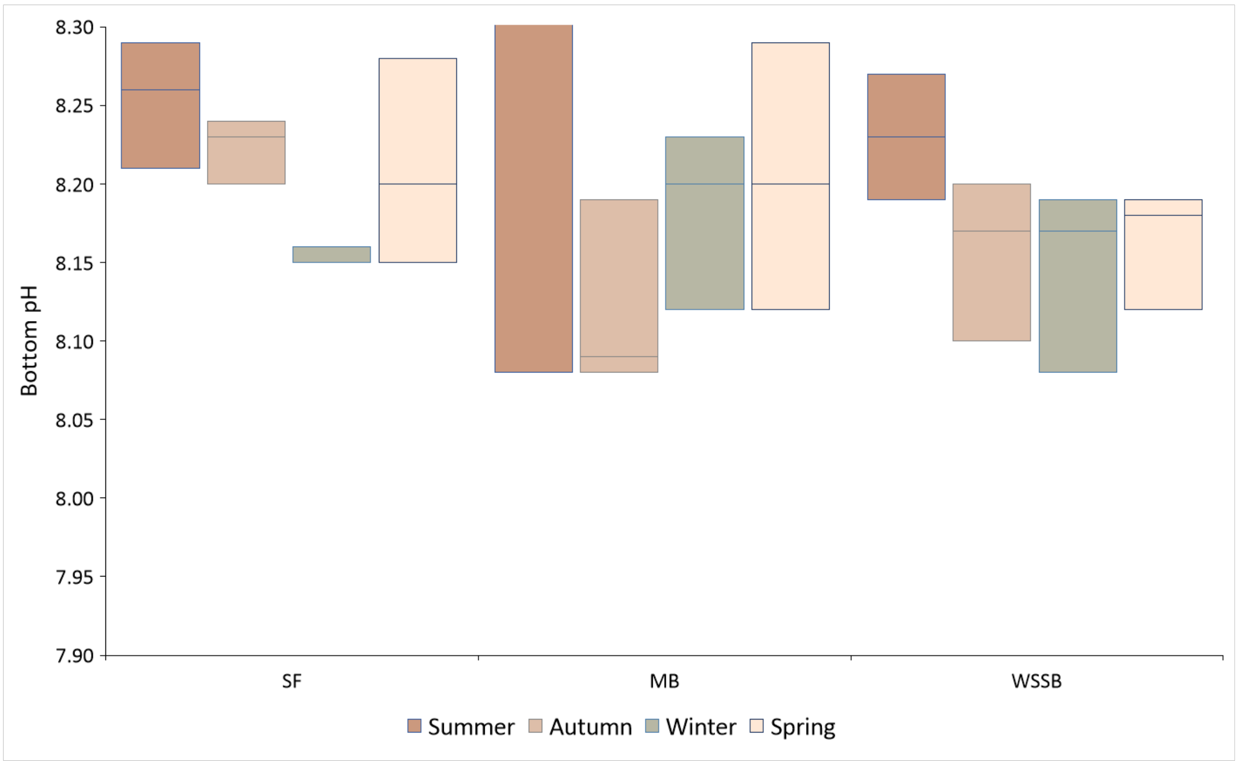

Figure E12. Bottom water pH at two shallow water sites compared with WSSB (shallow water reference site)

Appendix F: Qualitative observations of indicators of aesthetic quality

Table F1: Qualitative (visual) 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, between 1 December 2021 and 30 November 2022

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
Dec 2021	MB (slight algal bloom), CSSF (slight algal bloom), NH3 (algal bloom), WSSB (slight algal bloom)	-	MB, SF, NH3, WSSB	MB, SF, NH3, WSSB	-	-	CN10N (wheat dust), CSSF (floating macros), CSCB (floating seagrass wrack), G3 and CS4 (floating seagrass and macros)	-	-
Jan 2022	CS9 (slight algal bloom), CS9A (slight algal bloom), MB (algal bloom), CSSF (algal bloom), NH3 (algal)	-	CS9, CS9A, MB, CSSF, NH3	CS9, CS9A, MB, CSSF, NH3	-	-	CS9A (phytoplankton scum), SF (seagrass)	-	-
Feb 2022	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, CS8, CB, CS5, NH3, CS13, CS11, G1, G3 and CS4 (algal	-	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, CS8, CB, CS5, NH3, CS13, CS11, G1, G3 and	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, CS8, CB, CS5, NH3, CS13, CS11, G1, G3 and	-	-	CS6A, CS7, CS12 and CS9, NH3, CS13, CS11, G1, G3 and CS4 (phytoplankton scum), SF	-	WSSB (odour from dredging)

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
	bloom)		CS4	CS4			(seagrass)		
Mar 2022	CS13, CS11, WSSB, G1, G2 (slight algal bloom)	-	CS13, CS11, WSSB, G1, G2, CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, CS8, CB and NH3	CS13, CS11, WSSB, G1, G2, CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, CS8, CB and NH3	-	-	G3 (wrack and macros), MB, SF, NH3 (wrack), CS10N (wheat dust)	-	CS12 (odour from Alcoa)
Apr 2022	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, NH3, CS13, SC11, WSSB, WS4, G1 (algal bloom)	-	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, NH3, CS13, SC11, WSSB, WS4	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, NH3, CS13, SC11, WSSB, WS4	-	-	CS10N (wheat), WSSB (floating wrack), G1 and G3(floating wrack)	-	-
May 2022	CS6A, CS7, CS12, CS8, CB, NH3, CS11 (slight algal bloom), CS9A, CS10N, MB, SF, CS13, G1, G2 (algal bloom)	-	CS6A, CS7, CS12, CS9, CS9A, CS10N, SF, CS8, CB, NH3, CS13, CS11, WSSB, G1, G2	CS6A, CS7, CS12, CS9A, CS10N, SF, CS8, CB, NH3 (brown), CS13, CS11, G1, G2	-	-	CS12 (phytoplankton scum), CS9 (phytoplankton scum and surface dust), CS10N (wheat dust on surface), MB (seagrass wrack), G2 and CS4 (floating wrack)	-	-
Jun 2022	CS9A, CS10N, MB, SF, NH3,	-	CS9A, CS10N, MB, SF, NH3,	CS9A, CS10N, MB, SF, NH3,	-	-	CS10N (phytoplankton sum and	-	-

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
	CS13, CS11 (algal bloom), G1 (slight algal bloom)		CS13, CS11, WSSB, G1	CS13, CS11, G1			wheat dust), CS7 (wrack), CS13 (wheat dust), WSSB (wrack)		
Jul 2022	WS4 (slight algal bloom)	-	WSSB, WS4	WSSB, WS4	-	-	WSSB, MB and CB (wrack), WS10 (wheat dust from ship loading)	-	CS9 (odour from Alcoa)
Aug 2022	Data unavailable								
Sep 2022	CS13, CS11, WSSB, CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CB, CS5, NH3 (algal bloom)	-	CS13, CS11, WSSB, CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CB, CS5, NH3	CS13, CS11, WSSB, CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CB, CS5, NH3	-	-	CS10N (wheat dust)	-	NH3 (odour from smoke/haze/ bushfire)
Oct 2022	CS13, CS11, G1, G2, G3, CS4	-	CS13, CS11, G1, G2, G3 and CS4	CS13, CS11, G1, G2, G3 and CS4	-	-	CS8 (wrack), G1 (macrophytes)	-	-
Nov 2022	CS6A, CS7, CB and NH3 (algal bloom)	-	CS6A, CS7, CB and NH3	CS6A, CS7, CB and NH3	-	-	CS11, WSSB, G1 and MB (seagrass), CS10N (wheat dust), CS5 (macrophytes, seagrass and wrack)	-	-

Appendix G: Perth Seawater Desalination Plant intake data

Temperature

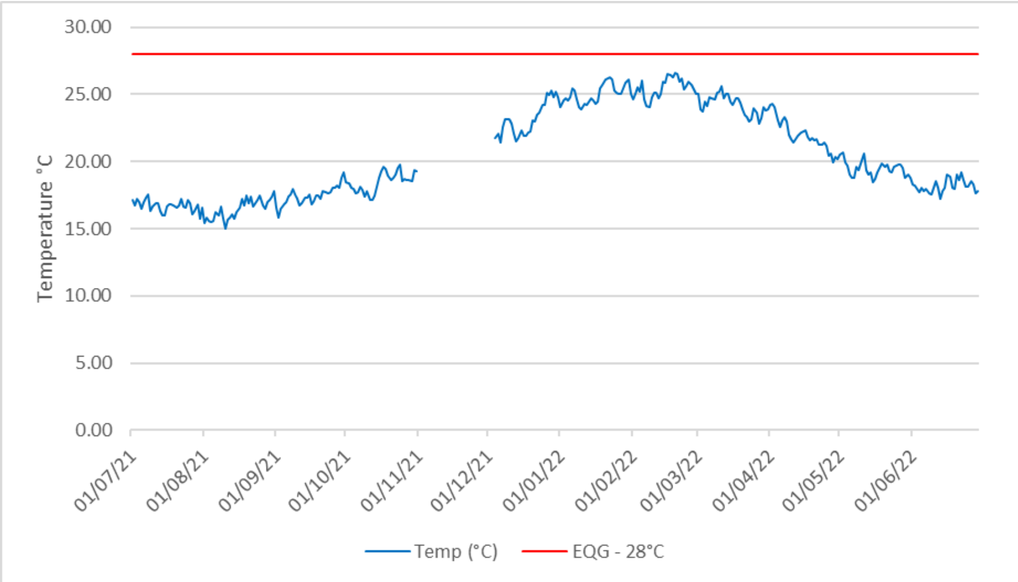

Figure G1: Daily average temperature of intake seawater over the 2021–22 monitored period

Figure G2: Daily average temperature of intake seawater over the 2022–23 monitored period

pH and DO

A few minor variations in pH and DO were associated with short-term plant shutdowns and may not be true representations of seawater quality. Data recorded during the scheduled plant shutdown, from 1 November 2021 to 3 December 2022, were removed.

For the 2022–23 monitored period, pH typically remained below the EQG of 8.5 (Figure G3 and Figure G4). Some anomalous results were recorded for which the daily average pH dropped below 8. Water Corporation advised that these instances aligned with power failure events at the plant during which intake suddenly ceases and slightly acidified seawater flows backwards through the pipes and passes the sample panel instrumentation, giving a misleading reading. Those results were also removed to prevent misrepresentation of seawater intake quality.

DO concentrations remained well above the EQG of 2 mg/L (Figure G5 and Figure G6). Note that data could not be accurately recorded during the scheduled plant shutdown, from 10 October 2022 to 14 November 2022, and has been removed where necessary.

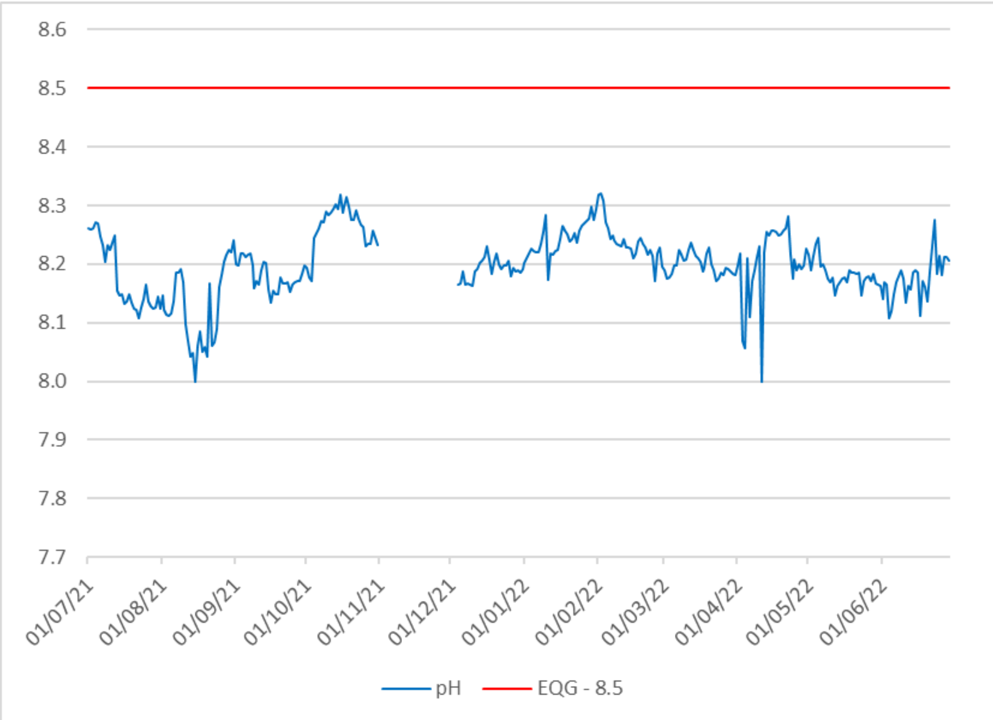

Figure G3: Daily average pH of intake seawater over the 2021–22 monitored period

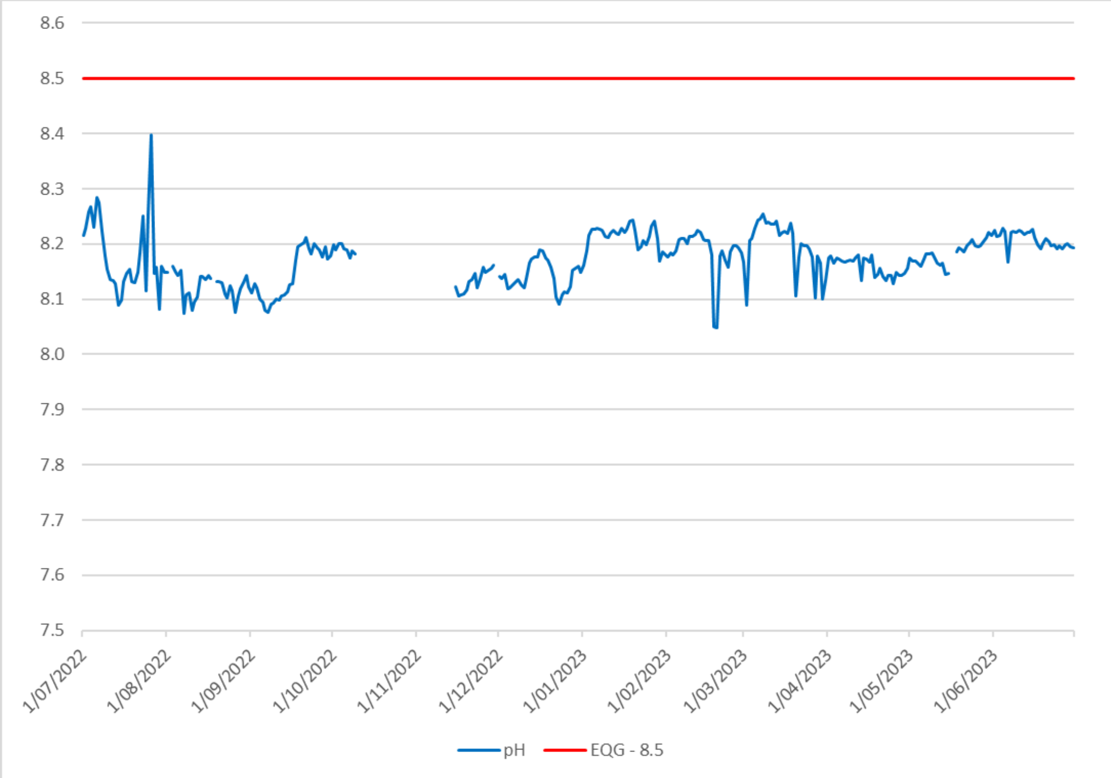

Figure G4: Daily average pH of intake seawater over the 2021–22 monitored period

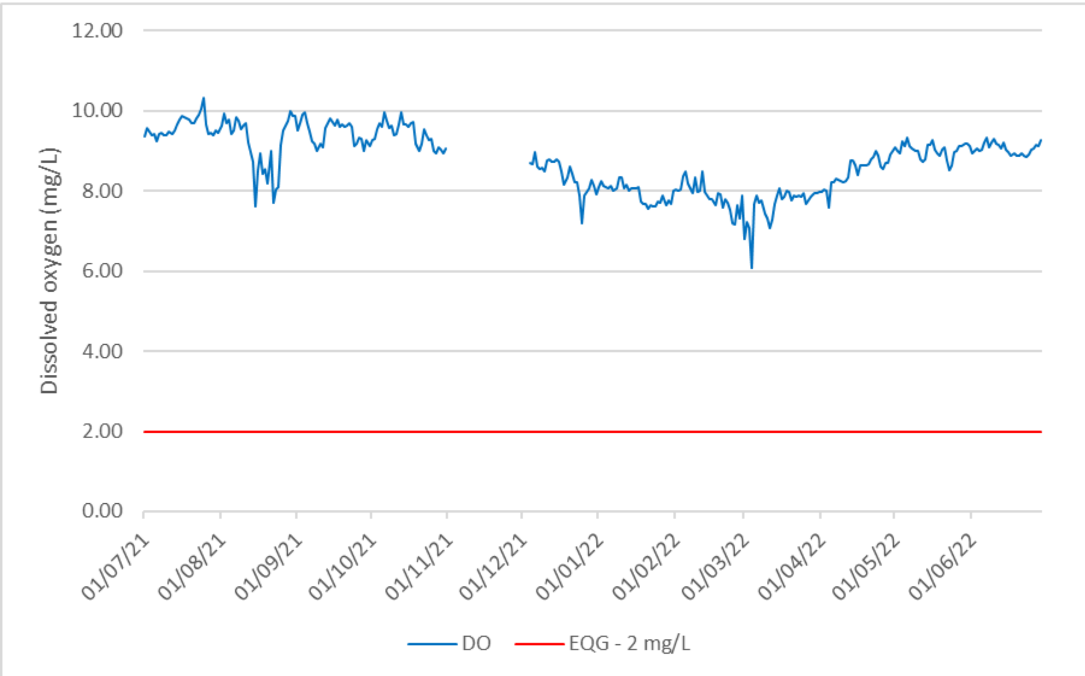

Figure G5: Daily average DO concentration of intake seawater over the 2021–22 monitored period

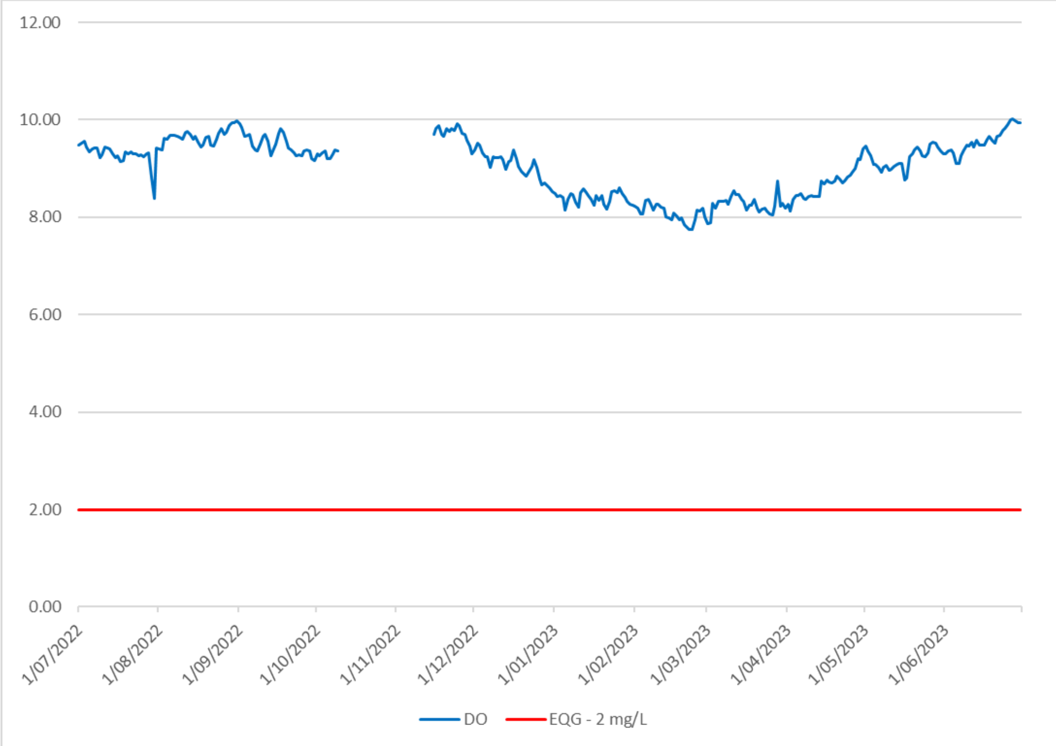

Figure G6: Daily average DO concentration of intake seawater over the 2022–23 monitored period

Total suspended solids (TSS)

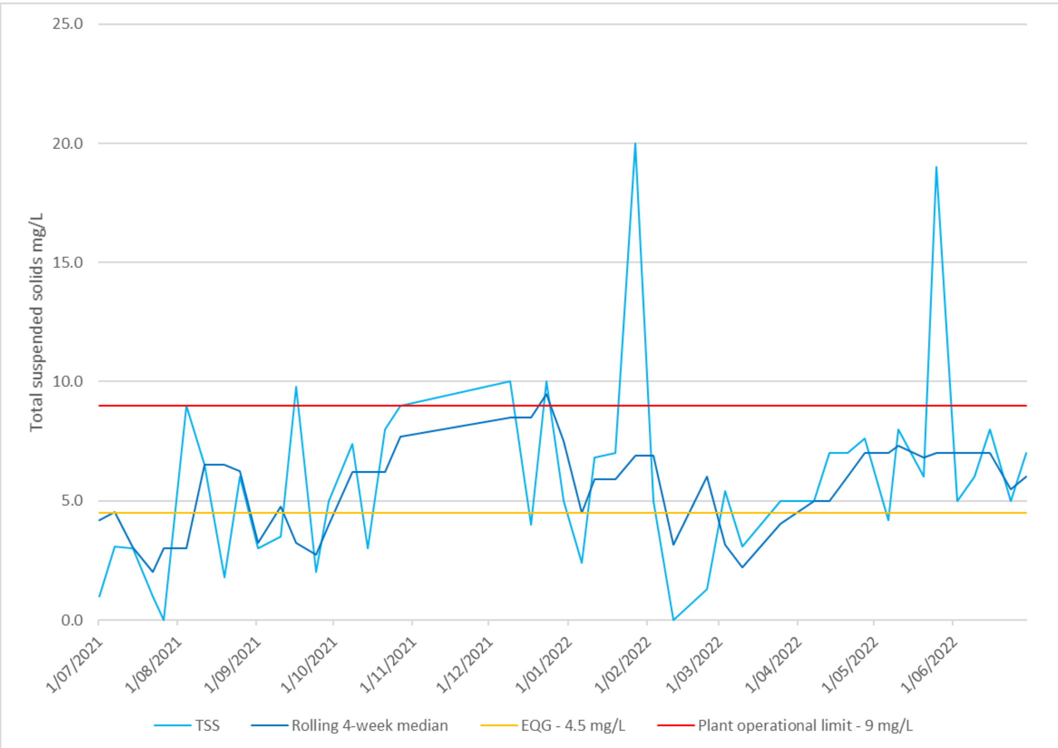

Figure G7: Weekly and rolling four-weekly median TSS concentration of intake seawater over 2021–22

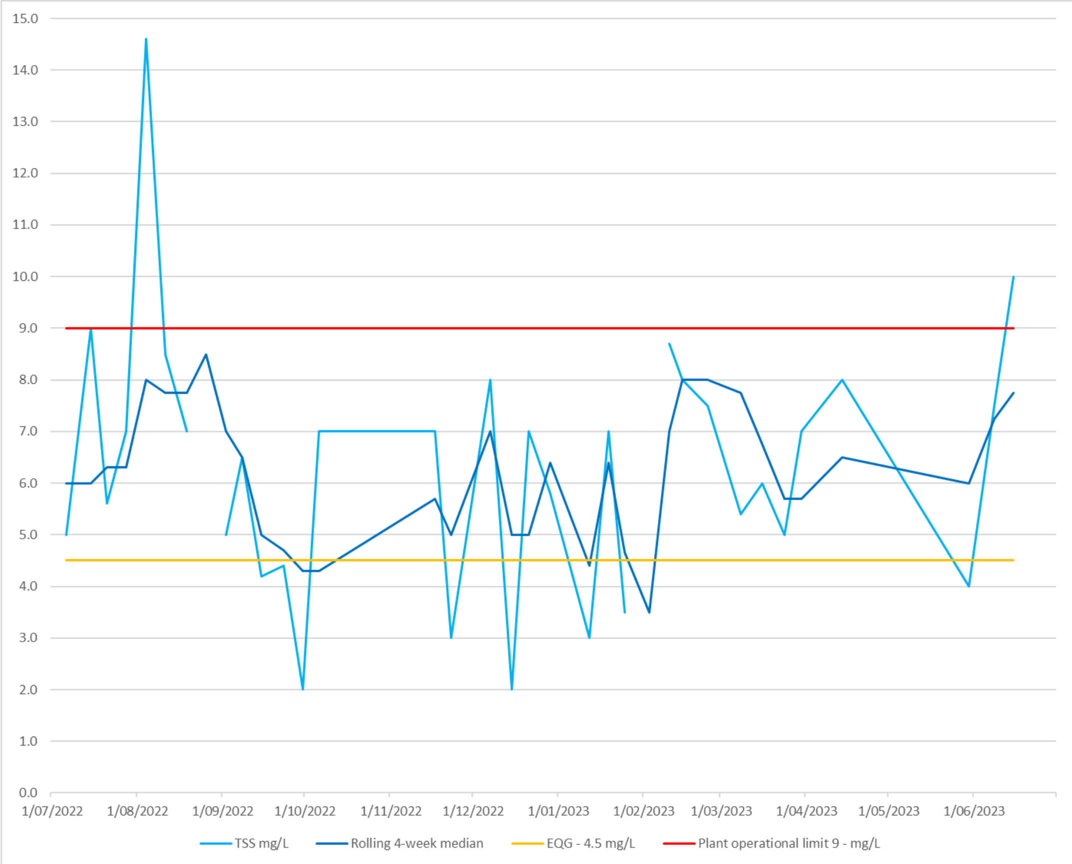

Figure G8: Weekly and rolling four-weekly median TSS concentration of intake seawater over 2022–23