GOVERNMENT OF
WESTERN AUSTRALIA

Cockburn Sound environmental monitoring report

2023 and 2024

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
Cockburn Sound Management Council
Prime House
8 Davidson Terrace
Joondalup, Western Australia 6027
Telephone +61 8 6364 6493
Facsimile +61 8 6364 7001

National Relay Service 13 36 77

May 2026

Acknowledgments

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

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

Contents

Executive summary

Western Australia's Environmental Protection Authority (EPA) first established an environmental quality management framework for Cockburn Sound through the *State Environmental (Cockburn Sound) Policy* (SEP) in 2005 (revised in 2015). An essential component of the framework is environmental quality monitoring. The monitoring provides data for measuring 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 (the Council) collates the monitoring results from its established water quality and seagrass health monitoring programs and the monitoring programs of other public authorities. The Council reports annually to the Western Australian Minister for Environment on the environmental quality monitoring results for Cockburn Sound, with specific reference to the Sound's EQC.

In addition to the results of monitoring programs undertaken by public authorities, a substantial amount of new data and information relevant to Cockburn Sound and Owen Anchorage was released from 2022 to 2025 through the government-subsidised $13.5 million WAMSI Westport Marine Science Program (WWMSP). The Cockburn Sound health assessment presented in this report considered all available data to determine whether the environmental objectives established for Cockburn Sound were achieved.

This report covers the period 1 December 2022 to 30 November 2024, providing assessments for both the 2022–23 and 2023–24 monitoring periods.

Environmental value: Ecosystem Health

Summary

Monitoring results highlighted some localised, albeit persistent, water quality issues in Cockburn Sound, but indicated that for most water and sediment quality parameters the relevant ecosystem health criteria were consistently met. A key observation was that a degree of nutrient enrichment appears to have persisted in the southern part of the Sound, despite evidence of significant reductions in nutrient loads to the Sound from outfalls, surface drains and contaminated groundwater plumes over recent decades. In the Sound's southern and eastern sections phytoplankton blooms were periodically observed.

The state of seagrass health in Cockburn Sound is uncertain at present – work is being done to investigate the identified issues. Observed seagrass shoot densities at several sites were depressed when compared with previous years. Based on the information at hand, there is high confidence that seagrass health has generally decreased within the Sound since the early 2000s. However, there is a degree of uncertainty with respect to the rate and cause of these observed declines, given: (i) preliminary evidence of 'sampling fatigue' (which is expressed as depressed health within monitoring quadrats and results in meadow health being underestimated); and (ii) the observation of similar declining seagrass health trends in Shoalwater Islands and Jurien Bay marine parks for the same period. Additional work to be undertaken in early 2026 will help address this uncertainty.

Through consideration of all the available information, it was concluded that the environmental quality objective of *maintenance of ecosystem integrity* was likely to have been achieved during the 2023 and 2024 monitoring period, but that additional work was required to improve confidence around that conclusion. More detail is provided below.

Nutrient enrichment

In recent years the water quality nutrient status of Cockburn Sound has become relatively stable, with a 2025 report suggesting the nutrient load from groundwater – the main source of nutrient input to the Sound – had reduced by 56–82% since 2003 (Donn et al. 2025) and was now more closely resembling baseline conditions before industrial development.

The areas with consistently higher concentrations of nutrients, chlorophyll-a and elevated turbidity were 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. The Sound's southern half exceeded 'early warning' guideline values for chlorophyll-a in both 2023 and 2024 and for light attenuation coefficient (LAC) in 2024, suggesting this area remained affected by a moderate level of chronic nutrient enrichment – likely associated with a nutrient-contaminated groundwater plume that releases into the Sound along the eastern shore south of James Point (Donn et al. 2025).

The 2023 and 2024 assessments concluded that environmental quality guidelines and standards for nutrient enrichment were generally being met, except in Northern Harbour – which consistently failed to meet EQC – and in less flushed areas of the Sound's southern half (e.g. Mangles Bay), which intermittently displayed moderate signs of nutrient enrichment.

Seagrass health

Seagrasses are slow to recover from disturbance, and this has been evident in Cockburn Sound. After a period of significant and long-term nutrient pollution between the 1960s and 1980s, water quality has largely been restored, with nutrient levels and light attenuation in the water column now generally meeting the relevant EQC across the Sound. Yet there is no evidence of any substantial recovery in seagrass health since monitoring began in the 1990s.

The 2023 and 2024 seagrass health data suggest a decline in health from previous years, with statistically significant declining trends at about half the established sites over a longer period. Considering all the data, there is a high degree of confidence that seagrass health has generally decreased within Cockburn Sound since the early 2000s. However, there is a degree of uncertainty around the cause and rate of the observed declines, owing to the following three findings:

1. There is no evidence of a single cause (e.g. nutrient enrichment) being responsible and, according to a review delivered as part of the WWMSP (McMahon et al. 2025), for most of these sites, the observed declines are more likely to have been caused by cumulative impacts from a mix of local and regional pressures, including erosion and sediment burial, anchor damage, sediment plumes associated with sand mining activities, increased temperature, storms and altered hydrodynamics.
2. A preliminary study undertaken during the 2025 monitoring season suggests evidence of sampling fatigue associated with the established 'fixed quadrat' monitoring methodology. If sampling fatigue proves to have been a factor, it is likely to have

increasingly, and artificially, depressed seagrass shoot counts and exaggerated declining trends. This issue is being investigated and will be reported on in 2026.

3. A review of seagrass health across the region over 20 years, published in July 2024 as part of the WWMSP (Webster et al. 2024), suggests the average decline observed in Cockburn Sound is similar to the declines observed in the more pristine waters of Jurien Bay and Shoalwater Islands marine parks between 2003 and 2022. Hence a regional source may be contributing to cumulative pressure affecting seagrass health in the Sound – likely associated with global warming and the increasing frequency, duration and intensity of extreme events.

Based on the findings above, it was concluded that the state of seagrass health in Cockburn Sound was 'uncertain' at present, and that additional work was required to: (i) understand current seagrass condition; and (ii) contemporise and strengthen the seagrass health monitoring methodology to improve the monitoring and reporting on seagrass health going forward. Both actions are being progressed.

Other physical and chemical stressors

Dissolved oxygen (DO) concentrations generally met guideline values across Cockburn Sound although less consistently in its southern half. Low DO events do occur naturally in the Sound as a result of stratification in late summer and autumn, which was reflected in the data. On two occasions DO fell below 60% saturation, exceeding both guideline and standard values. This occurred once on Kwinana Shelf near the desalination outfall in February 2023 and once in the deep basin of the Sound's southern half in February 2024. Values below 60% are a concern if they persist for a week or more, but a review of high-resolution data from loggers across the Sound suggested that significant dips in DO were short-lived during the monitoring period. Evidence of biological or ecological impacts were also not reported. This provides confidence that DO levels were only temporarily depressed below the environmental quality standard value and were unlikely to have resulted in ecological consequences.

A lack of available data meant that an assessment against the temperature, salinity and pH criteria could not be completed. However, there is a reasonable degree of confidence that the established criteria were generally met. Some anomalies were noted for each of the parameters, most typically in the Sound's southern and eastern parts. Localised elevated salinity concentrations near the desalination outlet were relatively persistent but generally met guideline values such that water quality and biological parameters continued to remain unaffected.

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 monitoring data show established criteria were met at all stations and sampling occasions, suggesting achievement of the relevant water quality objectives. These results and those from a 2024 Westport water quality toxicant survey in Cockburn Sound (Wilson & Wienczugow 2024b) indicate no significant threat to ecosystem integrity from toxicants in water.

Toxicants in sediments

Sampling by Fremantle Ports around its Kwinana operations found some exceedances of guideline values in 2023 (tributyltin known as TBT) and 2024 (cadmium, chromium, mercury and TBT) but the observed elevated concentrations were safely below the resampling trigger at each site. Overall, conservative guideline values were generally met. These results and those from a 2024 Westport baseline survey of sediment quality in Cockburn Sound (Wilson & Wienczugow 2024a) indicate no significant threat to ecosystem integrity from sediment toxicants.

Environmental value: Fishing and Aquaculture

There are no active aquaculture operations in Cockburn Sound, hence data was not collected for an assessment against *maintenance of aquaculture production*.

Toxins detected in sentinel mussels used in Fremantle Ports' annual monitoring program were assessed as a proxy, given no other information was available from other areas of the Sound or for wild shellfish or fish. No guideline values were exceeded, suggesting that for mussels in this locality the environmental quality objective *maintenance of seafood safe for human consumption* was achieved.

However, given the limited data available and a moderate level of risk of bioaccumulation of contaminants in the Sound's marine biota, there is a degree of uncertainty as to whether the objective *maintenance of seafood safe for human consumption* was achieved overall. This uncertainty is partially being addressed through a comprehensive environmental baseline study expected to be published in early 2026, funded by Westport, Water Corporation, Department of Primary Industries and Regional Development and Fremantle Ports.

Note that the Department of Health recommends only eating shellfish harvested commercially under strict quality assurance monitoring programs.

Environmental value: Recreation and Aesthetics

The 2023 and 2024 monitoring data generally met the relevant guidelines and provided some confidence that the objectives of *maintenance of primary contact recreation values* and *maintenance of secondary contact recreation values* were generally being achieved. However, it was noted that sampling was infrequent and did not generate the number of data points required for a robust assessment.

While there appeared to be some broad (green discolouration) and localised (surface debris) issues, the objective of *maintenance of aesthetic values* was generally being achieved.

Environmental value: Cultural and Spiritual

No criteria have yet been developed specific to this environmental value that *cultural and spiritual values of the marine environment are protected*. Existing criteria for protecting ecosystem integrity, seafood quality and recreational and aesthetic values may reasonably be expected to contribute to protecting cultural and spiritual values in Cockburn Sound. However, engagement with Traditional Owners is required to identify cultural and spiritual values for the Sound and to test whether additional objectives and/or criteria need to be developed to ensure these values are protected. This is being done as part of the SEP review project which is now underway.

Environmental value: Industrial Water Supply

Intake water temperature, pH, dissolved oxygen content, boron concentration and microbial quality met the relevant criteria and hence pose no threat to the function or efficiency of desalination plant operations.

However, the data indicated that total suspended solids near the desalination intake pipe in Cockburn Sound exceeded ‘early warning’ guideline values for extensive periods, and occasionally the more robust environmental quality standard values during the winter of 2023. Bromide concentrations measured in intake waters exceeded the ‘early warning’ guideline values on two occasions.

Despite the above exceedances, there was no adverse impact on the plant’s operations and Water Corporation did not report any need for mitigation measures, indicating the environmental quality objective *maintenance of water quality for industrial use* was achieved during the reporting period.

Additional work completed and response actions implemented

- The Department of Water and Environmental Regulation (DWER) installed seven strategically-placed water quality buoys across Cockburn Sound in 2021 to collect year-round high-resolution water quality data to better understand temporal and spatial variability, and help assess the potential risk of any reported exceedances of criteria as set out in the SEP. Some technical issues affected the buoys early-on but by late 2022 they were collecting data on key parameters. These data have been used to investigate or clarify issues identified by the boat-based monitoring program. Work is underway to contemporise this water quality monitoring program to ensure the continued collection of continuous data, supporting additional lines of evidence and the investigation of water quality issues..
- In 2025 a preliminary study investigated whether the effects of sampling fatigue were contributing to observed seagrass health declines within fixed quadrats. The findings suggested sampling fatigue to play a role and additional work is planned to investigate the extent of this role and to inform the development of a new approach (next point).
- DWER began a program of work in 2025 to review and strengthen the Sound’s environmental framework established by the SEP. A field study to trial a new methodology to monitor seagrass meadow health has been conducted and a series of expert workshops is underway to develop contemporary methodologies and criteria to support a more holistic and regionally relevant assessment of seagrass health.
- Engagement with Traditional Owners has commenced 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.
- A study investigating the bioaccumulation of contaminants in fish and invertebrates caught in Cockburn Sound has begun. The study’s objective is to establish an ‘environmental baseline’ through setting contaminant concentrations after grounding up the whole animal. The study is therefore not specifically aimed at addressing seafood quality questions, which are better investigated testing edible parts, but the results will

provide the first reliable data on bioaccumulation in the Sound's biota and are expected to give some indication of seafood quality.

- For the 2024–25 monitoring season, water quality monitoring frequency and duration was returned to weekly over the non-river-flow period (Dec–Mar) to improve statistical rigour and the assessment against the criteria.

Summary of the 2023 and 2024 assessments

EV	EQO	Parameter type	Status	Data source / comments
Environmental Value: Ecosystem Health				
	EQO: Maintenance of Ecosystem Integrity		?	Determined on the balance of all available information. **Seagrass health investigation required - in progress**
		Nutrients		CSMC data + Wilson & Wienczugow (2025) - Elevated nutrient concentrations and episodic phytoplankton blooms in HPA-S, MPA-ES and JB-NH
		Seagrass health	?	CSMC data + Webster et al. (2024) - **Declining trends but concerns around sampling fatigue and regional trend - Investigation in progress**
		Physical parameters		CSMC data + Wilson & Wienczugow (2025) + DWER data: continuous water quality buoy monitoring program
		Toxicants (water)		Wilson & Wienczugow (2024b): first ecosystem-wide snapshot survey since 2006 delivered by Westport
		Toxicants (sediment)		FPA data + Wilson & Wienczugow (2024a): first ecosystem-wide snapshot survey since 2006 delivered by Westport
Environmental Value: Fishing and Aquaculture				
	EQO: Seafood Safe for Human Consumption		?	Determined on the balance of all available information. **Investigation of toxicants in seafood required - in progress**
		Toxicants (water)		Wilson & Wienczugow (2024b)
		Toxicants (biota)	?	Lack of data and a moderate level of risk - **Investigation in progress**
	EQO: Maintenance of Aquaculture Production		✓	
		Toxicants		Determined on the basis of current FPA data and previously obtained WASQAP data (during aquaculture operation)
Environmental Value: Recreation and Aesthetics				
	EQO: Maintenance of Primary Contact Recreation Values		✓	Determined on the basis of available data (limited) but relatively low risk.
		Biological parameters		DoH data
		Physical parameters		CSMC data
		Toxicants		CSMC and FPA data
	EQO: Maintenance of Secondary Contact Recreation Values		✓	
		Biological parameters		DoH data
		Physico-chemical parameters		Wilson & Wienczugow (2024 & 2025) + FPA data
	EQO: Maintenance of Aesthetic Quality		✓	
		Visual		Limited CSMC data but relatively low risk - some evidence of localised and temporary impacts on aesthetics
		Fish tainting substances		No data but low risk
Environmental Value: Cultural and Spiritual				
	EQO: Cultural and Spiritual Values are protected		?	
		Criteria have not been defined	?	Development of criteria is being considered as part of the Review of the SEP
Environmental Value: Industrial Water Supply				
	EQO: Maintenance of Water Quality for Industrial Use		✓	No reports of impacts on operation of the desal plant
		Biological parameters		Water Corporation intake data
		Physico-chemical parameters		Water Corporation intake data - TSS criteria exceedances common, but no reported effect on operation

1. Introduction

1.1 *State Environmental (Cockburn Sound) Policy 2015*

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

The SEP provides an important mechanism to ensure the values and uses of Cockburn Sound are protected. The SEP's overall objective is 'to ensure that water quality of the Sound is maintained and where possible improved so that there is no further net loss and preferably a net gain in seagrass areas, and that other values and uses are maintained' (Government of Western Australia 2015).

The management framework established through the SEP is based on one that the National Water Quality Management Strategy recommends, which makes it an agreed Australia-wide approach to protecting water quality and associated environmental values. The framework and associated monitoring provide a strong basis for an adaptive management approach that protects 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.

A review of the SEP is underway and due for completion in 2027. This policy update is required to ensure the management framework remains fit-for-purpose to protect the environmental values of Cockburn Sound from contemporary issues and development pressures.

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

The key to successful environmental management is to maintain environmental quality within the bounds described by the EQC, thereby achieving the environmental quality objectives and ensuring the environmental values continue to be supported.

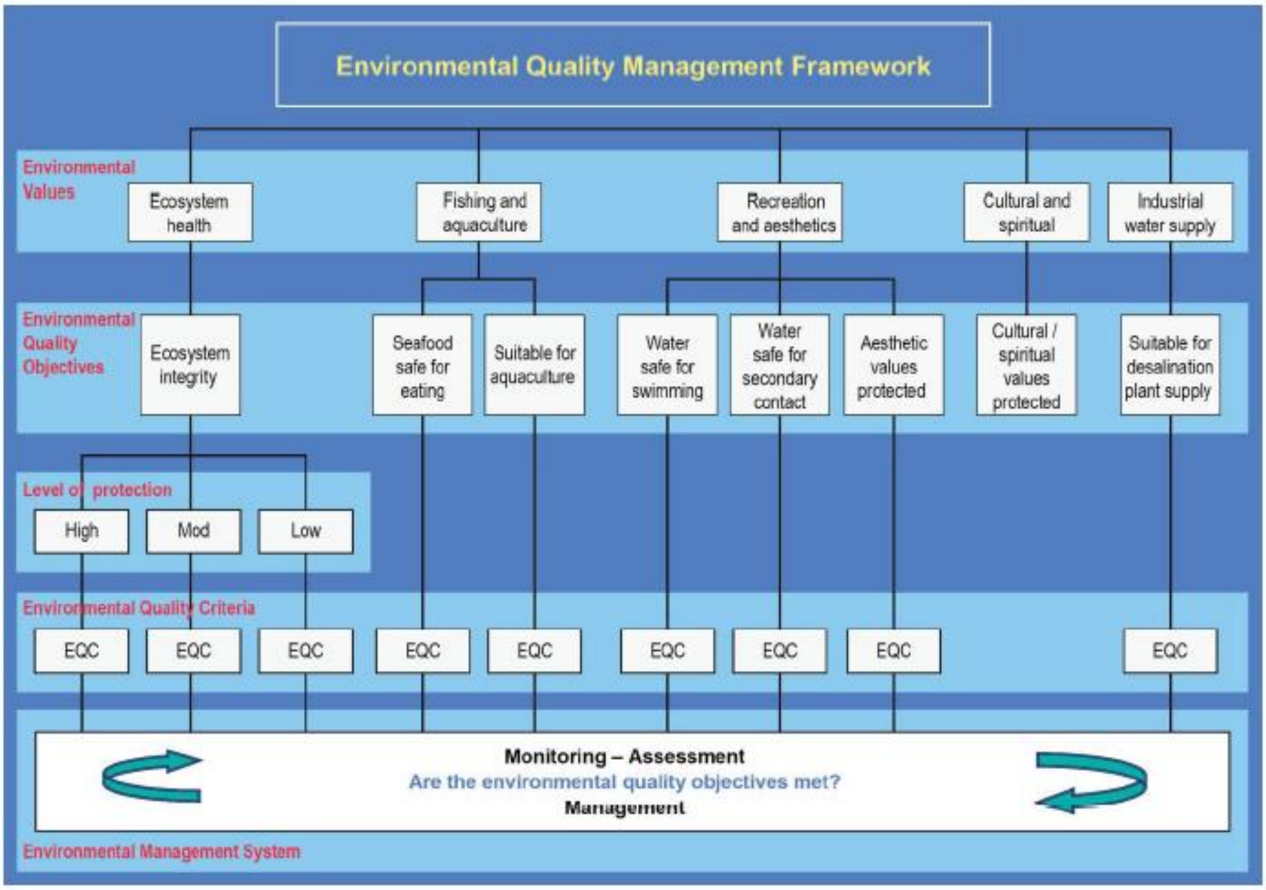

Figure 1: Environmental quality management framework for Cockburn Sound (EPA 2017)

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.

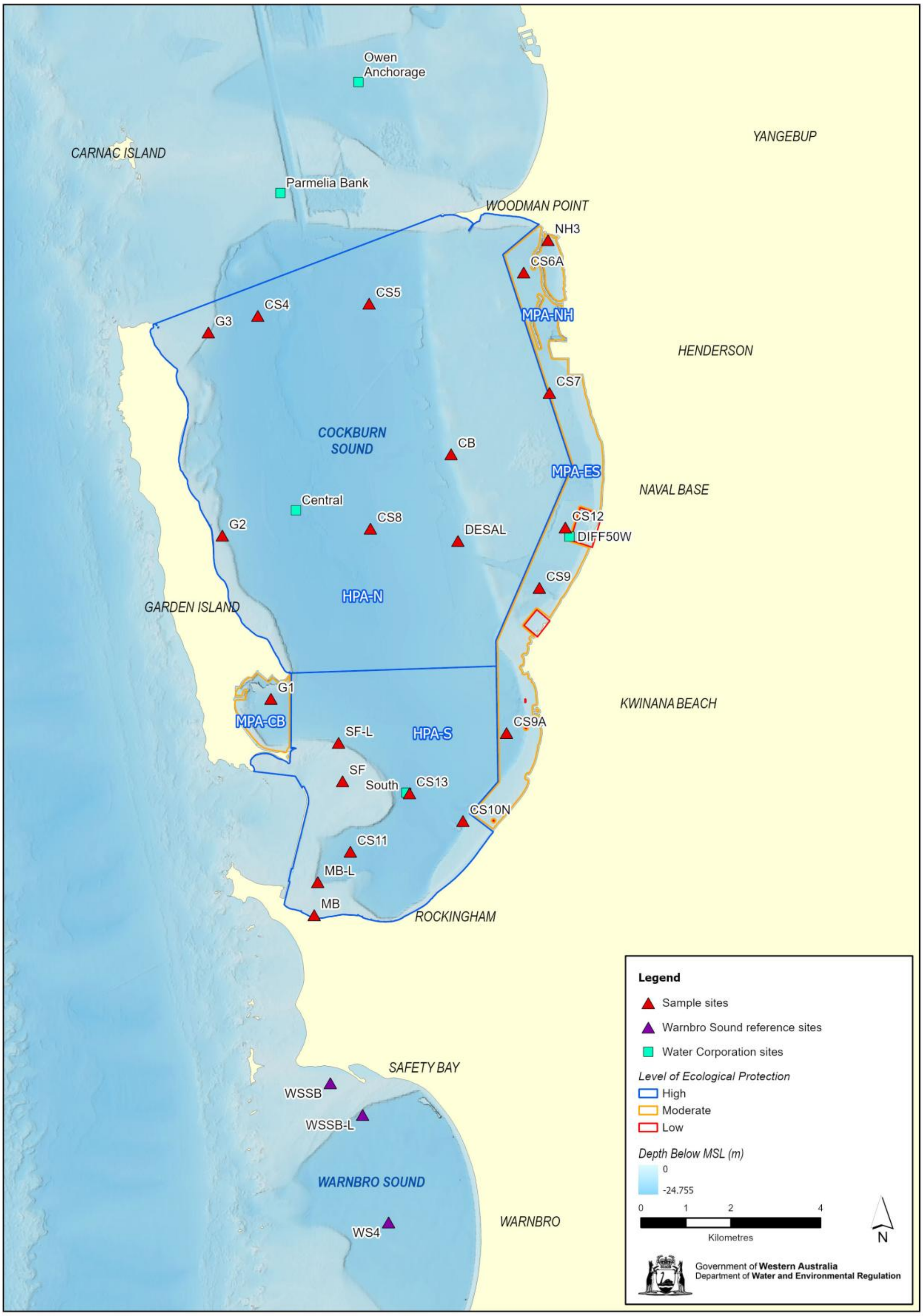

Figure 2: The ecological protection areas in Cockburn Sound and the location of water and sediment quality monitoring sites within Cockburn Sound and reference sites in Warnbro Sound (Flukes 2024).

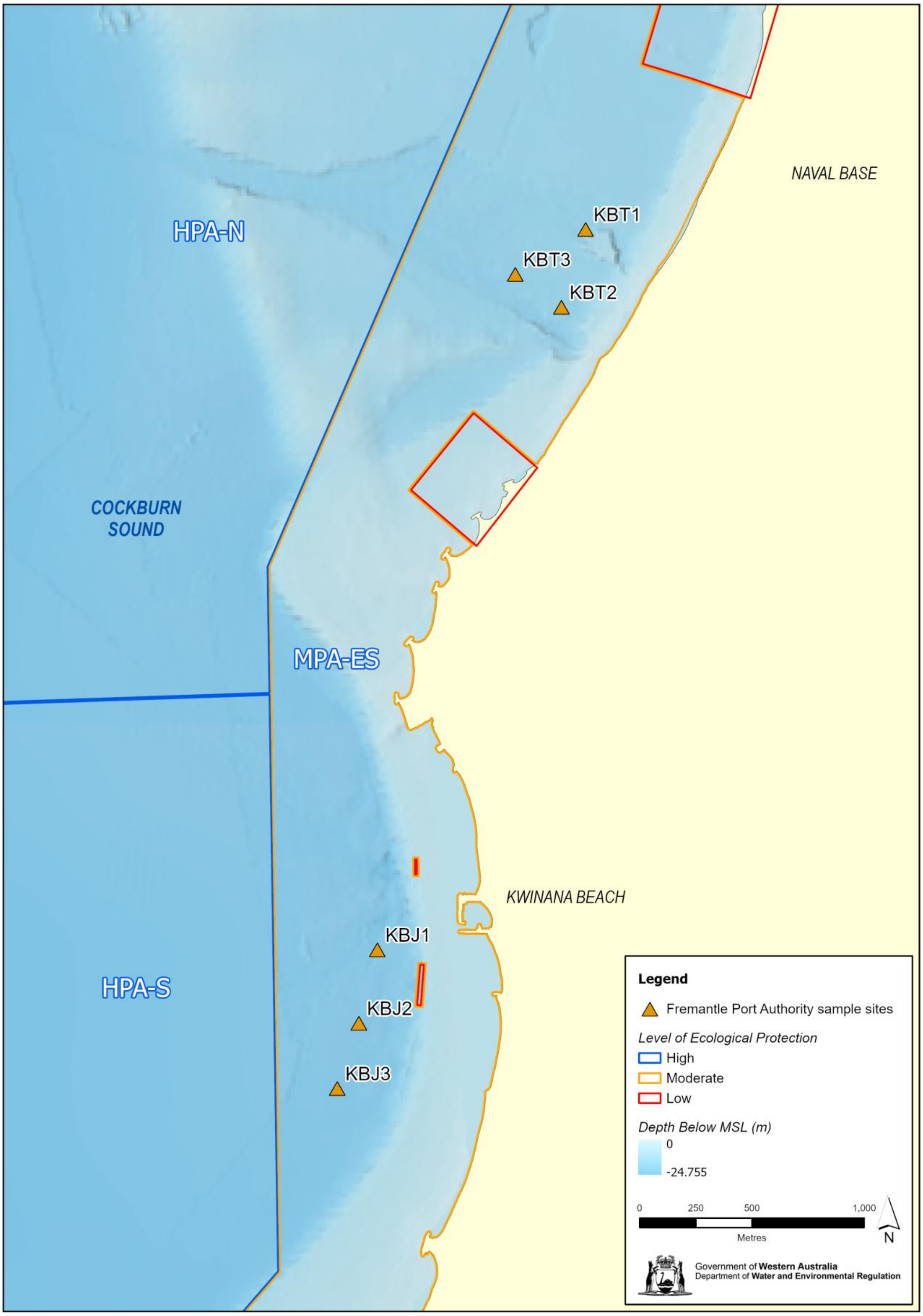

Figure 3: Fremantle Port Authority's marine water and sediment quality monitoring sites in Cockburn Sound (Flukes 2024).

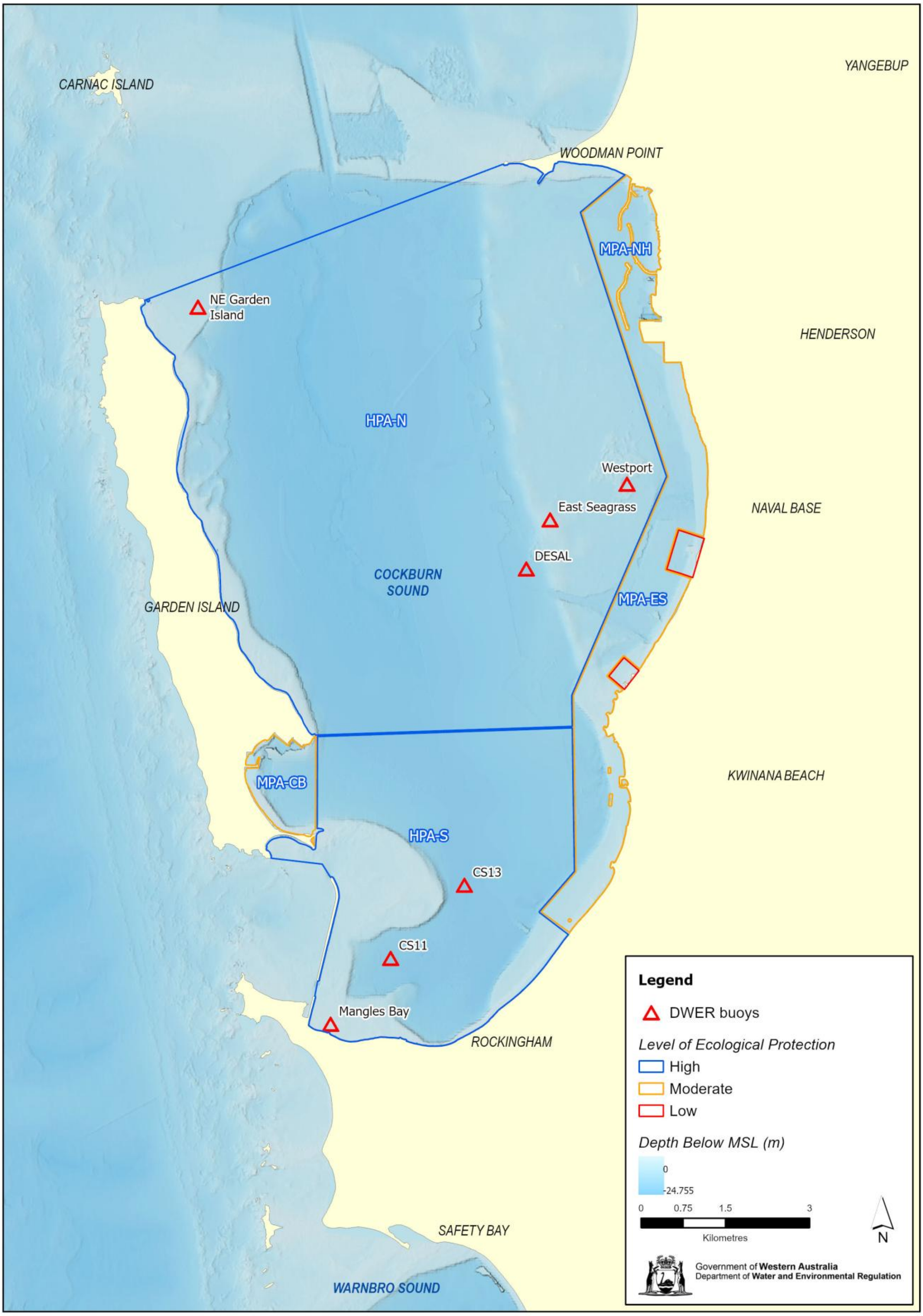

Figure 4: DWER water quality buoys monitoring sites (Flukes 2024)

Most of Cockburn Sound has been afforded a high level of ecological protection, except for Careening Bay and a coastal strip in the Sound's eastern part, 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 assigned a low level of ecological protection. For these areas compliance monitoring and reporting is completed by the relevant proponent and provided to the Department of Water and Environmental Regulation (DWER). Cockburn Sound Management Council (the Council) 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 Council and Department of Water and Environmental Regulation monitoring programs and recent changes

The EQC for Cockburn Sound were originally developed specifically to assess environmental quality during the non-river-flow periods in the summer months. During these months conditions in the Sound are relatively stable (e.g. low frequency of storm and rainfall events and limited input of fresh water from the Swan River), which allows useful comparisons to be made between years. This period is also critical for seagrass growth and recreational activity and largely covers the seasonal occurrence of phytoplankton blooms and stratification events. By concentrating monitoring effort during this season, the

---

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

monitoring programs were able to collect enough datapoints for statistically robust analyses. The Council-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 19 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 then.

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), expansion of Water Corporation's Perth Seawater Desalination Plant and potential expansion of the Australian Marine Complex for Commonwealth Defence purposes.

The current environmental monitoring programs include:

Cockburn Sound Management Council[2]

- Monthly field sampling (vessel based, year-round) and measurement of nutrient-related and physical-chemical water quality parameters at 19 impact sites plus two reference sites.
- An annual field program to monitor seagrass shoot density at 11 sites in Cockburn Sound, five reference sites and two additional nearby sites.
- An annual field program to monitor seagrass lower depth limit at four sites in Cockburn Sound and two reference sites.
- 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 seven sites across Cockburn Sound (Figure 4).

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 have on the one hand improved, and on the other, impeded the capacity to compare the results against established EQC. It is intended that the remaining issues be resolved as part of the SEP review project, which runs up to 2027.

[2] Currently undertaken by the Department of Water and Environmental Regulation on behalf of the Council.

Table 1: Recent changes to Cockburn Sound environmental monitoring programs and additional studies completed

Change	Rationale	Consequence for Council reporting, response actions and recommendations
Jan 2021 – DWER established eight telemetered water quality stations in Cockburn Sound (later reduced to seven)	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's recommendations.	Implementation of the telemetered water quality stations have generated a much-improved environmental baseline for Cockburn Sound and help with investigating criteria exceedances. A recommendation in the 2022 report was to complete QA/QC of the data collected by the buoys. *(Response action: QA/QC of the monitoring data captured by the buoys over 2022–24 was completed by the DWER in early 2025.)*
Jan 2021 – Council adopted year-round monthly water quality monitoring in favour of weekly monitoring over the summer period (Dec–Mar)	The Hatton Review recommended extending the manual water quality monitoring program over the full year. 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 four for a typical season. This was insufficient to derive medians or percentiles and compromised comparisons against several established EQC. The monthly data helped validate data collected by DWER's water quality buoys for the first three years. However, after this period, the costs were deemed to outweigh the benefits. *(Response action: weekly monitoring to re-commence from December 2024 onwards.)*
Jan–Feb 2022 – Council stopped monitoring 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, which rendered their use as reference sites unsuitable.	The loss of suitable shallow reference sites in Warnbro Sound confounds the assessment of seagrass health as required under the SEP. The 2022 report describes an attempt to use three alternative shallow reference sites in Shoalwater Islands Marine Park and Owen Anchorage, with mixed results. For the 2023 and 2024 reports insufficient data were available to continue this approach. *(Response action: given mounting evidence that the seagrass health monitoring approach was no longer fit-for-purpose, DWER began developing a contemporary monitoring program that incorporates new technologies and methodologies – this is set for implementation in early 2027.)*
Jan–Feb 2022 – the seagrass monitoring program adopted monitoring of random quadrats for shallow sites, inconsistent with the methodology	The change was adopted in response to the consultant reporting that the fixed monitoring sites could not be located.	The methodology change resulted in higher seagrass shoot counts than expected, preventing useful comparisons against data collected in previous years and generating data that were not collected in line with the established methodology. *(Response action: fixed quadrats were re-established for the 2024 survey)*
Jan 2024 – the seagrass monitoring program was reverted from random quadrats to fixed quadrats for shallow sites	The change was adopted to allow statistical comparison and reporting in accordance with the SEP. The fixed quadrats were re-established and the star pickets renewed for consistent monitoring.	The change confirmed the higher seagrass counts reported by the previous consultant in 2022 and 2023 were due to the methodology – a result that suggested 'sampling fatigue' in fixed quadrats may be responsible for depressed observed health. Sampling fatigue potential needs to be investigated. *(This issue was investigated in early 2025 at one site and will be investigated further in 2026 at six sites to inform the development of a new seagrass monitoring program as part of the SEP review.)*
Dec 2024 – Water quality monitoring frequency was reverted to weekly for the December to March period.	Data analysis of monthly data collected over three years concluded that monthly monitoring was of no benefit, given the deployment of seven WQ buoys providing year-round high-resolution data on physical and chemical parameters.	With 16 data points within the non-river-flow period, statistical robustness was re-established.

1.3.3 Data sources 2023 and 2024

Table 2 summarises the environmental quality indicators measured by the various 2023–24 monitoring programs for comparison against the EQC for Cockburn Sound, as well as the sources of these data.

See the relevant sections later in this report for more details on each of the monitoring programs. Note that data generated by relevant other studies or monitoring programs were used as additional lines of evidence where required to investigate exceedances.

Table 2: Environmental quality indicators and data sources for assessment against the EQOs.

<table>
<tr><th colspan="3">EQOs</th><th>Indicator</th><th>Data source</th></tr>
<tr><td colspan="5">Ecosystem Health – maintenance of ecosystem integrity</td></tr>
<tr><td rowspan="3">Physical and chemical stressors</td><td colspan="2">Nutrient enrichment</td><td>Chlorophyll-a concentration, light attenuation coefficient, seagrass shoot density</td><td rowspan="2">The Council</td></tr>
<tr><td colspan="2">Phytoplankton biomass</td><td>Phytoplankton biomass (measured as chlorophyll-a)</td></tr>
<tr><td colspan="2">Other physical and chemical stressors</td><td>Dissolved oxygen concentration, water temperature, salinity, pH</td><td>The Council, Water Corporation and Fremantle Port Authority</td></tr>
<tr><td rowspan="4">Toxicants (marine waters)</td><td colspan="2">Metals and metalloids</td><td>Copper</td><td rowspan="4">The Council and Fremantle Port Authority</td></tr>
<tr><td colspan="2">Non-metallic inorganics</td><td>Ammonia</td></tr>
<tr><td colspan="2">Organics</td><td>BTEX</td></tr>
<tr><td colspan="2">Oils and petroleum hydrocarbons</td><td>Total recoverable hydrocarbons (TRHs)</td></tr>
<tr><td rowspan="5">Toxicants (sediments)</td><td colspan="2">Metals and metalloids</td><td>Arsenic, cadmium, chromium, copper, lead, mercury, selenium, zinc</td><td rowspan="5">Fremantle Port Authority</td></tr>
<tr><td colspan="2">Organometallics</td><td>Tributyltin (TBT), dibutyltin (DBT), monobutyltin (MBT)</td></tr>
<tr><td colspan="2">Organics</td><td>Polycyclic aromatic hydrocarbons (PAHs)</td></tr>
<tr><td colspan="2">Oils and petroleum hydrocarbons</td><td>TRHs</td></tr>
<tr><td colspan="2">Per- and polyfluoroalkyl substances (PFAS)</td><td>Perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), perfluorohexane sulfonate (PFHxS)</td></tr>
<tr><td colspan="5">Fishing and aquaculture</td></tr>
<tr><td rowspan="2">Maintenance of seafood safe for human consumption</td><td rowspan="2">Chemicals</td><td>Metals</td><td>Arsenic, cadmium, chromium, copper, lead, mercury, selenium, zinc</td><td rowspan="2">Fremantle Port Authority</td></tr>
<tr><td>Organic chemicals</td><td>Polychlorinated biphenyls, PAHs</td></tr>
</table>

EQOs			Indicator	Data source
		Organometallics	TBT, DBT, MBT	
Recreation and Aesthetics				
Maintenance of primary contact recreation values	Biological		*Enterococci*	Department of Health
	Physical		pH, water clarity	The Council
	Toxic chemicals	Inorganic chemicals	Copper, nitrate-nitrite	The Council and Fremantle Port Authority
		Organic chemicals	BTEX	
Maintenance of secondary contact recreation values	Biological		*Enterococci*	Department of Health
	Physical and chemical		pH	The Council
			Toxic chemicals	The Council and Fremantle Port Authority
Maintenance of aesthetic quality	Visual indicators		Nuisance organisms, fauna deaths, water clarity, colour variation, surface films, debris, odour	The Council
Industrial Water Supply				
Maintenance of water quality for industrial use	Biological		*Escherichia coli/enterococci*	Water Corporation
	Physical and chemical		Temperature, pH, dissolved oxygen, total suspended solids, hydrocarbons, boron, bromide	

In addition to the results of monitoring programs undertaken by public authorities, a substantial amount of new data and information relevant to Cockburn Sound and Owen Anchorage was released from 2022 to 2025 through the government-subsidised $13.5 million WAMSI Westport Marine Science Program (WWMSP). The Cockburn Sound health assessment presented in this report considered all available data to determine whether the environmental objectives established for Cockburn Sound were achieved.

1.4 This report

The Council collates the monitoring results from its own water quality and seagrass health monitoring programs and those of other public authorities. It reports annually to the Minister for Environment on the extent to which the results meet the 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 combined findings of the environmental quality monitoring programs undertaken in Cockburn Sound for the reporting periods 1 December 2022 to 30 November 2024 (two years).

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 values and EQOs 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 (no aquaculture operations during this reporting period)
- **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 (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 Environmental quality objective

Under the framework, the EQO *maintenance of ecosystem integrity* is considered to be achieved when the EQC are met.

The EPA recommends ecosystem integrity 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 set by the SEP aims to ensure that Cockburn Sound's environmental values 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' – namely 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 other parameters of ecosystem integrity and biodiversity (such as fish and iconic species populations) are delivered by regulatory agencies with responsibilities under other relevant legislation.

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 Council water quality monitoring program

This program includes 19 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 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 the results used to identify differences between the surface water and water near the water/sediment interface at the two sites.

In addition to these analyses, physical and chemical parameters (i.e. water depth, water temperature, salinity, pH, turbidity, dissolved oxygen [DO] and 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 toxicant 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, CB, DESAL and 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 shallow site WSSB since December 2015	–

** See Figure 2 and Figure 3 for site locations*

2.2.2 Fremantle 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 February 2023 and 2024, along with measurements of the physical-chemical parameters of DO, salinity and temperature at 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 Murdoch University's Marine and Freshwater Research Laboratory (MAFRL) for nutrients, chlorophyll-a, phaeophytin-a and filtered copper. Samples were analysed by ChemCentre for TRHs and BTEX.

2.2.3 Fremantle 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 2023 and March 2024 at all six sites. Five 100 mm diameter sediment cores were collected within 1 m^2 at each site using polycarbonate corers. The top 2 cm of each core was separated and homogenised into one composite sample from each site. The sediment samples were stored on ice for transport to the laboratory. The samples were analysed by ChemCentre for total organic carbon, metals (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 had affected water quality and seagrass health was 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 define thresholds which, when met, achieve the following 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 Cockburn Sound’s eastern side, including the Kwinana Shelf, to depths of up to 10 m
- avoid impacts on seagrass health from phytoplankton blooms in Cockburn Sound.

2.3.1 Chlorophyll-a and light attenuation coefficient

Calculation of environmental quality guidelines

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

EQG were calculated using reference site data from the non-river-flow period of the current year and previous years, until *n* approximated 100 (*n*=107 for 2023, *n*=95 for 2024). See Table 4 for the updated EQG.

Table 4: The high and moderate protection EQG for chlorophyll-a concentration and light attenuation coefficient (LAC) for both years of the reporting period.

Year	Indicator	High protection (rolling 80th percentile)	Moderate protection (rolling 95th percentile)
2023	Chlorophyll-a (µg/L)	0.90	1.47
	LAC ($\log_{10}$ m^{-1})	0.094	0.115
2024	Chlorophyll-a (µg/L)	0.90	1.33
	LAC ($\log_{10}$ m^{-1})	0.093	0.115

Assessment against the environmental quality guidelines

The median ambient chlorophyll-a concentrations and light attenuation coefficients recorded from December 2022 to March 2023 (2023) (Table 5) and from December 2023 to March 2024 (2024) (Table 6), from each of the 19 water quality monitoring sites, were assessed against the respective nutrient enrichment EQG.

High protection: [For 2023] The median chlorophyll-a concentration/light attenuation coefficient during the non-river-flow period is not to exceed a chlorophyll-a concentration of 0.9 µg/L or a light attenuation coefficient of 0.094 $\log_{10}$ m^{-1}.

[For 2024] The median chlorophyll-a concentration/light attenuation coefficient during the non-river-flow period is not to exceed a chlorophyll-a concentration of 0.9 µg/L or a light attenuation coefficient of 0.093 $\log_{10}$ m^{-1}.

Moderate protection: [For 2023] 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}.

[For 2024] The median chlorophyll-a concentration/light attenuation coefficient during the non-river-flow period is not to exceed a chlorophyll-a concentration of 1.3 µg/L or a light attenuation coefficient of 0.115 $\log_{10}$ m^{-1}.

The nutrient enrichment EQG was not applied to MPA-NH because of the absence of macro-benthic primary producers such as seagrass within the harbour. Note, however, that median chlorophyll-a and light attenuation coefficient values continued to substantially exceed the MPA criteria at this site.

No other moderate protection area exceeded the chlorophyll-a or light attenuation coefficient EQG across the 2023 and 2024 reporting periods. Within these areas, the only sites to exceed the chlorophyll-a rolling 95th percentile were CS9 and CS9A (MPA-ES).

The high protection area HPA-S was the only area where nutrient enrichment guidelines were exceeded. The EQG for chlorophyll-a was exceeded in both 2023 and 2024. HPA-S also exceeded the light attenuation coefficient EQG in 2024.

See Appendix A for more details on the chlorophyll-a and LAC patterns at each site. See Appendix B for additional information on ammonium, total nitrogen and total phosphorus concentrations.

Table 5: 2023 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)			LAC (log10 m-1)			Assessment
		2023 EQG	2023 site median	2023 ecological protection area median	2023 EQG	2023 site median	2023 Ecological protection area median	
HPA-N	CS4	0.9	0.4	0.6	0.094	0.073	0.077	**EQG met**
	CS5		0.7			0.095		
	CS8		0.7			0.076		
	CB		0.6			0.095		
	G2		0.7			0.076		
	G3		0.5			0.073		
	DESAL		0.8			0.096		
HPA-S	CS11	0.9	1.2	1.1	0.094	0.086	0.088	**Chl-a EQG exceeded** **LAC EQG met**
	CS13		1.2			0.095		
	SF		0.6			0.082		
	MB/MB-L		1.2			0.096		
MPA-CB	G1	1.5	0.9	0.9	0.115	0.078	0.078	**EQG met**
MPA-ES	CS10N	1.5	1.2	1.2	0.115	0.104	0.102	**EQG met**
	CS12		1.1			0.097		
	CS6A		0.7			0.102		
	CS7		1.0			0.109		
	CS9		1.8			0.105		
	CS9A		1.5			0.102		
MPA-NH	NH3	n/a	2.7	2.7	n/a	0.145	0.145	n/a

Note: n/a indicates nutrient enrichment EQG were not applied because macro-benthic primary producers were absent.

Table 6: 2024 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)			LAC (log10 m-1)			Assessment
		2024 EQG	2024 site median	2024 ecological protection area median	2024 EQG	2024 site median	2024 ecological protection area median	
HPA-N	CS4	0.9	0.7	0.7	0.093	0.082	0.083	EQG met
	CS5		0.8			0.083		
	CS8		0.6			0.086		
	CB		0.7			0.093		
	G2		0.8			0.082		
	G3		0.5			0.075		
	DESAL		0.7			0.109		
HPA-S	CS11	0.9	1.2	1.2	0.093	0.104	0.098	Both chl-a and LAC EQG exceeded
	CS13		1.1			0.099		
	SF		0.7			0.097		
	MB/MB-L		1.5			0.111		
MPA-CB	G1	1.3	1.1	1.1	0.115	0.088	0.088	EQG met
MPA-ES	CS10N	1.3	0.6	0.7	0.115	0.083	0.095	EQG met
	CS12		0.6			0.098		
	CS6A		0.7			0.109		
	CS7		0.6			0.108		
	CS9		1.1			0.098		
	CS9A		1.0			0.095		
MPA-NH	NH3	n/a	3.0	3.0	n/a	0.137	0.137	n/a

Note: n/a indicates nutrient enrichment EQG were not applied because macro-benthic primary producers were absent.

2.3.2 Seagrass health

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

- EQS (i) and (ii) needed comparisons of shoot densities at Cockburn Sound sites against those at reference sites of similar depth and against baseline values. The assessment took in rolling percentiles calculated over several years.
- EQS (iii) involved an assessment to determine whether the edge of existing seagrass meadows (lower depth level) was maintained at the same depth as when monitoring began. A statistically significant result indicating the meadows were retreating into shallower waters would indicate the EQS had not been met.

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

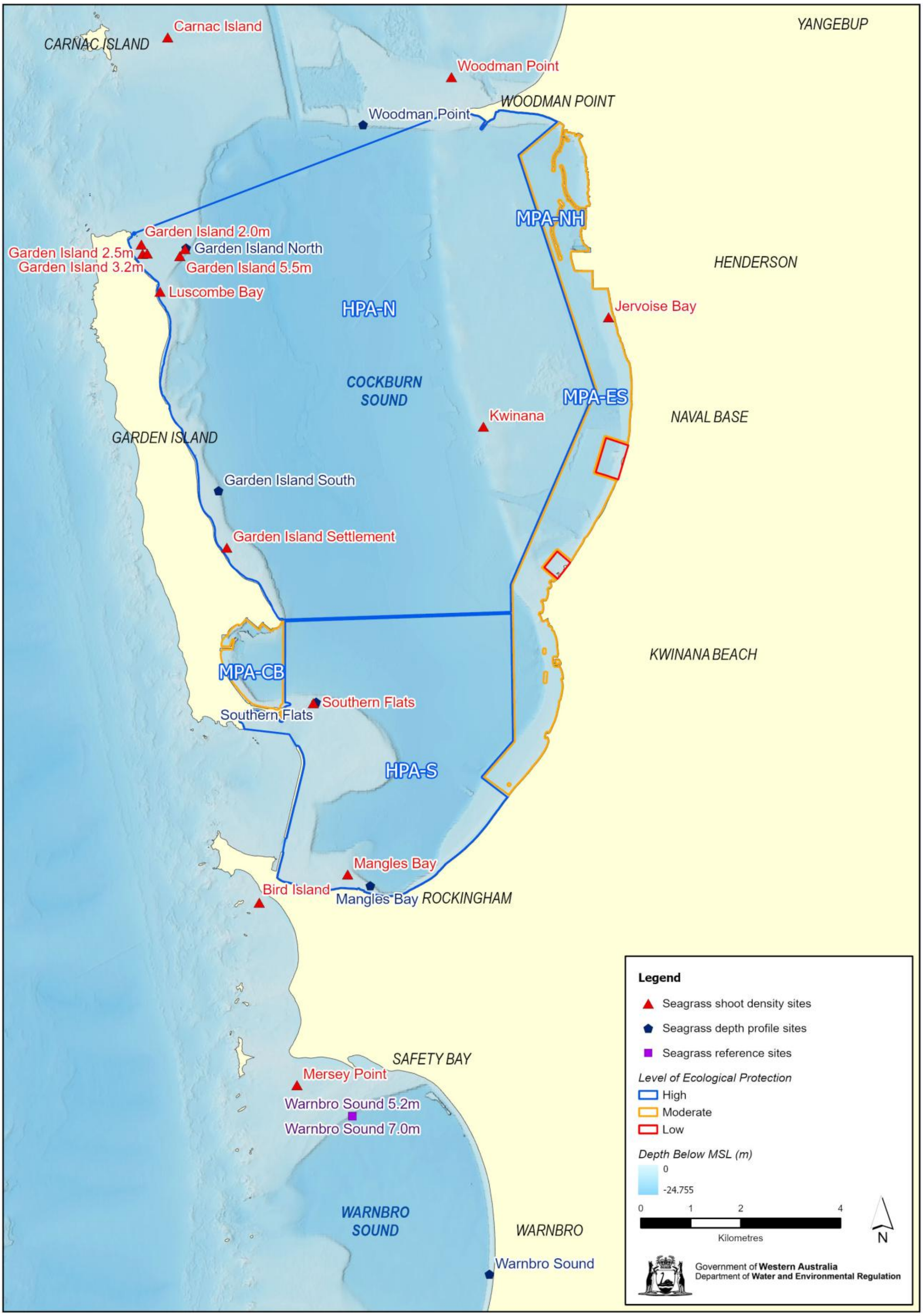

Figure 5: Seagrass monitoring sites (Flukes 2024)

Seagrass health was assessed for the high and moderate protection areas defined for Cockburn Sound. The established seagrass monitoring sites (Figure 5) enabled an assessment of 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); and Moderate Protection Area Eastern Shelf (MPA-ES).

Comparisons against the seagrass health criteria were undertaken for each site, but whether the criteria were met was assessed at the level of a protection area – requiring a judgment to be made if the criteria were not met for all sites within a zone.

This report includes an assessment of seagrass health for two assessment periods: 2023 and 2024.

Potential significant issue: sampling fatigue

Monitoring data for 2022 and 2023 suggested a significant increase in seagrass shoot densities at multiple sites – suspected to have been due to a change in methodology (a suspicion confirmed by the 2024 monitoring results). The 2022 and 2023 field surveys involved the sampling of random (as opposed to fixed) quadrats at multiple locations because the consultant was unable to locate the established fixed quadrats. The change in methodology presented a problem due to its deviation from the established Cockburn Sound methodology: the resulting monitoring outcomes could not be compared with data collected during previous years. Yet the results were still valuable, as they provided a first datapoint suggesting the established approach had started to result in sampling fatigue in fixed quadrats. Sampling fatigue results in increasingly lower observed seagrass shoot densities within fixed quadrats that do not represent trends in plant health within the meadow more broadly.

Response actions: *To investigate the potential issue of sampling fatigue, the fixed quadrats were re-established and sampled in accordance with the existing methodology during the 2024 season. The 2024 seagrass shoot densities were significantly lower when compared with the 2022 and 2023 results and strengthened the hypothesis that sampling fatigue was contributing to observed declining trends. A preliminary investigation, conducted in 2025, provided additional evidence. During the 2026 season, fixed and random quadrats will be sampled at six sites to further investigate this issue and inform the development of a new, more robust and holistic assessment of seagrass health in Cockburn Sound for implementation in 2027.*

Issue: Warnbro Sound reference sites

The assessment of EQS (i) and (ii) involved comparisons against shoot densities at the historic Warnbro Sound reference sites (Figure 5). Three of the established shallow Warnbro Sound references sites, however, were showing significant declines in shoot density over time due to natural and localised erosion processes, rendering them unsuitable for use as reference sites. Monitoring at these sites was abandoned after 2020, limiting comparisons against EQS (i) to an assessment against only the established ‘absolute minimum criteria’ derived from baseline data. Comparisons against EQS (ii) are no longer possible for the shallow sites.

For the 2022 report an attempt was made to use three alternative shallow reference sites in Shoalwater Islands Marine Park and Owen Anchorage, with mixed results. For the 2023 and 2024 reporting, insufficient data were available to continue this approach.

Response action: Given mounting evidence that the seagrass health monitoring approach was no longer fit-for-purpose, DWER began developing a contemporary monitoring program which takes advantage of new technologies and methodologies – for implementation in early 2027.

Notes relevant to EQS (iii) – lower depth limit

The assessment of EQS (iii) was based on changes in the lower depth distribution of seagrass meadows compared with baseline at selected monitoring sites. Six seagrass sites were monitored for lower depth limit, but only four had 2000–02 baselines against which the 2023 and 2024 monitoring results could be compared.

The 2023 seagrass health assessment

The 2023 seagrass health assessment (Table 7) suggests that seagrass health in Cockburn Sound generally met the criteria.

See Appendix C for a full assessment of the 2023 monitoring results against the established seagrass health criteria.

Table 7: Scorecard of EQG and EQS achievements using the traditional Warnbro Sound reference sites in 2023 (dashes indicate an absence of data).

Ecological protection area	EQG met	Monitoring site	Traditional reference sites			
			EQS (i)	EQS (ii)	EQS (iii)	Overall result
HPA-N	✓	Luscombe Bay	✓	–	n/a	✓
		Garden Island Settlement	✓	–	n/a	
		Garden Is. (2.0 m)	✓	–	n/a	
		Garden Is. (2.5 m)	✓	–	n/a	
		Garden Is. (3.2 m)	✓	–	n/a	
		Kwinana	✓	✓	n/a	
		Garden Is. (5.2 m)	✓	✓	n/a	
		Garden Is. (7.0 m)	✓	✓	n/a	
		Garden Is. North (depth)	n/a	n/a	×	
		Garden Is. South (depth)	n/a	n/a	✓	
HPA-S	✓	[1]Southern Flats	✓	–	n/a	✓
		[1]Mangles Bay	✓	–	n/a	
MPA-CB	✓	n/a	n/a	n/a	n/a	n/a
MPA-ES	✓	Jervoise Bay	✓	–	n/a	✓
MPA-NH	✓	n/a	n/a	n/a	n/a	n/a
Reference site	n/a	Warnbro Sound (depth)	n/a	n/a	✓	✓

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

Trends were analysed for each site as an additional line of evidence. *However, the observed trends in Cockburn Sound should be interpreted with caution, given the likelihood of sampling fatigue contributing to increasingly depressed counts over time.*

The above caution notwithstanding, the results of the median seagrass shoot density trend analyses suggest:

- Neutral trends at Garden Island sites Settlement, 2.0 m, 2.5 m, 3.2 m (HPA-N); Kwinana (HPA-N); Luscombe Bay (HPA-N); Mangles Bay (HPA-S); Southern Flats (HPA-S); and at Bird Island, Carnac Island and Mersey Point (undesignated zone).
- Declining (but not statistically significant) trends at Garden Island 5.5 m and Garden Island 7.0 m (HPA-N) (Figure 6).
- Statistically significant declining trends at Jervoise Bay (MPA-ES) (Figure 6) and Woodman Point (undesignated).
- No significant trends at active reference sites (Warnbro Sound 5.2 m and 7.0 m).
- No significant trends reported for lower depth limit.

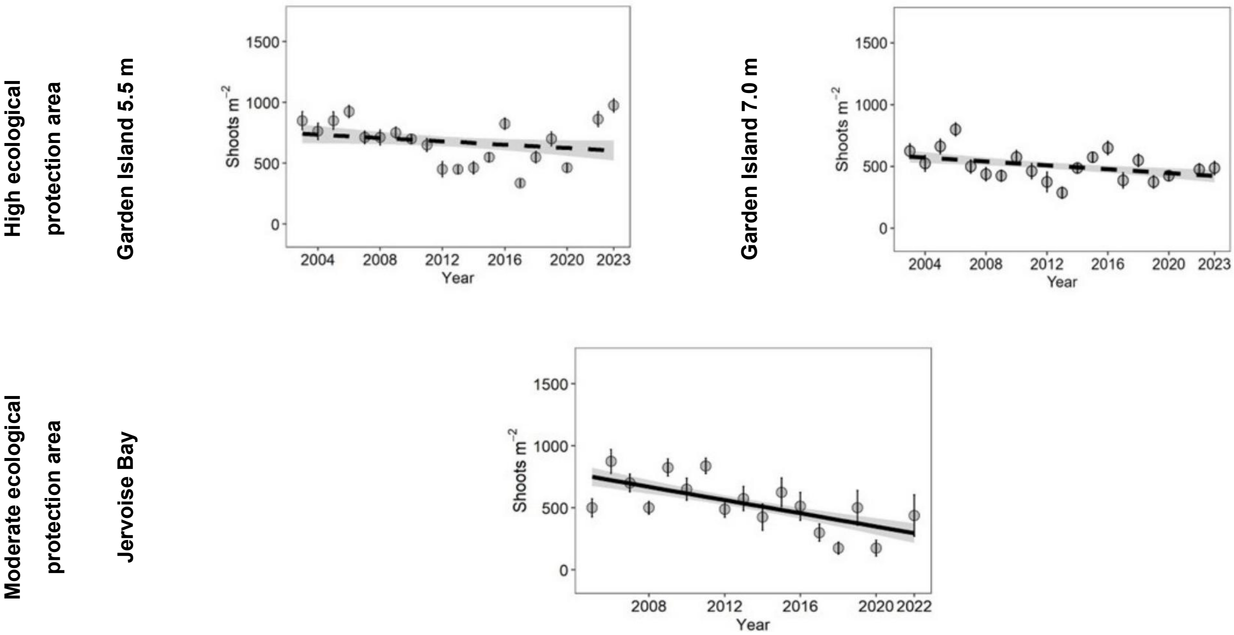

Figure 6: Mann-Kendall trend analysis results for median (+SE) Posidonia sinuosa shoot densities in the high and moderate ecological protection areas for 2023. A dashed line shows declining trends ($p<0.2$); a solid line shows significant trends ($p<0.05$).

Appendix C has figures for all the 2023 trends.

The 2024 seagrass health assessment

The 2024 seagrass health assessment (Table 8) excluded data from 2022 and 2023, due to the field sampling error during these years.

The 2024 seagrass health assessment demonstrates that EQS (i) was not achieved at four sites: Luscombe Bay, Garden Island Settlement, Garden Island (2.5 m) and Southern

Flats. EQS (ii) could not be calculated at many sites due to natural erosion and accretion processes causing loss of the shallow reference sites. EQS (iii) was achieved at Garden Island South (depth), but not at Garden Island North (depth) or Warnbro Sound (depth).

Despite some sites not meeting EQS (i), (ii) or (iii), the overall 2024 seagrass health assessment suggests that seagrass health in Cockburn Sound generally met the criteria.

See Appendix D for a full assessment of the 2024 monitoring results against the established seagrass health criteria.

Table 8: Scorecard of EQG and EQS achievements using the traditional Warnbro Sound reference sites in 2024

Where a dash (–) is present, it indicates there were no data recorded in 2024. Not all EQS are recorded at each monitoring site; hence 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			
			EQS (i)	EQS (ii)	EQS (iii)	Overall result
HPA-N	✓	Luscombe Bay	×	–	n/a	✓
		Garden Island Settlement	×	–	n/a	
		Garden Is. (2.0 m)	✓	–	n/a	
		Garden Is. (2.5 m)	×	–	n/a	
		Garden Is. (3.2 m)	✓	–	n/a	
		Kwinana	✓	✓	n/a	
		Garden Is. (5.2 m)	✓	✓	n/a	
		Garden Is. (7.0 m)	✓	✓	n/a	
		Garden Is. North (depth)	n/a	n/a	×	
		Garden Is. South (depth)	n/a	n/a	✓	
HPA-S	✓	[1]Southern Flats	×	–	n/a	✓
		[1]Mangles Bay	✓	–	n/a	
MPA-CB	✓	n/a	n/a	n/a	n/a	n/a
MPA-ES	✓	Jervoise Bay	✓	–	n/a	?
MPA-NH	✓	n/a	n/a	n/a	n/a	n/a
Reference site	n/a	Warnbro Sound (depth)	–	–	×	?

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

Trends were analysed at each site as an additional line of evidence. *However, the observed trends in Cockburn Sound should be interpreted with caution, given the likelihood of sampling fatigue contributing to increasingly depressed counts over time.*

The above caution notwithstanding, the results of the median seagrass shoot density trend analyses, which excludes 2022 and 2023 data (derived using an alternative methodology), suggest:

- Overall sites previously showing signs of decline were now in significant decline, and some *previously* stable sites were starting to show potential or clear downward trends.

- Neutral trends at Garden Island sites 2.0 m and 2.5 m, Luscombe Bay (HPA-N) and at Bird Island, Mersey Point and Carnac Island (undesignated zone).
- Declining but not statistically significant trends at Kwinana (HPA-N).
- Statistically significant declining trends at:
    - HPA-N: Garden Island Settlement, 3.2 m, 5.2 m and 7.0 m (Figure 7)
    - HPA-S: Southern Flats and Mangles Bay (Figure 7)
    - MPA-ES: Jervoise Bay (Figure 7).
- The active reference sites showed a significant declining trend at one site – Warnbro 5.2 m – but no trend at Warnbro Sound 7.0.
- No statistically significant trends reported for lower depth limit.

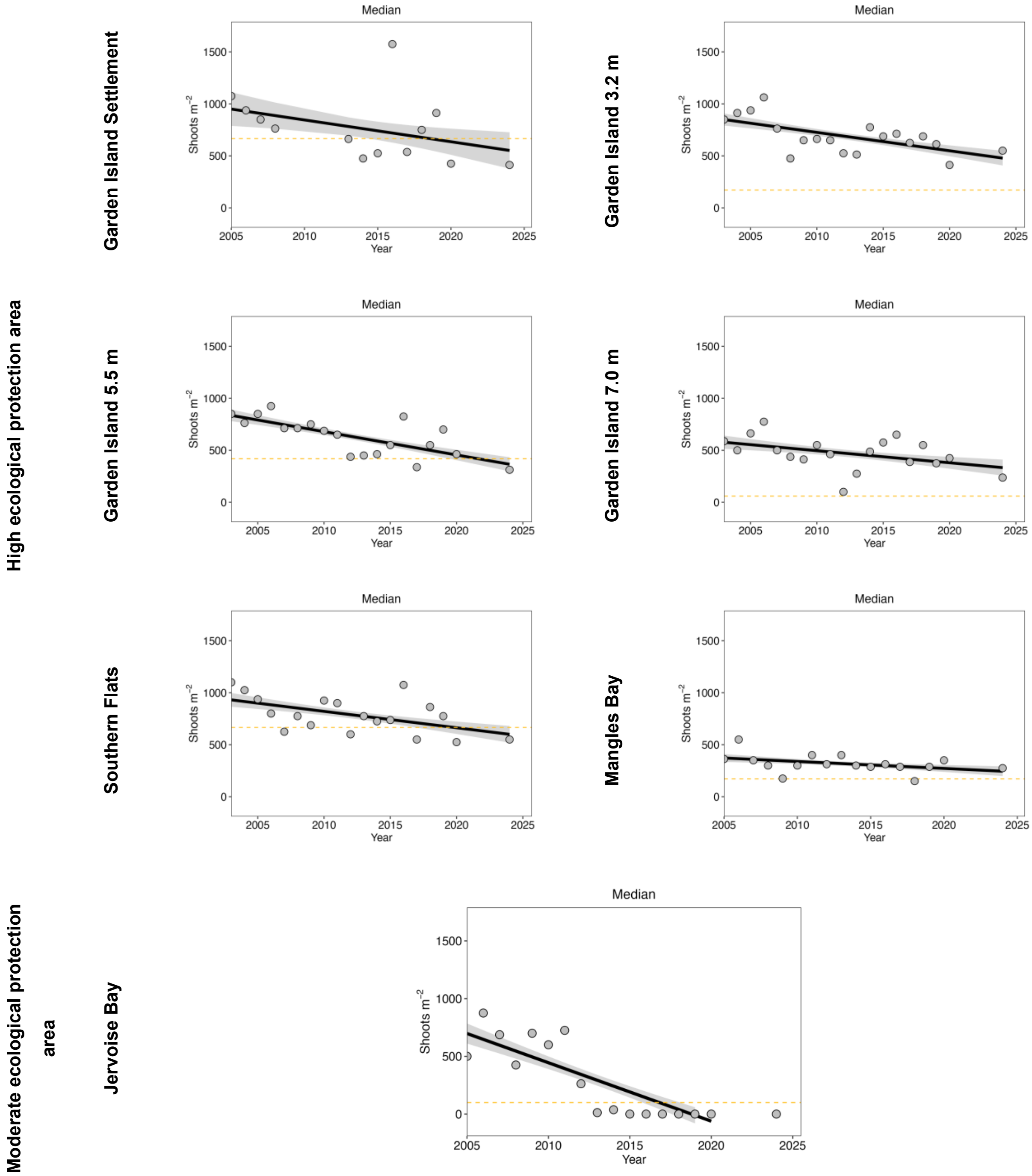

Figure 7: Mann-Kendall trend analysis results for median (+SE) Posidonia sinuosa shoot densities in the high and moderate ecological protection areas for 2024, excluding data from 2022 and 2023. A solid line shows significant trends (p<0.05).

Appendix D has figures for all 2024 trends.

Conclusion – 2023 and 2024 seagrass health assessments

Seagrasses are slow to recover from disturbance, and this has been evident in Cockburn Sound. After a period of significant and long-term nutrient pollution between the 1960s and 1980s, water quality has largely been restored. But despite nutrient levels and light attenuation in the water column generally meeting the relevant EQC across the Sound, no evidence of any substantial recovery in seagrass health has emerged since monitoring began in the 1990s.

The 2023 and 2024 seagrass health data indicate, overall, that seagrass health was broadly achieved for each of the ecological protection areas (HPA-N, HPA-S, MPA-ES) for both years – noting the EQS was not achieved at four sites in 2024 and that significant declines in shoot density were observed at seven sites. The data generally suggest a decline in health from previous years. Based on the information at hand, there is high confidence that seagrass health has generally decreased within the Sound since the early 2000s. However, there is an increasing degree of uncertainty around the cause and rate of the observed declines, owing to the following three findings:

1. The decrease in seagrass health does not appear to be related to water quality, with the EQG for chlorophyll-a and light attenuation coefficient generally being met for most monitoring sites. Hence there is no evidence of a single cause (e.g. nutrient enrichment) being responsible. For most of the sites where declines have been observed, these appear more likely to have been caused by cumulative impacts from a mix of local and regional pressures, according to a recent review delivered as part of the WWMSP (McMahon et al. 2025). Drivers of decline thought to have contributed are erosion and sediment burial in shallow sites, anchor damage at Mangles Bay and sediment plumes from the sand mining wash plant at Woodman Point. Warming trends, storms and altered hydrodynamics may also have affected seagrass health but local stressors are considered more significant.
2. A recent study commissioned by DWER for the 2025 monitoring season found evidence of sampling fatigue associated with the established ‘fixed quadrat’ monitoring methodology. Seagrass health is assessed through counting the number of shoots within each fixed quadrat, which is a manual process whereby divers physically handle each shoot. There are indications that this manual process and the securing of fixed quadrats may have increasingly affected seagrass shoot density over time. The 2025 study examined this potential cause at one site in Cockburn Sound, where divers counted seagrass shoots in the traditional fixed quadrats and in new random quadrats along the same established transect. The shoot counts were found to be much higher in the random quadrats compared with the fixed quadrats, providing evidence for sampling fatigue. If sampling fatigue proves to have been a factor, it is likely to have increasingly, and artificially, depressed seagrass shoot counts and exaggerated declining trends. This issue is being investigated and will be reported on in 2026. The Department of Biodiversity, Conservation and Attractions has identified sampling fatigue as a cause of seagrass decline at fixed quadrats in Shoalwater Islands Marine Park.
3. A study investigating regional trends in seagrass health observed at five sites across south-western Western Australia over 20 years, published in July 2024 as part of the WWMSP (Webster et al. 2024), found that declines and oscillations in seagrass health across the region were related to ocean warming attributed to La Niña events as a part of the ENSO cycle. The average decline observed in Cockburn Sound was reported to be similar to the declines observed in the more pristine waters of Jurien Bay and Shoalwater Islands marine parks between 2003 and 2022. These findings suggest a regional source may be contributing to cumulative pressure affecting seagrass health in the Sound – likely associated with global warming and the increasing frequency, duration and intensity of extreme events.

4. Based on the findings above, it was concluded that the state of seagrass health in Cockburn Sound was ‘uncertain’ at present, and that additional work was required to: (i) understand current seagrass condition; and (ii) contemporise and strengthen the seagrass health monitoring methodology to improve the monitoring and reporting on seagrass health going forward. This work is being progressed.

2.3.3 Phytoplankton biomass

The effect of nutrient enrichment on the frequency and severity of phytoplankton blooms was assessed by comparing monitoring data against two EQG and, where these were 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 numbers of occurrence and conducted over two years.

Numerical criteria were calculated for the non-river-flow period at three times the median chlorophyll-a concentration of the reference site for high ecological protection areas; and three times the 80th percentile of the reference site for moderate ecological protection areas. Note that there were two components to this EQG and EQS: site scale assessment; and broader regional scale assessment.

See Table 9 for the updated phytoplankton biomass criteria for 2023 and 2024.

Table 9: Updated phytoplankton biomass criteria (chlorophyll-a) for each of the current reporting years.

	n	High protection (3 × median Chl-a, µg/L)	Moderate protection (3 × Chl-a 80th percentile, µg/L)
2023	107	2.10	2.70
2024	95	2.10	2.70

Summary of outcomes

See Table 10 and Table 11 for compliance of each of the sites and protection areas against the phytoplankton biomass EQC.

Table 10: Assessment of phytoplankton biomass (chlorophyll-a concentrations) at Cockburn Sound sites from December 2022 to March 2023 against the phytoplankton biomass EQC.

<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 colspan="2">EQS (i)</th><th colspan="2">EQS (ii)</th><th rowspan="2">Overall result</th></tr>
<tr><th>2022</th><th>2023</th><th>2022</th><th>2023</th></tr>
<tr><td rowspan="6">HPA-N</td><td>CS4</td><td rowspan="6">✓</td><td>✓</td><td rowspan="6">✓</td><td rowspan="6">✓</td><td>✓</td><td>✓</td><td rowspan="6">EQG met
EQS met</td></tr>
<tr><td>CS5</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>CS8</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>CB</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>G2</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>G3</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td rowspan="4">HPA-S</td><td>CS11</td><td rowspan="4">✓</td><td>✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td>✓</td><td>✓</td><td rowspan="4">EQG met
EQS met</td></tr>
<tr><td>CS13</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>SF</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>MB/MB-L</td><td>✓</td><td>×</td><td>✓</td></tr>
<tr><td>MPA-CB</td><td>G1</td><td>–</td><td>✓</td><td>n/a</td><td>n/a</td><td>✓</td><td>✓</td><td>EQG met
EQS met</td></tr>
<tr><td rowspan="6">MPA-ES</td><td>CS10N</td><td rowspan="6">✓</td><td>✓</td><td rowspan="6"></td><td rowspan="6"></td><td>✓</td><td>✓</td><td rowspan="6">EQG met
EQS met</td></tr>
<tr><td>CS12</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>CS6A</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>CS7</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>CS9</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>CS9A</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>MPA-NH</td><td>NH3</td><td>×</td><td>×</td><td>n/a</td><td>n/a</td><td>×</td><td>×</td><td>EQG exceeded
EQS exceeded</td></tr>
</table>

Table 11: Assessment of phytoplankton biomass (chlorophyll-a concentrations) at Cockburn Sound sites from December 2023 to March 2024 against the phytoplankton biomass EQS (ii)

Ecological protection area	Monitoring site	EQG (i)	EQG (ii)	EQS (i)		EQS (ii)		Overall result
				2023	2024	2023	2024	
HPA-N	CS4	✓	✓	✓	✓	✓	✓	EQG met EQS met
	CS5		✓			✓	✓	
	CS8		✓			✓	✓	
	CB		✓			✓	✓	
	G2		✓			✓	✓	
	G3		✓			✓	✓	
HPA-S	CS11	✓	✓	✓	✓	✓	✓	EQG exceeded EQS met
	CS13		✓			✓	✓	
	SF		✓			✓	✓	
	MB/MB-L		×			✓	×	
MPA-CB	G1	–	✓	n/a	n/a	✓	✓	EQG met EQS met
MPA-ES	CS10N	✓	✓			✓	✓	EQG met EQS met
	CS12		✓			✓	✓	
	CS6A		✓			✓	✓	
	CS7		✓			✓	✓	
	CS9		✓			✓	✓	
	CS9A		✓			✓	✓	
MPA-NH	NH3	×	×	n/a	n/a	×	×	EQG exceeded EQS exceeded

Conclusion – phytoplankton biomass assessment

Assessment against the relevant updated EQG and EQS indicates that phytoplankton biomass in Cockburn Sound was generally within guideline values. The two exceptions were Mangles Bay (MB) – which exceeded the EQG (ii) but met the EQS – and Northern Harbour (NH3) – which continued to follow its recent historical pattern of exceeding the EQS.

NH3 is known to have a persistent nutrient enrichment problem, owing to a nutrient-contaminated groundwater plume which enters poorly flushed harbour waters at the coast. These conditions are thought to drive the consistent EQS exceedances at NH3**.** However, this criterion relates to the EQO of maintaining ecosystem integrity, and the Northern Harbour is an extensively modified environment with limited remaining natural values**.** It is this status that has seen a low level of importance assigned to EQS exceedances at NH3. Nevertheless, it is connected to the greater Cockburn Sound area and diminishing environmental quality at NH3 has the potential to negatively impact the wider region.

Of the four sites within the HPA-S, MB is the only site to have exceeded the phytoplankton biomass criteria in recent years. These exceedances occurred in January (2022 and 2024) with observations noting green discolouration and high turbidity. This site is in a poorly flushed area of the Sound and is also shallow, with an integrated sampling depth of close to 2 m. Both factors will tend to yield higher chlorophyll-a values.

See Appendix F for a full assessment of the 2023 and 2024 monitoring results against the phytoplankton criteria.

2.4 Assessment against the EQC for other physical and chemical stressors

2.4.1 Dissolved oxygen concentration

Monthly measurements of DO concentrations (% saturation) were collected in the bottom waters[3] at 19 water quality monitoring sites in the Sound (Figure 2) from 1 December 2022 to 31 November 2024 and 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.

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

The DO concentration recorded at each site was compared with the relevant EQG and EQS. The EQS was exceeded once during the 2023 season (Table 12). Bottom percent DO was recorded as 55.5% at CS9 in February 2023: this was the only exceedance of either EQG or EQS in any moderate protection area in Cockburn Sound that season. As

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

this was a single exceedance in relation to EQS (ii) or EQS (iii), it is unlikely to represent a sustained and potentially damaging threat to marine environmental quality.

Data collected by a DWER water quality monitoring buoy on Kwinana Shelf, sampling DO at 8.5 m water depth, about 2 km from CS9, were plotted to investigate the frequency and duration of low DO events on the Kwinana Shelf more generally. Data from February 2023 did not record any occurrence of DO below 60% saturation and suggest that DO events below 80% were typically short-lived; that is, in the order of a day (Figure 7).

Within the high protection areas, 31% and 10% of individual observations exceeded the EQG in HPA-S and HPA-N respectively. These exceedances were all in the January to June period.

In 2023–24, no site exceeded the EQS and fewer EQG exceedances were recorded (Table 13).

Table 12: 2023 Assessment of dissolved oxygen concentrations (% saturation) in bottom waters at Cockburn Sound sites against the dissolved oxygen 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)	2	×	✓	✓
	CS5 (19 m)	1	×	✓	✓
	CS8 (20 m)	0	✓	✓	✓
	CB (9.5 m)	0	✓	✓	✓
	G2 (11 m)	0	✓	✓	✓
	G3 (17 m)	2	×	✓	✓
	DESAL (16 m)	2	×	✓	✓
HPA-S	CS11 (18 m)	4	×	✓	✓
	CS13 (20 m)	5	×	✓	✓
	SF (3.5 m)	2	×	✓	✓
	MB/MB-L (1.5 m)	4	×	✓	✓
MPA-CB	G1 (15 m)	0	✓	✓	✓
MPA-ES	CS10N (16 m)	0	✓	✓	✓
	CS12 (10 m)	0	✓	✓	✓
	CS6A (10 m)	0	✓	✓	✓
	CS7 (10.5 m)	0	✓	✓	✓
	CS9 (13 m)	1	×	×	×
	CS9A (16 m)	0	✓	✓	✓
MPA-NH	NH3 (10 m)	0	✓	✓	✓

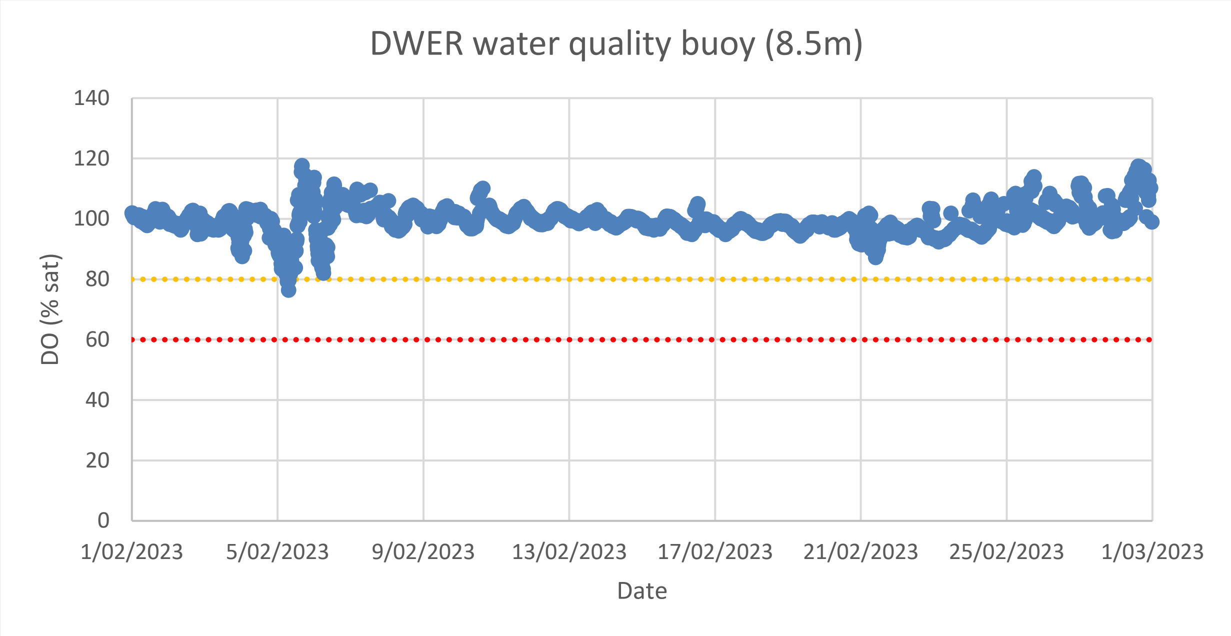

Figure 7: Dissolved oxygen (% saturation) in the bottom waters at DWER water quality buoy monitoring site on Kwinana Shelf (8.5 m depth) during February 2023. Orange dotted line is 80% saturation (EQG) and red dotted line is 60% saturation (EQS).

Table 13: 2024 assessment of dissolved oxygen concentrations (% saturation) in bottom waters at Cockburn Sound sites against the dissolved oxygen 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)	4	×	✓	✓
	CS5 (19 m)	4	×	✓	✓
	CS8 (20 m)	4	×	✓	✓
	CB (9.5 m)	0	✓	✓	✓
	G2 (11 m)	0	✓	✓	✓
	G3 (17 m)	0	✓	✓	✓
	DESAL (16 m)	4	×	✓	✓
HPA-S	CS11 (18 m)	3	×	✓	✓
	CS13 (20 m)	4	×	✓	✓
	SF (3.5 m)	0	✓	✓	✓
	MB/MB-L (1.5 m)	1	×	✓	✓
MPA-CB	G1 (15 m)	0	✓	✓	✓
MPA-ES	CS10N (16 m)	0	✓	✓	✓
	CS12 (10 m)	0	✓	✓	✓
	CS6A (10 m)	0	✓	✓	✓
	CS7 (10.5 m)	0	✓	✓	✓
	CS9 (13 m)	0	✓	✓	✓
	CS9A (16 m)	1	×	✓	✓
MPA-NH	NH3 (10 m)	0	✓	✓	✓

Dissolved oxygen concentrations at Water Corporation monitoring sites

DO concentrations, measured as percentage saturation, were collected quarterly in bottom waters at three Water Corporation sites in Cockburn Sound and two sites outside the Sound during both years of the reporting period. On each sampling occasion, additional DO measurements were taken at Cockburn Sound water quality monitoring sites CS9 and CS12 in MPA-ES. Assessment results for all the monitored sites are presented in Table 14 (2023) and Table 15 (2024). Results largely mirror those of the routine Cockburn Sound environmental monitoring program (Table 12 and Table 13); however, Water Corporation monitoring data indicate lower DO levels in HPA-S in February 2024, with an exceedance of the EQS for DO.

Table 14: Assessment of 2023 dissolved oxygen (% saturation) in the bottom waters at Water Corporation monitoring sites in and outside Cockburn Sound. Orange and red crosses are indicative of values not meeting the EQG and EQS respectively.

Ecological protection area	Site (depth)	Feb 2023	May 2023	Aug 2023	Nov 2023
		EQG/EQS 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)	×	✓	✓	✓

Table 15: Assessment of 2024 dissolved oxygen (% saturation) in the bottom waters at Water Corporation monitoring sites in and outside Cockburn Sound. Orange and red crosses are indicative of values not meeting the EQG and EQS respectively.

Ecological protection area	Site (depth)	Feb 2024	May 2024	Aug 2024	Nov 2024
		EQG/EQS 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 – dissolved oxygen assessment

Bottom water DO concentrations often met guideline values, particularly through the winter and spring seasons. The CS9 site in MPA-ES failed to meet EQS (i) in February 2023, as measured by both Council and Water Corporation monitoring. However, high-frequency data from a logger at a nearby DWER site provides some confidence that low DO events on Kwinana Shelf more generally are short-lived. The only other EQS (i) exceedance for

DO was detected by the Water Corporation monitoring program in February 2024 in HPA-S. There were no recorded changes in ecological or biological indicators linked to low DO or mortality events that would trigger an exceedance of EQS (ii) or EQS (iii) respectively. While the transient nature of EQS (i) exceedances and lack of events triggering EQS (ii) or EQS (iii) suggests that relevant water quality objectives are generally being achieved, the results suggest a future focus on possible drivers of low DO in the southern section of MPA-ES and HPA-S could be of benefit.

2.4.2 Water temperature

Monthly measurements of surface and bottom water temperature were collected at 19 water quality monitoring sites (Figure 2) from 1 December 2022 to 30 November 2024.

Following the guidance (EPA 2017: 31), median water temperature calculated at an individual site over any season was to be compared against the 80th percentile (high protection area) or 95th percentile (moderate protection area) derived from measurements at a suitable reference site for the same season. Deployed data loggers or weekly sampling events were to provide sufficient data for comparison against the criteria. However, for three seasons (2022–24), a monthly monitoring program was adopted. As such, for the 2023 and 2024 assessments, only three measurements per season were available, which prevented the calculation of statistically robust median and percentile values for assessment against the criteria.

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 have been grouped according to depth, with reference site WS4 accompanying deeper sites and reference site WSSB accompanying shallower sites (Figures G1–G8 in Appendix G).

Winter 2023 surface temperatures were higher at CS12 compared with other deep sites (Figure G1), but this was not reflected in bottom temperatures (Figure G2). NH3, being less connected to surrounding waters due to the harbour breakwater, had slightly higher summer temperatures and lower winter temperatures compared with other sites. Summer and winter temperatures were generally higher in 2024 compared with 2023, while spring temperatures were cooler.

Conclusion – water temperature assessment

Though a statistically meaningful assessment against the temperature criteria could not be completed, the collected data suggest established criteria were generally met and that water temperature in Cockburn Sound was not significantly adversely affected by anthropogenic activity at an ecosystem scale. At a site scale, the only potential exception to this appeared to be CS12 during the winter of 2023.

2.4.3 Salinity

Monthly measurements of surface and bottom water salinities were collected at 19 water quality monitoring sites (Figure 2) from 1 December 2022 to 30 November 2024.

Median salinity calculated over a season for individual sites were to be compared against the 80th percentile (high protection area) or 95th percentile (moderate protection area) values derived from measurements at reference sites. Deployed data loggers or weekly sampling events were to provide sufficient data for comparison against the criteria. However, for three years (2022–24), a monthly monitoring program was adopted. Hence, for the 2023 and 2024 assessments, only four measurements (during the non-river-flow periods) were available, which prevented the calculation of statistically robust median and percentile values for assessment against the criteria.

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 G9–G16 in Appendix G). Note that these have been grouped according to depth, with reference site WS4 accompanying deeper sites and reference site WSSB accompanying shallower sites.

Surface salinities had a consistent pattern across all sites (Figures G9–G12). The main exception to this was NH3, which had significantly lower salinities in winter and spring as a result of the harbour breakwater limiting exchange with the rest of the sound (Figures G9 and G10). The Mangles Bay shallow site (MB) also experienced low winter surface salinities – this was attributed its proximity to the shoreline and surface runoff, as well as reduced mixing with deeper waters.

During both 2023 and 2024, irregularities in bottom water salinities were observed at the MPA-ES sites CS9, CS12 and CS7. These sites had notably higher bottom salinities than other sites, including CS9A and CS10N. This has been observed in previous years but appears to have been more substantial in both 2023 and 2024.

Salinity concentrations at Water Corporation monitoring sites

Salinity concentrations were measured quarterly (February, May, August and November) from three Water Corporation sites in Cockburn Sound and two outside it, as well as from the CS9 and CS12 water quality monitoring sites in the Sound (Figure 2). The collected data supported Cockburn Sound monitoring program data, also indicating elevated bottom salinities at CS9 and CS12, and at the nearby Water Corporation site DIFF50W.

Conclusion – Salinity assessment

While the available data provides reasonable confidence that the EQO has been maintained, there is some indication that areas of the eastern shelf are being affected by a saline plume (primarily CS9 and CS12). These results might be explained by the proximity of the Perth Seawater Desalination Plant diffuser outfall to site CS12 (10 m depth), close to the Calista Channel, and to site CS9 (13 m depth), a small distance ‘downstream’ in the 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 southerly direction towards CS9 and into the Stirling Channel, where it is directed into the deeper central basin of the Sound.

Though notable, the salinity increases of about 0.6–0.9 are not large and are thus unlikely to push past the tolerance levels of benthic biota for causing significant negative effects. However, changes in salinity may have more significant consequences when combined with other stressors. Considering that previous monitoring reports have contained similar observations, any effort to increase the spatial and temporal extent of water quality data in the area in the future would be of benefit and could focus on whether other water quality and biological parameters remain unaffected.

2.4.4 pH

Monthly measurements of surface and bottom water pH were collected at 19 water quality monitoring sites (Figure 2) from 1 December 2022 to 30 November 2024.

Median pH calculated over a season for individual sites was not to deviate beyond the 20th and 80th percentile (high protection area) and 5th to 95th percentile (moderate protection area) values derived from measurements at reference sites. Deployed data loggers or weekly sampling events were to provide enough data for comparison against the criteria. However, for three seasons (2022–24), a monthly monitoring program was adopted. As such, for the 2023 and 2024 assessments, only three measurements per season were available, which prevented the calculation of statistically robust median and percentile values for assessment against the criteria.

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. These were grouped according to depth with reference site WS4 accompanying deeper sites and reference site WSSB accompanying shallower sites (Figures G17–G24 in Appendix G).

The collected surface pH data show that in the Sound's HPA-S zone, deep site CS11 and shallow site MB had unusually acidic conditions in autumn 2023. In addition, pH levels were lower in summer and winter 2024 compared with 2023. This may have been due to the higher temperatures experienced during these seasons in 2024 and associated enhanced decomposition and respiration rates.

Conclusion – pH assessment

Though a statistically meaningful assessment against the pH criteria could not be completed, the collected data suggest established criteria were generally met and that water pH in Cockburn Sound was not significantly adversely affected by anthropogenic activity at an ecosystem scale.

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 19 water quality monitoring sites (Figure 2) in Cockburn Sound from December 2022 to November 2024.

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) was not to 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 or moderate protection EQG value of 1,500 µg/L, the EQG for ammonia was deemed 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 February 2023 and 2024 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 to calculate a median value for comparison with the EQG and, where less than 20 samples are taken, 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, when 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 16).

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.

The total toxicity of the mixture (TTM),[4] based on the effects of ammonia, copper and benzene, was below 1 at all sites across both years (Table 16 and Table 17)

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 16: 2023 Assessment of toxicants in marine waters around Kwinana Bulk Terminal and Kwinana Bulk Jetty against the moderate protection EQG or LRV for toxicants.

Toxicant (µg/L)	EQG/LRV (µg/L)	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Ammonia	EQG: 1,200	<3[S]	<3[S]	<3[S]	<3[S]	<3[S]	<3[S]
		4[B]	<3[B]	3[B]	<3[B]	<3[B]	<3[B]
Copper (filtered)	EQG: 3.0	0.3[S]	0.3[S]	0.6[S]	0.3[S]	0.6[S]	0.3[S]
Benzene	EQG: 900	<1[S]	<1[S]	<1[S]	<1[S]	<1[S]	<1[S]
Toluene	LRV: 230	<2[S]	<2[S]	<2[S]	<2[S]	<2[S]	<2[S]
Ethylbenzene	LRV: 5.0*	<2[S]	<2[S]	<2[S]	<2[S]	<2[S]	<2[S]
Xylene	m-xylene LRV: 75* p-xylene LRV: 200*	<2[S]	<2[S]	<2[S]	<2[S]	<2[S]	<2[S]
TRHs (C6–C40)	LRV: 7^	<250	<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
* High protection LRV (there is no moderate protection LRV)
^ LRV for total petroleum hydrocarbons. Note that LOR for total recoverable hydrocarbons is over an order of magnitude higher than the LRV.

[4] 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.

Table 17: 2024 Assessment of toxicants in marine waters around Kwinana Bulk Terminal and Kwinana Bulk Jetty against the moderate protection EQG or LRV for toxicants.

Toxicant (µg/L)	EQG/LRV (µg/L)	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Ammonia	EQG: 1,200	$<3^{S}$	$<3^{S}$	$<3^{S}$	25^{S}	$<3^{S}$	$<3^{S}$
		$<3^{B}$	$<3^{B}$	–	–	–	–
Copper (filtered)	EQG: 3.0	0.3^{S}	0.3^{S}	0.3^{S}	0.3^{S}	0.7^{S}	0.6^{S}
Benzene	EQG: 900	$<1^{S}$	$<1^{S}$	$<1^{S}$	$<1^{S}$	$<1^{S}$	$<1^{S}$
Toluene	LRV: 230	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$
Ethylbenzene	LRV: 5.0*	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$
Xylene	m-xylene LRV: 75* p-xylene LRV: 200*	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$	$<2^{S}$
TRHs (C6–C40)	LRV: 7^	<250	<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
* High protection LRV (there is no moderate protection LRV)
^ LRV for total petroleum hydrocarbons. Note that LOR for total recoverable hydrocarbons is over an order of magnitude higher than the LRV.
'–' indicates that data were not available

2.5.3 Conclusion – toxicants in marine waters assessment

A lack of available data meant that robust 95th percentiles could not be determined. However, established criteria were met at all stations and sampling occasions, suggesting that relevant water quality objectives were being achieved. These results and the results from a 2024 Westport baseline survey of sediment quality in Cockburn Sound (Wilson & Wienczugow 2024b) indicate no significant threat to ecosystem integrity from toxicants in water.

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 2023 and 2024 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.

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 or PFAS in sediment.

No metals exceeded EQG values at any Kwinana Bulk Terminal or Jetty sites in 2023 (Table 18). In 2024, there was an exceedance of the chromium EQG around the Terminal, as well as exceedances of both the cadmium and mercury EQG values around the Jetty (Table 19). The re-sampling trigger was not exceeded on any occasion. After normalisation to 1% total organic carbon, median concentrations of TBT in the Terminal samples were below the EQG value (Table 18 and Table 19). Of the three Jetty sites, one site exceeded the TBT EQG value in 2023 and two exceeded it in 2024. The re-sampling trigger was not exceeded on any occasion.

Calculation of the Butyltin Degradation Index (BDI) was hampered by most DBT and MBT values being < limit of reporting (LOR). The index values at KBJ sites were < 1, suggesting relatively slow degradation.

EQG values for organic substances were not exceeded in either 2023 or 2024, however, these substances were detected more often in 2024, particularly around the Terminal (Table 18 and Table 19).

Table 18: 2023 Assessment of toxicants 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	EQC		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Metals (mg/kg dry wt)								
Arsenic	20	70	2.97	2.51	3.53	2.15	1.99	1.74
Cadmium	1.5	10	<0.1	<0.1	0.1	1.1	0.3	0.3
Chromium	80	370	15.0	14.8	10.6	14.0	8.9	11.7
Copper	65	270	12.0	9.9	8.4	10.9	1.8	5.8
Lead	50	220	6.5	6.8	4.1	4.6	1.2	3.6
Mercury	0.15	1	0.06	0.06	0.04	0.09	0.01	0.05
Selenium	–	–	0.3	0.3	0.2	0.5	0.3	0.4
Zinc	200	410	26.5	18.7	25.7	22.1	5.1	15.2
Organotins (µg Sn/kg normalised to 1% total organic carbon [TOC])								
TBT	5	70	<0.5	0.7	1.4	3.4	**12.6**	4.0
Dibutyltin	–	–	<1	<1	<1	1	<1	1
MBT	–	–	<1	<1	<1	<1	<1	<1
BDI	–	–	4	1.67	0.69	0.3	0.14	0.36
Organics – Polycyclic Aromatic Hydrocarbons (mg/kg normalised to 1% TOC)								
Acenaphthene	0.016	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Acenaphthylene	0.044	0.64	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Anthracene	0.085	1.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Benzo(a)anthracene	0.261	1.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Benzo(a)pyrene	0.43	1.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chrysene	0.384	2.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Dibenzo(a,h)anthracene	0.063	0.26	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fluoranthene	0.6	5.1	0.13	<0.1	<0.1	0.1	<0.1	<0.1
Fluorene	0.019	0.54	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Naphthalene	0.16	2.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Phenathrene	0.24	1.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pyrene	0.665	2.6	0.11	<0.1	<0.1	<0.1	<0.1	<0.1
Organics – Hydrocarbons and per-/poly-fluoroalkyl substances (mg/kg normalised to 1% TOC)								
TRH (C6–C40)	-	-	<250	<250	<250	<250	<250	<250
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

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

Table 19: 2024 Assessment of toxicants 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	EQC		Kwinana Bulk Terminal			Kwinana Bulk Jetty		
	EQG	Re-sampling trigger	KBT1	KBT2	KBT3	KBJ1	KBJ2	KBJ3
Metals (mg/kg)								
Arsenic	20	70	6.77	5.40	31.2	6.60	4.56	3.64
Cadmium	1.5	10	0.3	0.1	<0.1	**6.4**	0.5	0.2
Chromium	80	370	36.0	27.7	**145**	35.1	19.1	17.1
Copper	65	270	26.2	26.6	1.9	15.3	3.4	4.0
Lead	50	220	15.4	9.7	10.8	7.8	1.6	1.8
Mercury	0.15	1	0.10	0.07	0.02	**0.16**	<0.01	0.02
Selenium	–	–	0.5	0.4	0.5	0.8	0.6	0.6
Zinc	200	410	63.0	36.1	6.6	139	6.6	7.5
Organotins (µg Sn/kg normalised to 1% total organic carbon [TOC])								
TBT	5	70	<0.5	1	1	4.7	**7.1**	**5.8**
Dibutyltin	–	–	<1	<1	2	<1	<1	1.4
MBT	–	–	<1	<1	2	<1	<1	1.4
BDI	–	–	4.0	1.25	4.0	0.19	0.22	0.5
Organics – Polycyclic Aromatic Hydrocarbons (mg/kg normalised to 1% TOC)								
Acenaphthene	0.016	0.5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acenaphthylene	0.044	0.64	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Anthracene	0.085	1.1	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a)anthracene	0.261	1.6	0.09	0.03	<0.1	0.04	<0.1	<0.1
Benzo(a)pyrene	0.43	1.6	0.09	0.03	<0.1	0.03	<0.1	<0.1
Chrysene	0.384	2.8	0.09	0.03	<0.1	0.05	<0.1	<0.1
Dibenzo(a,h)anthracene	0.063	0.26	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene	0.6	5.1	0.19	0.07	<0.01	0.08	<0.01	<0.01
Fluorene	0.019	0.54	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Naphthalene	0.16	2.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phenathrene	0.24	1.5	0.07	0.03	<0.01	0.02	<0.01	<0.01
Pyrene	0.665	2.6	0.19	0.06	<0.01	0.09	<0.01	<0.01
Organics – Hydrocarbons and per-/poly-fluoroalkyl substances (mg/kg normalised to 1% TOC)								
TRH (C6–C40)	–	–	<250	<250	<250	<250	<250	<250
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

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

2.6.2 Conclusion – toxicants in sediments assessment

In 2023 a single EQG exceedance was observed, while in 2024 sediment toxicant values in localised risk areas exceeded the EQG five times. All except one of these exceedances were around the Kwinana Bulk Jetty. Overall, conservative guideline values were generally met and all recorded toxicant concentrations remained below the re-sampling trigger. Noting that Fremantle Ports' sampling is targeted at localised risk areas around shipping activities and that a recent ecosystem-wide sediment quality survey of Cockburn Sound (Wilson & Wienczugow 2024a) found no exceedance of guidelines, it is unlikely that relevant water quality objectives have come under threat.

Although slightly elevated concentrations of TBT were observed in both 2023 and 2024, the levels detected in mussels were low.

2.8 Conclusion – environmental value: Ecosystem Health

Monitoring results highlighted some localised, albeit persistent, water quality issues, but indicated that for most water and sediment quality parameters the relevant ecosystem health criteria were consistently met across Cockburn Sound. Water quality issues were regularly reported in Jervoise Bay Northern Harbour – a known problem area. Issues were also frequently observed in the Sound's southern part, with exceedances of EQG for chlorophyll-a, light attenuation and phytoplankton biomass – keeping in mind that March 2024 was a notably poor month. However, the environmental quality standards for parameters in the southern part were not exceeded, suggesting the observed level of increase is acceptable. The consistency of the results for the Sound's southern part over time indicates that a degree of nutrient enrichment persists here, despite evidence of significant reductions in nutrient loads to the Sound from outfalls, surface drains and contaminated groundwater plumes in recent decades (Donn et al. 2025).

In addition, some localised water quality issues with respect to dissolved oxygen and salinity were reported in the southern part of Kwinana Shelf, which could be investigated further with additional monitoring.

The state of seagrass health in Cockburn Sound is uncertain at present – work is being done to investigate the identified issues. Observed seagrass shoot densities at several sites were depressed when compared with previous years. Based on the information at hand, there is high confidence that seagrass health has generally decreased within the Sound since the early 2000s. However, there is a degree of uncertainty with respect to the rate and cause of these observed declines, given preliminary evidence of sampling fatigue (within the established seagrass health quadrats) and the observation of similar declining seagrass health trends in Shoalwater Islands Marine Park and Jurien Bay for the same period. Additional work to be undertaken in early 2026 will help address this uncertainty.

Through consideration of all the available information, it was concluded that the environmental quality objective of *maintenance of ecosystem integrity* was likely to have been achieved during the 2023 and 2024 monitoring period, but that additional work was required to improve confidence around that conclusion.

A breakdown of the results for each component is presented in Table 20.

Table 20: Summarised assessment of ecosystem health criteria.

Group	Subgroup	Variable	Assessment*
Physical and chemical stressors	Nutrients	Chlorophyll-a	Localised issues noted (HPA-S)
		Light attenuation coefficient	Localised issues noted (HPA-S)
		Seagrass shoot density	Uncertain
		Seagrass leaf and lead cluster	n/a
		Seagrass lower depth limit	Criteria met
		Phytoplankton biomass	Localised, temporary issues noted (HPA-S; NH3)
	Other	DO	Several monthly measurements at multiple sites exceeded EQG values but met EQS. A single exceedance of EQS at CS9 in 2023.
		Water temperature	Generally, criteria appear to be met.
		Salinity	Generally, criteria appear to be met (persistent high salinity in MPA-ES).
		pH	Generally, criteria appear to be met.
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
Toxicants (sediment)	Metals and metalloids	Arsenic, cadmium, chromium, copper, lead, mercury, selenium and zinc	Minor issues localised at Fremantle Ports' Kwinana sites
	Organometallics	TBT, DBT, monobutyltin (MBT)	Minor issues localised at Fremantle Ports' Kwinana sites
	Organics	PAHs	Criteria met
	Oils and petroleum hydrocarbons	TRHs	No criteria available
	PFAS	PFOA, PFOS, and perfluorohexane sulfonate (PFHxS)	No criteria available

* White fill = could not be formally assessed; Green fill = criteria were met; Orange fill = EQG exceedances occurred; Red fill = EQS exceedances occurred.

3. Environmental value: Fishing and Aquaculture

3.1 Environmental quality objectives

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 Cockburn Sound's shellfish growing areas.

No commercial aquaculture operations were active within Cockburn Sound during the assessment period. Hence monitoring of phytoplankton and marine biotoxins in accordance with WASQAP requirements did not occur. Assessment against criteria for maintenance of aquaculture production was not undertaken.

Monitoring of toxicants in 'sentinel' mussels, undertaken by Fremantle Port Authority in March each year, provides data on 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 from lines with baskets suspended about 1 m below the water surface. These were deployed for six weeks before 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, with analyses undertaken at ChemCentre.

3.3 Assessment against the seafood safe for human consumption EQC

3.3.1 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 EQC (EPA 2017: 67–68) (Table 21 and Table 22).

Median chemical concentration in the flesh of seafood should not exceed the EQG. If an

EQG is exceeded, results are compared against the EQS in consultation with the Department of Health.

Pesticide residues in the flesh of seafood are typically not measured. However, should concerns trigger additional analyses for pesticides in seafood, concentrations 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.

These data did not detect any EQG exceedances. Chemical toxicants in mussels at these sites were all below the analytical limits of reporting.

Table 21: 2023 assessment of chemicals against the chemical concentration in seafood flesh EQC for mussels in Cockburn Sound.

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	0.052	<0.05	<0.05	<0.05	<0.05
Cadmium	–	2.0	0.075	0.096	0.064	0.088	0.086	0.091
Chromium	–	–	0.091	0.3	0.1	0.11	0.16	0.14
Copper	30	–	0.42	0.74	0.56	0.54	0.66	0.61
Lead	–	2.0	0.076	0.17	0.15	0.082	0.099	0.11
Mercury	–	*0.5 (mean)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium	1.0	–	0.27	0.39	0.29	0.28	0.29	0.39
†Zinc	290	–	20	26	19	20	21	21
TBT	–	–	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
DBT	–	–	<0.5	<0.5	0.57	<0.5	<0.5	<0.5
MBT	–	–	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Organics (mg/kg)								
PAHs	–	–	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

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

† Value is for adductor muscle (not whole organism).

* 1.0 mg/kg if n<5

Table 22: 2024 assessment of chemicals against the chemical concentration in seafood flesh EQC for mussels in Cockburn Sound.

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	0.08	0.073	0.063	0.081	0.07	0.076
Chromium	–	–	0.22	0.15	0.16	0.17	0.14	0.2
Copper	30	–	1	0.98	1	1.1	1	0.99
Lead	–	2.0	0.27	0.19	0.26	0.21	0.18	0.22
Mercury	–	*0.5 (mean)	0.01	<0.01	<0.01	<0.01	<0.01	0.01
Selenium	1.0	–	0.77	0.65	0.57	0.56	0.48	0.53
[†]Zinc	290	–	22	22	23	24	20	20
TBT	–	–	<1	<1	<1	<1	<1	<1
DBT	–	–	<1	<1	<1	<1	<1	1.6
MBT	–	–	<1	<1	<1	<1	<1	1.3
Organics (mg/kg)								
PAHs	–	–	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

3.4 Conclusion – environmental value: Fishing and Aquaculture

Compliance with criteria for aquaculture was not considered in this report, as there have been no aquaculture operations (for human consumption) in Cockburn Sound since August 2022. No monitoring for aquaculture quality assurance, as required by the WASQAP, has taken place since then.

While the chemical toxicants in mussels (Table 21 and Table 22) were below the relevant EQC, the data should not be interpreted as indicating that mussels or other seafood collected within Cockburn Sound are safe to eat. Several factors that may result in seafood being unsuitable for consumption were not monitored. These include marine biotoxins and a range of potentially pathogenic bacteria (e.g. *Vibrio* spp.). Sampling programs designed to provide assurance around seafood quality and safety are intensive and, as a result, expensive. For this reason, providing coverage of a large area such as Cockburn Sound is difficult and, as with all environmental waters, there is a level of risk assumed when recreationally harvesting food from these areas.

The Department of Health recommends only eating shellfish harvested commercially under strict quality assurance monitoring programs.

A study investigating the bioaccumulation of contaminants in fish and invertebrates caught in Cockburn Sound is underway. The study's objective is to establish an 'environmental baseline' through setting contaminant concentrations after grounding up the whole animal. The study is therefore not specifically aimed at addressing seafood quality questions, which are better investigated testing edible parts, but the results will provide the first reliable data on bioaccumulation in the Sound's biota and are expected to give some indication of seafood quality.

4. Environmental value: Recreation and Aesthetics

4.1 Environmental quality objectives

The EQOs for the environmental value of Recreation and Aesthetics are:

- *maintenance of primary contact recreation values* (primary contact recreation, such as swimming, is safe to undertake)
- *maintenance of secondary contact recreation values* (secondary contact recreation, such as 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 undertake bacterial water sampling at several popular recreational beaches (program sites) in Cockburn Sound during the peak recreational season between November and May each year (Figure 8). The Department of Health administers the program and encourages a minimum of 65 samples to be collected over five consecutive years. This is equivalent to 13 samples per season (i.e. about one sample being 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.[5]

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

Samples were analysed for *enterococci* by PathWest Laboratory. *Enterococci* are the bacterial indicator that the National Health and Medical Research Council (2008) guidelines recommend as they are more resistant to environmental stresses, making them useful indicators in marine environments.

[5] 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

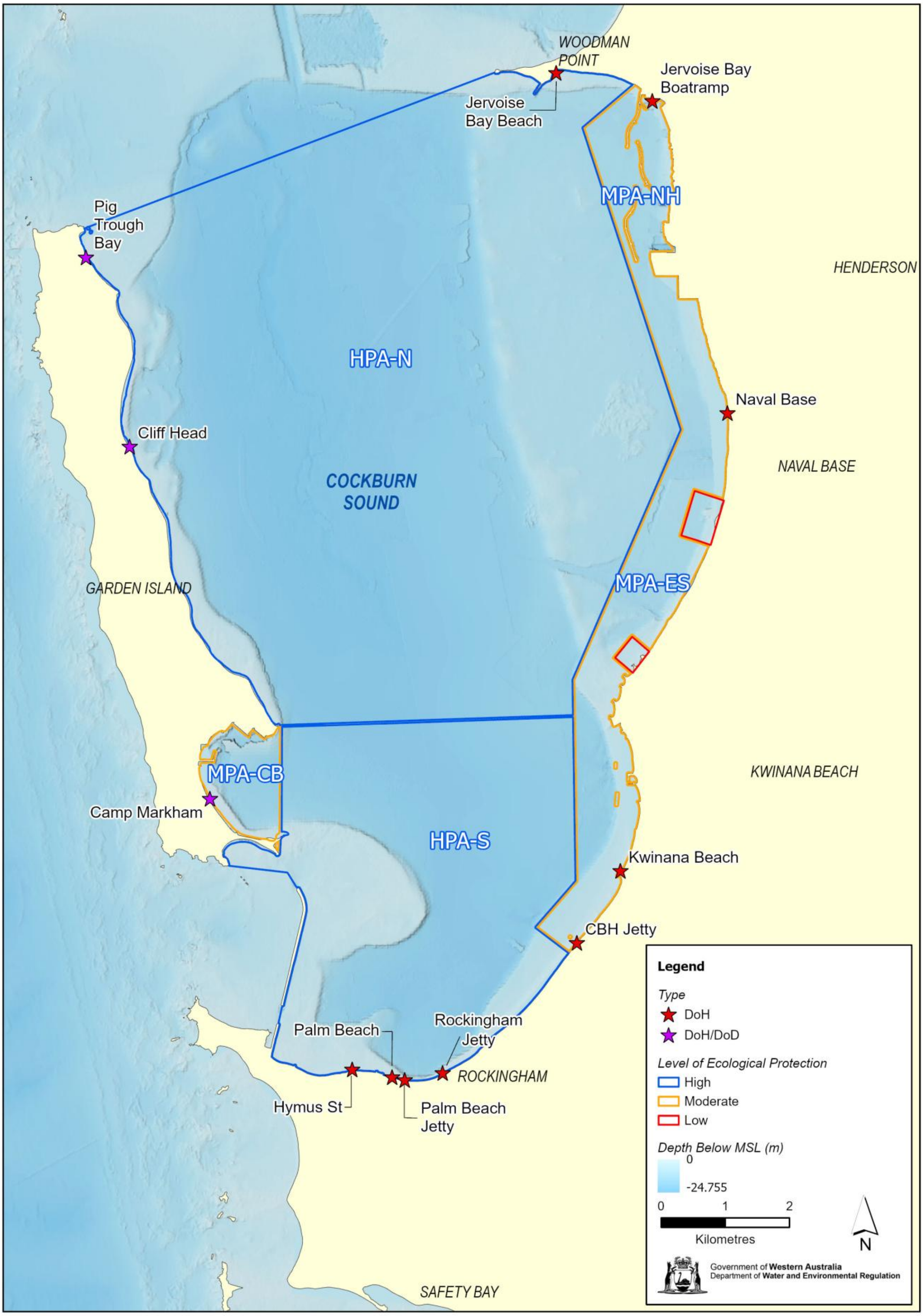

Figure 8: Sampling locations near recreational beaches in Cockburn Sound (Flukes 2024)

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 and May each year 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 23 and Table 24 below present the measured *Enterococci* counts reported by the Department of Health for 2023 and 2024 respectively. The faecal pathogens EQG for both primary and secondary contact recreation were met at all monitored sites.

Table 23: 2023 assessment of the 95th percentile of Enterococci counts at 12 locations in Cockburn Sound against the faecal enterococci EQG.

Location	Type of site	No. of measurements	Rolling 5-year 95th percentile of enterococci counts (MPN/100 ml)	EQG	
				Primary contact	Secondary contact
North Hymus Street[1]	Program	38	2	✓	✓
Jervoise Bay Beach[1]	Program	56	65	✓	✓
Rockingham Jetty[1]	Program	45	9	✓	✓
Palm Beach Jetty[1]	Program	43	16	✓	✓
Naval Base[1]	Program	23	10	✓	✓
Kwinana Beach[1]	Program	23	6	✓	✓
Jervoise Bay Boat Ramp[1]	Non-core	56	6	✓	✓
Palm Beach[1]	Non-core	39	2	✓	✓
CBH Jetty[1]	Non-core	18	100	✓	✓
Camp Markham	Program	65	5	✓	✓
Cliff Head	Program	65	10	✓	✓
Pig Trough Bay[1]	Program	57	2	✓	✓
Assessment		Primary and secondary contact recreation EQG were 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.

Table 24: 2024 assessment of the 95th percentile of Enterococci counts at 12 locations in Cockburn Sound against the faecal enterococci EQG.

Location	Type of site	No. of measurements	Rolling 5-year 95th percentile of enterococci counts (MPN/100 ml)	EQG	
				Primary contact	Secondary contact
North Hymus Street[1]	Program	62	2	✓	✓
Jervoise Bay Beach[1]	Program	55	70	✓	✓
Rockingham Jetty[1]	Program	48	2	✓	✓
Palm Beach Jetty[1]	Program	46	16	✓	✓
Naval Base[1]	Program	24	3	✓	✓
Kwinana Beach[1]	Program	24	2	✓	✓
Jervoise Bay Boat Ramp[1]	Non-core	55	22	✓	✓
Palm Beach[1]	Non-core	62	18	✓	✓
CBH Jetty[1]	Non-core	46	22	✓	✓
Camp Markham	Program	87	2	✓	✓
Cliff Head	Program	87	2	✓	✓
Pig Trough Bay	Program	78	2	✓	✓
Assessment		Primary and secondary contact recreation EQG were 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 19 water quality monitoring sites during the non-river-flow period between November 2022 and May 2024 (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.[6]

pH EQS: The median of the sample concentrations from the area of concern (either from one sampling run or from a single site over

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

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 in both 2023 and 2024 (Table 25 and Table 26).

Table 25: 2023 (November 2022 – May 2023) assessment of pH and water clarity in Cockburn Sound 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	8.1	8.1	>1.6 m	6.5 – 13.5	EQC met at all sites
CS5		8.2	8.2		6.2 – 13.4	
CS6A		8.1	8.2		3.6 – 10.0	
CS7		8.2	8.2		4.2 – 9.5	
CS8		8.2	8.2		5.5 – 13.0	
CS9		8.2	8.1		4.5 – 9.5	
CS10N		8.1	8.1		5.1 – 11.0	
CS11		8.2	8.1		7.5 – 11.0	
CS12		8.2	8.1		5.3 – 9.0	
CS13		8.1	8.1		6.8 – 10.4	
CS9A		8.2	8.1		4.5 – 9.2	
CB		8.2	8.2		4.3 – 10.0	
G1		8.1	8.1		6.9 – 9.0	
G2		8.1	8.2		6.2 - 9.5	
G3		8.1	8.2		7.0 – 11.0	
SF		8.1	8.2		3.0 – 4.0	
MB		8.1	8.1		1.7 – 2.2	
NH3		8.2	8.2		3.0 – 9.1	
DESAL		8.1	8.1		6.0 – 11.0	

* Maximum depth at site at time of monitoring

Table 26: 2024 (November 2023 – May 2024) assessment of pH and water clarity in Cockburn Sound 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	7.0 – 10.5	EQC met at all sites
CS5		8.2	8.2		5.8 – 9.2	
CS6A		8.2	8.2		4.5 – 8.9	
CS7		8.2	8.2		3.8 – 9.0	
CS8		8.2	8.2		5.1 – 10.0	
CS9		8.2	8.1		3.7 – 8.9	
CS10N		8.2	8.2		4.6 – 9.5	
CS11		8.2	8.1		4.8 – 9.7	
CS12		8.2	8.1		3.2 – 7.5	
CS13		8.2	8.1		4.1 – 10.3	
CS9A		8.2	8.2		3.9 – 9.7	
CB		8.2	8.2		5.5 – 9.2	
G1		8.2	8.2		4.0 – 11.9	
G2		8.2	8.2		2.5 – 8.5	
G3		8.2	8.2		7.0 – 10.3	
SF		8.2	8.2		3.0 – 4.1	
MB		8.2	8.2		1.5* – 2.9	
NH3		8.2	8.2		3.5 – 6.8	
DESAL		8.2	8.2		3.3 – 10.0	

* 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 in marine waters against the criteria established for ecosystem health. These criteria were met at all sites and on all 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 that this assessment did not need to be completed.

4.4 Assessment against aesthetic quality EQC

The community highly values the ecological, recreational and aesthetic attributes of Cockburn Sound, hence a set of qualitative EQC were developed to protect its aesthetic values (EPA 2017). Guidelines for aesthetic quality relate to the general appreciation and enjoyment of Cockburn Sound by the surrounding and visiting community. Additional factors considered are whether any negative 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 19 water quality monitoring sites between 1 December 2022 and 30 November 2024:

- 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 indicated recurrent issues around water discolouration and surface debris. Water discolouration was noted in all monthly sampling events from December 2022 to November 2024. Typically this was widespread green discolouration throughout Cockburn Sound. Least impacted sites were the Garden Island G2 and G3 sites and CS4 in the Sound’s north-west corner. Wheat grain debris on the surface was noted at CS10N on 14 of 24 monthly sampling occasions, with grain also being noted at CS13, CS8 and MB on one or two sampling occasions.

Records indicate a single reported fish-kill event in 2023 and none in 2024. The 2023 event occurred in March and involved about 25 dead fish (blowfish, western smooth boxfish and a mullet) observed at Challengers Beach, Naval Base. This is not considered a large-scale faunal death event, and therefore does not trigger an exceedance of EQG B for aesthetic quality (EPA 2017: 95).

Odour was reported at CS12 (April 2023), CS6A (July 2023) and CS13 (July 2024).

A slight scum of the marine cyanobacterium *Trichodesmium* was observed on 16 April 2024 at G1, G3 and CS4.

See Table H1 in Appendix H for details of the qualitative observations.

EQC for aesthetic quality also include guidelines for fish-tainting substances (EPA 2017: 96–97). Given no evidence or reports of tainted catch from recreational fishers, targeted monitoring for these substances is not being conducted at present. Using the data presented in Section 2.5.2, copper was below the EQG for fish-tainting substances, however other relevant measured chemicals (e.g. ethylbenzene, napthalene and toluene) could not be assessed as the EQG was below the analytical limit of reporting.

4.5 Conclusions – environmental value: Recreation and Aesthetics

Assessments of monitoring data against primary and secondary contact recreation criteria indicated guideline values were met. Yet these outcomes were based on fewer data points than the required minimum for sufficient confidence.

Noting that data for assessment against primary and secondary contact EQCs is limited, results provide some confidence that the EQOs of *maintenance of primary contact* *recreation values* and *maintenance of secondary contact recreation values* are generally being achieved in Cockburn Sound.

Green discolouration of Cockburn Sound's marine waters was frequently and broadly noted, while floating debris (wheat grain) was largely localised around the CBH Kwinana Grain Terminal (CS10N). Whilst the collected observations suggest some challenges may exist, a paucity of reports or complaints from the public indicates the EQO of *maintenance of aesthetic values* is generally being achieved.

5. Environmental value: Cultural and Spiritual

5.1 Environmental quality objective

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

No criteria have yet been developed specific to this environmental value. Existing EQC for protecting ecosystem integrity, seafood quality and recreational and aesthetic values may reasonably be expected to contribute to protecting cultural and spiritual values in Cockburn Sound. However, engagement with Traditional Owners is required to identify cultural and spiritual values for the Sound and to test whether additional objectives and/or criteria need to be developed to ensure these values are protected. This is being done as part of the SEP review project which is now underway.

6. Environmental value: Industrial Water Supply

6.1 Environmental quality objective

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, located in the industrial zone on Cockburn Sound's eastern shore, takes seawater from the Sound and uses reverse osmosis to produce drinking water for the Perth metropolitan area. The desalination plant produces up to 15% of Perth's water supply. Seawater of good quality is fundamental to the desalination plant's operation and helps prevent fouling and scaling.

Any reduced quality in the incoming seawater can significantly impact the pre-treatment requirements, and potentially the efficiency of the reverse osmosis membranes, resulting in additional costs to produce drinking water. Hence, given the development pressures in this area, water quality criteria have been defined for the intake seawater to protect the efficacy of the desalination process and maintain the quality of the desalinated water.

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

6.2 Desalination plant intake water quality monitoring

Water Corporation undertakes real-time continuous monitoring of a suite of parameters including temperature, pH, DO and electrical conductivity (EC) of intake seawater. Total dissolved solids (TDS) concentration is calculated from EC using a conversion factor of 700. All equipment at the desalination plant is routinely calibrated 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 bacterial indicators, which are monitored weekly; and boron and bromide, which are monitored quarterly. Sampling for the bacterial indicator *Escherichia coli* was replaced with sampling for *Enterococci* in May 2017, as this gives a more robust pathogen indicator in salt water. For water quality parameters, water samples are collected by an in-house process chemist and analysed by accredited laboratories.

Most of the data recorded from the seawater intake water quality instruments during major scheduled plant shutdowns, from 9 October to 6 November 2023 and 11 August to 16 September 2024, were removed as they are misrepresentative of seawater intake quality.

6.3 Assessment against industrial water supply EQC

6.3.1 Biological indicators

The EQS for biological content (*Enterococc*i) stipulates that the bacterial concentrations of intake water should not exceed 32 colony forming units per 100 millilitres (CFU/100 mL) on any occasion.

In both the 2023 and 2024 reporting periods, *Enterococci* numbers remained below the EQS of 32 CFU/100 mL. *Enterococci* concentrations also remained below the laboratory limit of reporting of 10 CFU/100 mL, except for three sampling occasions in 2023 and four in 2024.

6.3.2 Physical and chemical indicators

Temperature

Both real-time measures in the intake pipe and quarterly marine water quality monitoring adjacent to the desalination plant intake structure were used for assessment against the EQG.

Water temperature EQG: The 90th percentile of temperature measurements adjacent to the Perth Seawater Desalination Plant intake over a period not exceeding one month should not exceed 28°C.

Data indicate that temperature of the intake seawater remained below the EQG of 28°C at all times (Table 27; Figure 9 and Figure 10). The usual seasonal oscillation in water temperatures was observed, however temperatures tended to be higher in 2024 compared with 2023.

Table 27: Comparison of quarterly 90th percentile temperature of marine waters (full depth profile) adjacent to desalination plant intake structure against the EQG for both 2023 and 2024.

Sampling month/year	EQG (°C)	Depth-integrated 90th percentile
Dec-22	28	21.1
Feb-23		24.5
May-23		19.3
Aug-23		16.4
Nov-23		22.2
Feb-24		27.1
May-24		20.6
Aug-24		17.8
Nov-24		20.8

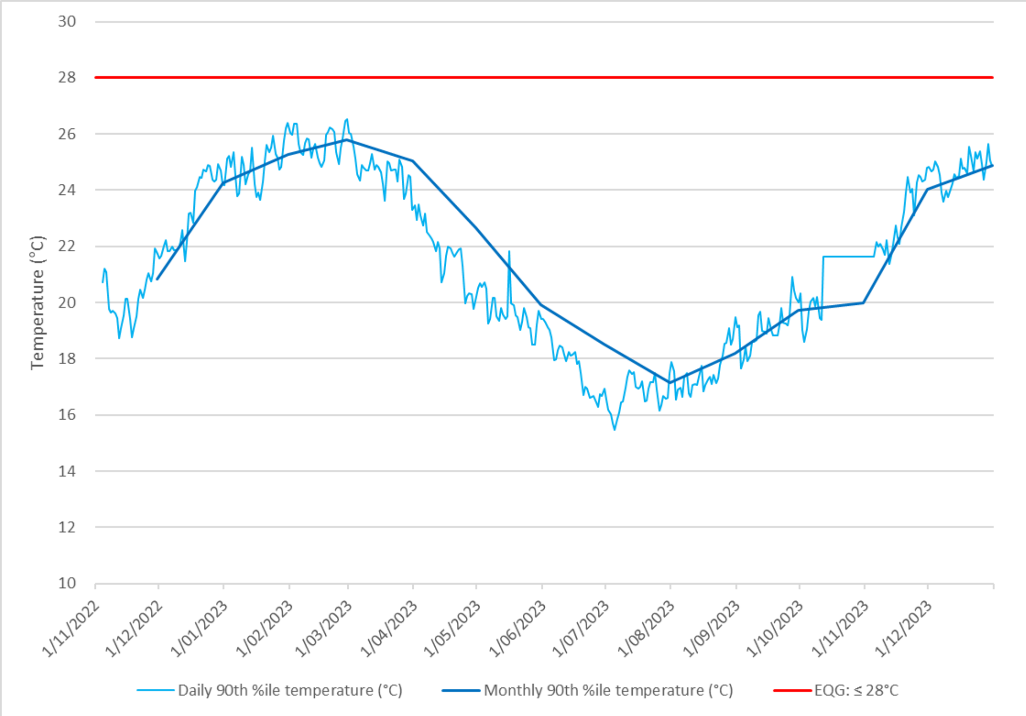

Figure 9: Daily and monthly 90th percentile temperature of intake seawater across the 2023 sampling season.

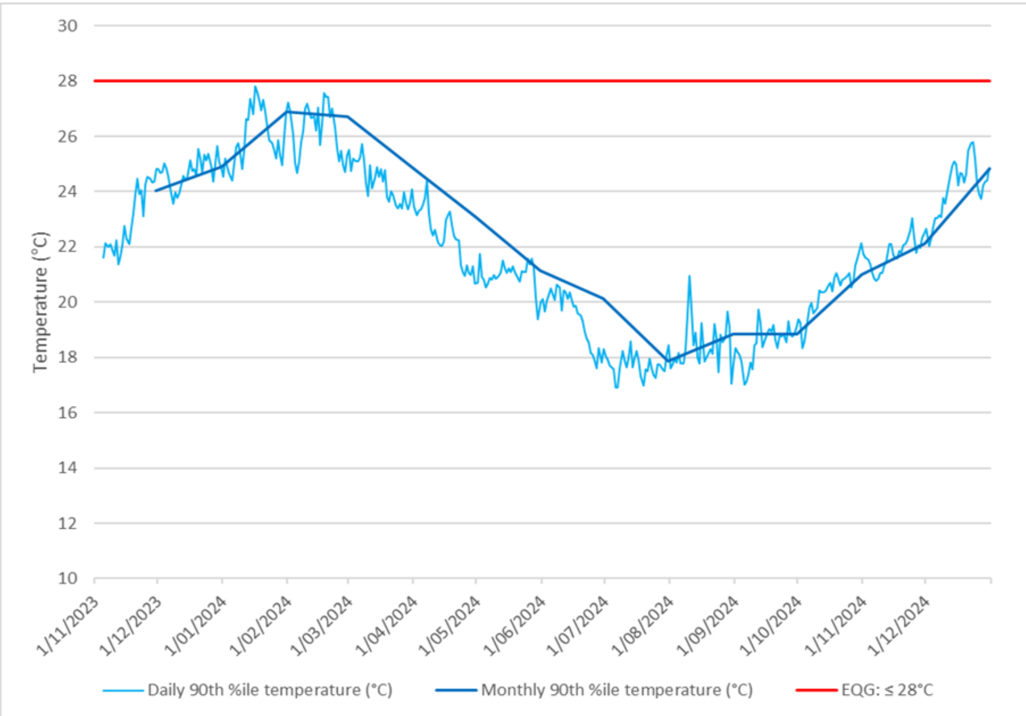

Figure 10: Daily and monthly 90th percentile temperature of intake seawater across the 2024 sampling season.

pH

Real-time measures in the intake pipe were used for assessment against the EQG.

Water pH EQG: The median pH adjacent to the Perth Seawater Desalination Plant intake over a period not exceeding one month should not exceed 8.5.

Median daily and monthly pH of intake water remained below the EQG of 8.5 (Figure 11 and Figure 12).

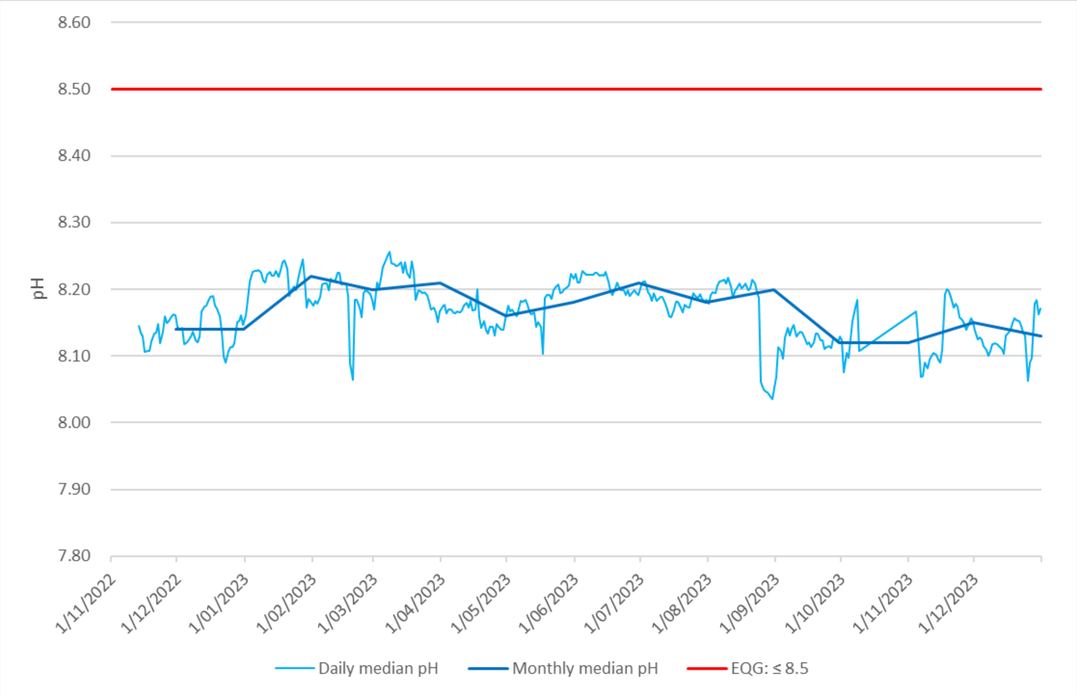

Figure 11: Median pH of intake seawater across the 2023 sampling season.

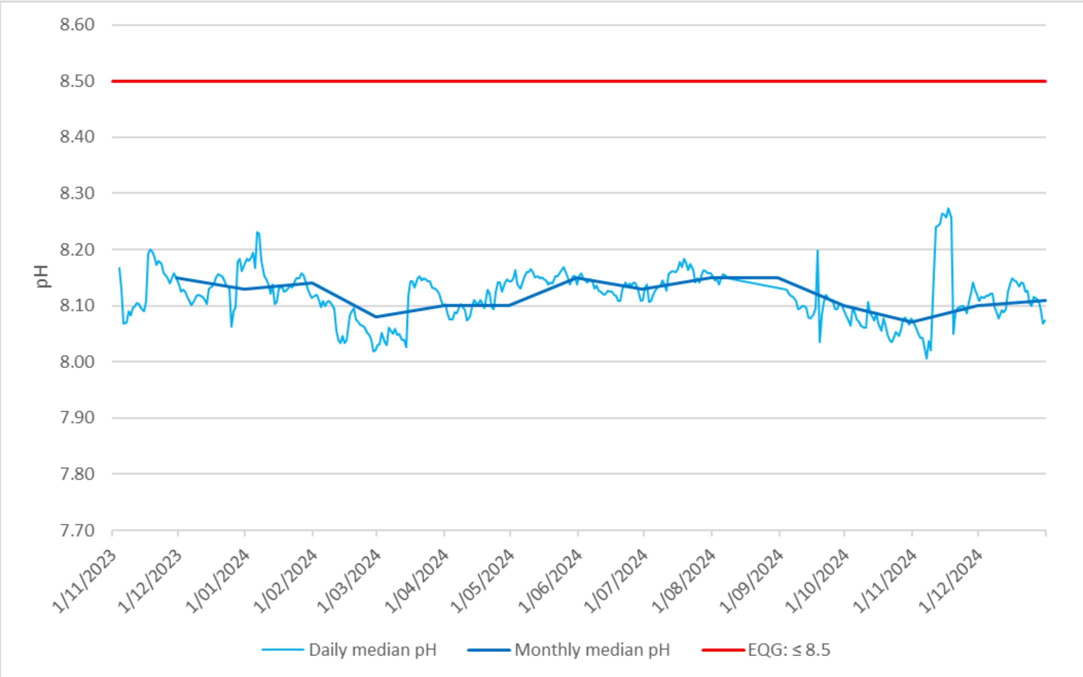

Figure 12: Median pH of intake seawater across the 2024 sampling season.

Dissolved oxygen

Both real-time measures in the intake pipe and quarterly marine water quality monitoring adjacent to the desalination plant intake structure were used for assessment against the EQG.

Dissolved oxygen EQG: The median dissolved oxygen concentration 5 m above the sea floor adjacent to the Perth Seawater Desalination Plant intake, calculated over a period not exceeding one month, should be ≥ 2 mg/L.

The median, and minimum, DO concentration in marine waters adjacent to the desalination plant intake (based on full depth profile) remained above the EQG minimum of 2 mg/L for each monitoring event (Table 28). High-frequency data logged within the intake pipe were consistently well above the EQG (Figure 13 and Figure 14).

Table 28: Median dissolved oxygen concentrations of marine waters (full depth profile) adjacent to the desalination plant intake structure for both 2023 and 2024.

Sampling month/year	EQG (mg/L)	Depth-integrated median
Dec-22	2.0	7.21
Feb-23		6.32
May-23		7.55
Aug-23		8.36
Nov-23		7.98
Feb-24		6.89
May-24		7.25
Aug-24		7.82
Nov-24		7.62

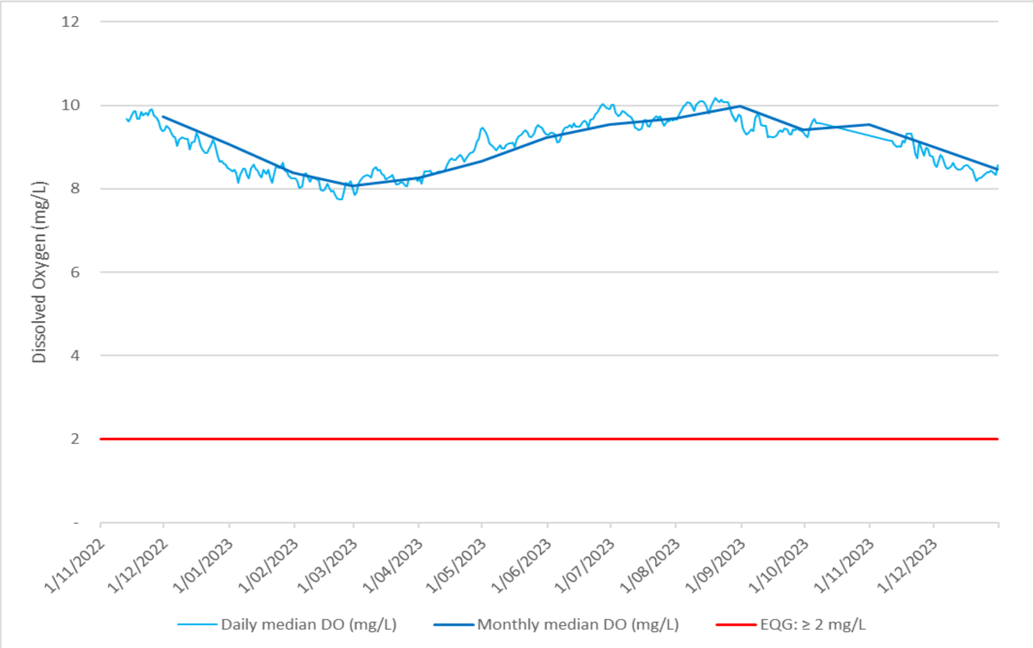

Figure 13: Median DO concentration of intake seawater across the 2023 sampling season.

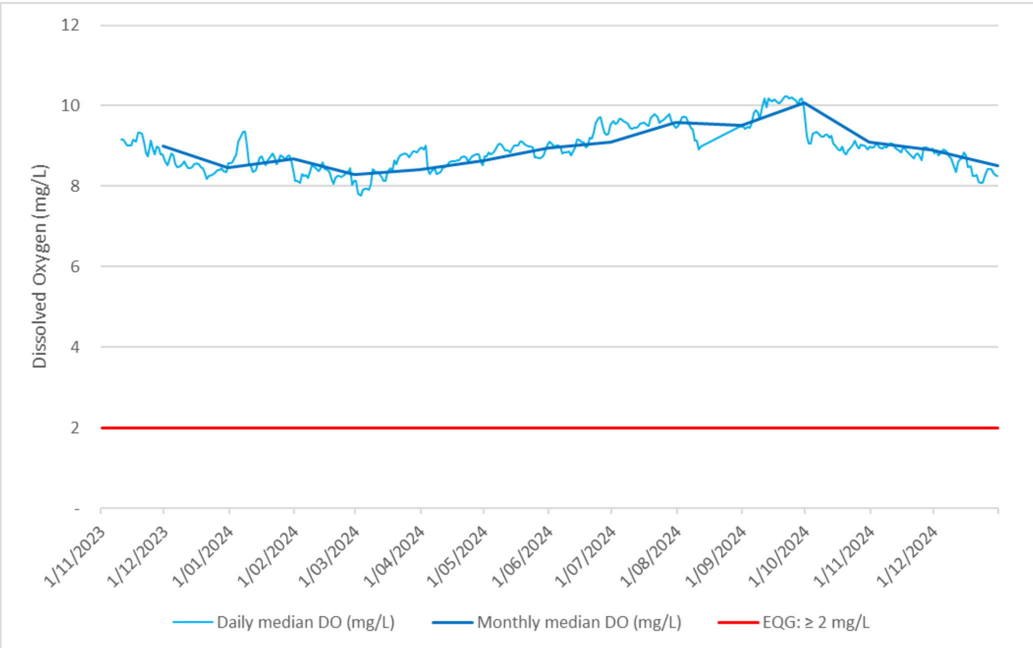

Figure 14: Median DO concentration of intake seawater across the 2024 sampling season.

Total suspended solids

Total suspended solids (TSS) samples were collected from the intake pipe and used for assessment against the EQG.

TSS EQG: The rolling median concentration of TSS adjacent to the Perth Seawater Desalination Plant intake, calculated over a period not exceeding four weeks, should not exceed 4.5 mg/L and no individual TSS value should exceed 9 mg/L at any time.

The 'rolling' four-week median concentration of TSS exceeded the EQG of 4.5 mg/L 91% of the time during 2022–23 and 70% of the time during 2023–24 (Figure 15 and Figure 16). The plant's operational limit, equivalent to the EQS of 9 mg/L, was exceeded twice in 2022–23 but not at any time in 2023–24.

Dosing of coagulant in the desalination plant's pre-treatment process is automated to adjust to variances in TSS up to the plant's operational limit of 9 mg/L.

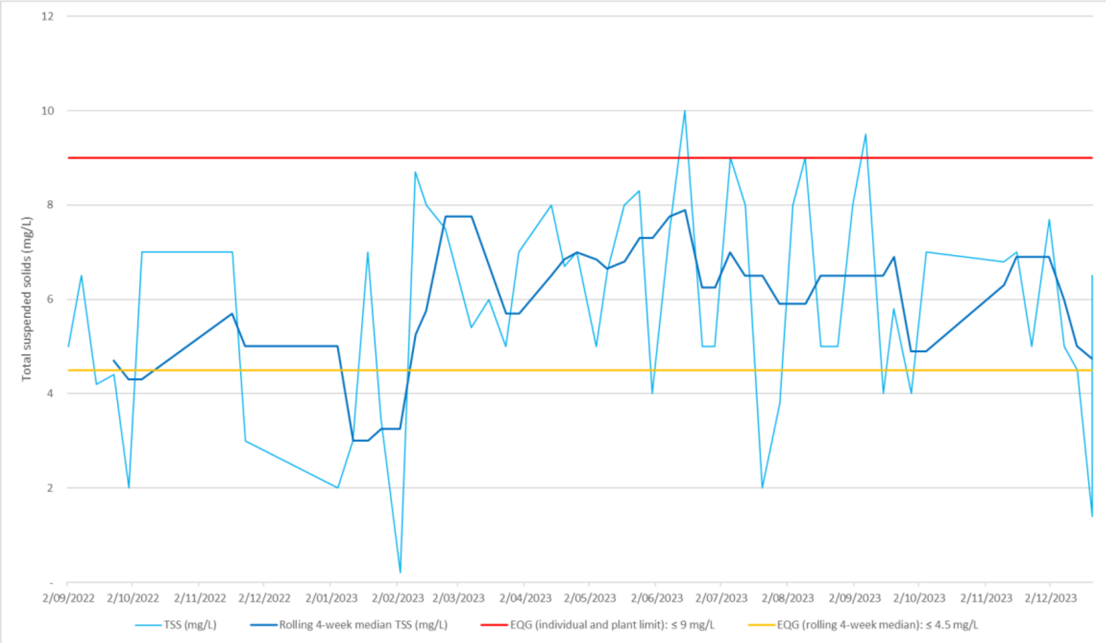

Figure 15: Weekly and 'rolling' four-weekly median total suspended solids (TSS) concentration of intake seawater during 2022–23.

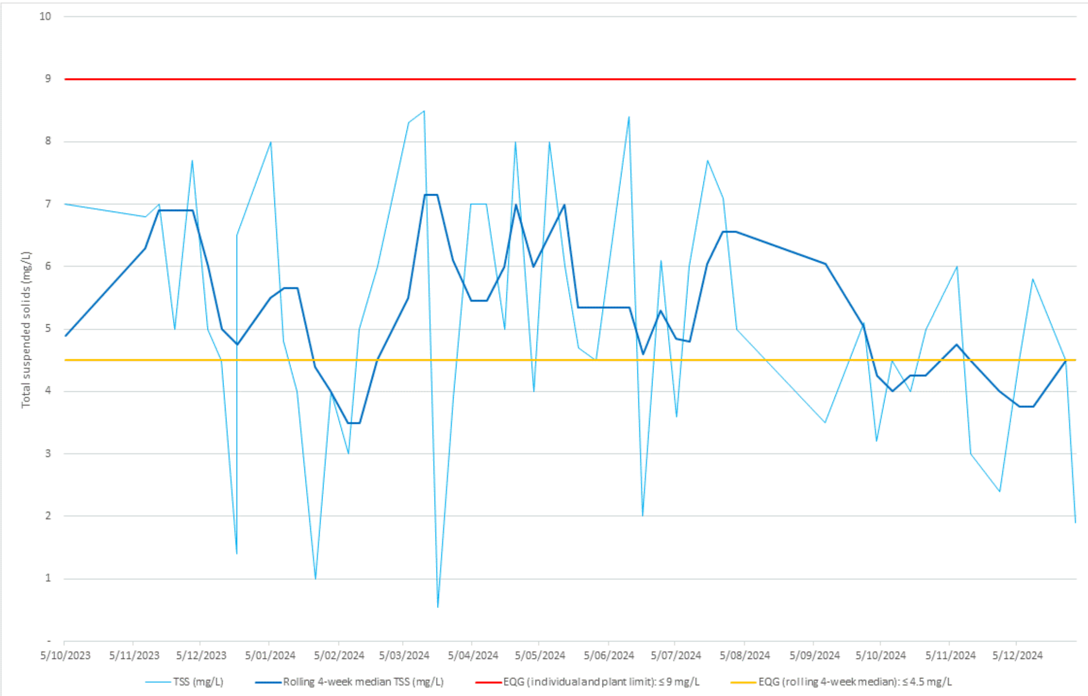

Figure 16: Weekly and 'rolling' four-weekly median total suspended solids (TSS) concentration of intake seawater during 2023–24.

Total dissolved solids (TDS)

Quarterly monitoring of marine waters adjacent to the seawater intake structure were analysed for EC as a proxy for total dissolved solids (TDS).

TDS EQG: The rolling median concentration of TDS adjacent to the Perth Seawater Desalination Plant intake over a period not exceeding one month should not exceed 40,000 mg/L.

The median and monthly TDS concentration of intake seawater remained below the EQG maximum of 40,000 mg/L for the monitoring period 2023–24.

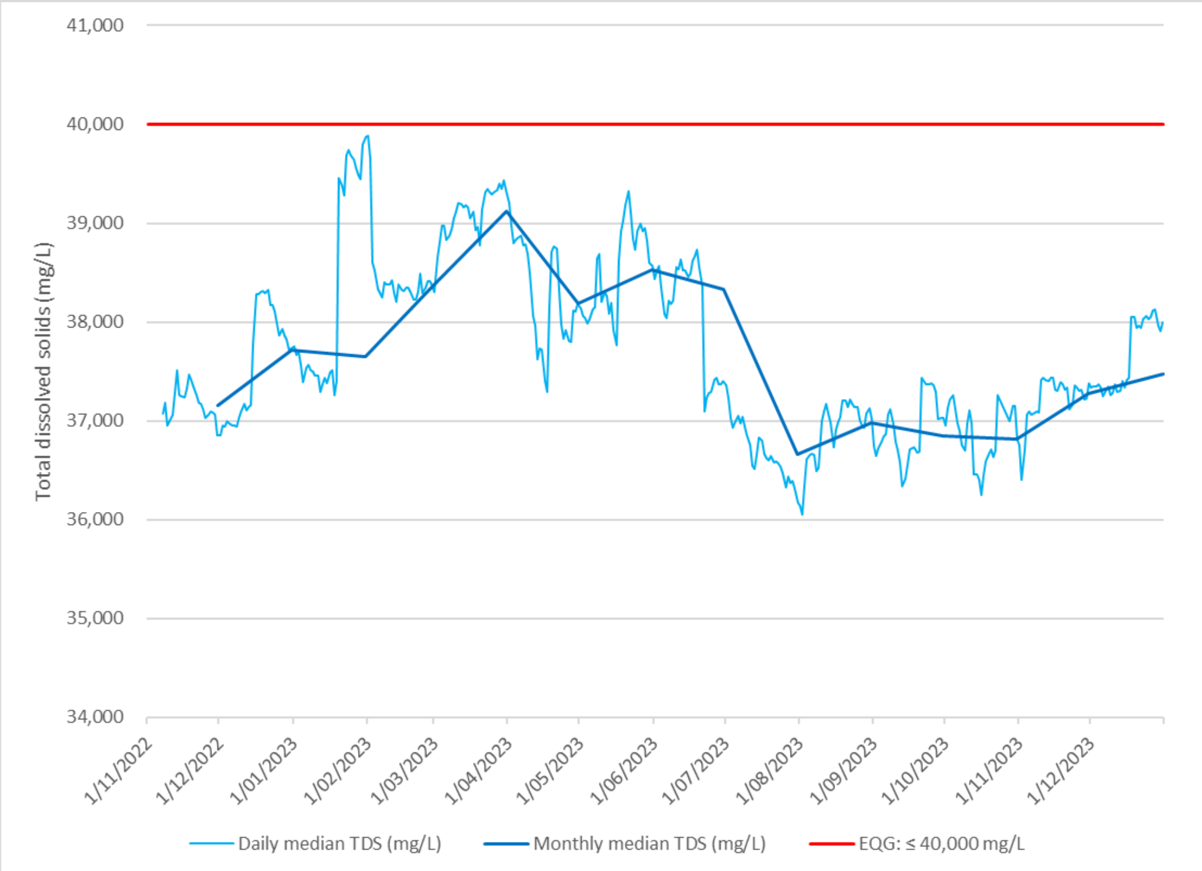

Figure 17: Daily and monthly median total dissolved solids concentration of intake seawater during 2022–23.

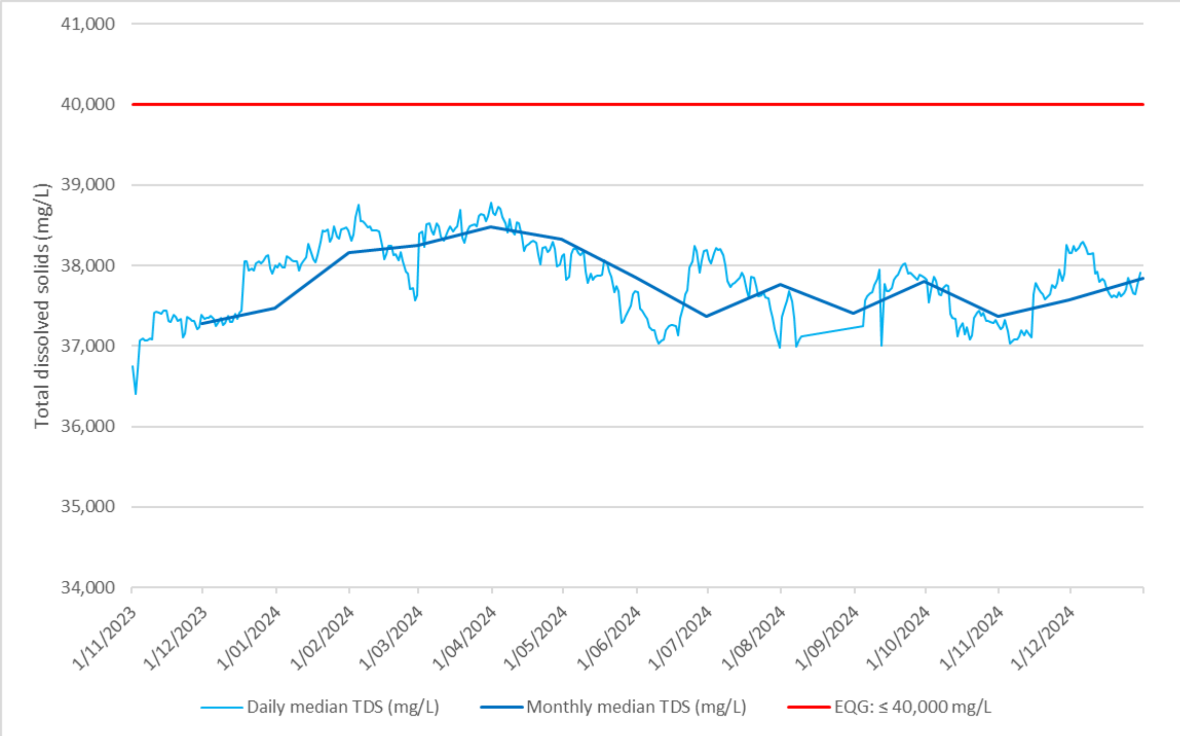

Figure 18: Daily and monthly median total dissolved solids concentration of intake seawater during 2023–24.

Boron and bromide concentrations

During 2023–24, boron concentrations reached the EQG maximum of 5.2 mg/L in April 2024 but did not exceed it (Table 29). Bromide concentrations exceeded the EQG maximum of 77 mg/L in February 2023 and April 2024. Boron and bromide are removed from the water by the reverse osmosis process; however, higher concentrations reduce the efficiency of this process.

Table 29: Boron and bromide concentrations of intake seawater for 2023 and 2024.

Sampling month	Boron (mg/L)		Bromide (mg/L)	
	EQG	Concentration	EQG	Concentration
Feb-23	5.2	4.9	77	**81**
May-23		5.0		66
July-23		4.7		60
Jan-24		4.9		58
Apr-24		5.2		**80**
Jun-24		4.8		66
Sep-24		4.8		54
Oct-24		4.8		53

6.4 Conclusions – Environmental value: Industrial Water Supply

Data collected at the Perth Seawater Desalination Plant intake throughout the 2023 and 2024 monitoring periods indicate that intake water temperature, pH, DO content, boron concentration, and microbial quality met the relevant criteria and hence posed no threat to the function or efficiency of desalination plant operations.

Total suspended solids exceeded the EQG for extensive periods and the EQS was also exceeded a couple of times during the winter of 2023. Bromide concentrations measured in intake waters exceeded the EQG on two occasions. Despite these exceedances, there was no adverse impact on the plant’s operations and Water Corporation did not report any need for mitigation measures, indicating 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 shifts 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* is a non-statutory instrument developed by the Environmental Protection Authority under the *Environmental Protection Act 1986* which 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 nitrogen; 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.

References

Australian Government 2017, *Health based guidance values for PFAS for use in site investigations in Australia*, Department of Health, Canberra, Australian Capital Territory.

ANZG 2018, *Australian and New Zealand guidelines for fresh and marine water quality*, Australian and New Zealand governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines.

Batley GE, Scammell MS & Brockbank CI 1992, 'The impact of the banning of tributyltin-based antifouling paints on the Sydney rock oyster, 45T*Saccostrea commercialis* 45T', *Science of the Total Environment* 122: 301–314.

BMT Western Australia 2018, *Cockburn Sound drivers-pressures-state-impacts-responses assessment 2017 final report*, report prepared for the Department of Water and Environmental Regulation, Kwinana Industries Council, City of Rockingham and City of Kwinana on behalf of the Cockburn Sound Management Council.

Cockburn Sound Management Council 2018, *2018 State of Cockburn Sound marine area report*, Cockburn Sound Management Council, Perth, Western Australia.

Commonwealth of Australia 2013, *Characterising the relationship between water quality and water quantity*, report prepared by Sinclair Knight Merz for the Department of Sustainability, Environment, Water, Population and Communities.

CRC CARE (Cooperative Research Centre for Contamination Assessment and Remediation of the Environment) 2017, *Assessment, management and remediation guidance for perfluorooctanesulfonate (PFOS) and perfluorooctanoic acid (PFOA) – Part 4: Application of HSLs and ESLs*, CRC CARE Technical report no. 38, Cooperative Research Centre for Contamination Assessment and Remediation of the Environment, Newcastle, Australia.

Department of Environment 2004, *Background quality for coastal marine waters of Perth, Western Australia*, Technical Series 117, Department of Environment, Perth, Western Australia.

Department of Environment Regulation 2017, *Interim guideline on the assessment and management of perfluoroalkyl and polyfluoroalkyl substances (PFAS),* version 2.0, Department of Environment Regulation, Perth, Western Australia.

Department of Health 2010, *Wild shellfish collection*, Environmental Health Directorate, Department of Health. [source: healthywa.wa.gov.au, accessed 24 December 2015].

—2022, *Recreational Waters Bacterial Monitoring Program – site status overview – 2022 – metro ocean coastline*, Department of Health, Perth, Western Australia.

Department of Health 2022, *Western Australia Shellfish Quality Assurance Program (WASQAP) operations manual*, *version 6*, Department of Health, Perth, Western Australia.

Donn M, Bekele E, Wu H, Prommer H, Furness A, Woodbury R, Rayner J & Davis G 2025, *Baseline assessment of groundwater/surface water nitrogen flux into Cockburn Sound – final report*. Prepared for the WAMSI Westport Marine Science Program, Western Australian Marine Science Institution, Perth, Western Australia. 72 pp.

Dowson PH, Bubb JM & Lester JN 1996, ‘Persistence and degradation pathways of tributyltin in freshwater and estuarine sediments’, *Estuarine, Coastal and Shelf Science* 42: 551–562.

EPA (Environmental Protection Authority) 2005a, *Environmental quality criteria reference document for Cockburn Sound (2003–2004), a supporting document to the State Environmental (Cockburn Sound) Policy 2005*, Environmental Protection Authority Report 20. Environmental Protection Authority, Perth, Western Australia.

—2005b, *Manual of standard operating procedures for environmental monitoring against the Cockburn Sound environmental quality criteria (2003–2004), a supporting document to the State Environmental (Cockburn Sound) Policy 2005*, Environmental Protection Authority report 21, Environmental Protection Authority, Perth, Western Australia.

—2017, *Environmental quality criteria reference document for Cockburn Sound, a supporting document to the State Environmental (Cockburn Sound) Policy 2015*, Environmental Protection Authority, Perth, Western Australia.

Flukes E 2024, *Multi-resolution bathymetry composite surface for Australian waters (EEZ)*, Institute for Marine and Antarctic Studies (IMAS), data accessed from https://metadata.imas.utas.edu.au/geonetwork/srv/eng/catalog.search#/metadata/69e9ac91-babe-47ed-8c37-0ef08f29338a on 14 November 2024.

Garg A, Anton-Martin R, Garcia-Luque E, Riba I & DelValls TA 2009, ‘Distribution of butyltins (TBT, DBT, MBT) in the sediments of Gulf of Cadiz (Spain) and its bioaccumulation in the clam 45T *Ruditapes philippinarum* 45T’, *Ecotoxicology* 18: 1029–1035.

Gaughan DJ & Santoro K (eds.) 2018, *Status reports of the fisheries and aquatic resources of Western Australia 2016/17: The State of the Fisheries*, Department of Primary Industries and Regional Development, Western Australia.

GHD 2016, *Defence per- and poly-fluoroalkyl substances (PFAS) Environmental Management Preliminary Sampling Program, HMAS Stirling (Garden Island)*, report prepared by GHD for Jones Lang LaSalle.

Government of Western Australia 2005, *State Environmental (Cockburn Sound) Policy 2005*.

—2015, *State Environmental (Cockburn Sound) Policy 2015*.

McMahon K, Strydom S, Dunham N, Whale J, Webster C & Said N 2025, *Drivers of seagrass decline in Perth waters and actions to halt decline*. Prepared for the WAMSI Westport Marine Science Program, Western Australian Marine Science Institution, Perth, Western Australia. 60 pp.

National Health and Medical Research Council 2008, *Guidelines for managing risks in recreational water*.

Stewart I & Turnbull A 2015, *Arsenic in Australian seafood: a review and analysis of monitoring data 2000–2013*, South Australian Research and Development Institute and Food & Water Toxicology Consulting.

Webster C, McMahon K, Ross C, Afrifa-Yamoah E, Said N, Hovey R, Martin B & Strydom S 2024, *Two decades of seagrass monitoring data show drivers include ENSO, climate warming and local stressors*. Prepared for the WAMSI Westport Marine Science Program, Western Australian Marine Science Institution, Perth, Western Australia. 31 pp.

Wilson C 2024, *Water quality of Cockburn and Warnbro sounds (January 2023 to December 2023)*, report no. MAFRL 24-2, prepared for the Department of Water and Environmental Regulation on behalf of the Cockburn Sound Management Council by the Marine and Freshwater Research Laboratory, Environmental and Conservation Sciences, Harry Butler Research Institute, Murdoch University.

—2025, *Water quality of Cockburn and Warnbro sounds (January 2024 to December 2024)*, report no. MAFRL 25-2, prepared for the Department of Water and Environmental Regulation on behalf of the Cockburn Sound Management Council by the Marine and Freshwater Research Laboratory, Environmental and Conservation Sciences, Harry Butler Research Institute, Murdoch University.

Wilson C & Wienczugow K 2024a, *Baseline sediment quality survey of Cockburn Sound and Owen Anchorage*. Prepared for the WAMSI Westport Marine Science Program, Western Australian Marine Science Institution, Perth, Western Australia. 106 pp.

—2024b, *Water quality toxicant snapshot survey and diffusive gradient thin films September 2023*. Prepared for the WAMSI Westport Marine Science Program, Western Australian Marine Science Institution, Perth, Western Australia. 104pp.

—2025, *Water quality of Cockburn Sound and Owen Anchorage – September 2022 to August 2024.* Prepared for the WAMSI Westport Marine Science Program, Western Australian Marine Science Institution, Perth, Western Australia. 54 pp.

Appendix A: Chlorophyll-a concentrations and light attenuation coefficient

Chlorophyll-a

The monthly chlorophyll-a concentrations measured at water quality monitoring sites from January to December 2023 (Figures A1 – A3) and January to December 2024 (Figures A4 – A6).

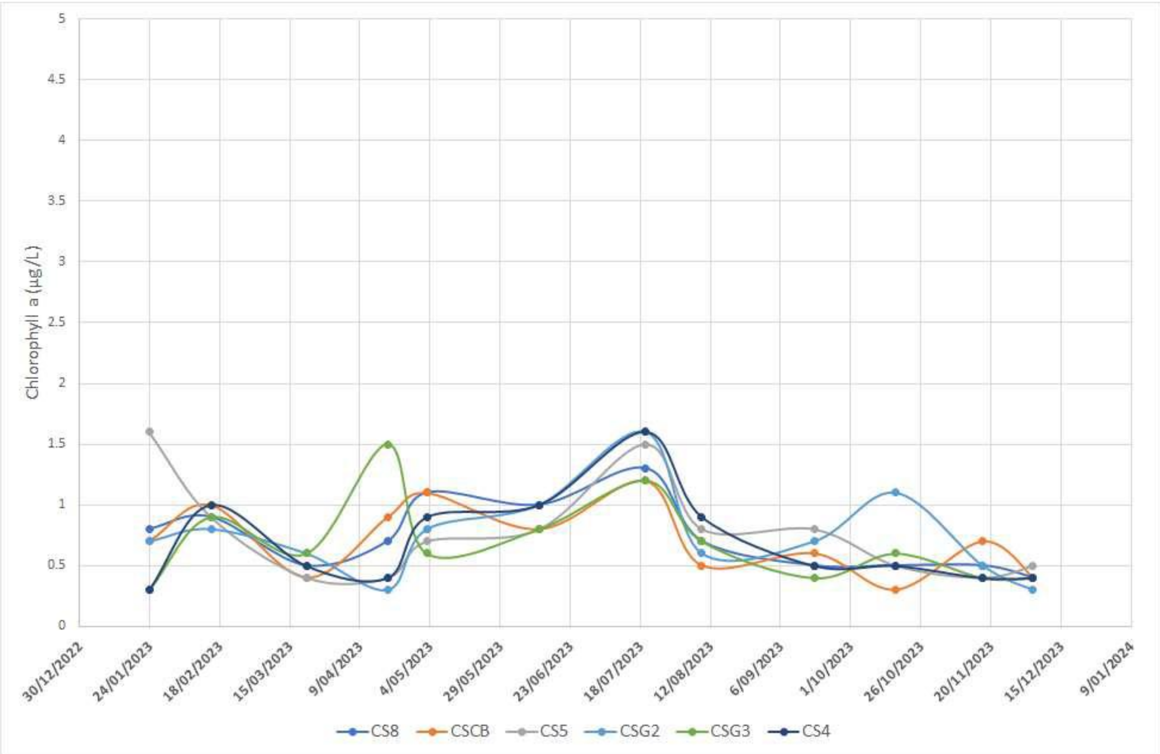

Figure A1: Monthly chlorophyll-a concentrations measured at monitoring sites in HPA-N from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

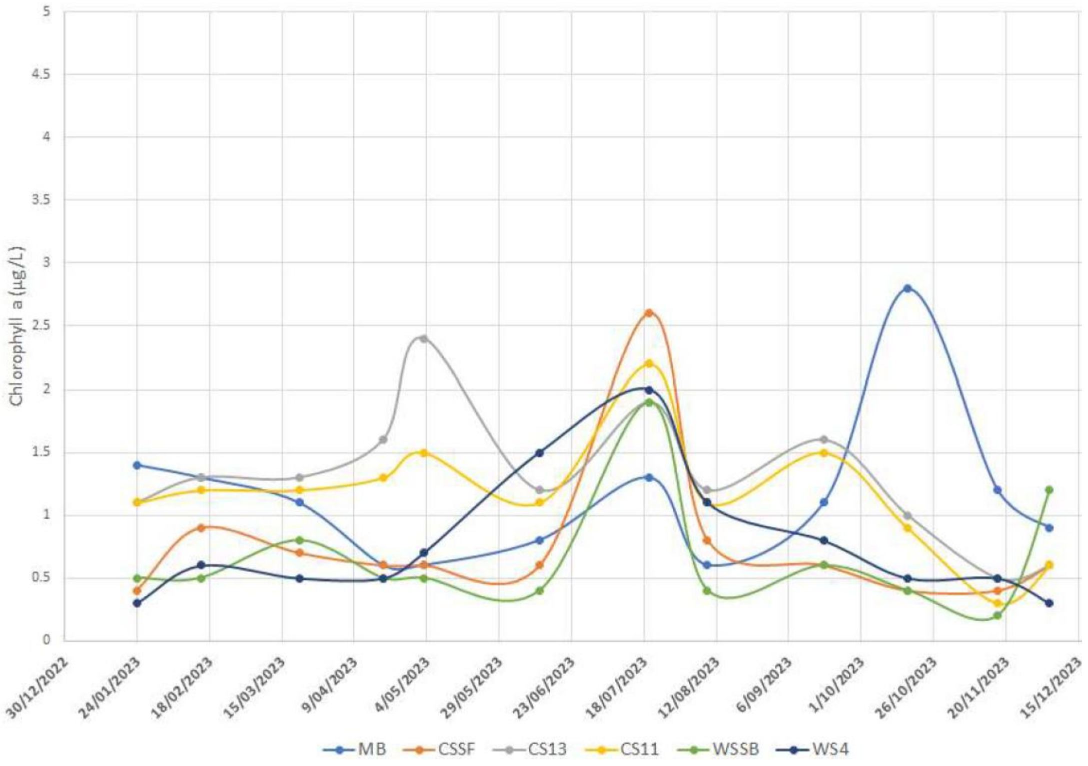

Figure A2: Monthly chlorophyll-a concentration measured at monitoring sites in HPA-S and Warnbro Sound from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

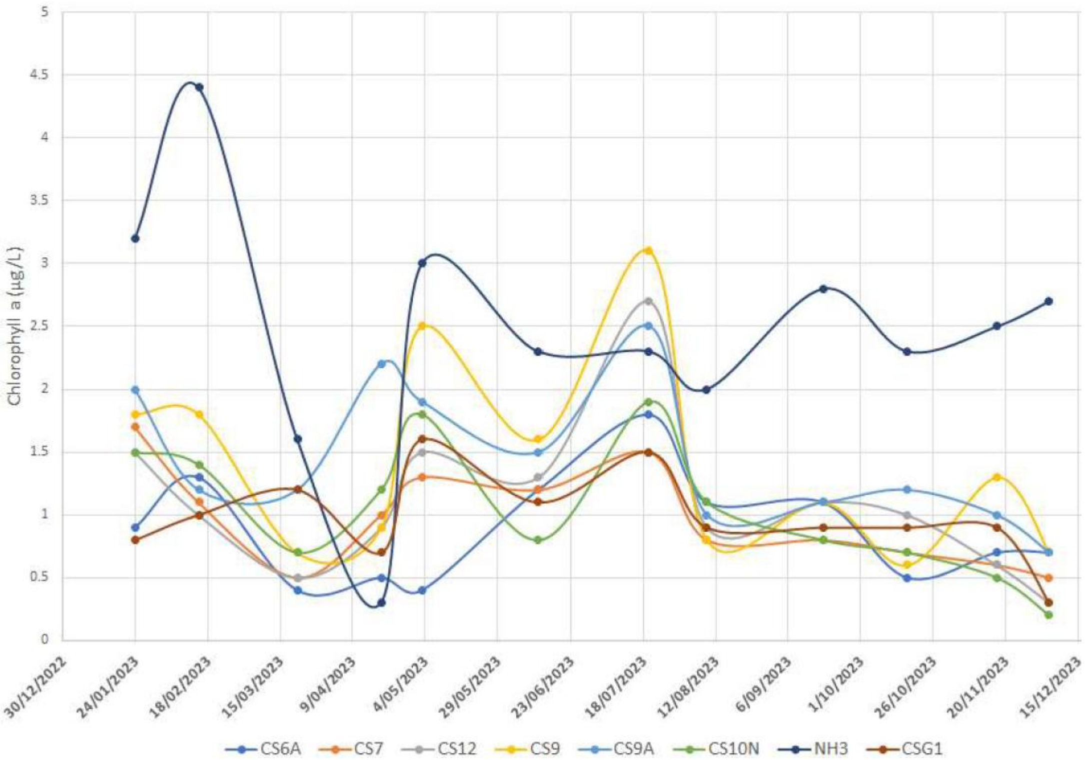

Figure A3: Monthly chlorophyll-a concentration measured at monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

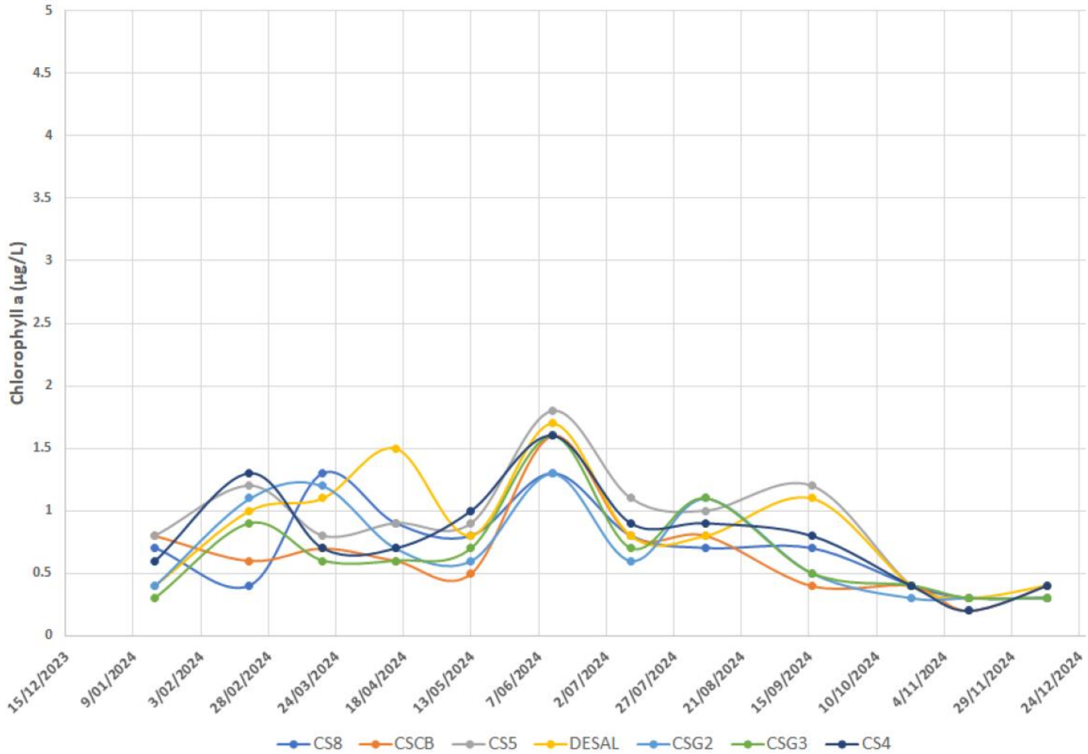

Figure A4: Monthly chlorophyll-a concentrations measured at monitoring sites in HPA-N from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

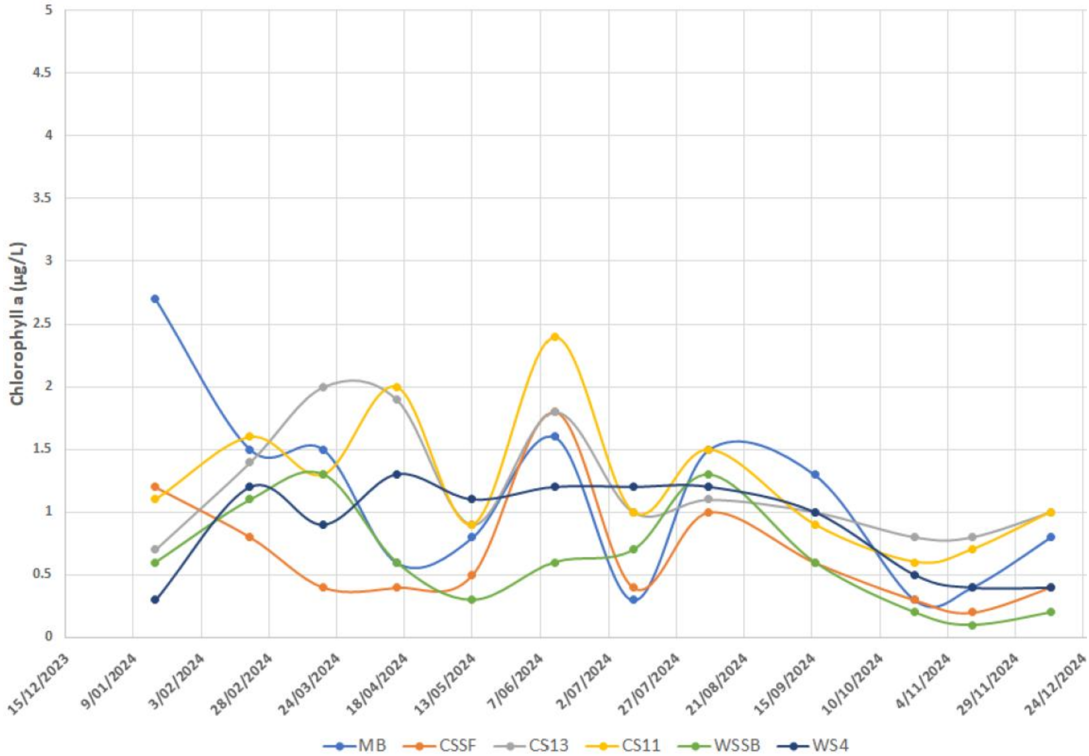

Figure A5: Monthly chlorophyll-a concentration measured at monitoring sites in HPA-S and Warnbro Sound from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

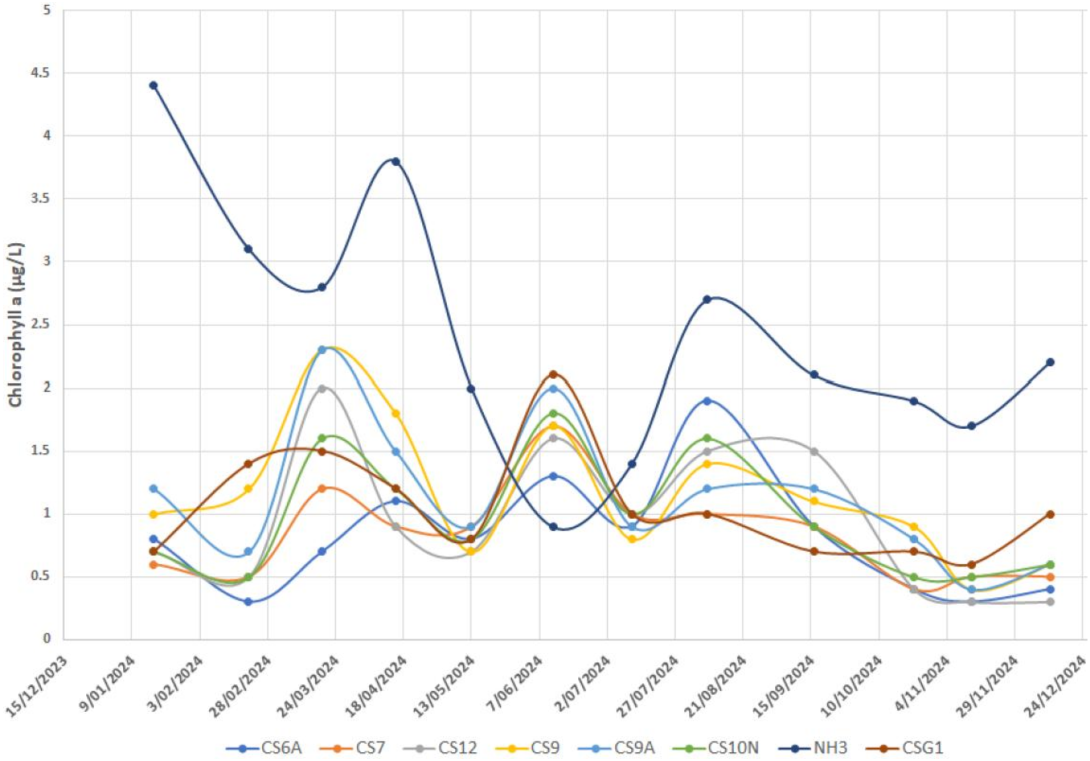

Figure A6: Monthly chlorophyll-a concentration measured at monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

Light attenuation coefficient

The monthly light attenuation coefficient was measured at water quality monitoring sites from January to December 2023 (Figures A7 – A9) and January to December 2024 (Figures A10 – A12).

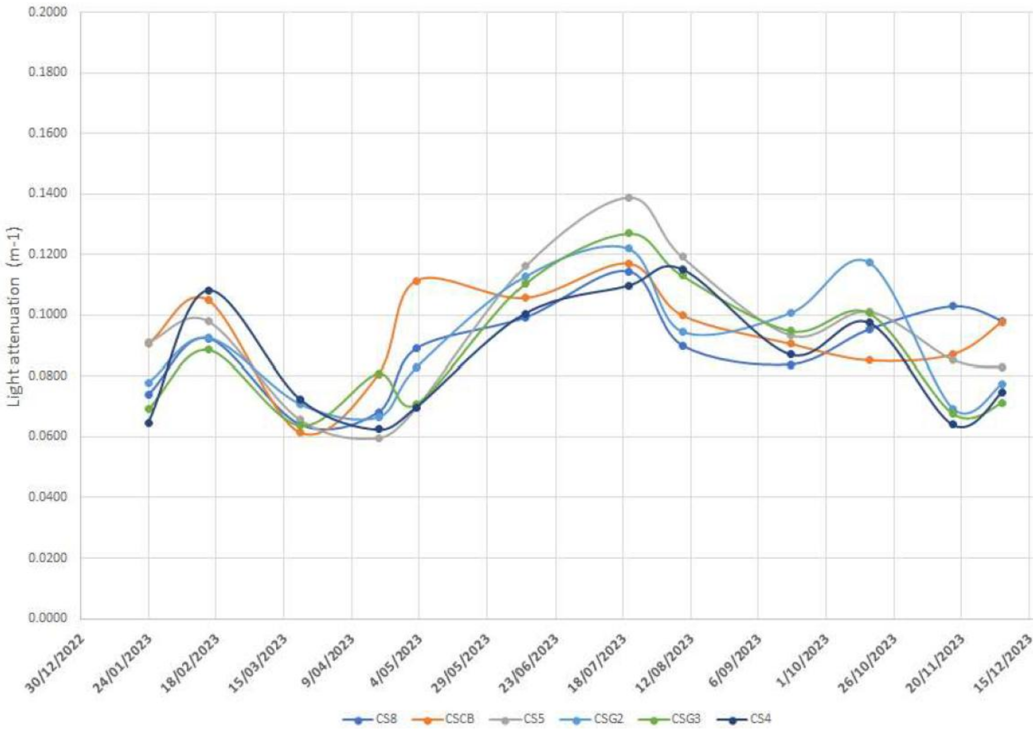

Figure A7: Monthly light attenuation at monitoring sites in HPA-N from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

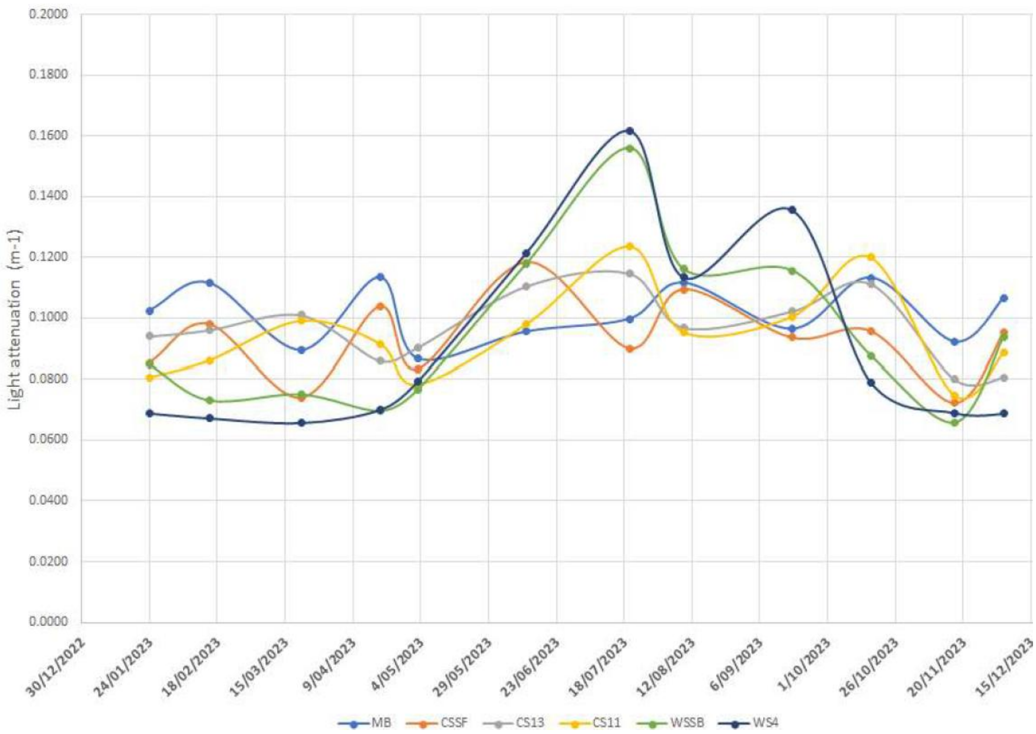

Figure A8: Monthly light attenuation at monitoring sites in HPA-S from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

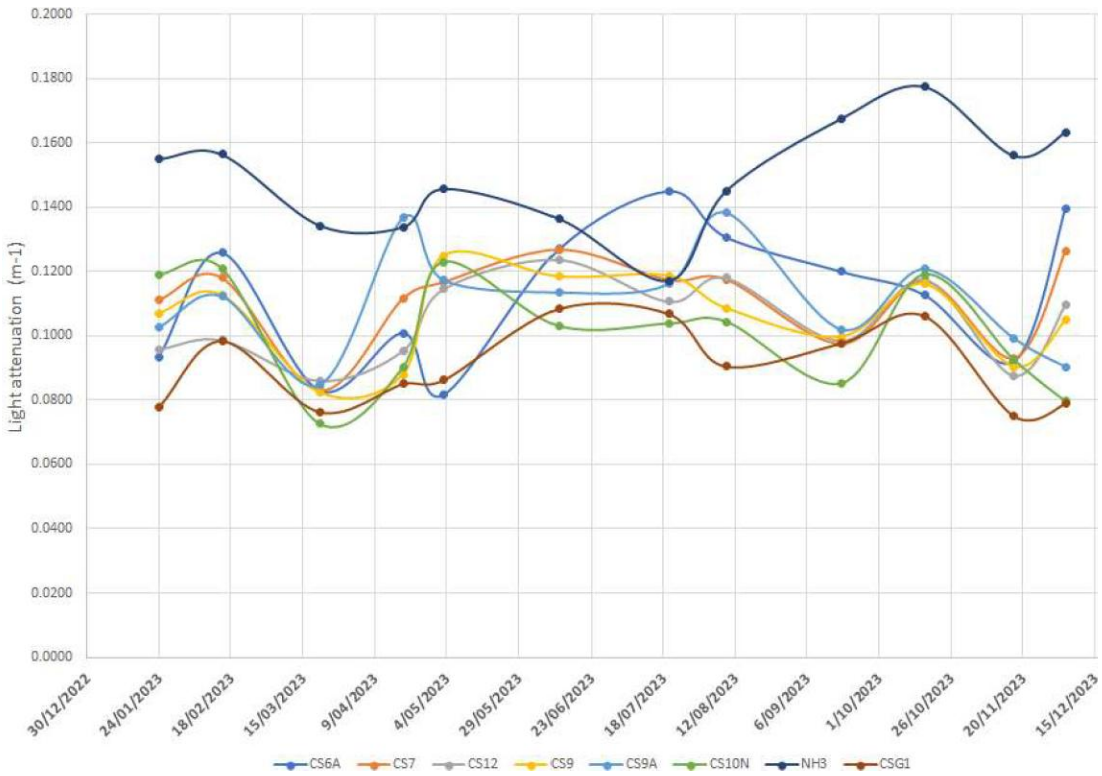

Figure A9: Monthly light attenuation at monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

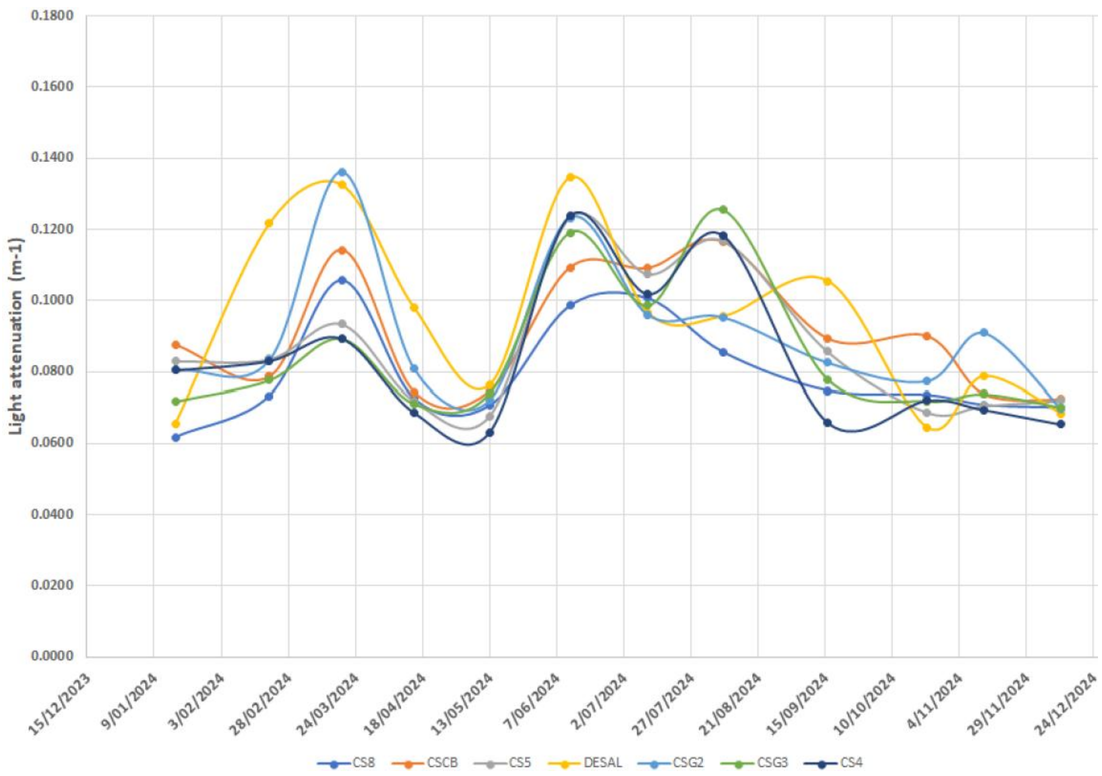

Figure A10: Monthly light attenuation at monitoring sites in HPA-N from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

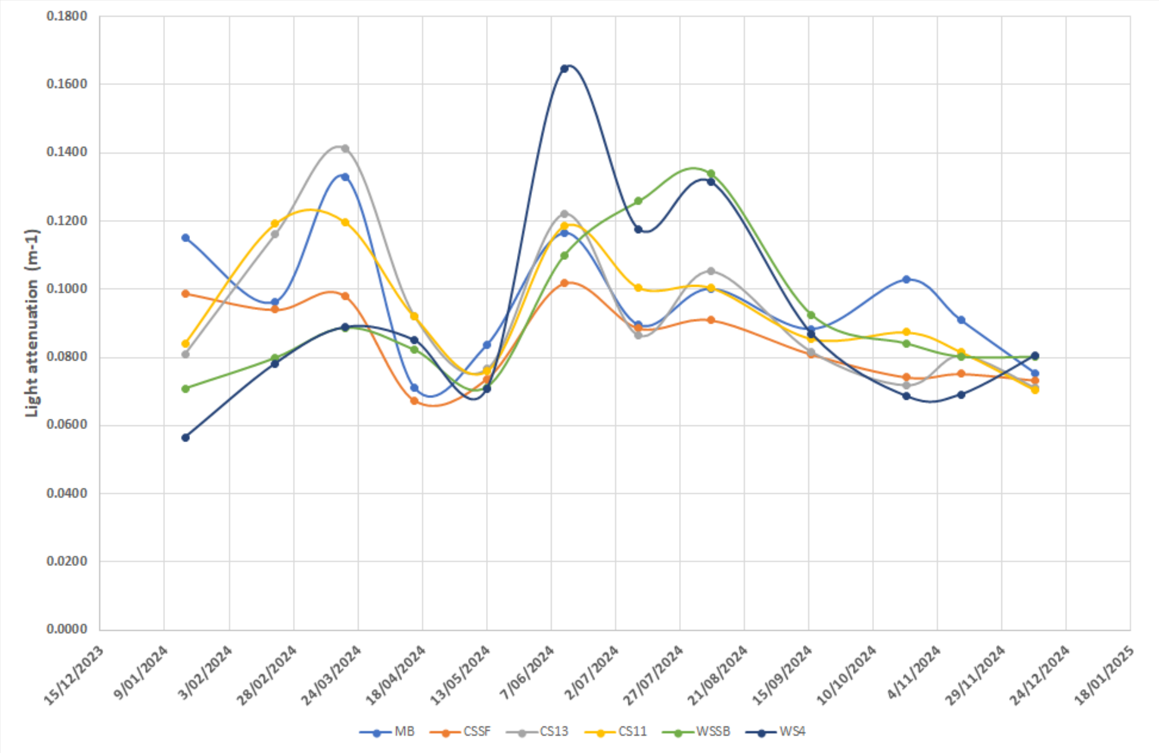

Figure A11: Monthly light attenuation at monitoring sites in HPA-S from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

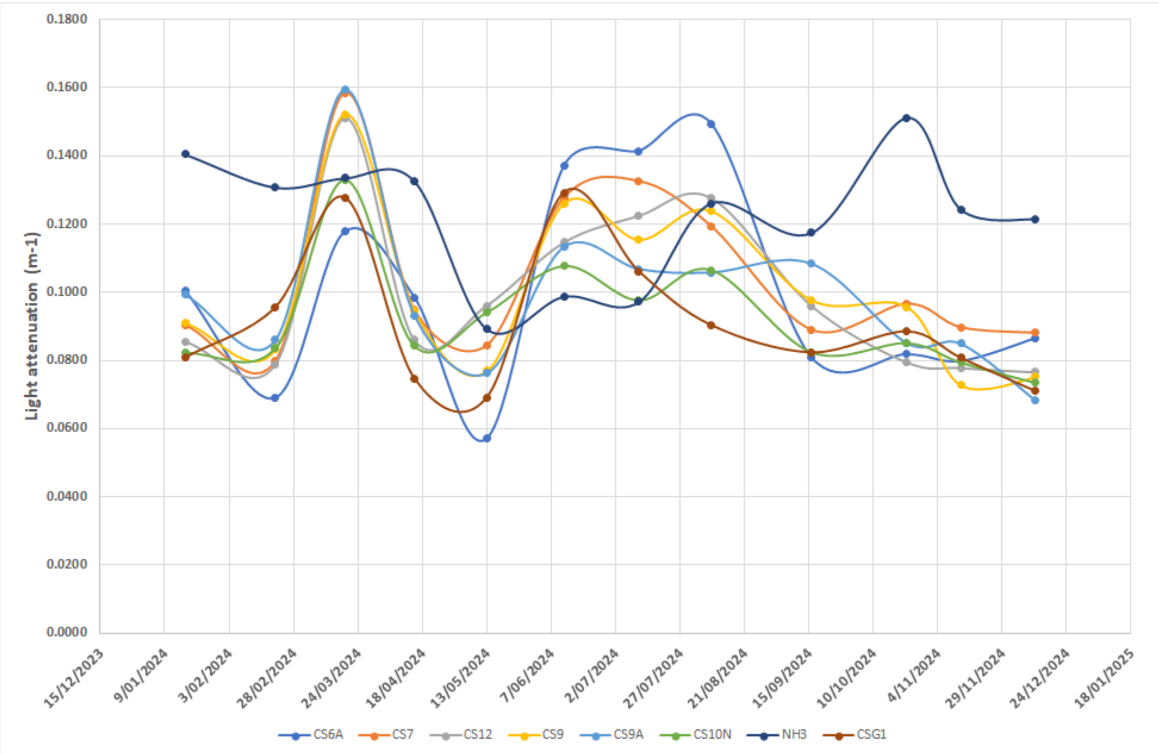

Figure A12: Monthly light attenuation at monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

Appendix B: Monthly nutrient concentrations

Ammonium

The monthly ammonium was measured at water quality monitoring sites from January to December 2023 (Figures B1–B3) and January to December 2024 (Figures B4–B6).

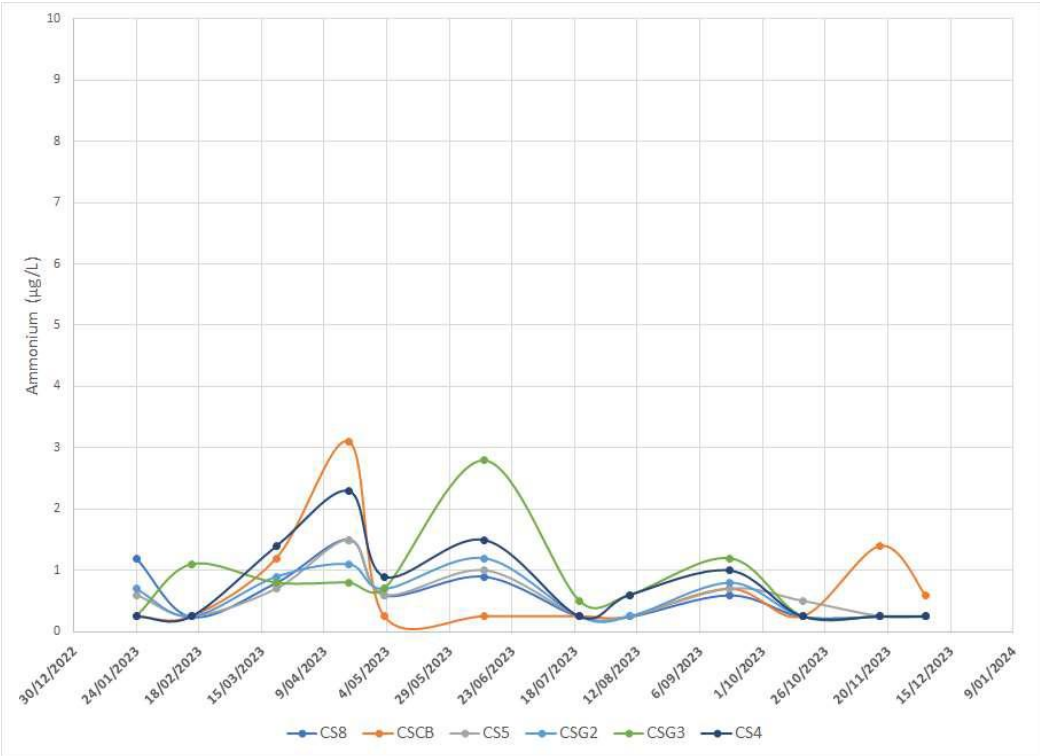

Figure B1: Monthly ammonium concentrations at water quality monitoring sites HPA-N from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

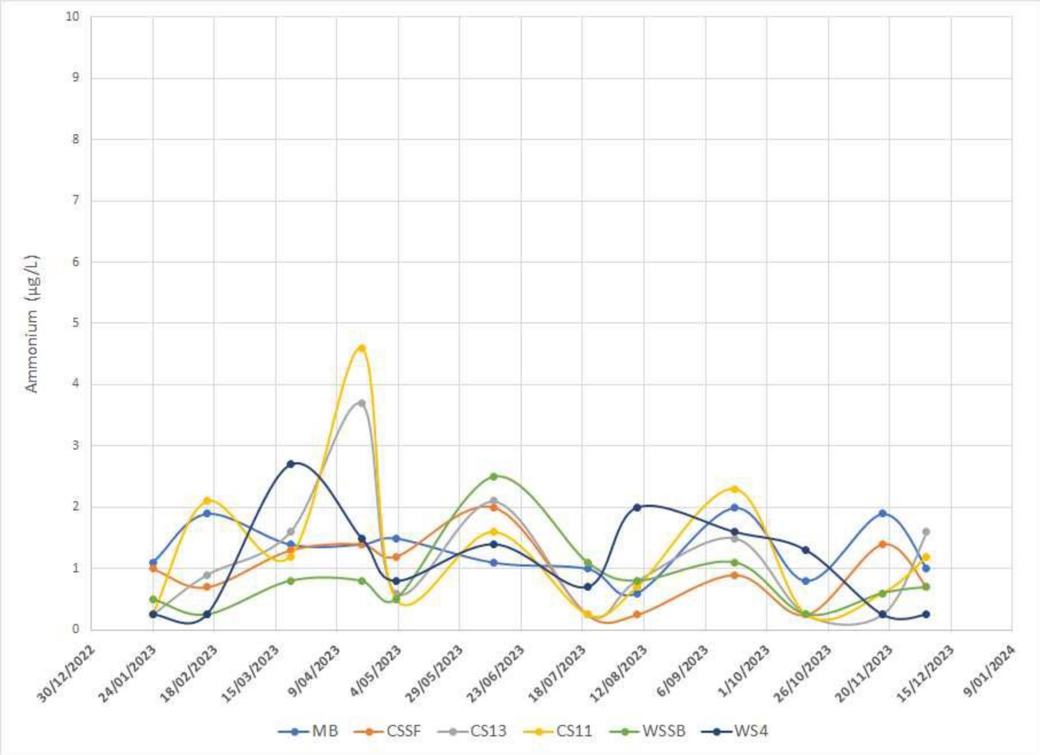

Figure B2: Monthly ammonium concentrations at water quality monitoring sites HPA-S from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

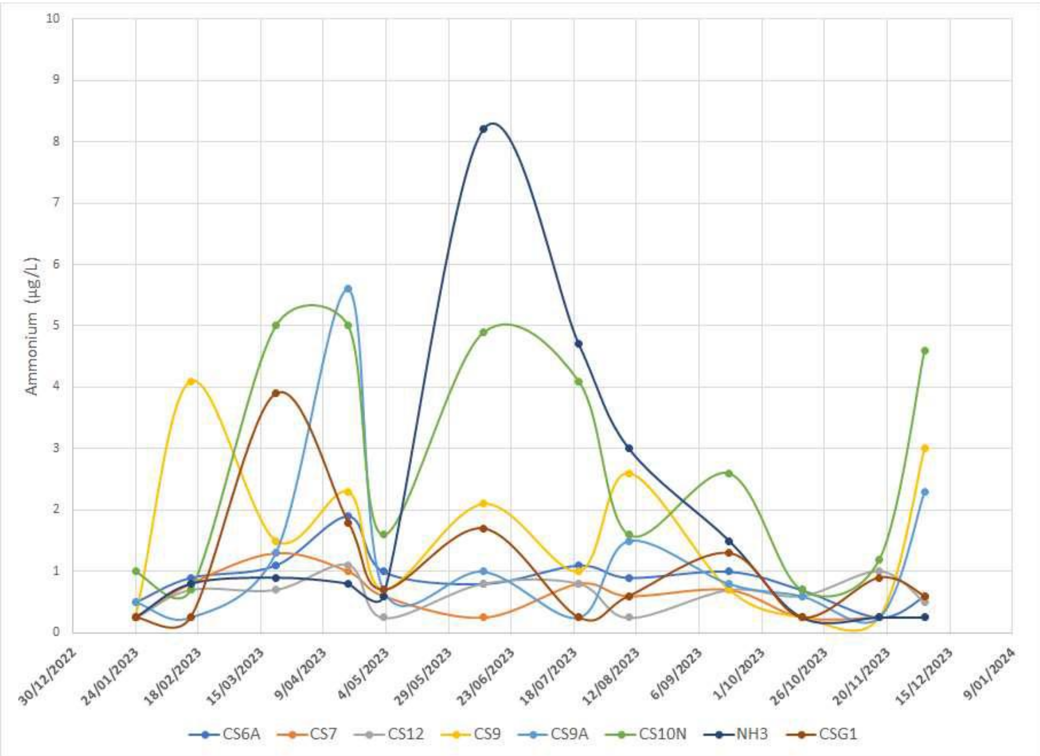

Figure B3: Monthly ammonium concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

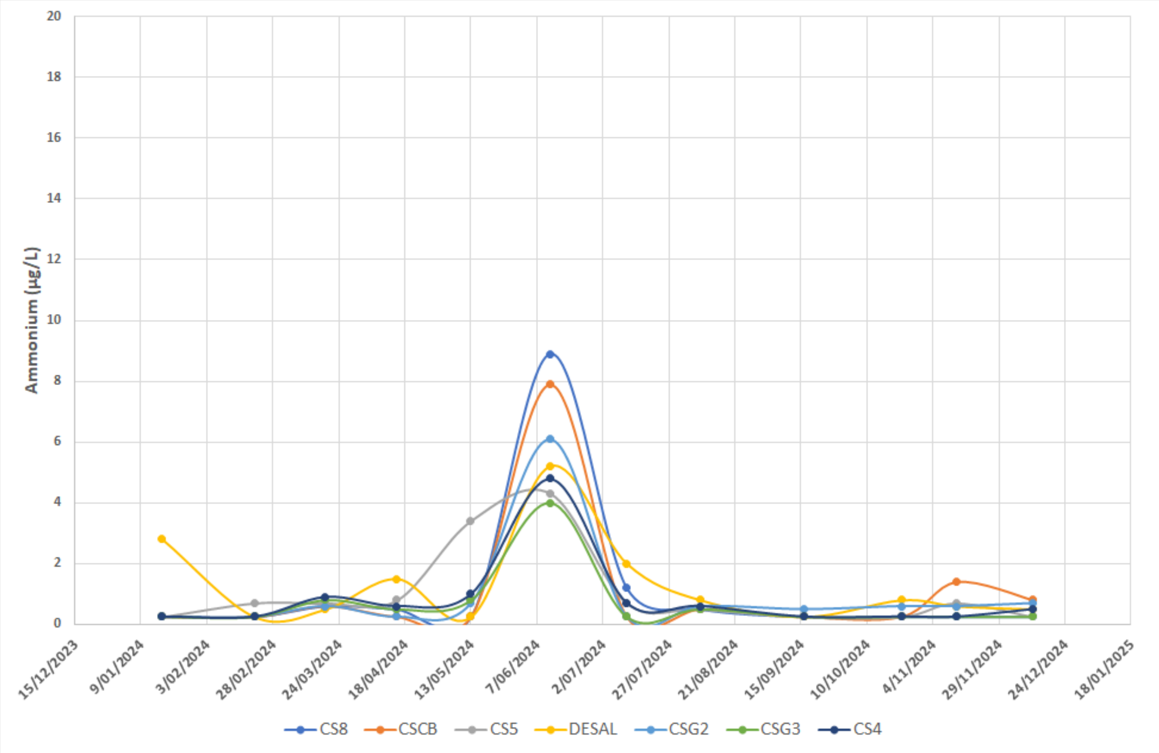

Figure B4: Monthly ammonium concentrations at water quality monitoring sites HPA-N from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

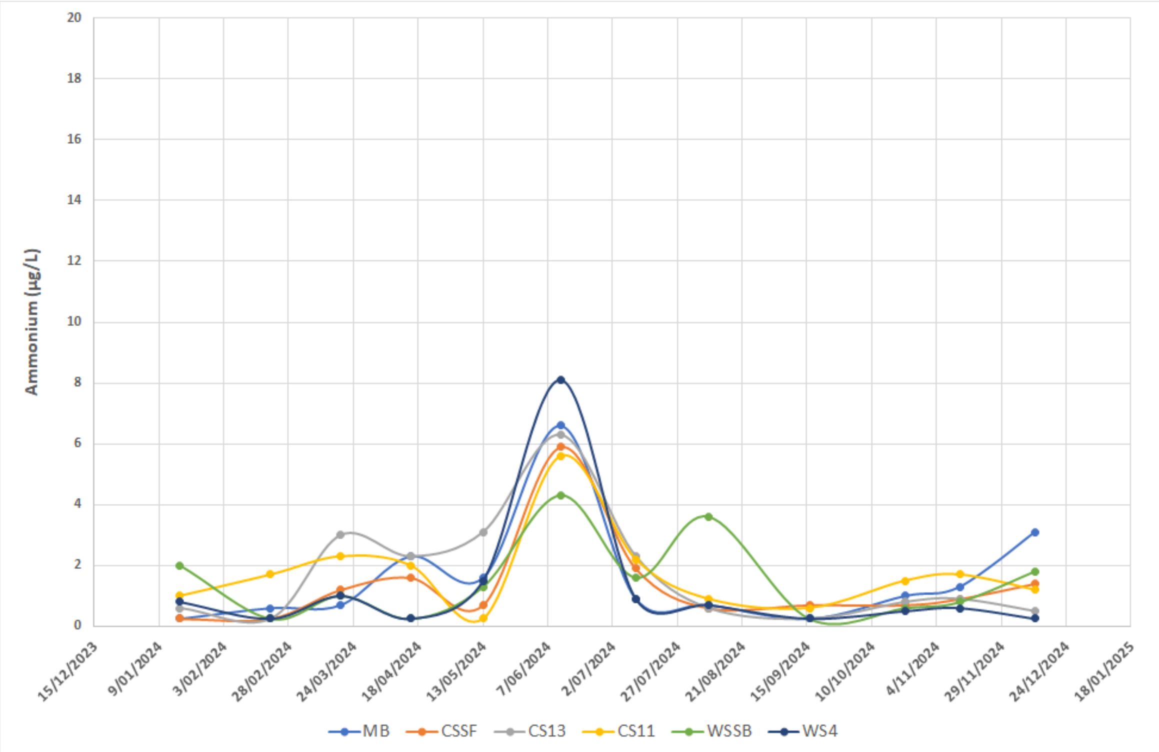

Figure B5: Monthly ammonium concentrations at water quality monitoring sites HPA-S from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

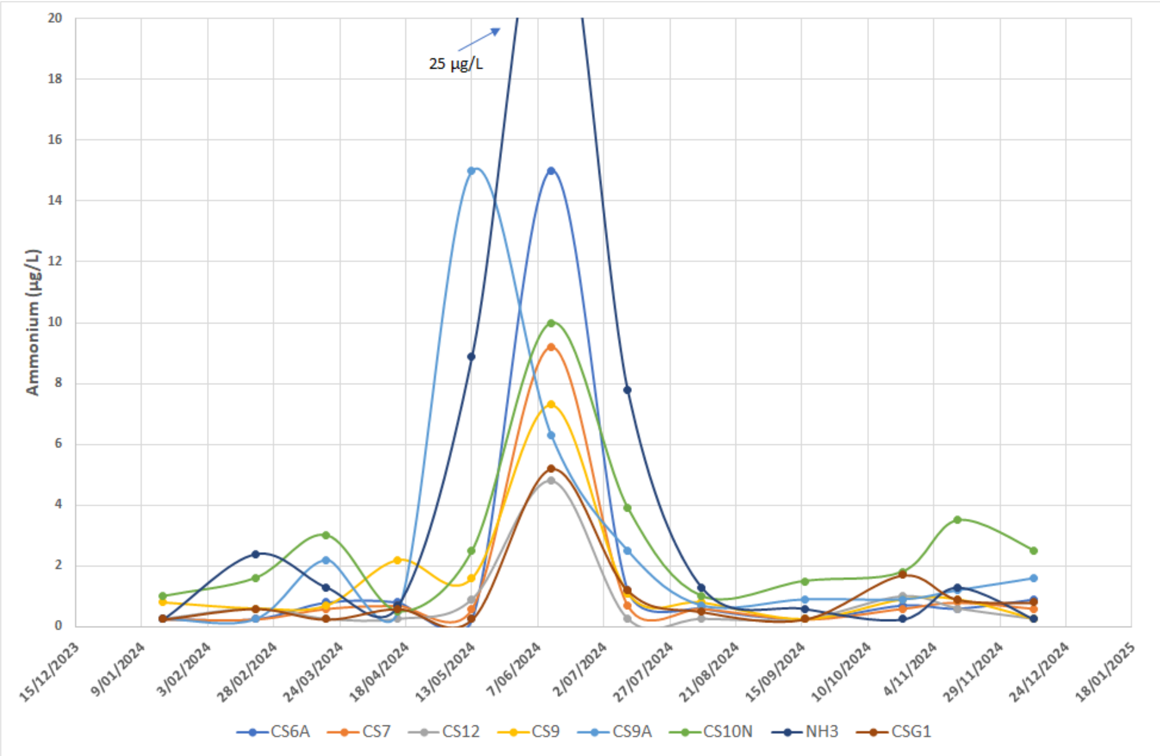

Figure B6: Monthly ammonium concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

Total nitrogen

Monthly total nitrogen was measured at water quality monitoring sites from January to December 2023 (Figures B7–B9) and January to December 2024 (Figures B10–B12).

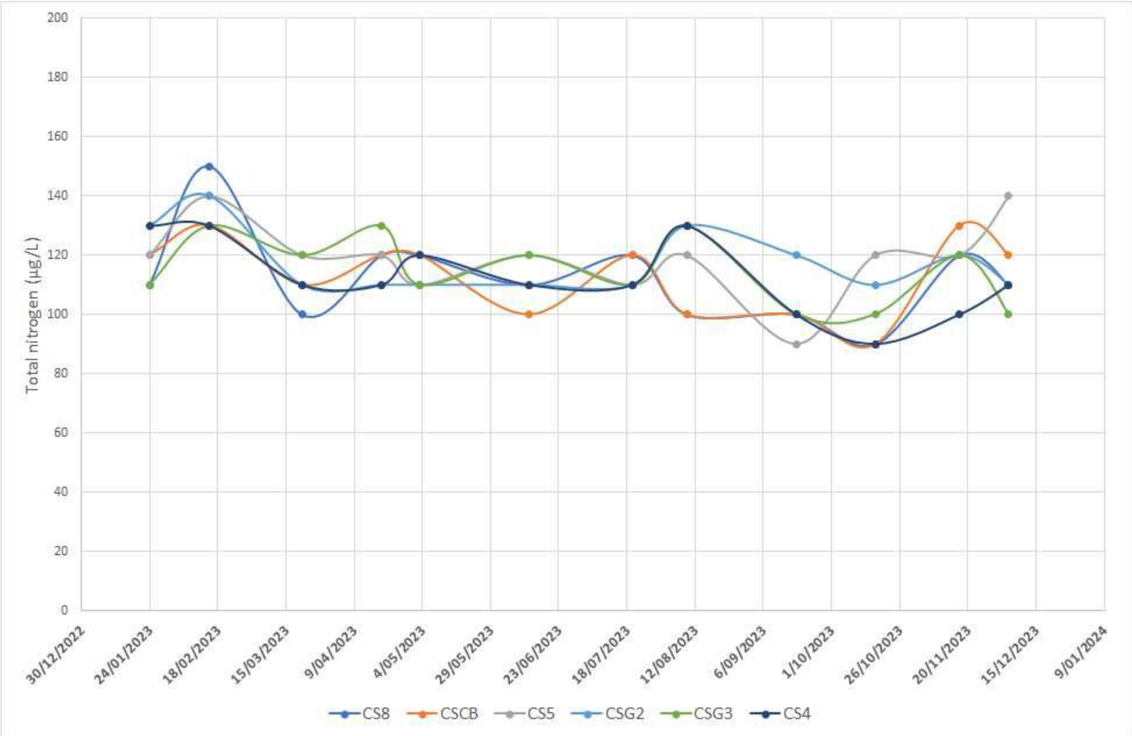

Figure B7: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-N from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

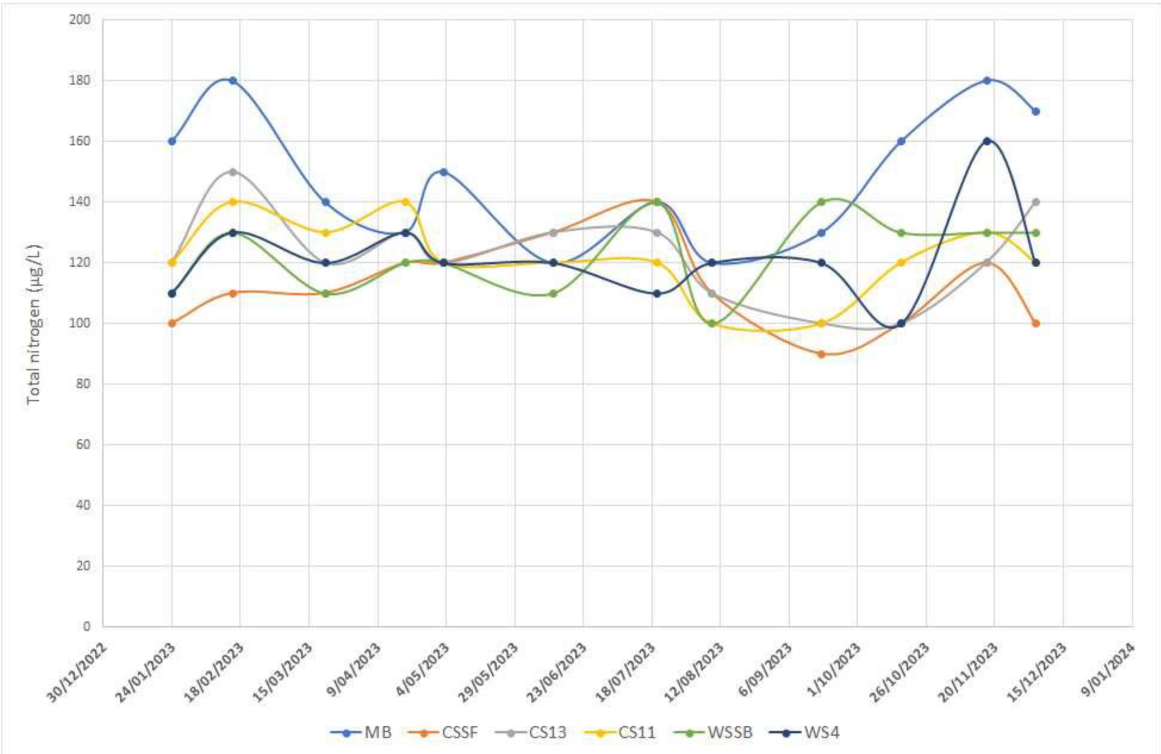

Figure B8: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-S from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

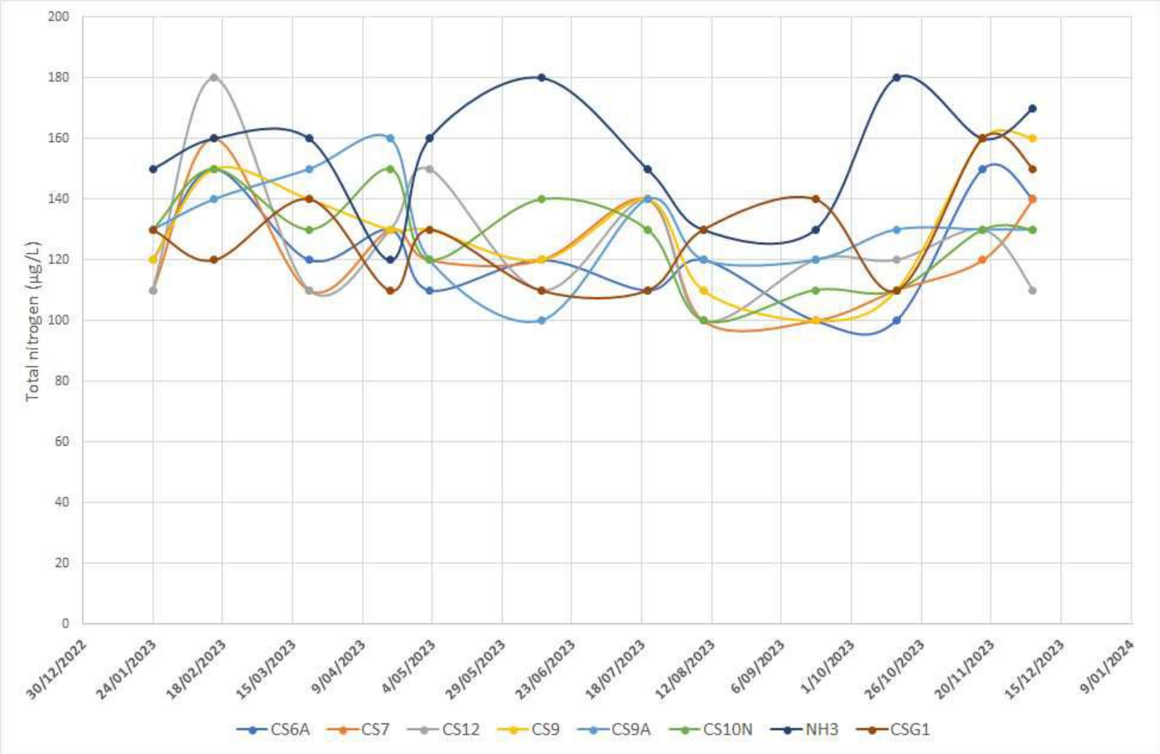

Figure B9: Monthly total nitrogen concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

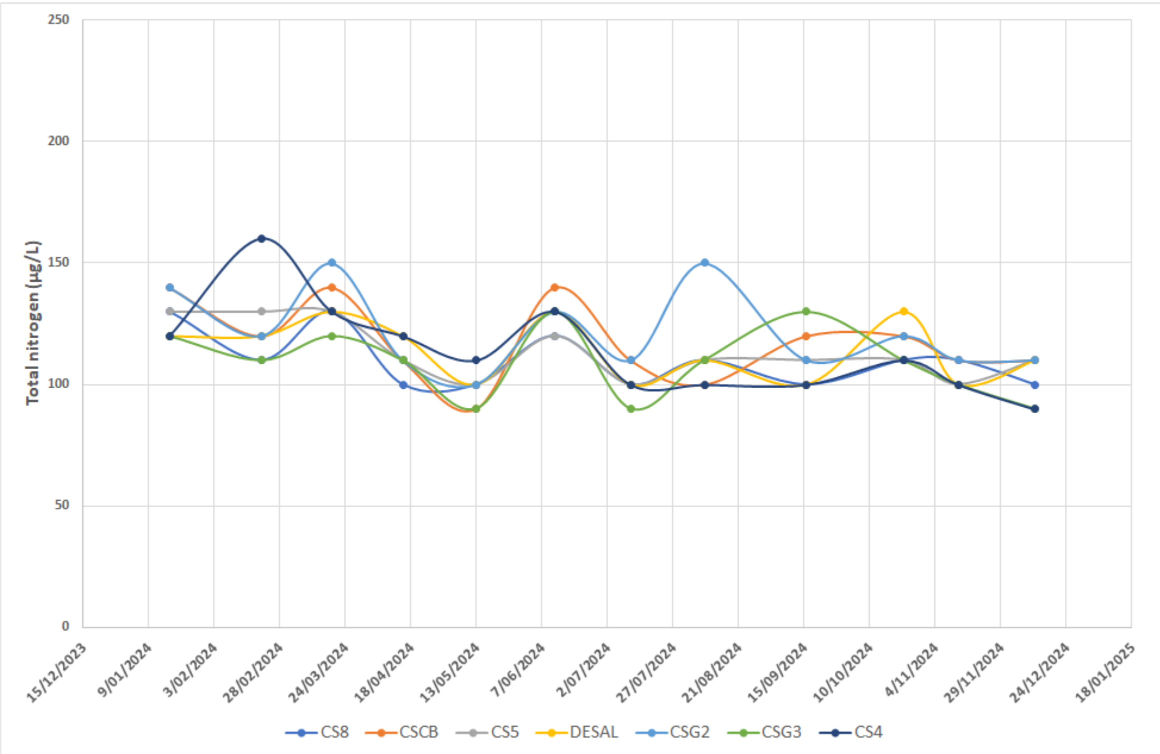

Figure B10: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-N from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

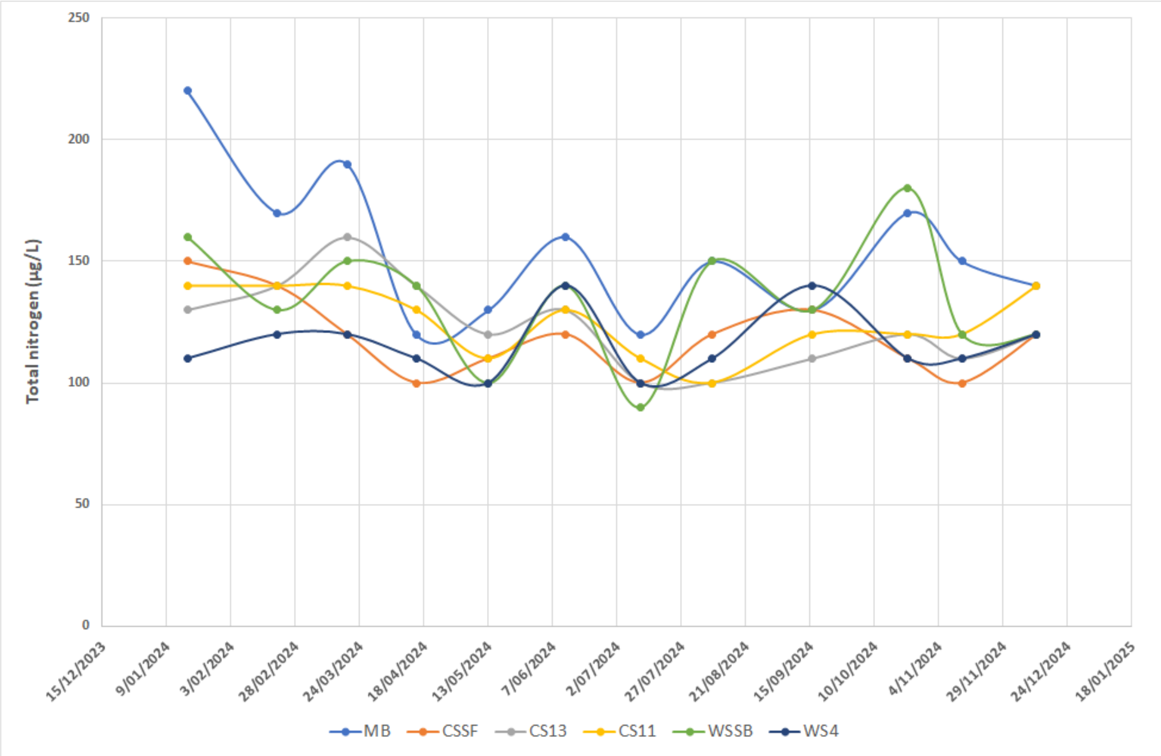

Figure B11: Monthly total nitrogen concentrations at water quality monitoring sites in HPA-S from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

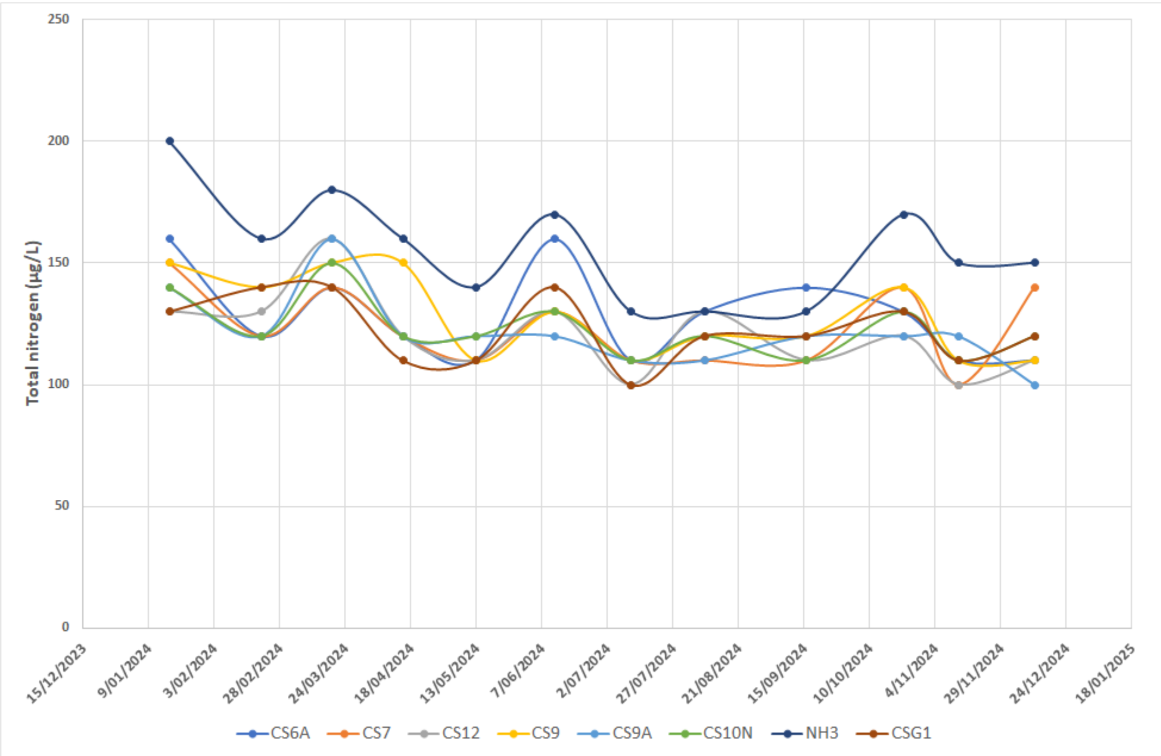

Figure B12: Monthly total nitrogen concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

Total phosphorus

Monthly total phosphorus was measured at water quality monitoring sites from January to December 2023 (Figures B13–B15) and January to December 2024 (Figures B16–B18).

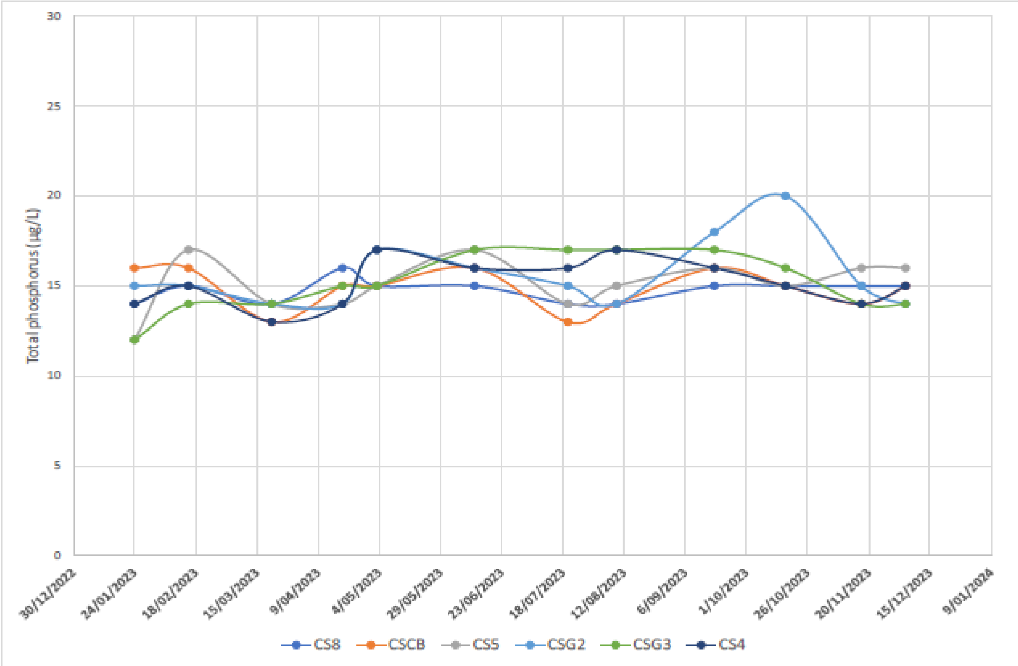

Figure B13: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-N from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

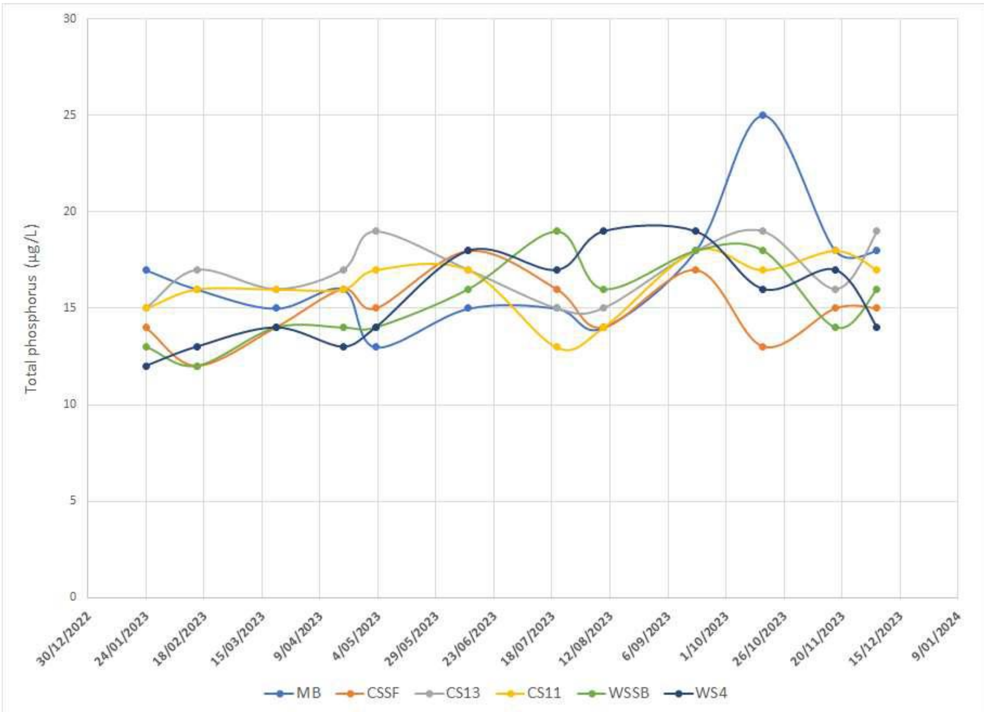

Figure B14: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-S from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

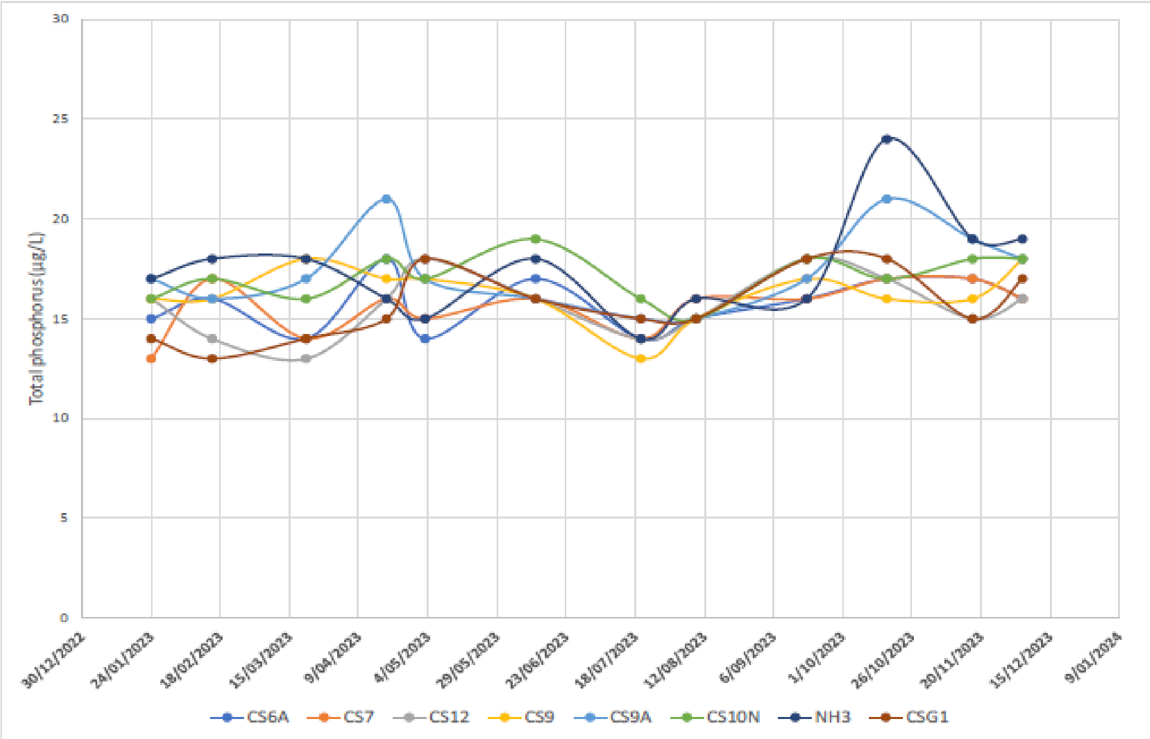

Figure B15: Monthly total phosphorus concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2023. Taken from C. Wilson (2024) MAFRL report no. 24-2.

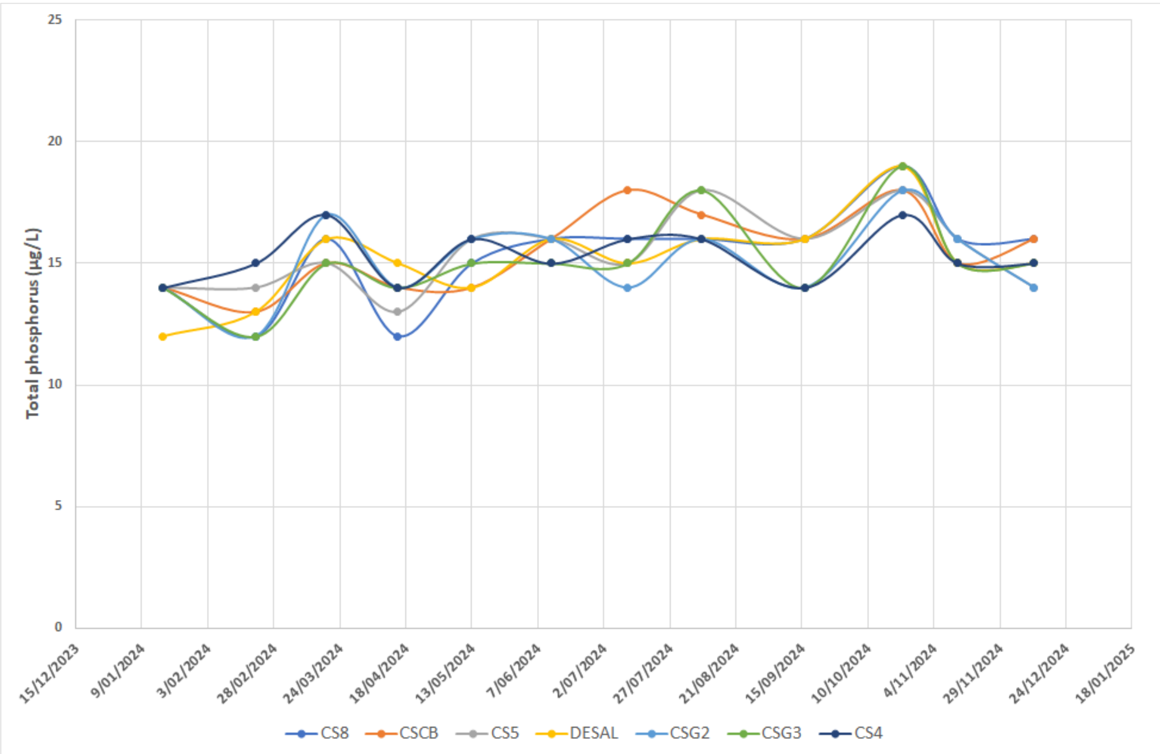

Figure B16: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-N from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

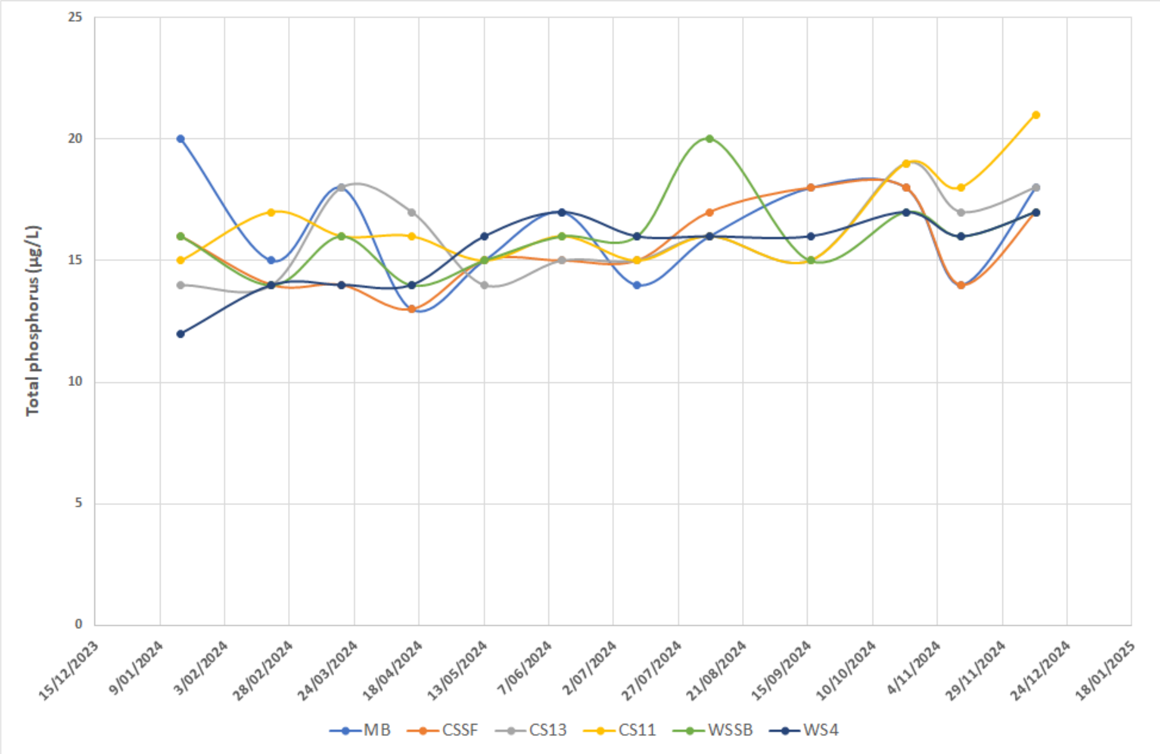

Figure B17: Monthly total phosphorus concentrations at water quality monitoring sites in HPA-S from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

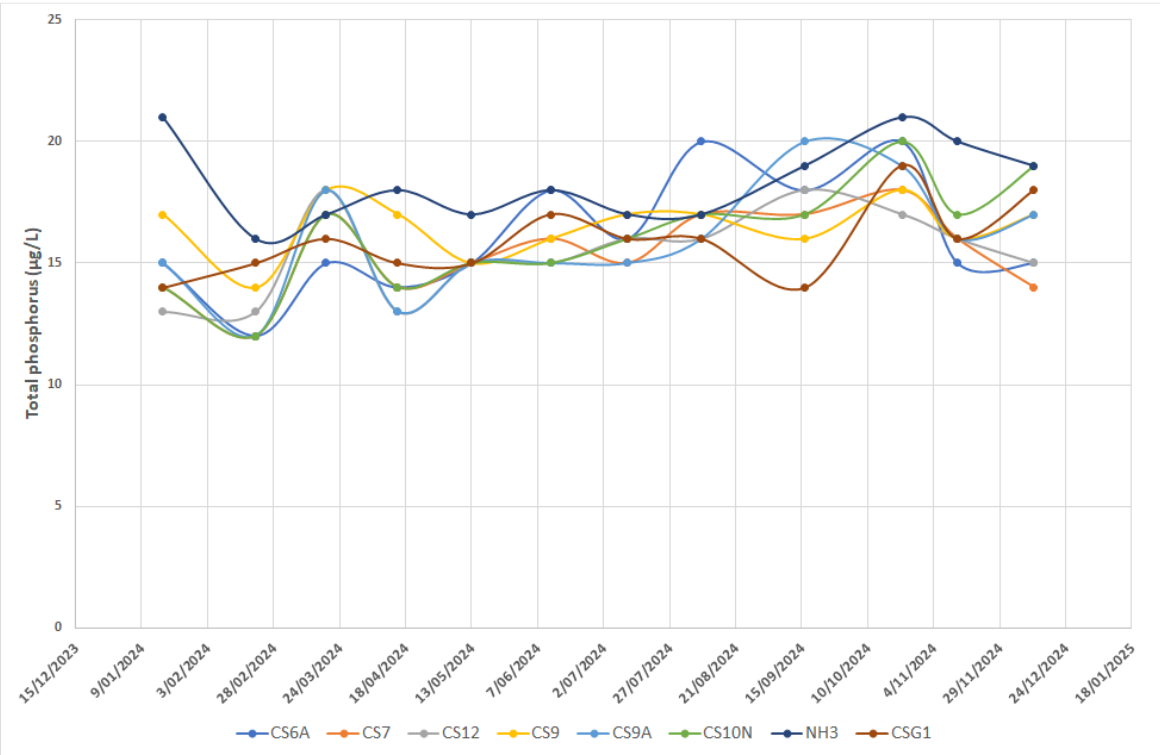

Figure B18: Monthly total phosphorus concentrations at water quality monitoring sites in MPA-ES, MPA-CB and MPA-NH from January to December 2024. Taken from C. Wilson (2025) MAFRL report no. 25-2.

Appendix C: Seagrass health in 2023

This section presents the 2023 seagrass health trend assessment. A note on a data integrity issue relevant to this assessment is included below.

Issue

In 2022 and in 2023 the standard operating procedures (EPA 2005) were not followed during field surveys, due to the consultant not being able to locate the established fixed quadrats. The change in methodology adopted by the consultant, at a number of sites, generated data that could not reasonably be compared with data collected during previous years. A resolution was made to run an alternative analysis to address these issues for the 2024 assessment (Appendix D); however, this was not possible for the 2023 assessment.

The assessment against EQS (iii) – which relates to the lower depth limit and does not involve fixed quadrats – was unaffected.

Also note an absence of data for 2021, as monitoring was suspended due to the Covid-19 pandemic.

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

See Table C1 for the calculated rolling percentiles for EQS (i) and (ii) for seagrass shoot density. The rolling percentiles could only be calculated for the deeper Warnbro reference sites (5.2 m and 7.0 m reference sites). Monitoring ceased at the shallow Warnbro Sound reference sites (2.0 m, 2.5 m and 3.5 m) in 2022 due to near-total seagrass loss from natural 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 had declined over time. The values used in the assessment against EQS (i) are denoted in bold.

There are no absolute minimum criteria for EQS (ii). The EQS (ii) rolling percentiles (the 5th percentile) could only be determined for Warnbro Sound 5.2 m and 7.0 m reference sites, as these sites are in good condition. Due to the loss of the shallow sites, EQS (ii) could not be calculated for Warnbro Sound 2.0 m, 2.5 m and 3.5 m.

Table C1: The 2022 and 2023 rolling 20th and 5th percentiles of seagrass shoot density for the Warnbro Sound reference sites for each depth category

		Warnbro Sound reference sites 2022					Warnbro Sound reference sites 2023				
Site name	**Depth category (m)**	**N**	**20th**	**5th**	**AMC 5th**	**AMC 1st**	**N**	**20th**	**5th**	**AMC 5th**	**AMC 1st**
Warnbro Sound (2.0 m)	1.5–2.0	0	–	–	**666**	**412**	0	–	–	**666**	**412**
Warnbro Sound (2.5 m)	2.0–3.0	0	–	–	**500**	**275**	0	–	–	**500**	**275**
Warnbro Sound (3.2 m)	3.0–4.0	0	–	–	**171**	**100**	0	–	–	**171**	**100**
Warnbro Sound (5.2 m)	5.0–6.0	96	375	244	**419**	**324**	96	**425**	244	**419**	**324**
Warnbro Sound (7.0 m)	7.0	90	**200**	**50**	59	25	91	**200**	**62.5**	59	25

If the rolling 20th and 5th percentiles are below the AMC, the AMC values are used instead. Percentiles for 2022 are based on data from 2018, 2019, 2020 and 2022, while percentiles for 2023 are based on data from 2019, 2020, 2022 and 2023.

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

EQS (i)

The assessment of EQS (i) was based on data from two consecutive years, 2022 and 2023.

Seagrass health EQS (i) was successfully met at most monitored sites in Cockburn Sound in 2022 and 2023 (Table C2). In 2023, Coogee, Bird Island and Woodman Point were not monitored, and it was not possible to assess EQS (i).

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 (Kwinana, Garden Island 5.2 m, Garden Island 7.0 m) all met the EQS (ii) (Table C2).

Table C2: Assessment of EQS (i) for each potential impact site in 2022 and 2023, and EQS (ii) for 2023 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 are 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	Ref. site depth (m)	2023 (no. of non-0 quadrants)	Median (shoots m^{-2})		EQS (i)			EQS (ii)	Results			
				2022	2023	2022 20th	2023 20th	AMC 5th	2023 5th	2022 EQS (i)	2023 EQS (i)	2023 EQS (ii)	Overall result
HPA-N	Luscombe Bay	1.5–2.0	18	1450	1150	–	–	**666**	–	✓	✓	–	?
	Garden Is. Settlement	1.5–2.0	24	838	975	–	–	**666**	–	✓	✓	–	?
	Garden Is. 2.0 m	1.5–2.0	24	1110	1138	–	–	**666**	–	✓	✓	–	?
	Garden Is. 2.5 m	2.0–3.0	23	638	925	–	–	**500**	–	✓	✓	–	?
	Garden Is. 3.2 m	3.0–4.0	24	1125	1138	-	–	**171**	–	✓	✓	–	?
	Kwinana	5.0–6.0	24	888	900	375	**425**	**419**	244	✓	✓	✓	✓
	Garden Is. 5.2 m	5.0–6.0	23	863	975	375	**425**	**419**	244	✓	✓	✓	✓
	Garden Is. 7.0 m	6.0–7.0	24	475	488	**200**	**200**	59	62.5	✓	✓	✓	✓
HPA-S	Southern Flats	1.5–2.0	20	1138	1013	–	–	**666**	–	✓	✓	–	?
	Mangles Bay	3.0–4.0	18	363	238	–	–	**171**	–	✓	✓	–	?
High – undesignated	Woodman Point	3.0–4.0	–	650	–	–	–	**171**	–	✓	–	–	?

Ecological protection area	Site name	Ref. site depth (m)	2023 (no. of non-0 quadrants)	Median (shoots m^{-2})		EQS (i)			EQS (ii)	Results			
				2022	2023	2022 20th	2023 20th	AMC 5th	2023 5th	2022 EQS (i)	2023 EQS (i)	2023 EQS (ii)	Overall result
	Bird Island	1.5–2.0	–	675	–	–	–	**666**	–	✓	–	–	?
	Mersey Point	2.0–3.0	24	1525	1288	–	–	**500**	–	✓	✓	–	?
	Carnac Island	3.0–4.0	24	813	813	–	–	**171**	–	✓	✓	–	?
	Coogee	5.0–6.0	–	537	–	375	–	**419**	–	✓	–	–	?
Protection level	**Site name**	**Ref. site depth (m)**	**2023 (no. of non-0 quadrants)**	**Median (shoots/m^{-2})**		**EQS (i)**			**EQS (ii)**	**Interpretation of EQS (i) and (ii)**			
				2022	**2023**	**2022 5th**	**2023 5th**	**AMC 1st**	**2023 1st**	**2022 EQS (i)***	**2023 EQS (i)**	**2023 EQS (ii)**	**Overall result**
MPA-NH	Jervoise Bay	3.0–4.0	2	175	1500	–	–	**100**	–	✓	✓	–	?

Percentiles for 2022 are based on data from 2018, 2019, 2020 and 2022, while percentiles for 2023 are based on data from 2019, 2020, 2022 and 2023. No sampling was undertaken in 2021 due to Covid-19.

Assessment against EQS (iii) – lower depth limit

Lower depth limit ranged from 6.6 m at Mangles Bay to 8.8 m at Woodman Point and Garden Island North (Table C3).

EQS (iii) for depth limit was achieved at three out of four sites for which 2000–02 baseline values were available (Table C3). Garden Island North failed EQS (iii), with the 2023 depth limit above the expected range of the baseline mean LDL (Table C3).

This provided some indication that seagrasses had retreated into shallower waters at the Garden Island North site in 2023, however these changes did not present as a significant declining trend (Table C4).

Table C3: Mean lower depth limit (LDL) ± standard error in 2020 and 2022, with 2022 compared with the baseline LDL.

Ecological protection area	Site	Mean LDL 2022 (m)	Mean LDL 2023 (m)	Baseline	Assessment
				Mean LDL 2000–02 (m)	EQS (iii)
High	Garden Island North (depth)	9.4 ± 0.4	8.8 ± 0.4	9.8 ±0.2	✗
	Garden Island South (depth)	6.9 ± 0.3	7.7 ± 0.7	7.6 ±0.4	✓
	Southern Flats (depth)	8.6 ± 0.2	7.4 ± 0.7	–	n/a
	Mangles Bay (depth)	6.5 ± 0.4	6.6 ± 0.6	–	n/a
Reference depth site	Warnbro Sound (depth)	8.2 ± 0.4	8.6 ± 0.9	8.4 ±0.5	✓
Undesignated	Woodman Point (depth)	11.3 ± 0.5	8.8 ± 0.5	8.7 ±0.8	✓

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

Table C4: Trend analyses of LDL at 'depth transect'. Significant trends (i.e. p<0.05) are denoted in bold.

Ecological protection area	Site	Trend Statistic	P value	Significant trends
High	Garden Island North (depth)	-0.21	0.54	–
	Garden Island South (depth)	0	1	–
	Southern Flats (depth)	0.07	1	–
	Mangles Bay (depth)	0.41	0.34	–
Reference depth site	Warnbro Sound (depth)	0.03	1	–
Undesignated	Woodman Point	0.03	1	–

Trend analysis of shoot density (additional line of evidence)

Figures C1–C4 display the results of 2023 trend analyses, with statistically significant trends indicated by solid lines and weaker identified trends indicated by dashed lines. Figure C5 displays results of Warnbro Sound reference site trend analyses. Note the shallow reference site trends are only to 2020. Due to declining trends, they were considered no longer suitable as reference sites.

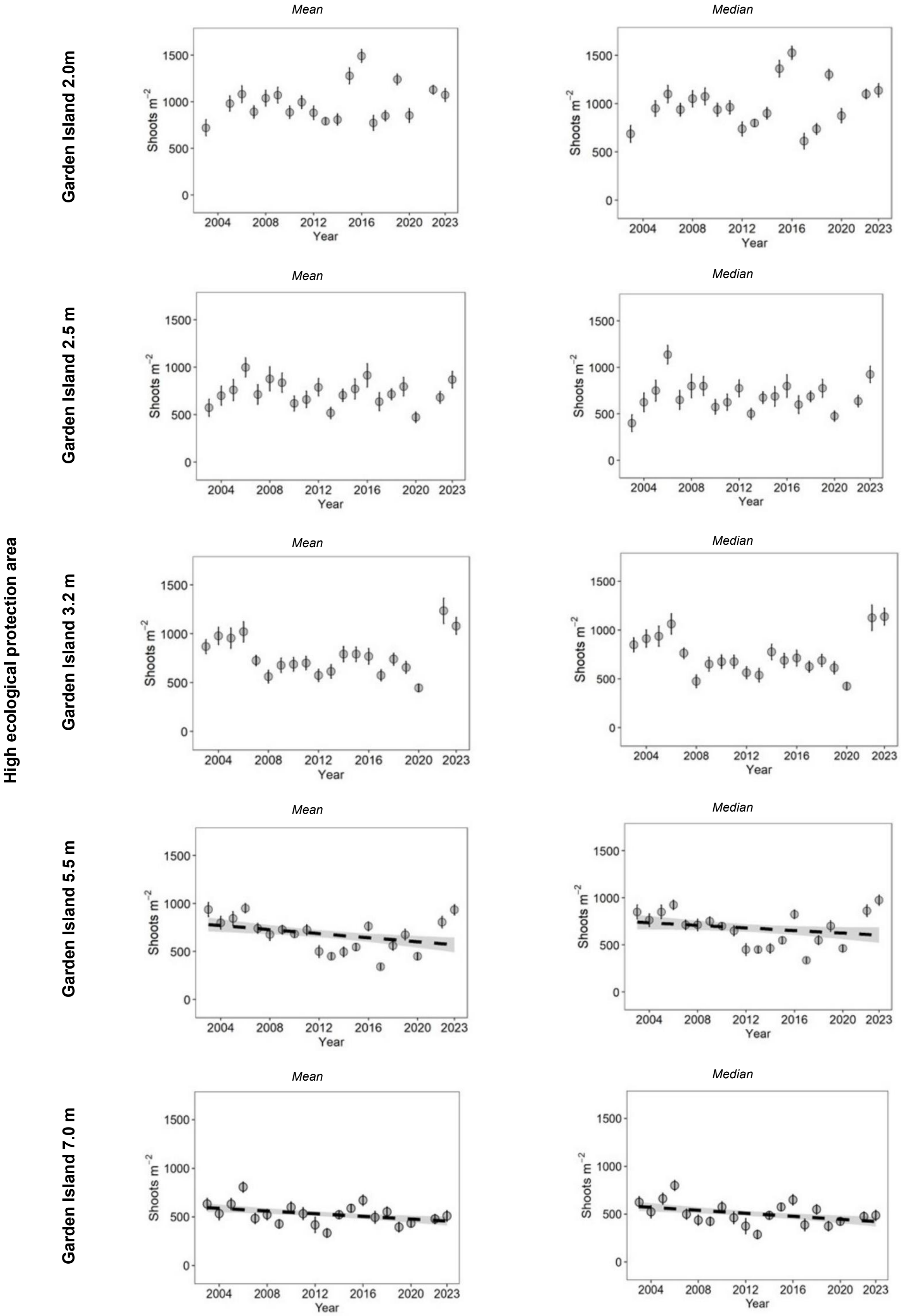

Figure C1: Mann-Kendall trend analysis results for mean and median (+SE) Posidonia sinuosa shoot densities at Garden Island 'potential impact' sites in the Cockburn Sound high ecological protection area in 2023. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) are designated by a dashed line.

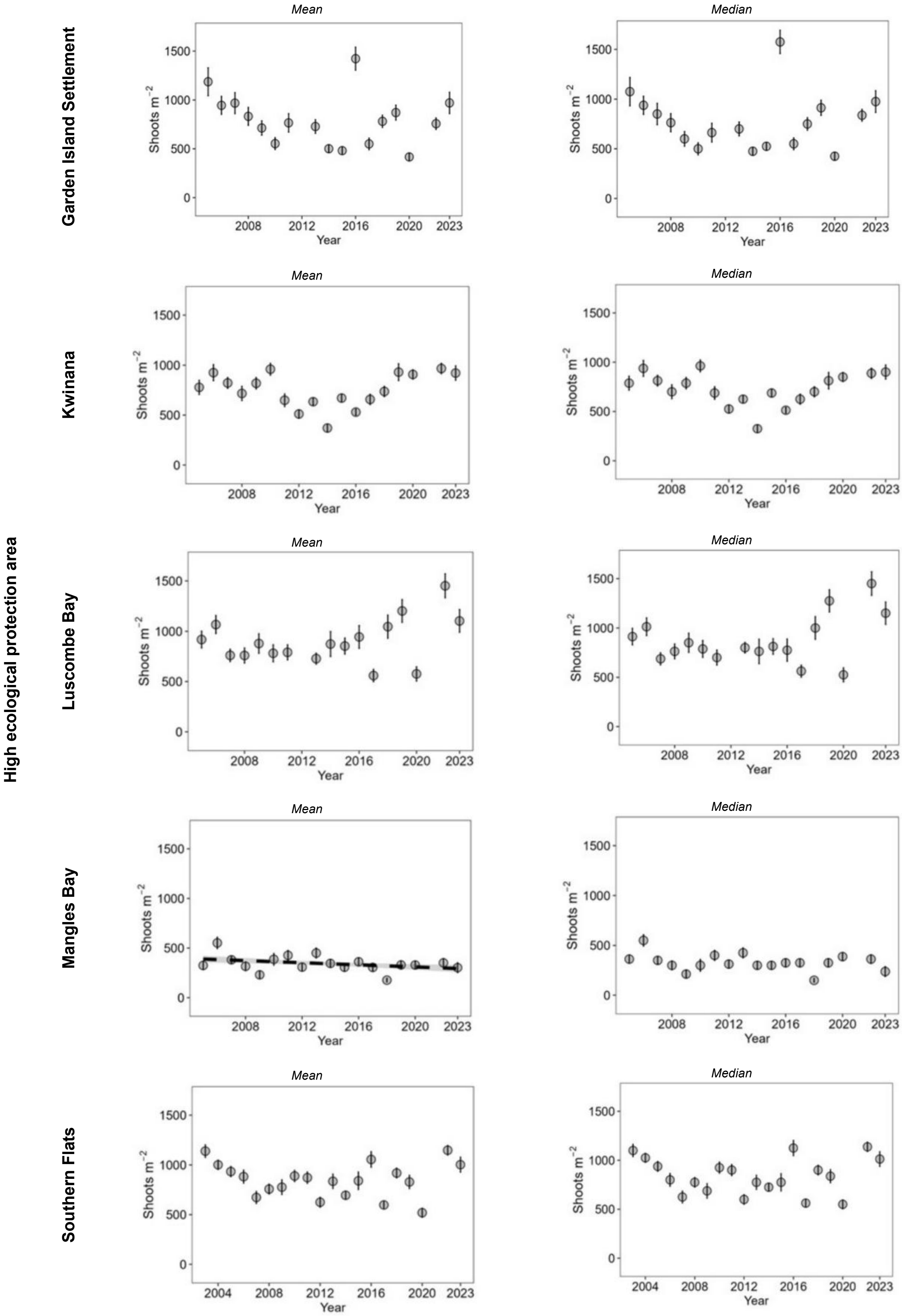

Figure C2: Mann-Kendall trend analysis results for mean and median (+SE) Posidonia sinuosa shoot densities at 'potential impact' sites in the Cockburn Sound high ecological protection area in 2023. Significant trends ($p<0.05$) are designated by a solid line and potential trends ($p<0.2$) are designated by a dashed line.

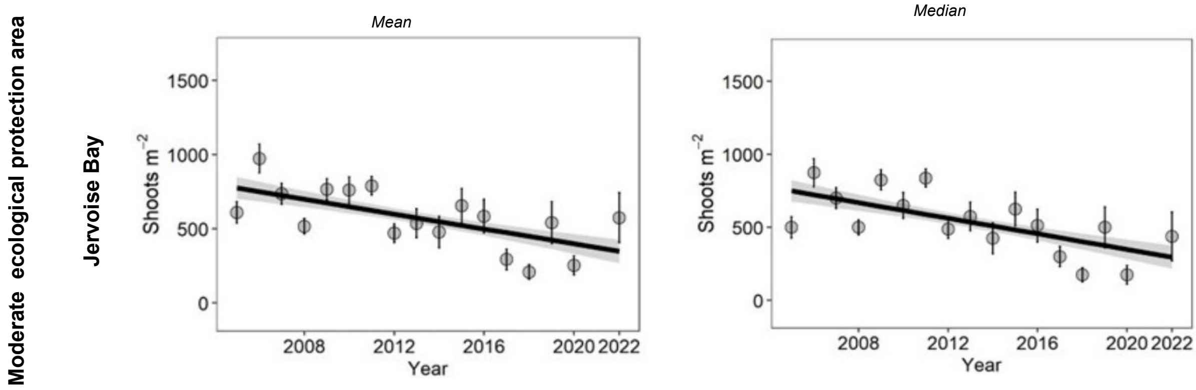

Figure C3: Mann-Kendall trend analysis results for mean (+SE) and median (+SE) Posidonia sinuosa shoot densities at 'potential impact' site Jervoise Bay in the Cockburn Sound moderate ecological protection area for 2023. Significant trends (p<0.05) are designated by a solid line.

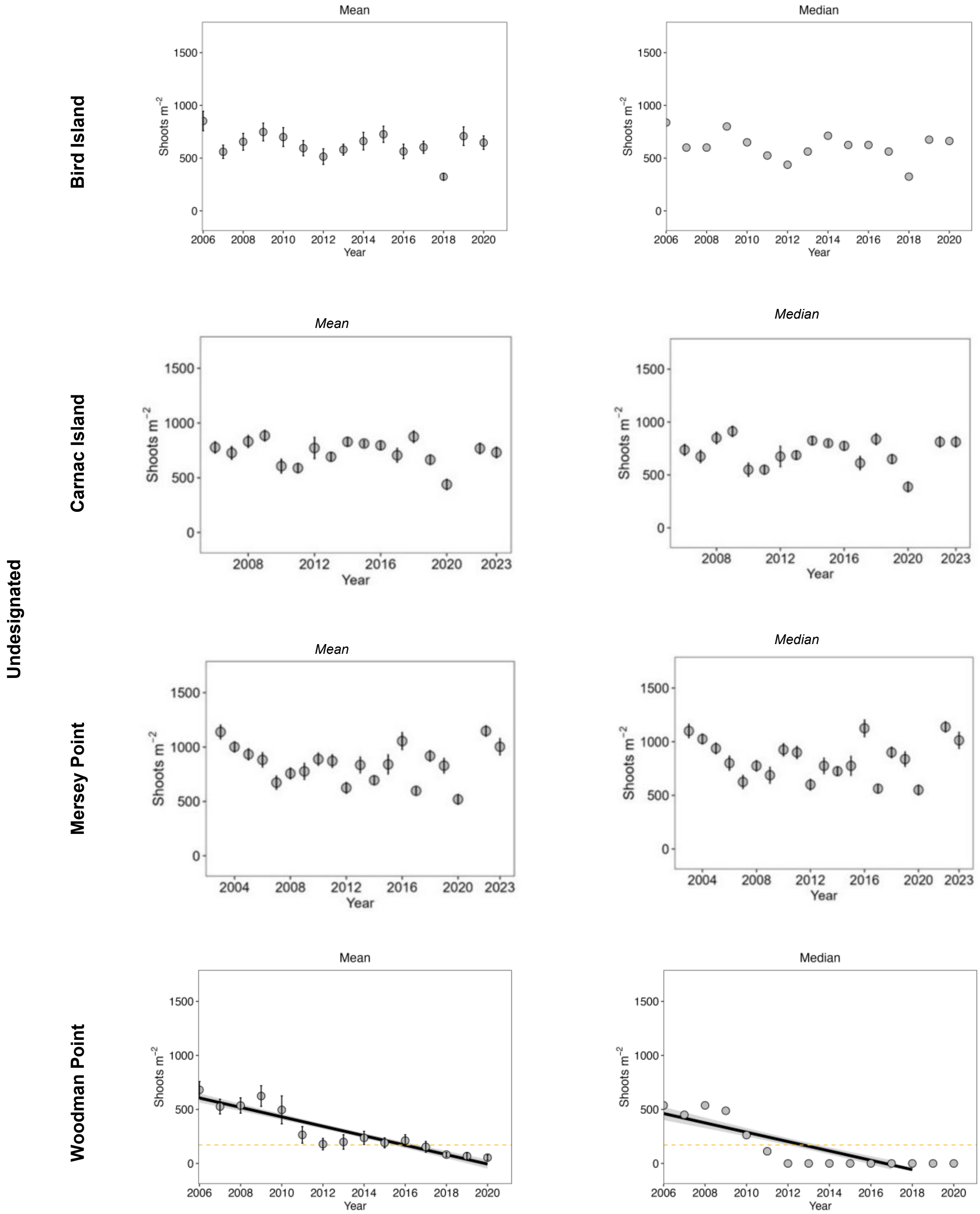

Figure C4: Mann-Kendall trend analysis results for mean and median (+SE) Posidonia sinuosa shoot densities in the undesignated areas in 2023. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) by a dashed line. Bird Island and Woodman Point represent trends up to 2020.

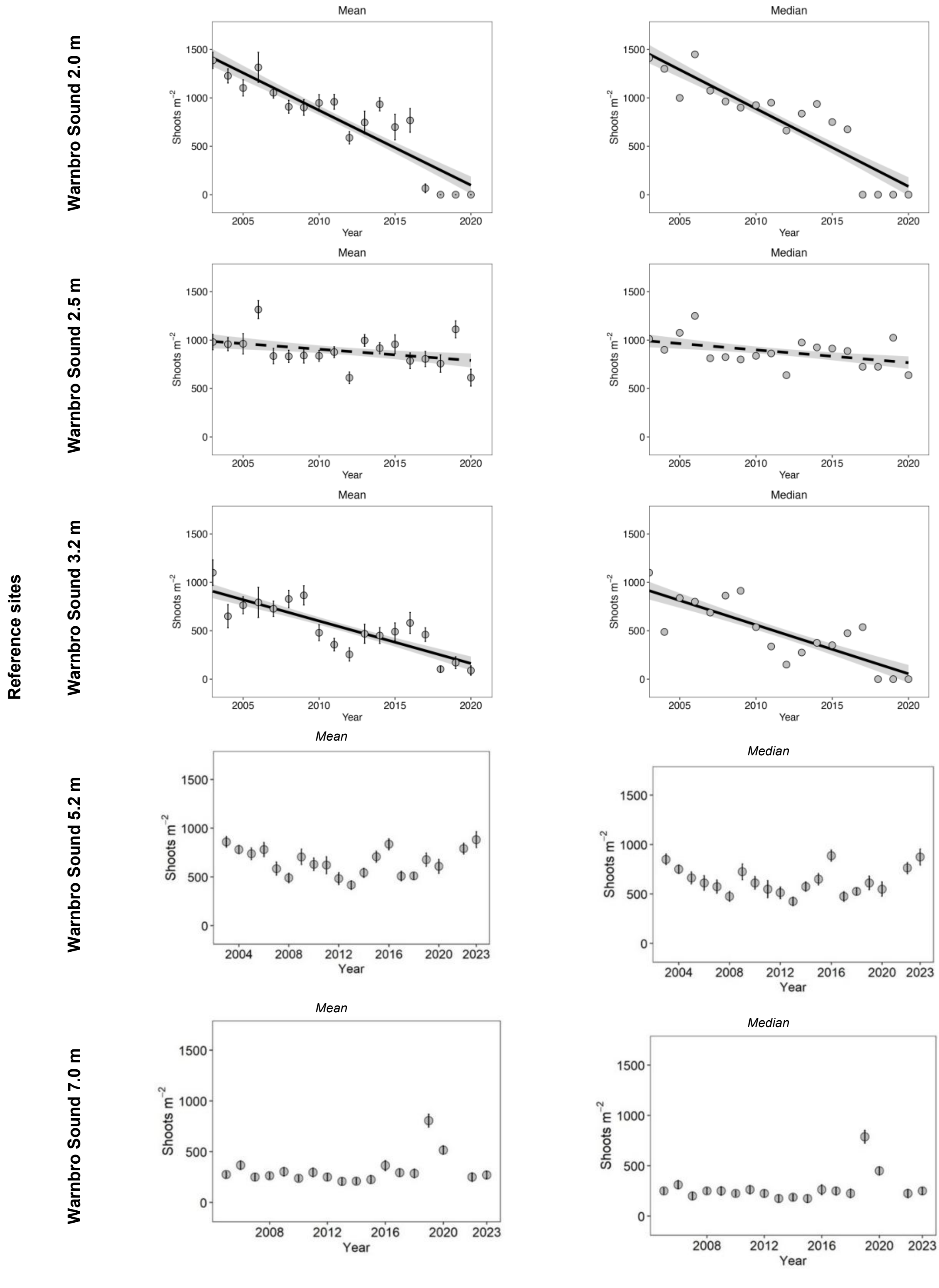

Figure C5: Mann-Kendall trend analysis results for mean (+SE) Posidonia sinuosa shoot densities at Warnbro Sound 'reference' sites for 2023. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) are designated by a dashed line. Shallow reference sites (up to 3.2 m) trends are up to 2020.

Warnbro Sound reference sites

Table C5 presents the Mann-Kendall trend analyses for changes in shoot density for each reference site in Warnbro Sound in 2023. These are only shown for the deeper reference sites (Warnbro 5.2 m and Warnbro 7.0 m), for which no significant trends in shoot density were found in 2023. The shallow Warnbro reference sites ceased to be used after 2020 due to declining shoot densities attributed to natural erosion/accretion.

Table C5: Summary of Mann-Kendall trend analysis for Warnbro Sound reference sites in 2023 based on the mean, median and the 20th, 5th and 1st percentiles since the inception of monitoring.

Site name	Mean 2023		Median 2023		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
Warnbro Sound (5.2 m)	-0.07	0.67	-0.07	0.67	-0.07	0.74	0.03	0.90	0.1	0.61
Warnbro Sound (7.0 m)	0.04	0.85	0.03	0.88	-0.01	1	-0.16	0.40	-0.16	0.48

Significant trends are identified in bold ($p<0.05$) and potential trends denoted by italic and '*' ($p<0.2$). Negative trends are identified by red, and positive trends by green.

Cockburn Sound sites

Shoot density at most sites in Cockburn Sound followed a neutral trend in 2023 (Table C6).

Sites with potentially declining trends (defined as $p<0.2$) include Garden Island 5.2 m and Garden Island 7.0 (HPA-N), and Mangles Bay (HPA-S).

Significant declines ($p<0.05$) were reported for Jervoise Bay (MPA-ES).

Bird Island, Coogee and Woodman Point were not monitored in 2023 so the trends from 2022 were reported.

Table C6: Summary of trend analysis on the mean and median shoot densities at potential impact sites in 2023.

Ecological protection area	Site	Mean	P value	Median	P value	Significant trends (median)
HPA-N	Luscombe Bay	0.19	0.30	0.13	0.51	–
	Garden Is. Settlement	-0.21	0.27	-0.10	0.59	–
	Garden Is. (2.0 m)	0.09	0.62	0.11	0.55	–
	Garden Is. (2.5 m)	0	1	0.05	0.77	–
	Garden Is. (3.2 m)	-0.11	0.52	-0.12	0.50	–
	Garden Is. (5.5m)	*-0.31*	*0.06**	*-0.23*	*0.18**	↘
	Kwinana	0.09	0.65	0.03	0.91	–
	Garden Is. (7.0 m)	*-0.30*	*0.07**	*-0.27*	*0.11**	↘
HPA-S	Southern Flats	-0.19	0.26	-0.17	0.33	–
	Mangles Bay	*-0.26*	*0.15**	-0.12	0.54	–
Undesignated	[1]Bird Island	-0.10	0.62	-0.09	0.65	–
	[1]Woodman Point	**-0.48**	**0.01**	-0.19	0.32	–
	[1]Coogee	-0.14	0.49	-0.16	0.4	–
	Mersey Point	0.21	0.27	0.22	0.25	–
	Carnac Island	-0.19	0.26	-0.17	0.33	–
MPA-ES	Jervoise Bay	**-0.41**	**0.02**	**-0.51**	**<0.01**	↓

Significant trends (p<0.05) are denoted in bold text with potential trends denoted by italics and '*' (p<0.2). Negative trends are identified by red, and positive trends by green.

[1] Sites not monitored in 2023 and therefore trends from 2022 were used instead.

Appendix D: Seagrass health assessment 2024 (excluding 2022 and 2023 data)

This section presents the 2024 seagrass health assessment, supported by an additional long-term trend analysis that excludes data from 2022 and 2023 (see note below). These years were omitted because their sampling methodology differed from other years, making them not directly comparable (see **Issue** in Appendix C).

Note

In 2024, the fixed quadrats were re-established, confirming that seagrass shoot counts in random quadrats tended to be significantly higher than those in the established fixed quadrats. This led to two response actions:

1) A decision to conduct the 2024 seagrass shoot density assessment against EQS (i) and (ii), both with and without consideration of the 2022 and 2023 data for the purpose of this report. This option was not available for the 2023 annual assessment.
2) A decision to conduct a preliminary investigation as to whether seagrass shoot density within the established fixed quadrats was being affected by repeated sampling over many years ('sampling fatigue'), as outlined in the main report.

The assessment against EQS (iii) – which relates to the lower depth limit and does not involve fixed quadrats – was unaffected.

Note the absence of data for 2021: monitoring was suspended due to the Covid-19 pandemic.

For completeness, the 2024 trend assessment that included all data is provided in Appendix E.

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

The calculation of rolling percentiles from the Warnbro Sound reference sites is based on data from 2020 and 2024. The calculated rolling percentiles for EQS (i) and (ii) for seagrass shoot density are presented in Table D1. Rolling percentiles for the shallow Warnbro Sound reference sites are only shown for 2020. These shallow sites were abandoned from 2022 as almost all seagrass was lost because of natural sediment accretion/erosion. Rolling percentiles for the deeper Warnbro sites 5.2 m and 7.0 m are shown for 2024.

The values used in the assessment against EQS (i) are denoted in bold (Table D1). If the rolling 20th and 5th percentiles are below the absolute minimum criteria (AMC), the AMC values are used instead. The AMC are used in most instances.

The assessment of EQS (ii) for all shallow sites was confounded by lack of data at the shallow sites and could not be completed.

Table D1: The 2020 and 2024 rolling 20th, 5th and 1st rolling percentiles, and AMC values of seagrass shoot density for the Warnbro Sound reference sites (excluding data from 2022 and 2023).

		Warnbro Sound reference sites 2020					Warnbro Sound reference sites 2024				
Site name	**Depth category (m)**	**N**	**20th**	**5th**	**AMC 5th**	**AMC 1st**	**N**	**20th**	**5th**	**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 (5.2 m)	5.0–6.0	96	350	225	**419**	**324**	96	275	122.7	**419**	**324**
Warnbro Sound (7.0 m)	7.0	92	**200**	**89**	59	25	91	**75**	**25**	59	25

If the rolling 20th and 5th percentiles are below the AMC, the AMC values are used instead. All percentiles for 2020 are based on data from 2017, 2018, 2019 and 2020, and percentiles for 2024 are based on data from 2018, 2019, 2020 and 2024. No sampling was undertaken in 2021 due to Covid. The numbers used for the EQS assessment are denoted in bold. AMC values were used for the shallow sites.

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

EQS (i)

The assessment of EQS (i) is based on data from two *non-consecutive* years, 2020 and 2024.

Six of the 12 monitoring sites met EQS (i) in 2020 and 2024. Two sites achieved EQS (i) in only one year (Garden Island 5.2 m and Woodman Point) and four sites did not meet the health criteria in both 2020 and 2024 (Luscombe Bay, Garden Island Settlement, Garden Island 2.5 m and Southern Flats) (Table D2).

EQS (ii)

The assessment of EQS (ii) could only be completed at the three deeper sites (Kwinana, Garden Island 5.2 m, Garden Island 7.0 m) in the high protection area; each met EQS (ii) (Table D2).

Kwinana and Garden Island 7.0 m met both EQS (i) and EQS (ii) for seagrass health in the 2020/2024 assessment (Table D2).

Table D2: Assessment of EQS (i) for each potential impact site in 2020 and 2024, and EQS (ii) for 2024 only

Median shoot densities (shoots/m²) 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 are 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	Ref. site depth (m)	2024 (no. of non-0 quadrants)	Median (shoots.m^{-2})		EQS (i)			EQS (ii)	Results			
				2020	2024	2020 20th	2024 20th	AMC 5th	2024 5th	2020 EQS (i)	2024 EQS (i)	2024 EQS (ii)	Overall result
HPA-N	Luscombe Bay	1.5–2.0	22	520	388	**720**	–	**666**	–	×	×	–	?
	Garden Is. Settlement	1.5–2.0	24	425	413	**720**	–	**666**	–	×	×	–	?
	Garden Is. 2.0 m	1.5–2.0	24	875	675	**720**	–	**666**	–	✓	✓	–	?
	Garden Is. 2.5 m	2.0–3.0	24	475	450	480	–	**500**	–	×	×	–	?
	Garden Is. 3.2 m	3.0–4.0	24	425	550	165	–	**171**	–	✓	✓	–	?
	Kwinana*	5.0–6.0	24	850	525	350	275	**419**	122.7	✓	✓	✓	✓
	Garden Is. 5.2 m	5.0–6.0	24	463	313	350	275	**419**	122.7	✓	×	✓	✓
	Garden Is. 7.0 m	6.0–7.0	23	425	250	**200**	**75**	59	25	✓	✓	✓	✓
HPA-S	Southern Flats	1.5–2.0	20	550	575	**720**	–	**666**	–	×	×	–	?
	Mangles Bay	3.0–4.0	22	388	300	165	–	**171**	–	✓	✓	–	?
High – undesignated	Woodman Point	3.0–4.0	–	100	–	**–**	–	**171**	–	×	–	–	?

Ecological protection area	Site name	Ref. site depth (m)	2024 (no. of non-0 quadrants)	Median (shoots.m^{-2})		EQS (i)			EQS (ii)	Results			
				2020	2024	2020 20th	2024 20th	AMC 5th	2024 5th	2020 EQS (i)	2024 EQS (i)	2024 EQS (ii)	Overall result
	Bird Island	1.5–2.0	–	675	–	–	–	**666**	–	✓	–	–	?
	Mersey Point	2.0–3.0	24	600	713	–	–	**500**	–	✓	✓	–	?
	Carnac Island	3.0–4.0	24	388	750	–	–	**171**	–	✓	✓	–	?
	Coogee	5.0–6.0	–	588	–	–	–	**419**	–	✓	–	–	?

Protection level	Site name	Ref. site depth (m)	2024 (no. of non–0 quadrants)	Median (shoots/m^{-2})		EQS (i)			EQS (ii)	Interpretation of EQS (i) and (ii)			
				2020	2024	2020 5th	2024 5th	AMC 1st	2024 1st	2020 EQS (i)*	2024 EQS (i)	2024 EQS (ii)	Overall result
MPA-NH	Jervoise Bay	3.0–4.0	4	175	850	25	–	**100**	–	✓	✓	–	?

If the rolling 20th and 5th percentiles are below the AMC, the AMC values are used instead. All percentiles for 2020 are based on data from 2017, 2018, 2019 and 2020, and percentiles for 2024 are based on data from 2018, 2019, 2020 and 2024. The numbers used for the EQS assessment are denoted in bold. AMC values were used for the shallow sites.

Assessment against EQS (iii) – lower depth limit

Lower depth limit ranged from 5.5 m at Mangles Bay to 8.6 m at Garden Island North in 2024.

EQS (iii) was met at two out of four sites for which a 2000–02 baseline was available (Table D3). Garden Island North and Woodman Point have become shallower and therefore failed the EQS (iii) in 2024.

Whilst some sites did not meet EQS (iii) in 2024 there were no significant trends in seagrass depth distribution at all sites (Table D4).

Table D3: Mean lower depth limit (LDL) ± standard error in 2020 and 2024, with 2024 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 2024 (m)	Baseline	Assessment
				Mean LDL 2000–02 (m)	EQS (iii)
High	Garden Island North (depth)	10.3 ± 0.5	**8.6 ± 0.1**	9.8 ±0.2	✗
	Garden Island South (depth)	12.9 ± 0.2	8.5 ± 0.5	7.6 ±0.4	✓
	Southern Flats (depth)	8.6 ± 0.5	8.1 ± 0.1	n/a	n/a
	Mangles Bay (depth)	6.3 ± 0.4	5.5 ± 0.1	n/a	n/a
Reference depth site	Warnbro Sound (depth)	9.8 ± 0.1	**7.4 ± 0.1**	8.4 ±0.5	✗
Undesignated	Woodman Point (depth)	12.7 ± 0.1	8.3 ± 0.1	8.7 ±0.8	✓

Table D4: Trend analyses of LDL at 'depth transect'. Significant trends (i.e. p<0.05) denoted in bold

Ecological protection area	Site	Trend Statistic	P value	Significant trends
High	Garden Island North (depth)	-0.048	1	–
	Garden Island South (depth)	0.21	0.54	–
	Southern Flats (depth)	0.60	0.22	–
	Mangles Bay (depth)	0.41	0.34	–
Reference depth site	Warnbro Sound (depth)	0.18	0.62	–
Undesignated	Woodman Point	-0.11	0.80	–

Trend analysis of shoot density (additional line of evidence)

Figures D1–D4 display the results of 2024 trend analyses, with statistically significant trends indicated by solid lines and weaker identified trends indicated by dashed lines. Figure D5 displays the results of Warnbro Sound reference site trend analyses. Note the shallow reference site trends are only to 2020. Due to declining trends, they were considered no longer suitable as reference sites.

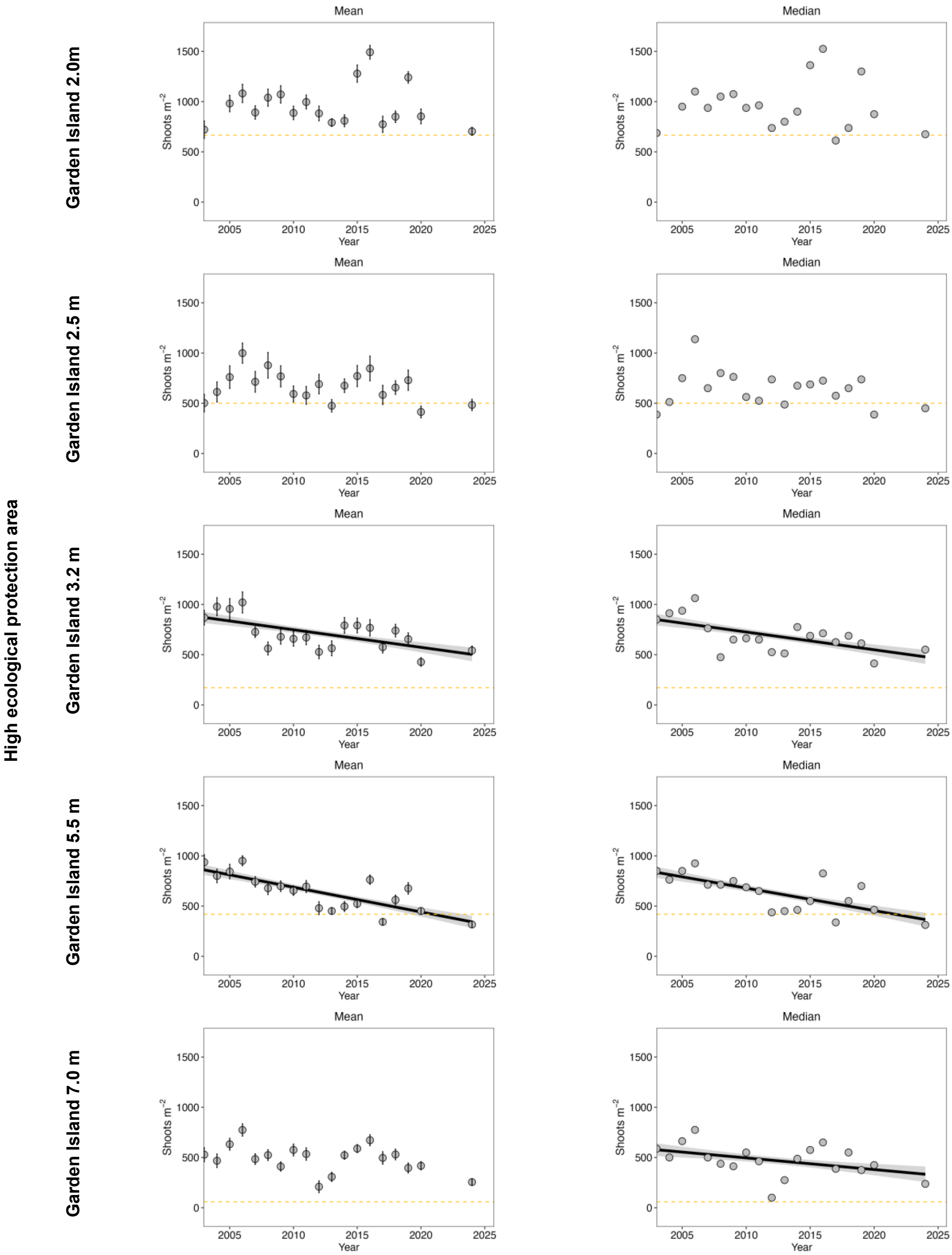

Figure D1: Mann-Kendall trend analysis results for mean (+SE) and median (+SE) Posidonia sinuosa shoot densities at Garden Island 'potential impact' sites in the Cockburn Sound high ecological protection areas for 2024, excluding data from 2022 and 2023. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) by a dashed line.

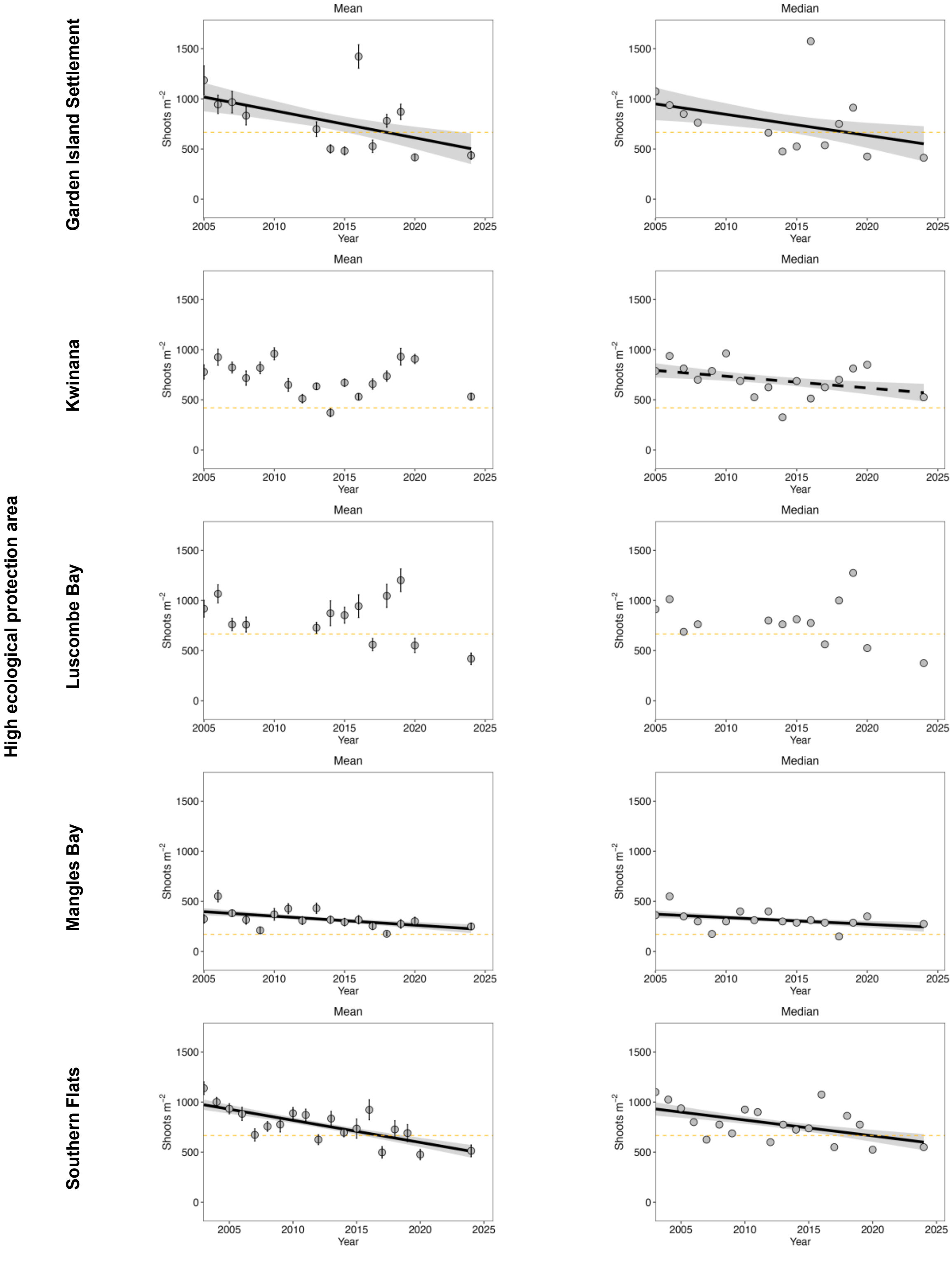

Figure D2: Mann-Kendall trend analysis results for mean (+SE) and median (+SE) Posidonia sinuosa shoot densities at other 'potential impact' sites in the Cockburn Sound high ecological protection areas for 2024, excluding data from 2022 and 2023. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) are designated by a dashed line.

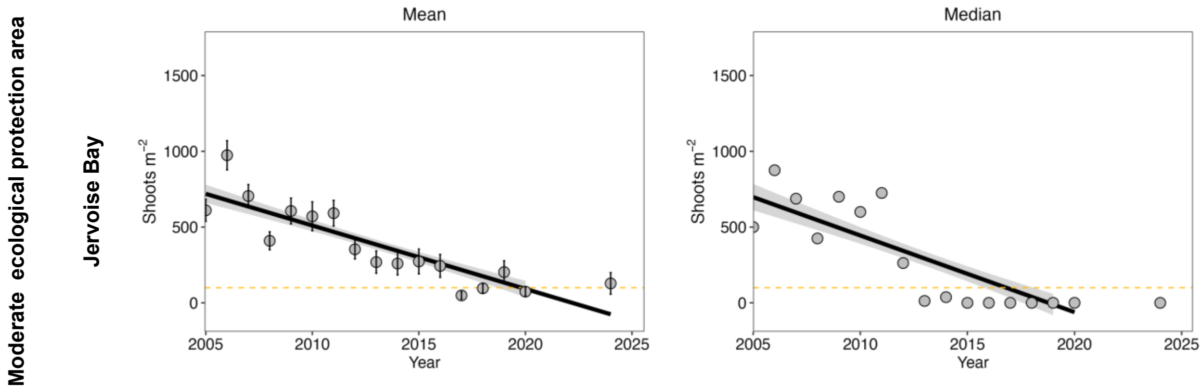

Figure D3: Mann-Kendall trend analysis results for mean (+SE) and median (+SE) Posidonia sinuosa shoot densities at 'potential impact' site Jervoise Bay in the Cockburn Sound moderate ecological protection area for 2024, excluding data from 2022 and 2023. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) are designated by a dashed line.

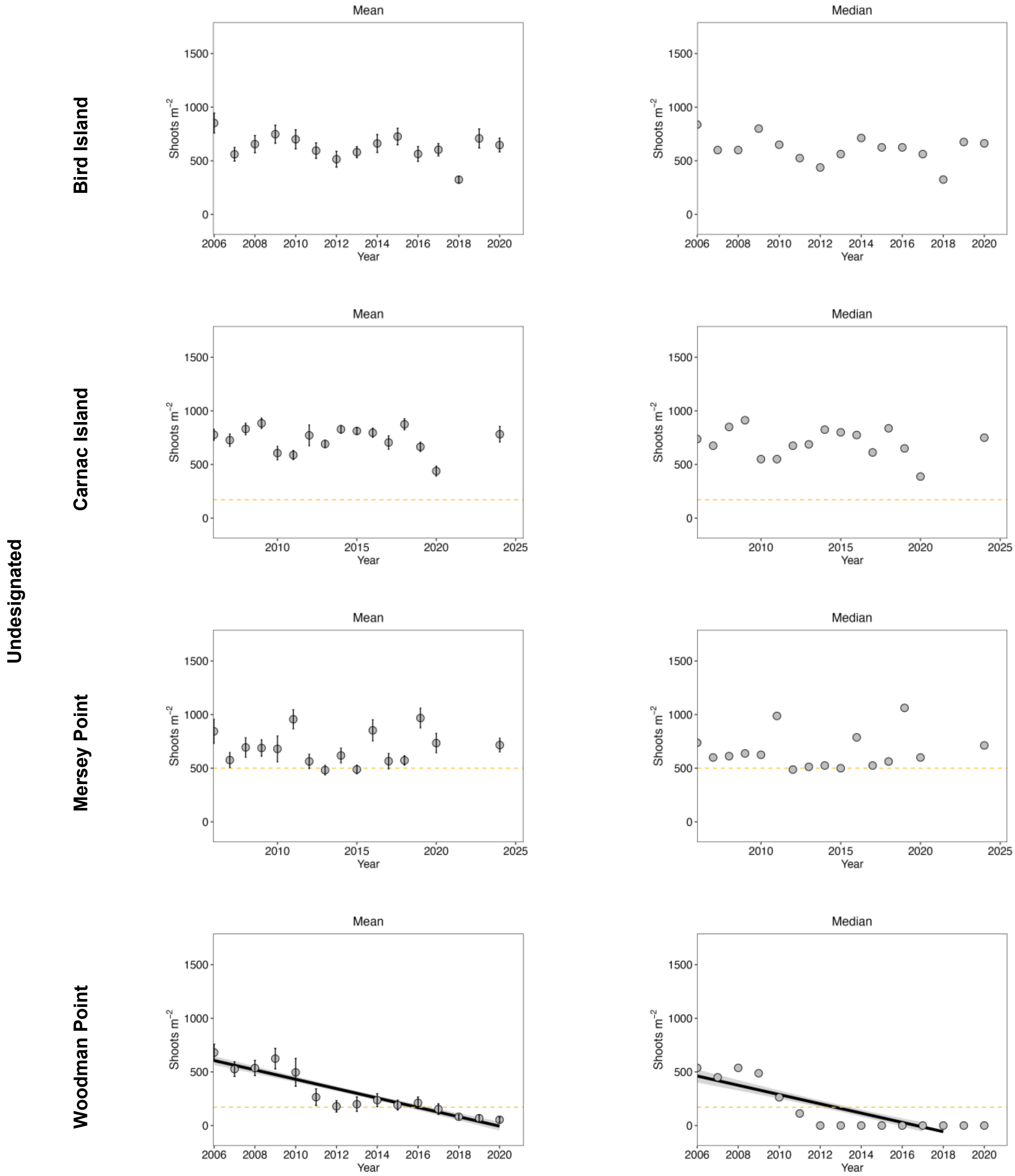

Figure D4: Mann-Kendall trend analysis results for mean (+SE) Posidonia sinuosa shoot densities in the undesignated areas for 2024, excluding data from 2022 and 2023. Significant trends ($p<0.05$) are designated by a solid line. Woodman Point and Bird Island figures represent trends up to 2020 only.

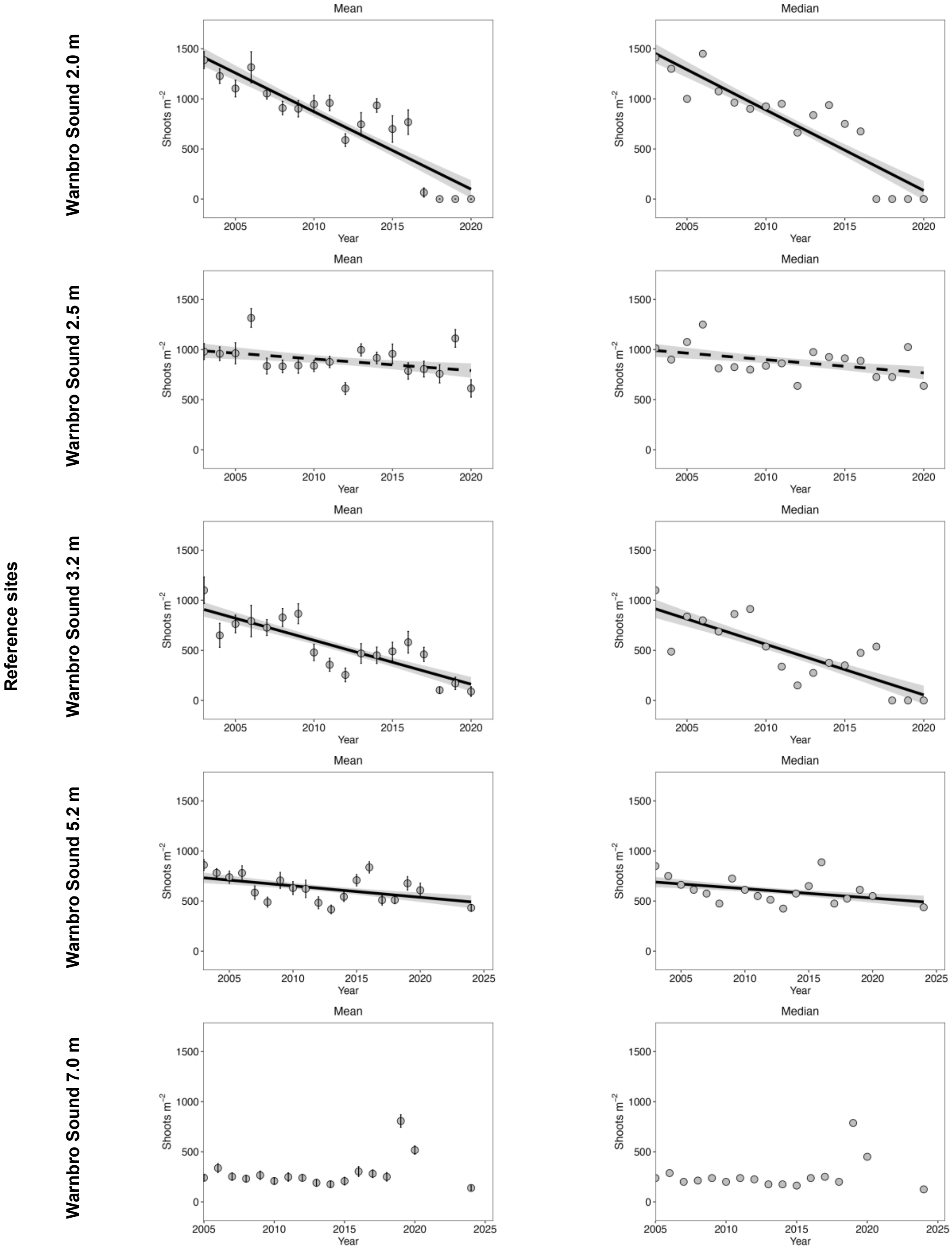

Figure D5: Mann-Kendall trend analysis results for mean (+SE) Posidonia sinuosa shoot densities at Warnbro Sound ‘reference’ sites for 2024, excluding data from 2022 and 2023. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) are designated by a dashed line. Shallow reference site (up to 3.2 m) trends are to 2020.

Warnbro Sound reference sites

Table D5 presents the Mann-Kendall trend analyses for changes in shoot density for each reference site in Warnbro Sound in 2024. These are only shown for the deeper reference sites (Warnbro 5.2 m and Warnbro 7.0 m), for which no significant trends in shoot density were found.

The shallow Warnbro sites are no longer included given the loss of these sites due to natural erosion/accretion.

Table D5: Summary of Mann-Kendall trend analysis for Warnbro Sound reference sites in 2023 based on the mean, median and the 20th, 5th and 1st percentiles since the inception of monitoring, but excluding 2022 and 2023 data.

Site name	Mean 2024		Median 2024		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
Warnbro Sound (5.2 m)	**-0.37**	**0.03**	-0.06	0.77	*-0.25*	*0.15*	-0.15	0.40	-0.17	0.33
Warnbro Sound (7.0 m)	0.00	1.00	0.03	0.88	*-0.27*	*0.156*	0.19	0.345	0.25	0.24

Significant trends are identified in bold (p<0.05) and potential trends denoted by italic and '*' (p<0.2). Negative trends are identified by red, and positive trends by green.

Cockburn Sound sites

A significant decline in shoot density (p<0.05) was recorded at seven sites: Garden Island Settlement, Garden Island 3.2 m, Garden Island 5.2 m, Garden Island 7.0 m, Southern Flats, Mangles Bay and Jervoise Bay (Table D6). A potential decline (p<0.2) was observed at Kwinana.

Three sites were not monitored in 2024: Bird Island, Coogee and Woodman Point. For these sites trend data up until 2020 are presented.

Table D6: Summary of trend analysis on the mean and median shoot densities at potential impact sites for years up to 2024 excluding data from 2022 and 2023.

Ecological protection area	Site	Mean shoot density		Median shoot density		
		Mean	P value	Median	P value	Significant trends
HPA-N	Luscombe Bay	-0.21	0.36	-0.22	0.33	–
	Garden Is. Settlement	**-0.46**	**0.03**	**-0.46**	**0.03**	↓
	Garden Is. (2.0 m)	-0.14	0.45	-0.13	0.49	–
	Garden Is. (2.5 m)	-0.19	0.26	-0.15	0.38	–
	Garden Is. (3.2 m)	**-0.43**	**0.01**	**-0.42**	**0.01**	↓
	Garden Is. (5.2m)	**-0.60**	**>0.001**	**-0.55**	**>0.001**	↓
	Kwinana	-0.16	0.39	*-0.24*	*0.199*	↘
	Garden Is. (7.0 m)	-0.22	0.21	**-0.34**	**0.05**	↓
HPA-S	Southern Flats	**-0.56**	**>0.001**	**-0.42**	**0.01**	↓
	Mangles Bay	**-0.47**	**0.01**	**-0.39**	**0.04**	↓
Undesignated	[1]Bird Island	-0.11	0.62	-0.15	0.49	–
	[1]Woodman Point	**-0.52**	**<0.01**	*-0.35*	*0.08*	↘
	[1]Coogee	0.19	0.38	0.18	0.41	–
	Mersey Point	0.02	0.96	0.03	0.89	–
	Carnac Island	-0.12	0.56	-0.10	0.62	–
MPA-ES	Jervoise Bay	**-0.78**	**>0.001**	**-0.71**	**>0.001**	↓

Significant trends (p<0.05) are denoted in bold text with declining trends (p<0.2) denoted by '*'. Negative trends are in red, positive trends are in green.

[1] Bird Island, Woodman Point and Coogee trends are from 2020 as these sites were not monitored in 2024.

Appendix E: Seagrass health in 2024 (including 2022 and 2023 data)

This section summarises the 2024 seagrass health assessment using all available data. This section has been included for completeness only. These results were not used to inform the annual assessment due to the previously noted data collection issues.

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 E1. Rolling percentiles are only shown for Warnbro sites 5.2 m and 7.0 m reference sites. Sampling of the shallow Warnbro Sound reference sites was abandoned in 2022 due to near-total seagrass loss from natural sediment accretion/erosion.

The values used in the assessment against EQS (i) are denoted in bold. In most instances the absolute minimum criteria (AMC) were used, even at the deeper sites where seagrass shoot density had declined.

There are no absolute minimum criteria for EQS (ii). The EQS (ii) rolling percentiles (the 5th percentile) could only be determined for the deeper reference sites for which there is monitoring data. This limited the EQS (ii) assessment to sites using these reference depths (Table E2).

Table E1: The 2023 and 2024 rolling 20th, 5th and 1st rolling percentiles, and AMC values of seagrass shoot density for the Warnbro Sound reference sites

		Warnbro Sound reference sites 2023					Warnbro Sound reference sites 2024				
Site name	Depth category (m)	N	20th	5th	AMC 5th	AMC 1st	N	20th	5th	AMC 5th	AMC 1st
Warnbro Sound (2.0 m)	1.5–2.0	0	–	–	**666**	**412**	0	–	–	**666**	**412**
Warnbro Sound (2.5 m)	2.0–3.0	0	–	–	**500**	**275**	0	–	–	**500**	**275**
Warnbro Sound (3.2 m)	3.0–4.0	0	–	–	**171**	**100**	0	–	–	**171**	**100**
Warnbro Sound (5.2 m)	5.0–6.0	96	**425**	244	419	**324**	96	350	219	**419**	**324**
Warnbro Sound (7.0 m)	7.0	92	**200**	**62.5**	59	25	91	**135**	50	**59**	25

If the rolling 20th and 5th percentiles are below the AMC, the AMC values are used instead. All percentiles for 2023 are based on data from 2019, 2020, 2022 and 2023, and percentiles for 2024 are based on data from 2020, 2022, 2023 and 2024. There was no sampling in 2021 due to Covid-19. The numbers used for the EQS assessment are denoted in bold. AMC values were used for the shallow sites.

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

EQS (i)

The assessment of EQS (i) is based on data from two consecutive years, 2023 and 2024 (Table E2).

In 2023 EQS (i) was met at all sites, besides Woodman Point, Bird Island and Coogee which were not sampled. In 2024 EQS (i) was not met at Luscombe Bay, Garden Island Settlement, Garden Island 2.5 m and 5.2 m and Southern Flats.

EQS (ii)

Seagrass health at the three deeper sites (Kwinana, Garden Island 5.2 m, Garden Island 7.0 m) in the high protection area each met EQS (ii) (Table E2).

Kwinana and Garden Island 7.0 m were the only sites to meet both EQS (i) and EQS (ii) for seagrass health in the 2023–24 assessment period (Table E2).

Table E2: Assessment of EQS (i) for each potential impact site in 2023 and 2024, and EQS (ii) for 2024 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 are 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	Ref. site depth (m)	2024 (no. of non-0 quadrants)	Median (shoots.m^{-2})		EQS (i)			EQS (ii)	Results			
				2023	2024	2023 20th	2024 20th	AMC 5th	2024 5th	2023 EQS (i)	2024 EQS (i)	2024 EQS (ii)	Overall result
HPA-N	Luscombe Bay	1.5–2.0	22	1150	388	–	–	**666**	–	✓	×	–	?
	Garden Is. Settlement	1.5–2.0	24	975	413	–	–	**666**	–	✓	×	–	?
	Garden Is. 2.0 m	1.5–2.0	24	1138	675	–	–	**666**	–	✓	✓	–	?
	Garden Is. 2.5 m	2.0–3.0	24	925	450	–	–	**500**	–	✓	×	–	?
	Garden Is. 3.2 m	3.0–4.0	24	1138	550	–	–	**171**	–	✓	✓	–	?
	Kwinana*	5.0–6.0	24	900	525	**425**	350	**419**	219	✓	✓	✓	✓
	Garden Is. 5.2 m	5.0–6.0	24	975	313	**425**	350	**419**	219	✓	×	✓	✓
	Garden Is. 7.0 m	6.0–7.0	23	488	250	**200**	**135**	59	50	✓	✓	✓	✓
HPA-S	Southern Flats	1.5–2.0	20	1013	575	–	–	**666**	–	✓	×	–	?
	Mangles Bay	3.0–4.0	22	238	300	–	–	**171**	–	✓	✓	–	?
High – undesignated	Woodman Point	3.0–4.0	–	–	–	–	–	**171**	–	–	–	–	?

Ecological protection area	Site name	Ref. site depth (m)	2024 (no. of non-0 quadrants)	Median (shoots.m^{-2})		EQS (i)			EQS (ii)	Results			
				2023	2024	2023 20th	2024 20th	AMC 5th	2024 5th	2023 EQS (i)	2024 EQS (i)	2024 EQS (ii)	Overall result
	Bird Island	1.5–2.0	–	–		–	–	**666**	–	–	–	–	?
	Mersey Point	2.0–3.0	24	1288	713	–	–	**500**	–	✓	✓	–	?
	Carnac Island	3.0–4.0	24	813	750	–	–	**171**	–	✓	✓	–	?
	Coogee	5.0–6.0	–	–	–	–	–	**419**	–	–	–	–	?

Protection level	Site name	Ref. site depth (m)	2022 n	Median (shoots/m^{-2})		EQS (i)			EQS (ii)	Interpretation of EQS (i) and (ii)			
				2022	2023	2022 5th	2023 5th	AMC 1st	2024 1st	2022 EQS (i)*	2023 EQS (i)	2023 EQS (ii)	Overall result
MPA–NH	Jervoise Bay	3.0–4.0	4	1500	850	–	–	**100**	–	✓	✓	–	?

If the rolling 20th and 5th percentiles are below the AMC, the AMC values are used instead. All percentiles for 2023 are based on data from 2019, 2020, 2022 and 2023, and percentiles for 2024 are based on data from 2020, 2022, 2023 and 2024. Sampling was not undertaken in 2021 due to Covid. The numbers used for the EQS assessment are denoted in bold. AMC values were used for the shallow sites.

Assessment against EQS (iii) – lower depth limit

Lower depth limit ranged from 5.5 m at Mangles Bay to 8.6 m at Garden Island North (Table E3).

EQS (iii) was achieved at two out of four sites for which a 2000–02 baseline was available (Table E3). Garden Island North and Warnbro South failed EQS (iii) for depth limit in 2024. Both sites were lower than the expected range of the baseline mean LDL (Table D4).

The results provide some indication that seagrasses may have retreated into shallower waters at the Garden Island North, Mangles Bay and Warnbro South sites. No trends were significant (Table E4).

Table E3: Mean lower depth limit (LDL) ± standard error in 2023 and 2024, with 2024 compared with the baseline LDL (2000–02)

Ecological protection area	Site	Mean LDL 2023 (m)	Mean LDL 2024 (m)	Baseline	Assessment
				Mean LDL 2000–02 (m)	EQS (iii)
High	Garden Island North (depth)	8.8 ± 0.4	**8.6 ± 0.1**	9.8 ±0.2	✗
	Garden Island South (depth)	7.7 ± 0.7	8.5 ± 0.5	7.6 ±0.4	✓
	Southern Flats (depth)	7.4 ± 0.7	8.1 ± 0.1	n/a	n/a
	Mangles Bay (depth)	6.6 ± 0.6	5.5 ± 0.1	n/a	n/a
Reference depth site	Warnbro Sound (depth)	8.6 ± 0.9	**7.4 ± 0.1**	8.4 ±0.5	✗
Undesignated	Woodman Point (depth)	8.8 ± 0.5	8.3 ± 0.1	8.7 ±0.8	✓

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

Table E4: Trend analyses of LDL at 'depth transect' sites in 2024. Significant trends (i.e. p<0.05) are denoted in bold

Ecological protection area	Site	Trend statistic	P value	Significant trends
High	Garden Island North (depth)	-0.22	0.47	–
	Garden Island South (depth)	-0.14	0.65	–
	Southern Flats (depth)	0.43	0.23	–
	Mangles Bay (depth)	0.10	0.87	–
Reference depth site	Warnbro Sound (depth)	0.20	0.53	–
Undesignated	Woodman Point	-0.18	0.52	–

Trend analysis of shoot density (additional line of evidence)

Figures E1–E4 display the results of the 2024 trend analyses, with statistically significant trends indicated by solid lines and weaker identified trends indicated by dashed lines. Figure E5 displays the results of Warnbro Sound reference site trend analyses. Note the shallow reference site trends are only to 2020. Due to declining trends, they were considered no longer suitable as reference sites.

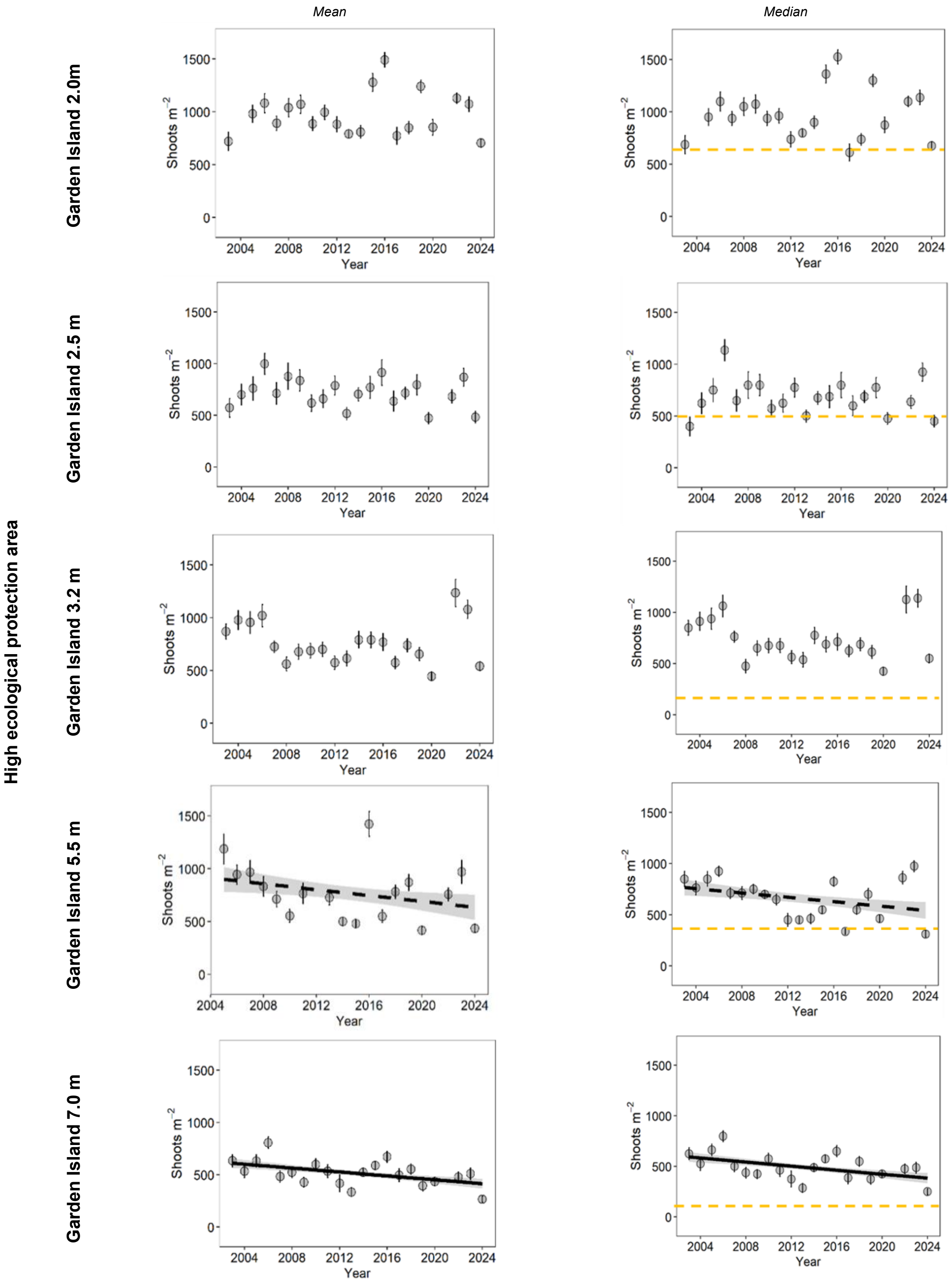

Figure E1: Mann-Kendall trend analysis results for mean (±SE) and median (±SE) Posidonia sinuosa shoot densities at Garden Island 'potential impact' sites in the Cockburn Sound high ecological protection areas for 2024, including all data. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) by a dashed line.

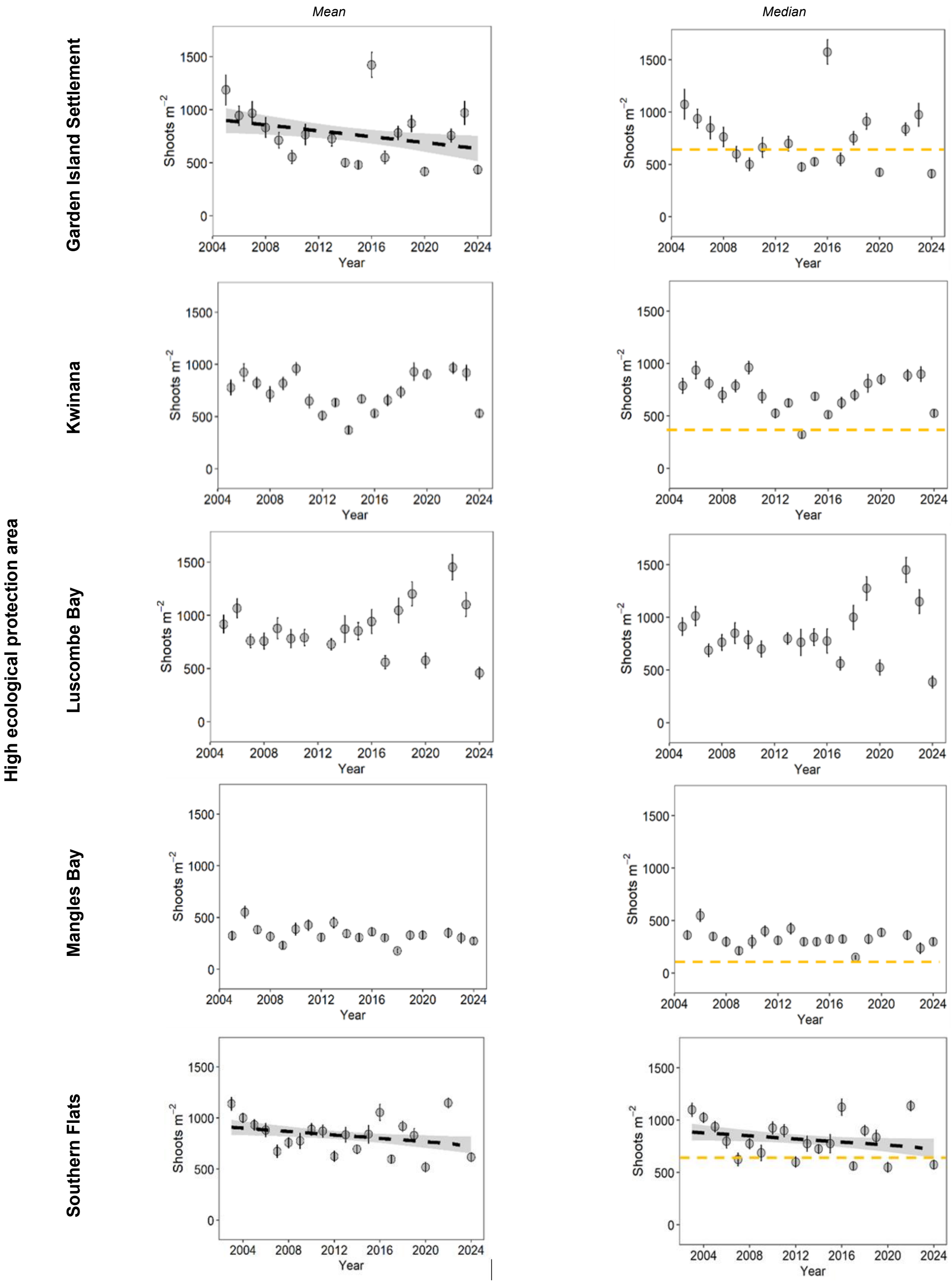

Figure E2: Mann-Kendall trend analysis results for mean (±SE) and median (±SE) Posidonia sinuosa shoot densities at other 'potential impact' sites in the Cockburn Sound high ecological protection areas for 2024, including all data. Significant trends (p<0.05) are designated by a solid line and potential trends (p<0.2) are designated by a dashed line.

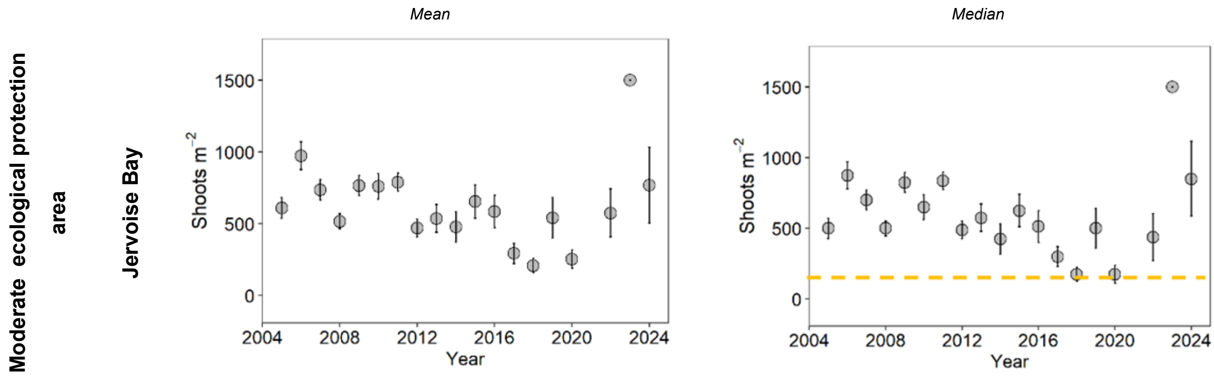

Figure E3: Mann-Kendall trend analysis results for mean (±SE) and median (±SE) Posidonia sinuosa shoot densities at 'potential impact' site Jervoise Bay in the Cockburn Sound moderate ecological protection area for 2024, including all data. Significant trends ($p<0.05$) are designated by a solid line and potential trends ($p<0.2$) are designated by a dashed line.

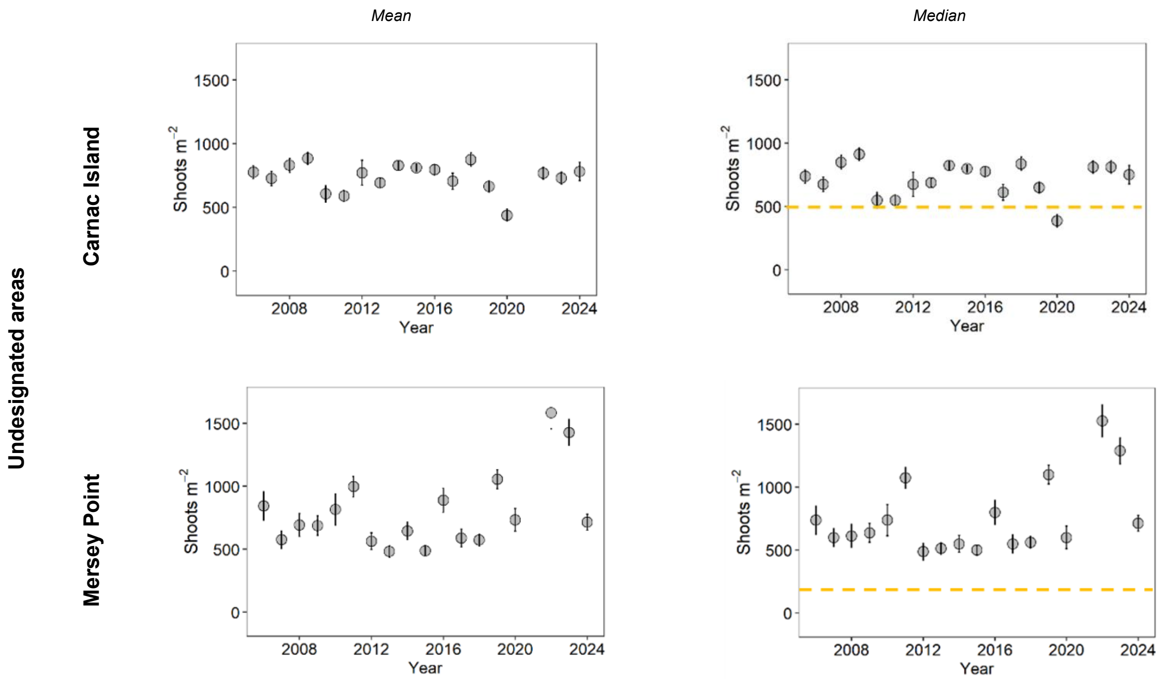

Figure E4: Mann-Kendall trend analysis results for mean (+SE) Posidonia sinuosa shoot densities in the undesignated areas for 2024, including all data. Significant trends ($p<0.05$) are designated by a solid line. Woodman Point and Bird Island were not sampled in 2024.

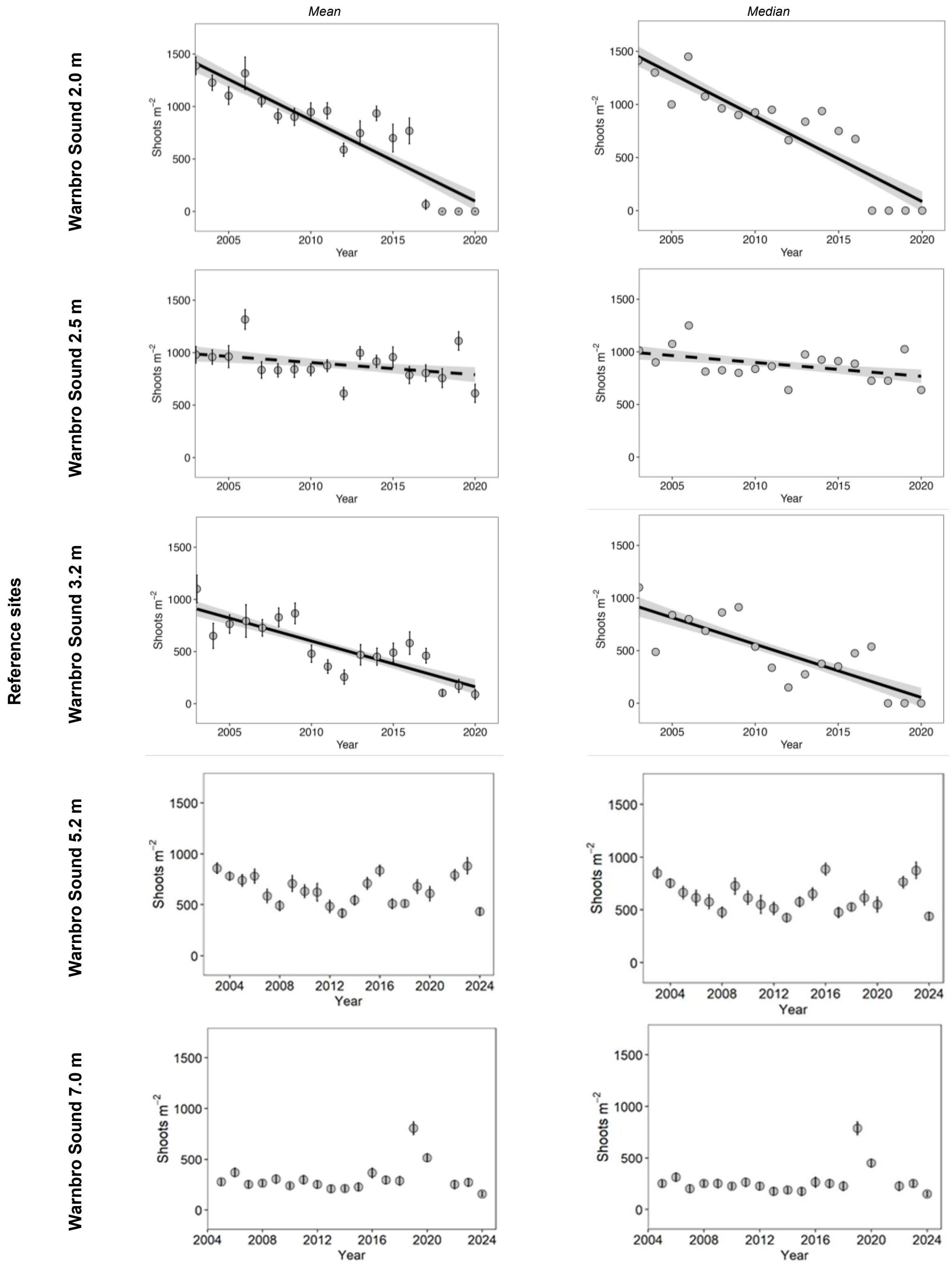

Figure E5: Mann-Kendall trend analysis results for mean (+SE) Posidonia sinuosa shoot densities at Warnbro Sound 'reference' sites for 2024, including all data. Significant trends ($p<0.05$) are designated by a solid line and potential trends ($p<0.2$) are designated by a dashed line. Shallow reference site (up to 3.2 m) trends are to 2020.

Table E5 presents the Mann-Kendall trend analyses for changes in shoot density for each reference site in Warnbro Sound in 2024. These are only shown for the deeper reference sites (Warnbro 5.2 m and Warnbro 7.0 m), for which no significant trends in shoot density were found in 2024.

The shallow Warnbro sites were removed as reference sites when trends in 2020 indicated a significant decline in shoot density, most likely due to natural erosion/accretion at these dynamic sites.

Table E5: Summary of Mann-Kendall trend analysis for Warnbro Sound reference sites in 2024 based on the mean, median and the 20th, 5th and 1st percentiles since the inception of monitoring

Site name	Mean 2024		Median 2024		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
Warnbro Sound (5.2 m)	-0.15	0.35	-0.16	0.35	-0.05	0.82	0.05	0.82	0.11	0.56
Warnbro Sound (7.0 m)	-0.07	0.70	-0.08	0.67	-0.01	1	-0.20	0.27	-0.19	0.37

Significant trends are identified in bold (p<0.05) and potential trends denoted by italic and '*' (p<0.2). Negative trends are identified by red, and positive trends by green.

Cockburn Sound sites

Shoot density at most sites in Cockburn Sound followed a neutral trend in 2024.

Sites with potentially declining trends (defined as p<0.2) include Garden Island Settlement, Garden Island 5.2 m and Garden Island 7.0 (HPA-N), and Southern Flats (HPA-S).

Significant declines (p<0.05) were reported for Garden Island 7.0 m.

Shoot density trends which were in decline at Mangles Bay (HPA-S) and Jervoise Bay (MPA-ES) in 2023, appear to have stabilised in 2024. [1]Woodman Point and [1]Coogee, which both had declining trends in 2022, have not since been monitored (Table E6).

Table E6: Summary of trend analysis on the mean and median shoot densities at potential impact sites

Ecological protection area	Site	Mean shoot density		Median shoot density		
		Mean	P value	Median	P value	Significant trends
HPA-N	Luscombe Bay	0.06	0.76	0.01	1	–
	Garden Is. Settlement	_-0.28_	_0.11*_	-0.20	0.26	–
	Garden Is. (2.0 m)	-0.02	0.92	0.01	1	–
	Garden Is. (2.5 m)	-0.09	0.61	-0.04	0.83	–
	Garden Is. (3.2 m)	-0.186	0.25	-0.17	0.29	–
	Garden Is. (5.2 m)	**-0.377**	**0.02**	_-0.30_	_0.06*_	↘
	Kwinana	0.01	1	-0.5	0.77	–
	Garden Is. (7.0 m)	**-0.36**	**0.02**	**-0.34**	**0.03**	↓
HPA-S	Southern Flats	_-0.25_	_0.13*_	_-0.24_	_0.16*_	↘
	Mangles Bay	-0.31	0.69	-0.15	0.39	–
Undesignated	[1]Bird Island	-0.10	0.62	-0.09	0.65	–
	[1]Woodman Point	**-0.48**	**0.01**	-0.19	0.32	–
	[1]Coogee	-0.14	0.49	-0.16	0.4	–
	Mersey Point	0.19	0.29	0.21	0.24	–
	Carnac Island	-0.098	0.60	0.01	1	–
MPA-ES	Jervoise Bay	-0.16	0.36	0.22	0.21	–

Significant trends (p<0.05) are denoted in bold text, with potential trends denoted by italics and '*' (p<0.2). Negative trends are identified by red, and positive trends by green.

[1] Bird Island, Woodman Point and Coogee were not sampled in 2022 and 2023 and trend data is to 2022 only.

Appendix F: 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 the current and previous five years. While this methodology has been maintained, note that because of changes to the Council's monitoring program in 2021, the number of data points during the non-river-flow period has decreased from 16 to four, meaning that data from more years needs to be considered.

The calculated EQC values for 2023 and 2024 are presented in Table 4 and were applied in the 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 2.7 µg/L on more than one occasion during the non-river-flow period.
ii) Phytoplankton biomass at any site is not to exceed 2.7 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 2.7 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 2.7 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 F1 and Table F2 below.

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

Table F1: Assessment of phytoplankton biomass, as median chlorophyll concentration (μg/L), against EQG (i) for each sampling occasion and for each of the ecological protection areas. Orange text indicates EQG exceedance.

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

Ecological protection area	December		January		February		March	
	2023	2024	2023	2024	2023	2024	2023	2024
HPA-N EQG = 2.1	0.3	0.4	0.7	0.7	0.9	1.0	0.5	0.8
HPA-S EQG = 2.1	0.6	0.6	1.1	1.2	1.3	1.5	1.2	1.4
MPA-ES EQG = 2.7	1.1	0.6	1.6	0.8	1.3	0.5	0.6	1.8

Table F2: Assessment of phytoplankton biomass against EQG (ii) for each sampling occasion and each monitoring site. Orange text indicates EQG exceedance. Red text indicates EQS exceedance.

Ecological protection area	Sites	EQG (ii) value and fail percentage	Proportion of occasions exceeded 2023	Proportion of occasions exceeded 2024
HPA-N	CS4	2.1µg/L exceeded on ≥25% occasions	0%	0%
	CS5		0%	0%
	CS8		0%	0%
	CB		0%	0%
	G2		0%	0%
	G3		0%	0%
HPA-S	CS11	2.1µg/L exceeded on ≥25% occasions	0%	0%
	CS13		0%	0%
	SF		0%	0%
	MB/MB-L		0%	**25%**
MPA-CB	G1	2.7µg/L exceeded on ≥50% occasions	0%	0%
MPA-ES	CS10N	2.7µg/L exceeded on ≥50% occasions	0%	0%
	CS12		0%	0%
	CS6A		0%	0%
	CS7		0%	0%
	CS9		0%	0%
	CS9A		0%	0%
MPA-NH	NH3	2.7µg/L exceeded on ≥50% occasions	**50%**	**75%**

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 to be assessed. Table F3 shows the exceedance at MB in 2024 did not follow an exceedance in 2023 – hence EQS (ii) was not exceeded. In 2022, NH3 exceeded EQG (ii) 50% of the time (Table F3) and thus EQS (ii) was exceeded at this site in both 2023 and 2024.

Table F3: Chlorophyll-a concentrations at NH for the 2022 season, for assessment of 2023 season EQS (ii) for phytoplankton biomass.

Ecological protection area	Site	Date of sampling	Chlorophyll-a (µg/L)
MPA-NH 2022 EQS (ii): 2.9 µg/L	NH3	December 2021	1.7
		January 2022	**3.9**
		February 2022	2.7
		March 2022	**4.8**

Appendix G: Physical and chemical parameters – data plots

Temperature

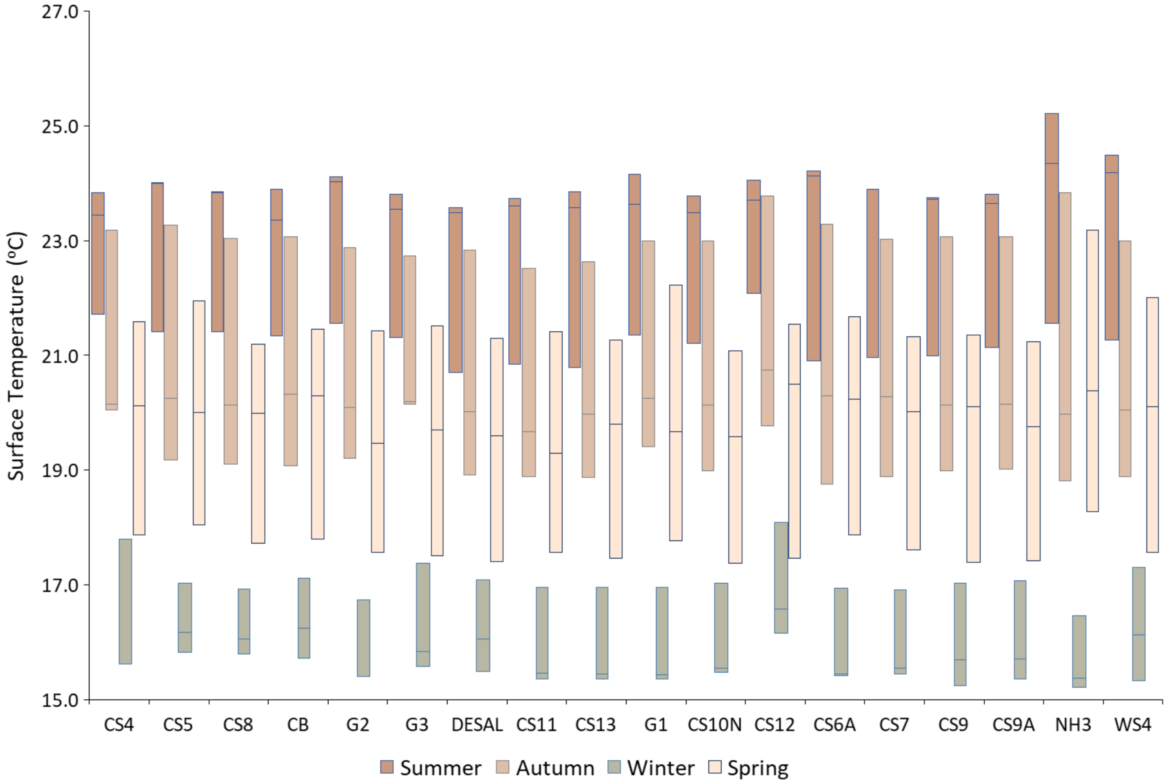

Figure G1: 2023 seasonal surface water temperatures at 17 deep water sites compared with WS4 (deep water reference site).

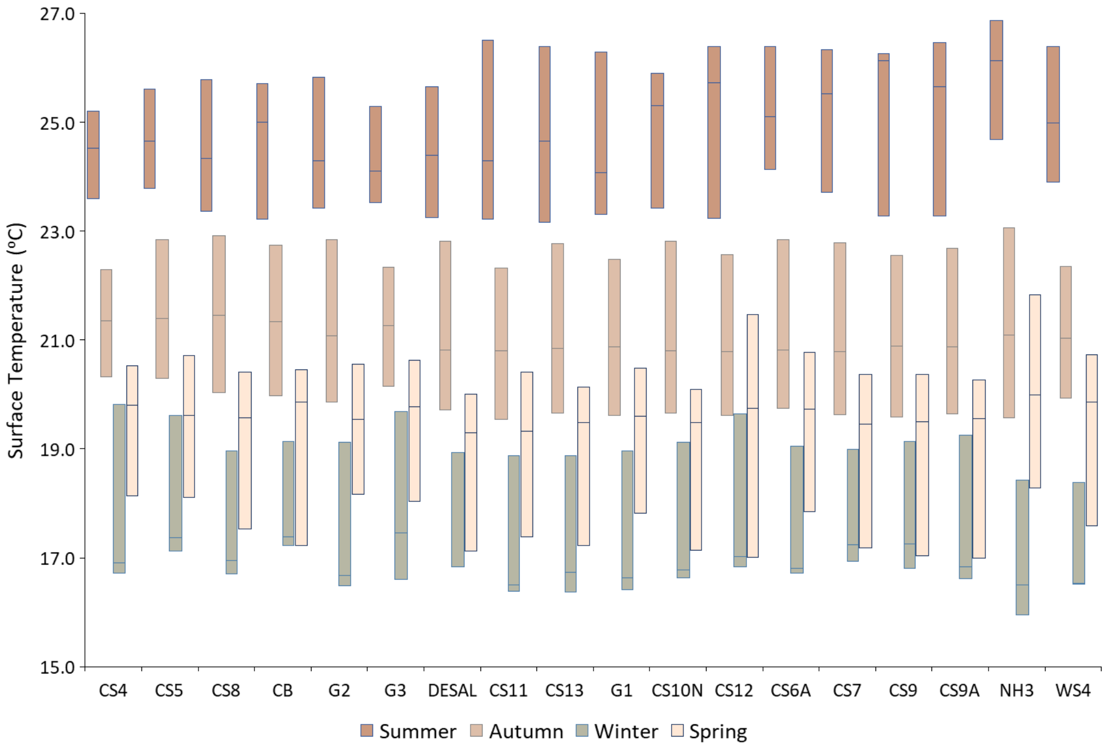

Figure G2: 2024 seasonal surface water temperatures at 17 deep water sites compared with WS4 (deep water reference site).

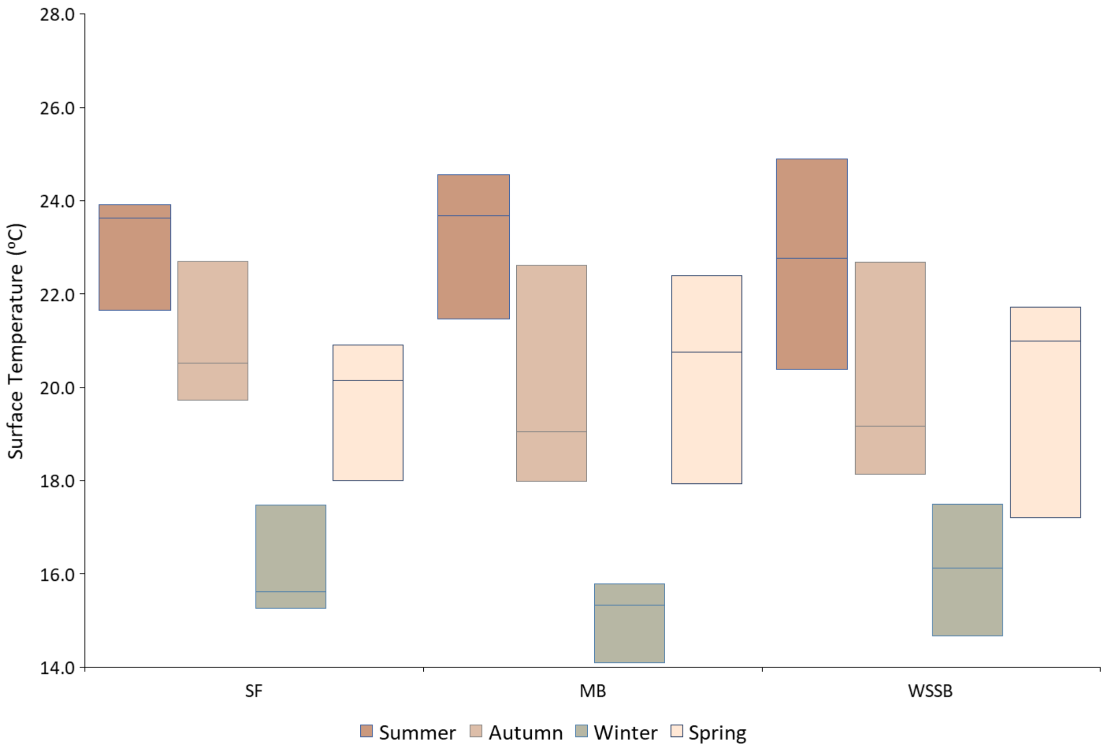

Figure G3: 2023 seasonal surface water temperatures at two shallow water sites compared with WSSB (shallow water reference site).

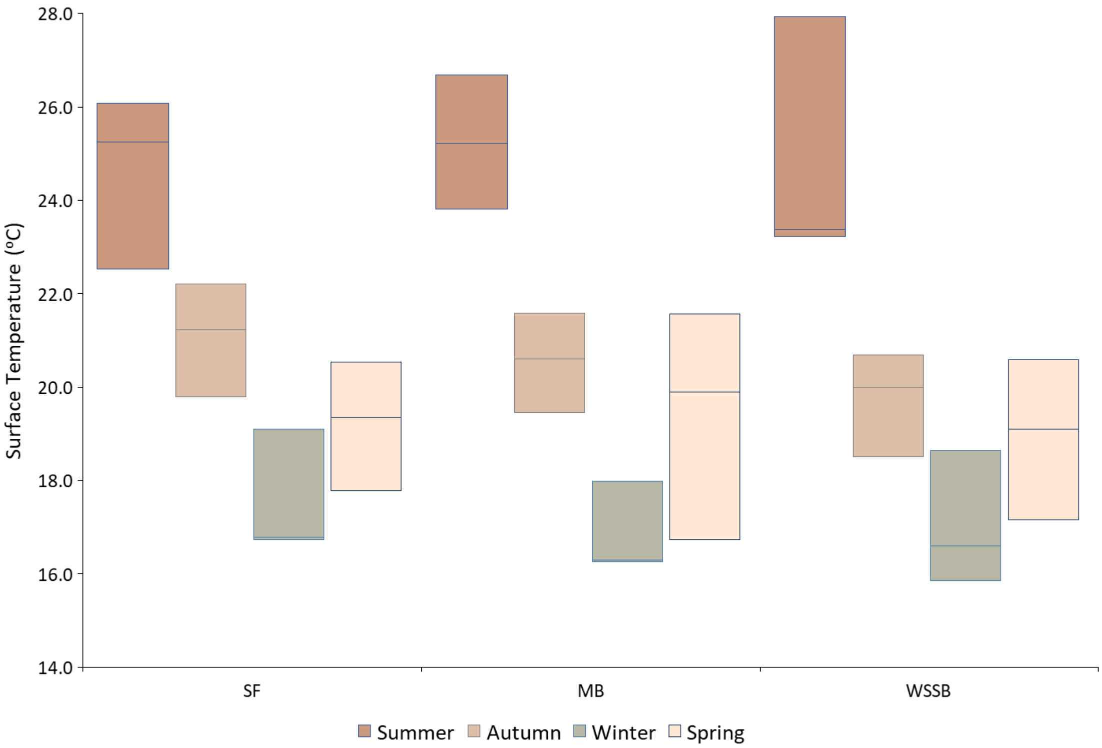

Figure G4: 2024 seasonal surface water temperatures at two shallow water sites compared with WSSB (shallow water reference site).

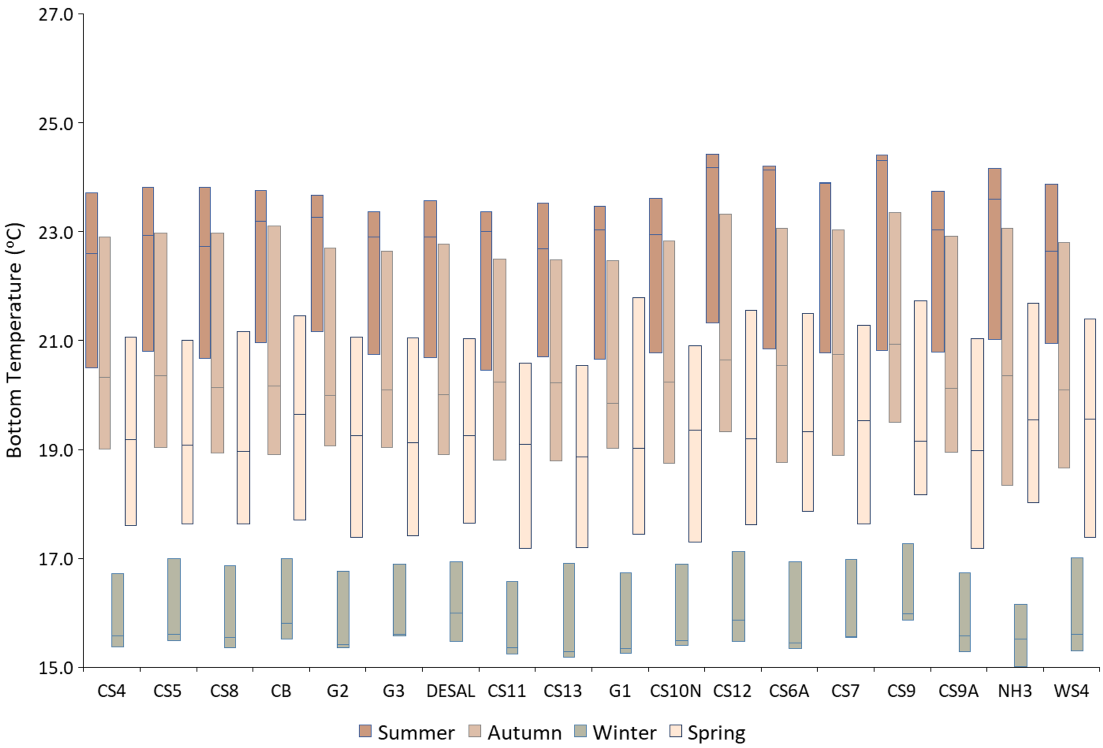

Figure G5: 2023 seasonal bottom water temperatures at 17 deep water sites compared with WS4 (deep water reference site).

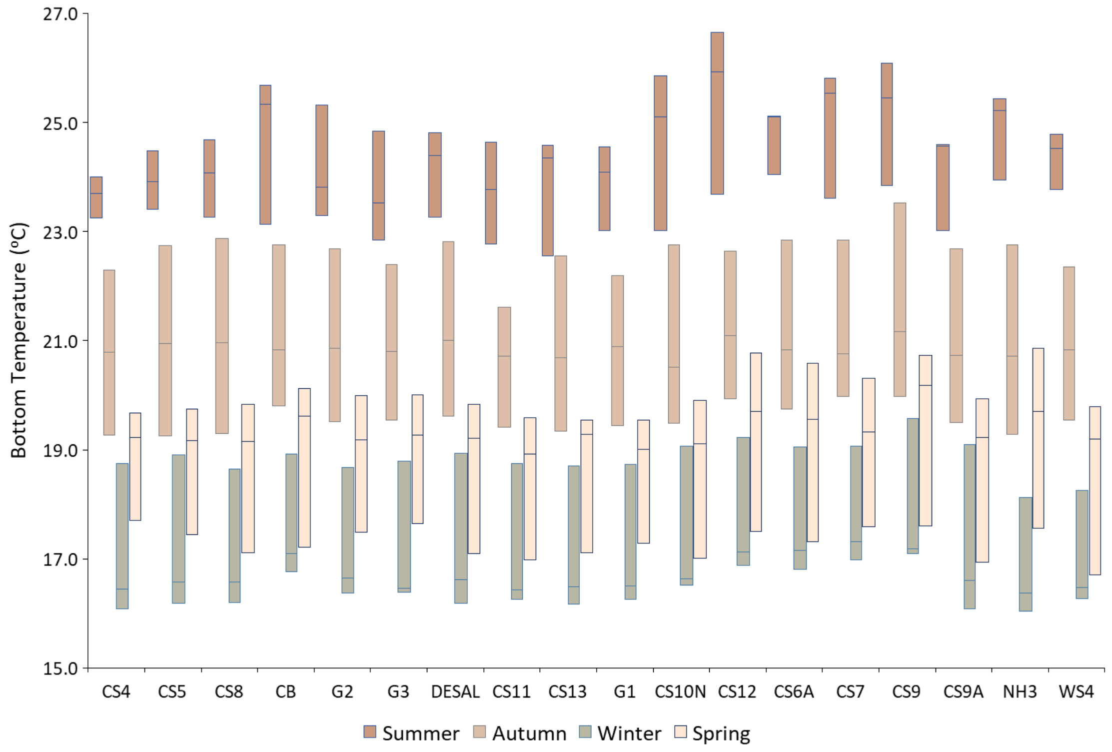

Figure G6: 2024 seasonal bottom water temperatures at 17 deep water sites compared with WS4 (deep water reference site).

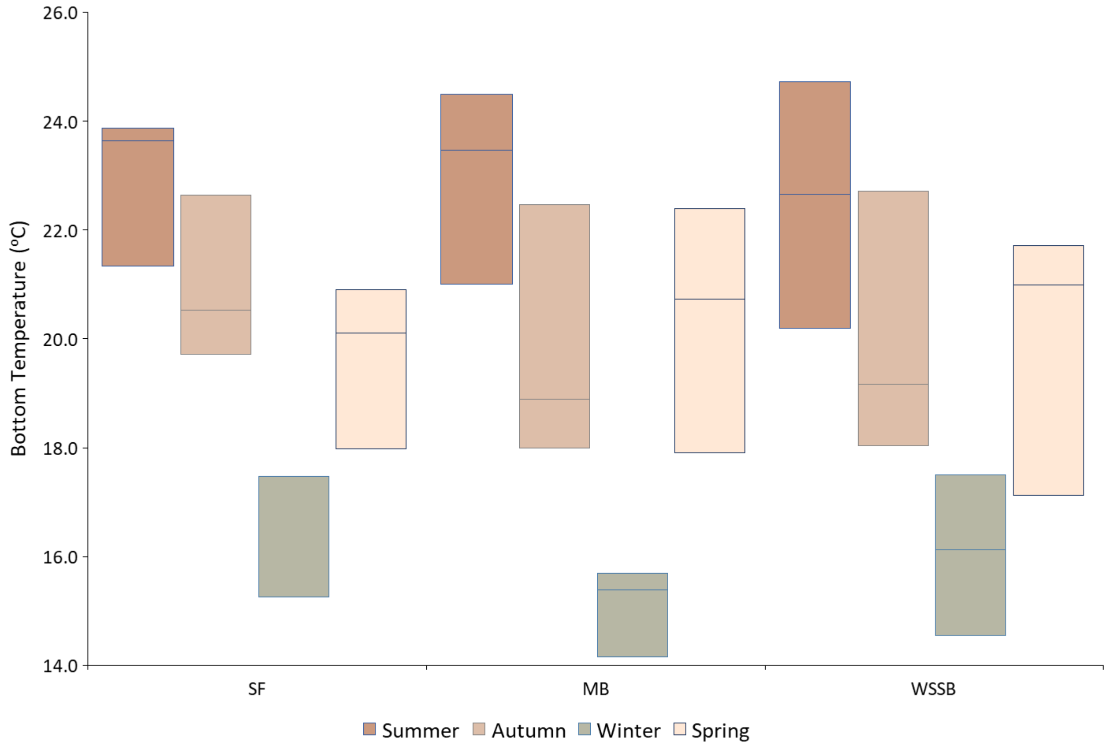

Figure G7: 2023 seasonal bottom water temperatures at two shallow water sites compared with WSSB (shallow water reference site).

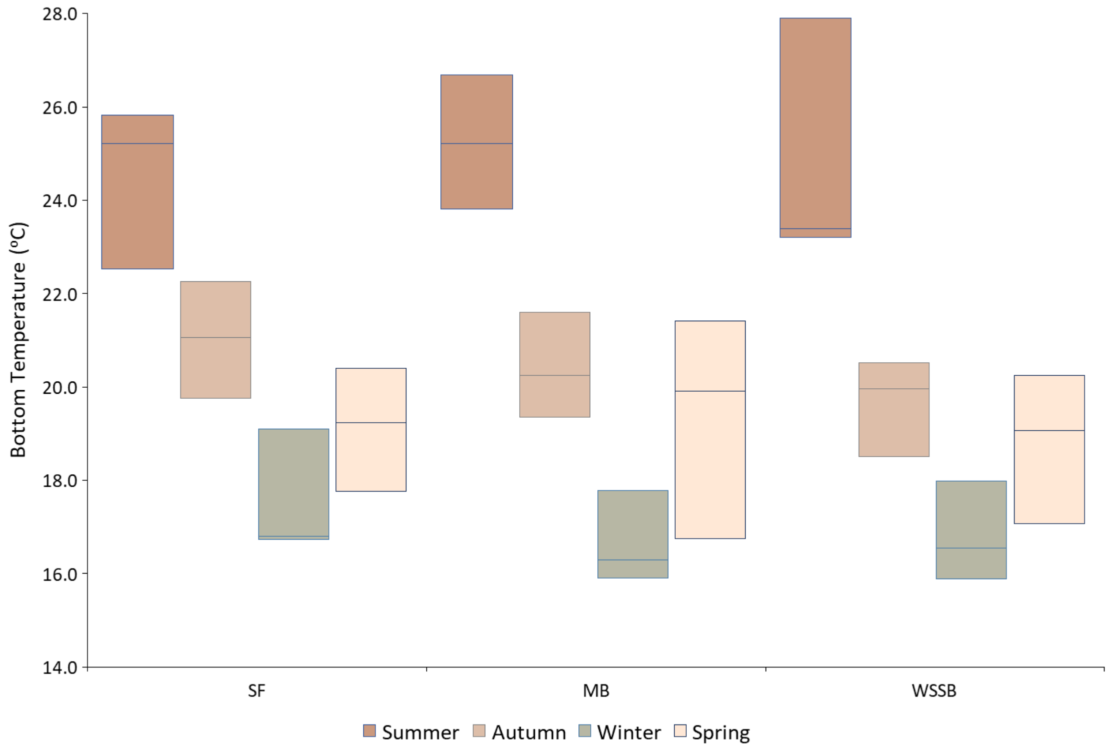

Figure G8: 2024 seasonal bottom water temperatures at two shallow water sites compared with WSSB (shallow water reference site).

Salinity

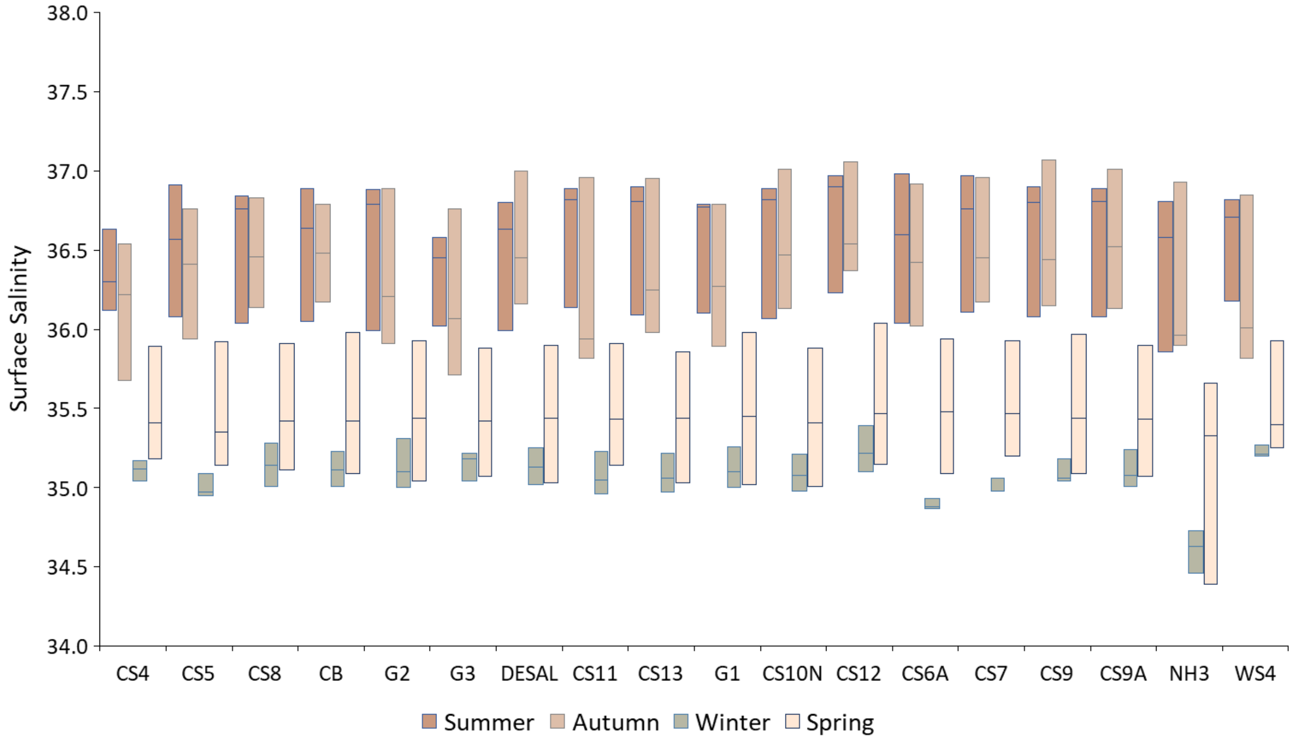

Figure G9: 2023 seasonal surface water salinities at 17 deep water sites compared with WS4 (deep water reference site).

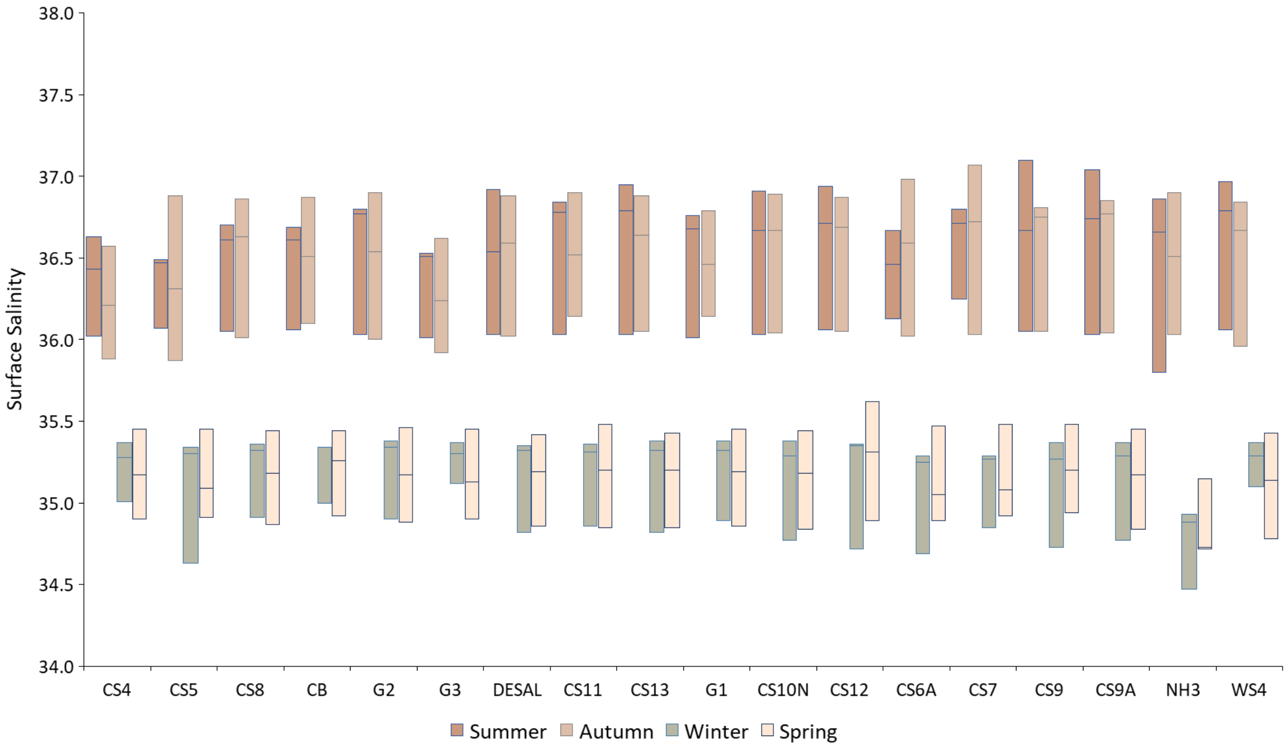

Figure G10: 2024 seasonal surface water salinities at 17 deep water sites compared with WS4 (deep water reference site).

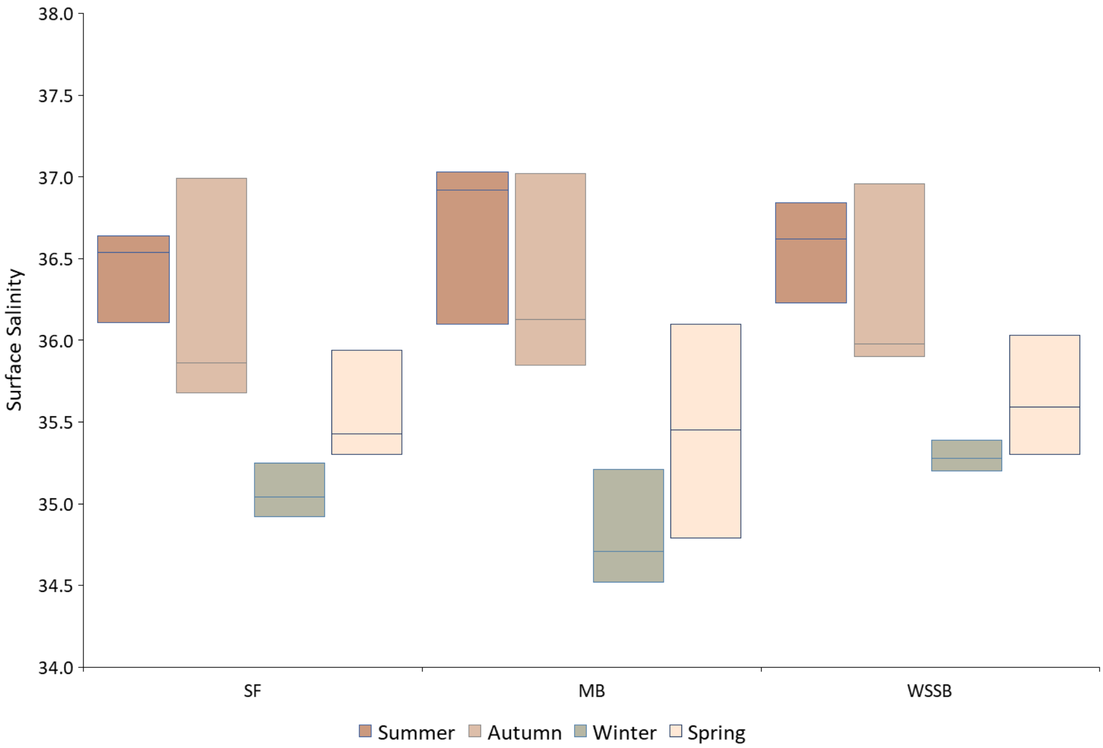

Figure G11: 2023 surface water salinities at two shallow water sites compared with WSSB (shallow water reference site).

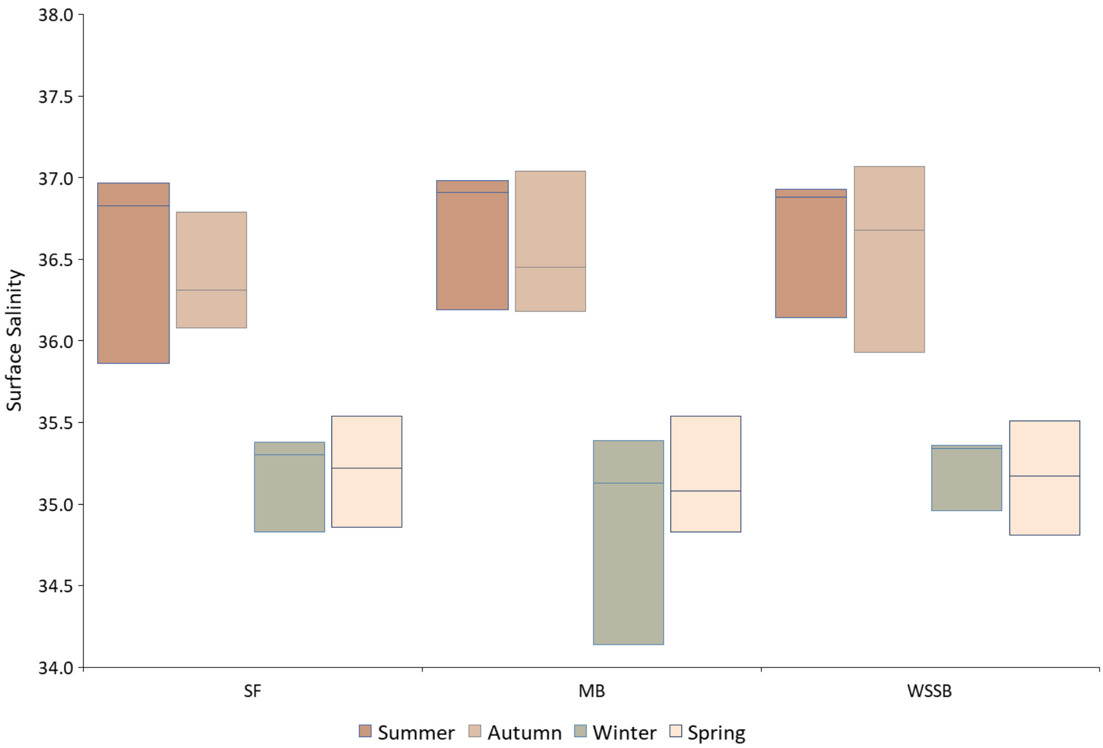

Figure G12: 2024 surface water salinities at two shallow water sites compared with WSSB (shallow water reference site).

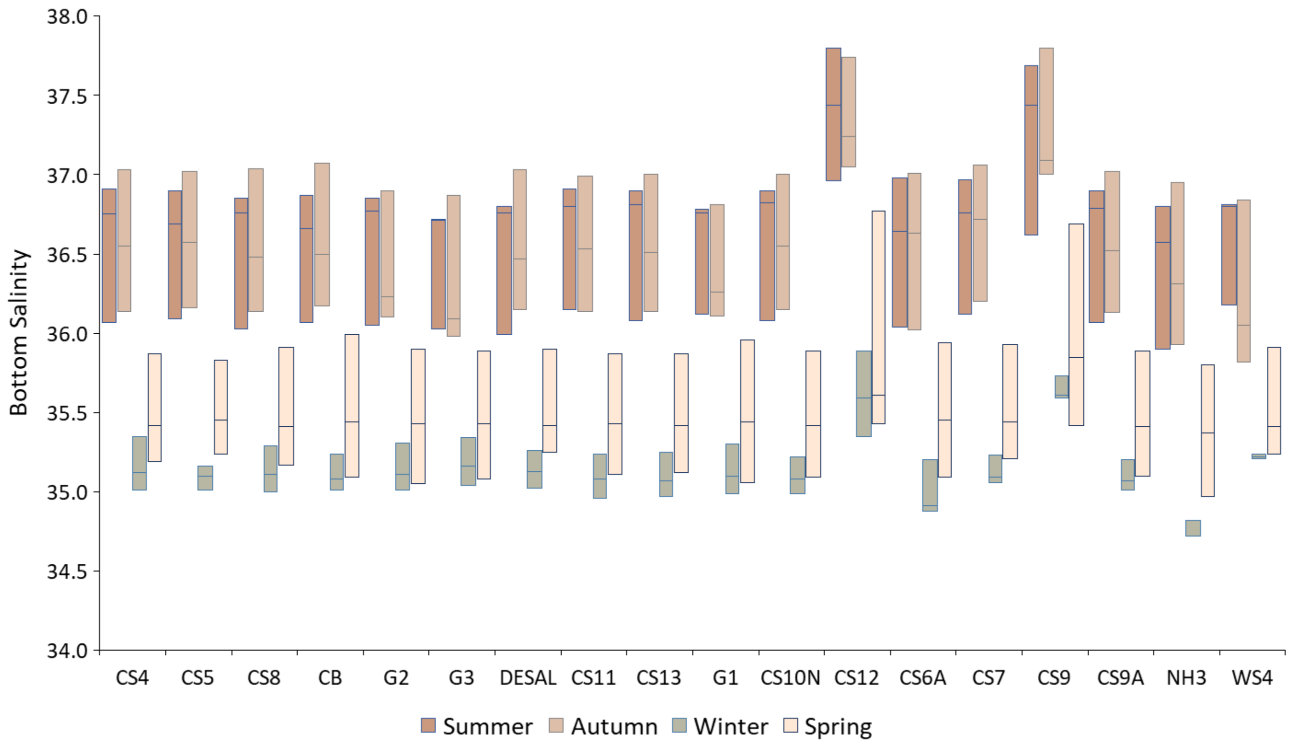

Figure G13: 2023 bottom water salinities at 17 deep water sites compared with WS4 (deep water reference site).

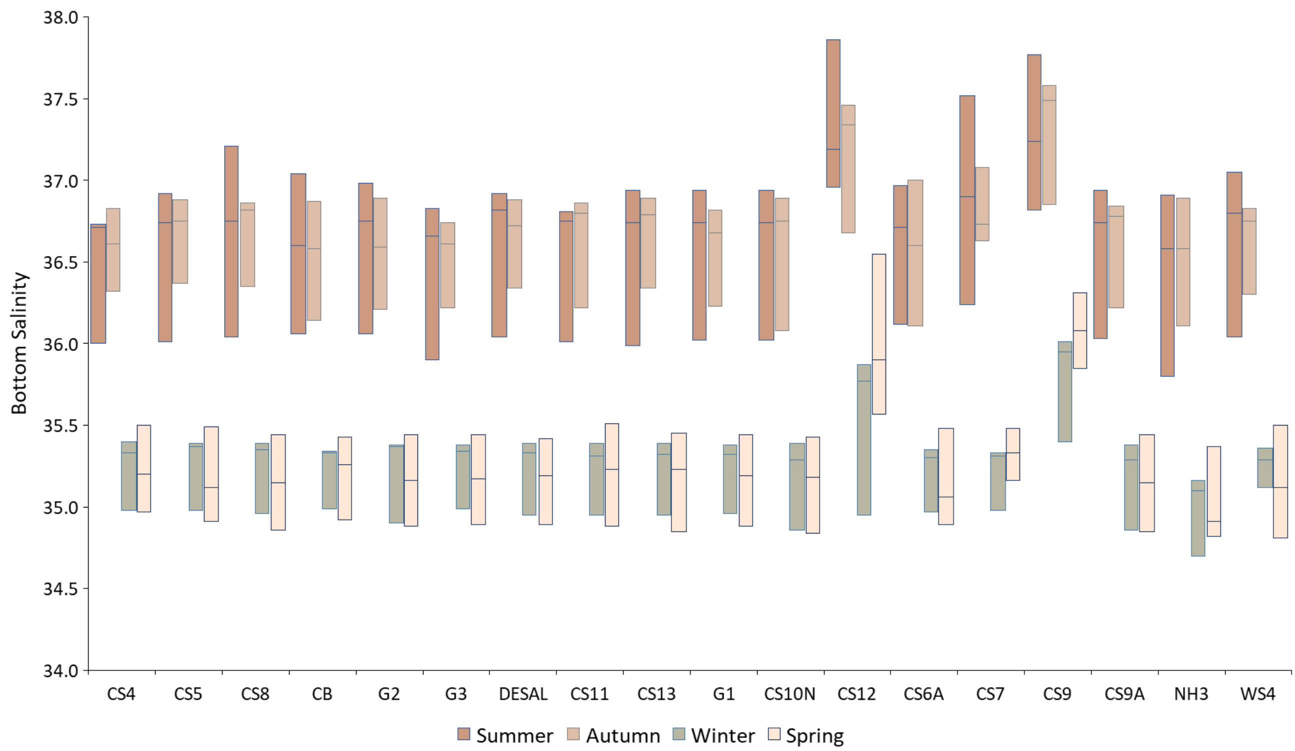

Figure G14: 2024 bottom water salinities at 17 deep water sites compared with WS4 (deep water reference site).

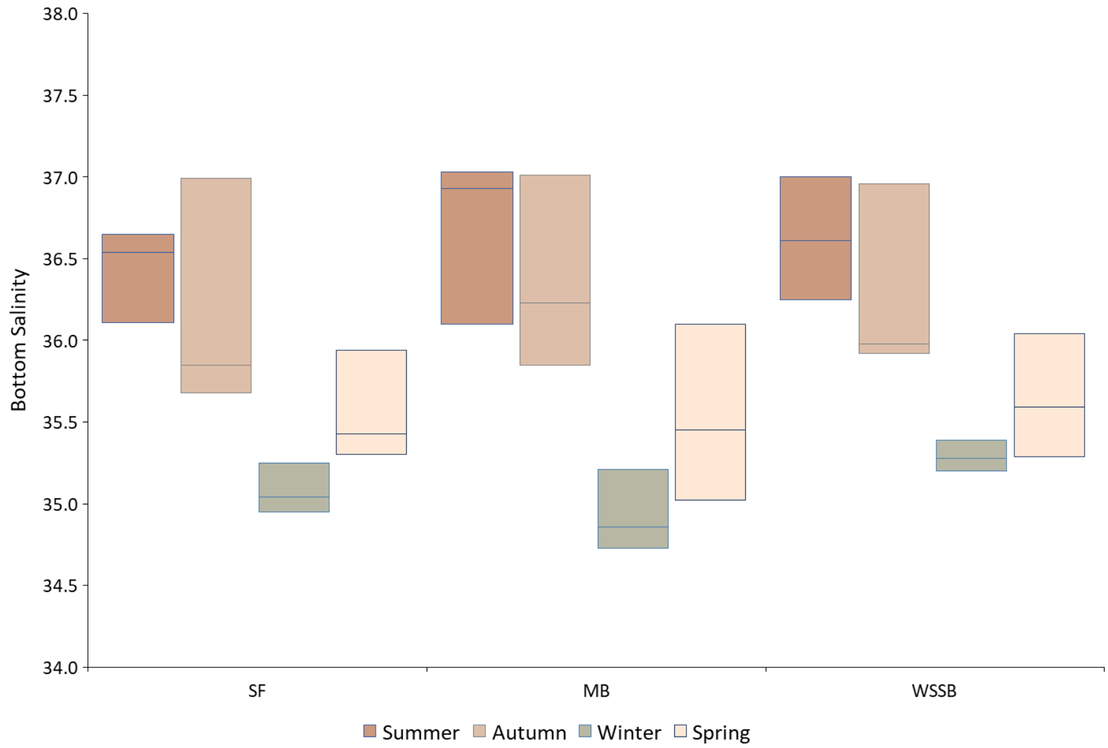

Figure G15: 2023 bottom water salinities at two shallow water sites compared with WSSB (shallow water reference site).

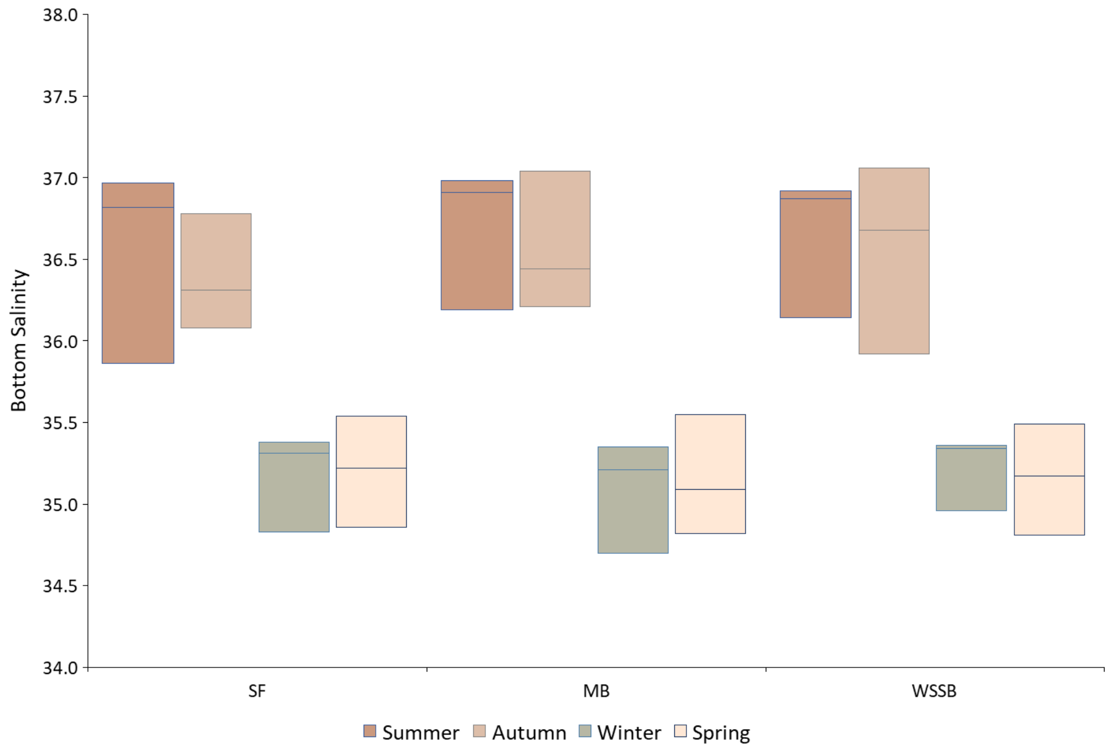

Figure G16: 2024 bottom water salinities at two shallow water sites compared with WSSB (shallow water reference site).

pH

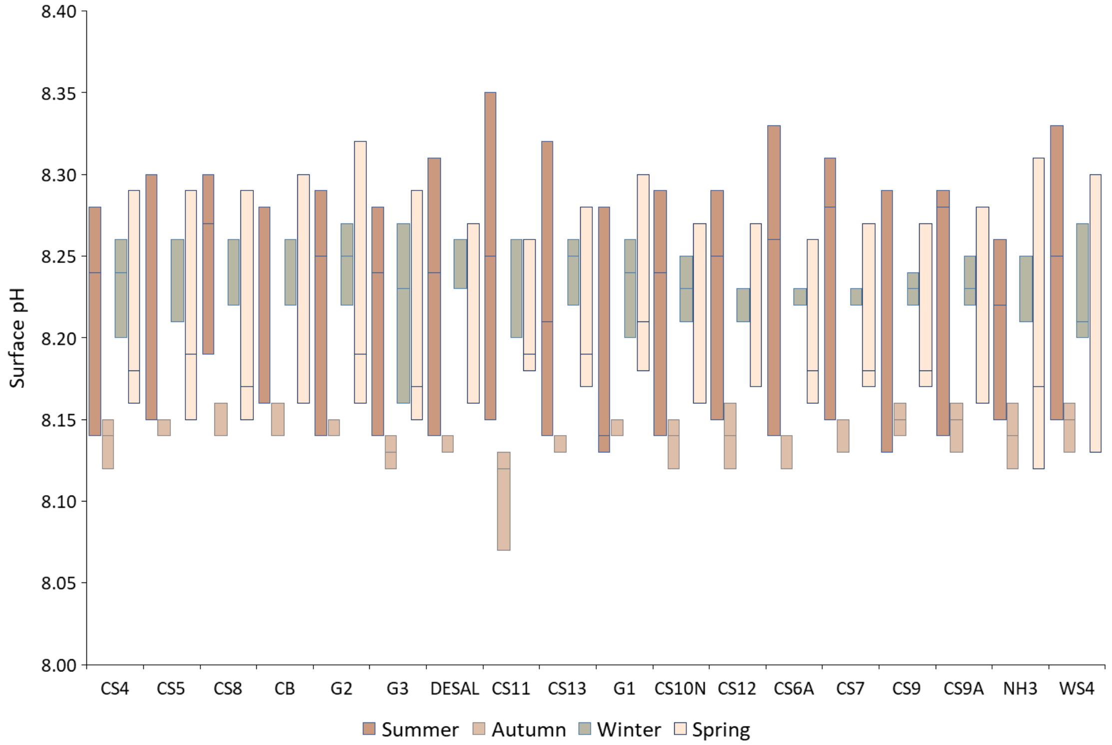

Figure G17: 2023 surface water pH at 17 deep water sites compared with WS4 (deep water reference site).

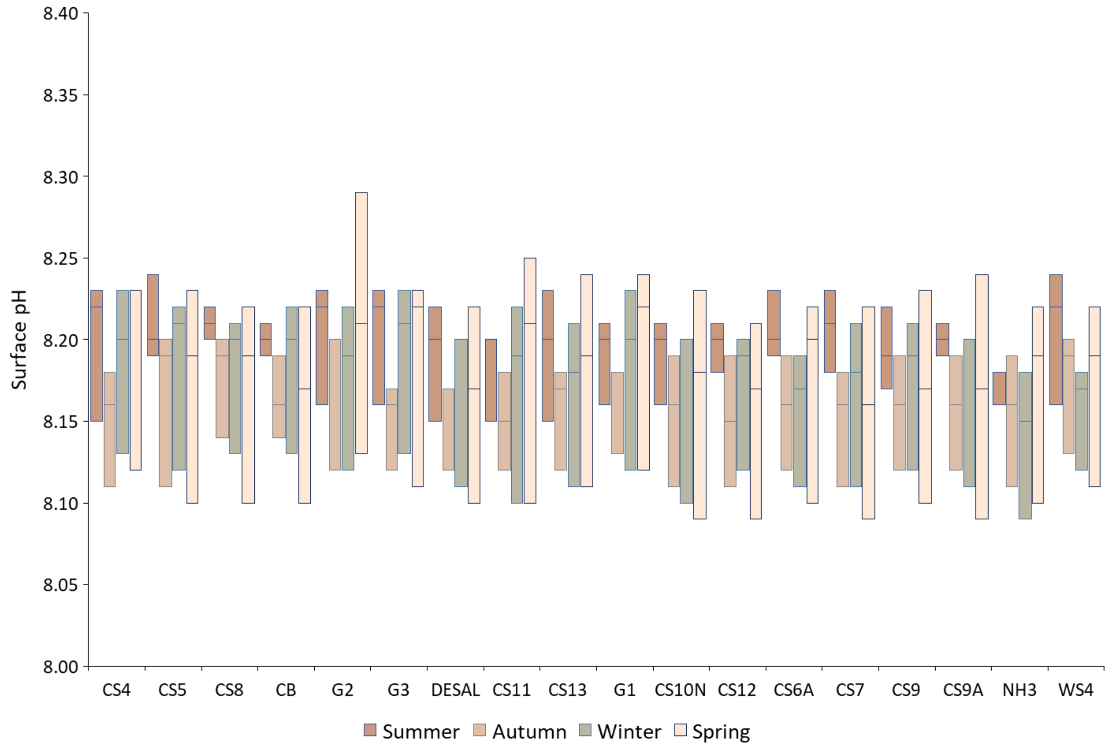

Figure G18: 2024 surface water pH at 17 deep water sites compared with WS4 (deep water reference site).

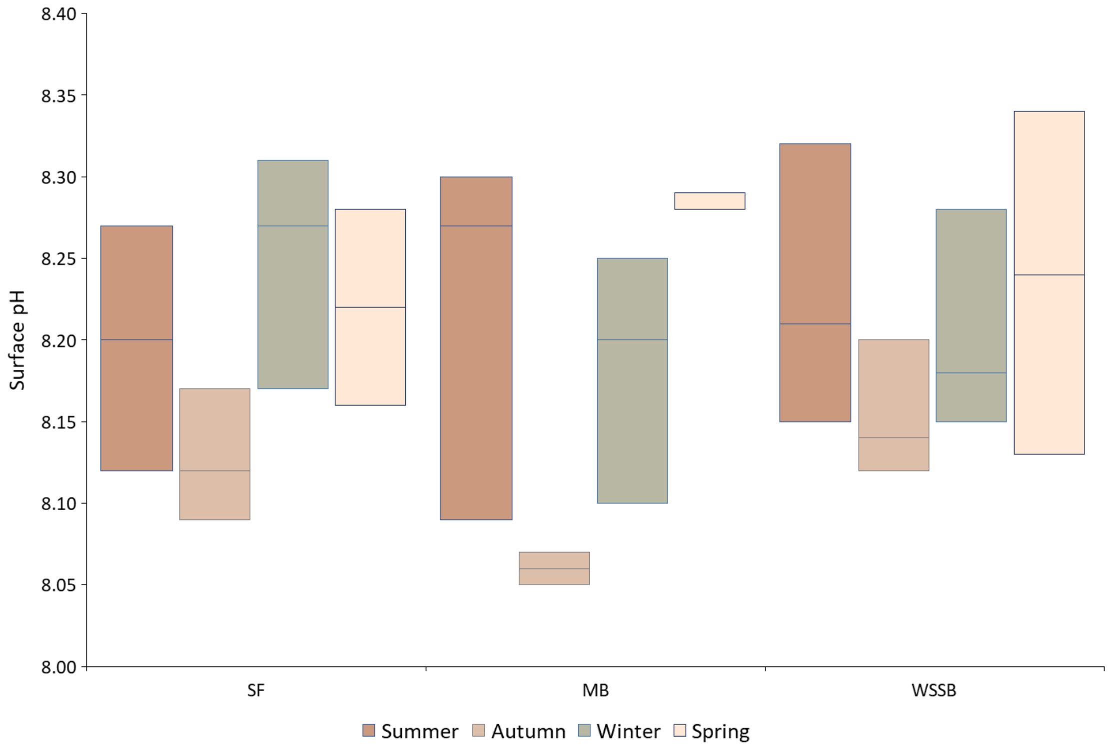

Figure G19: 2023 surface water pH at two shallow water sites compared with WSSB (shallow water reference site).

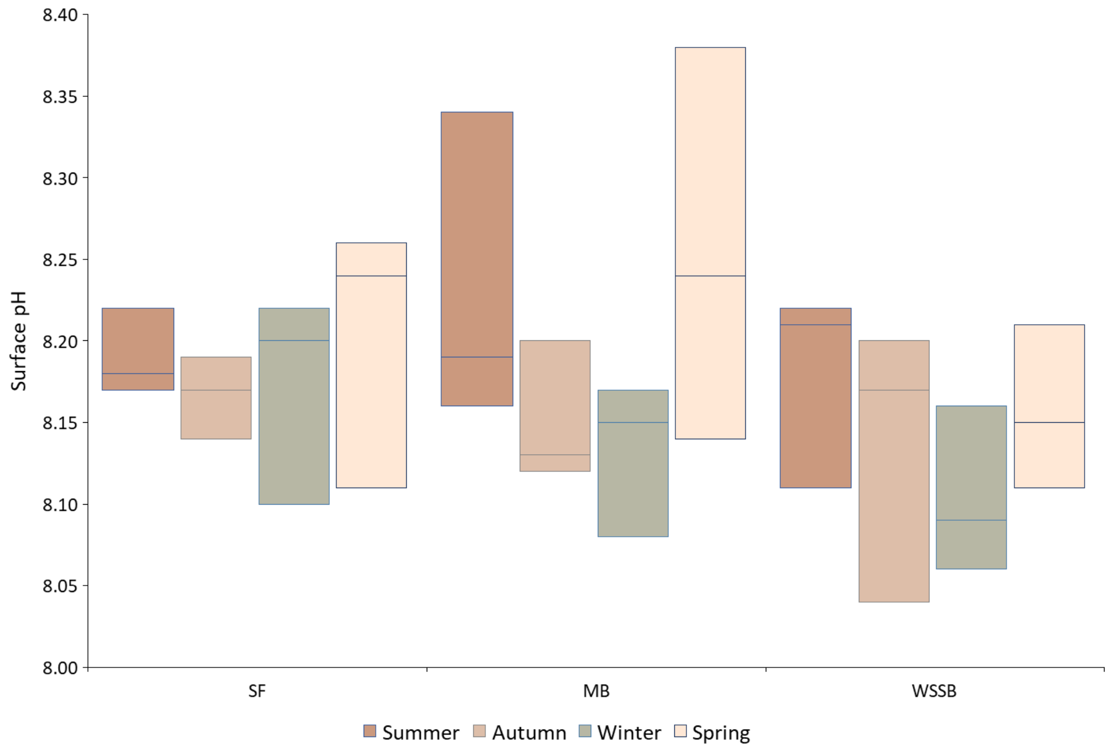

Figure G20: 2024 surface water pH at two shallow water sites compared with WSSB (shallow water reference site).

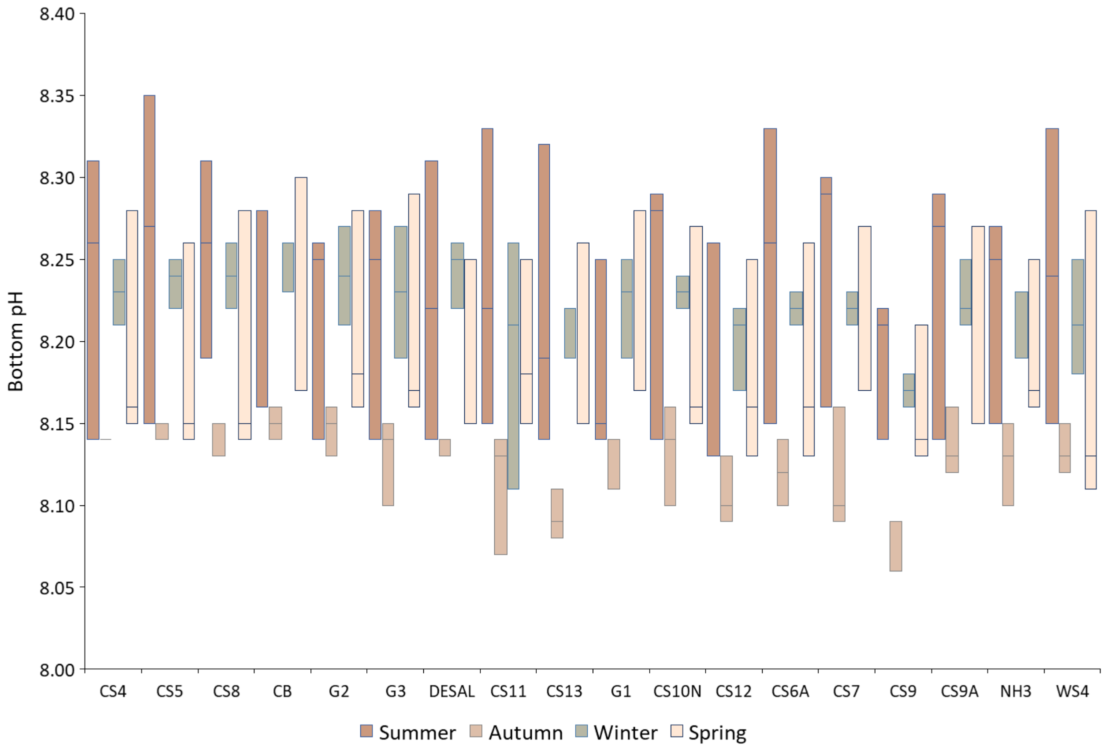

Figure G21: 2023 bottom water pH at 17 deep water sites compared with WS4 (deep water reference site).

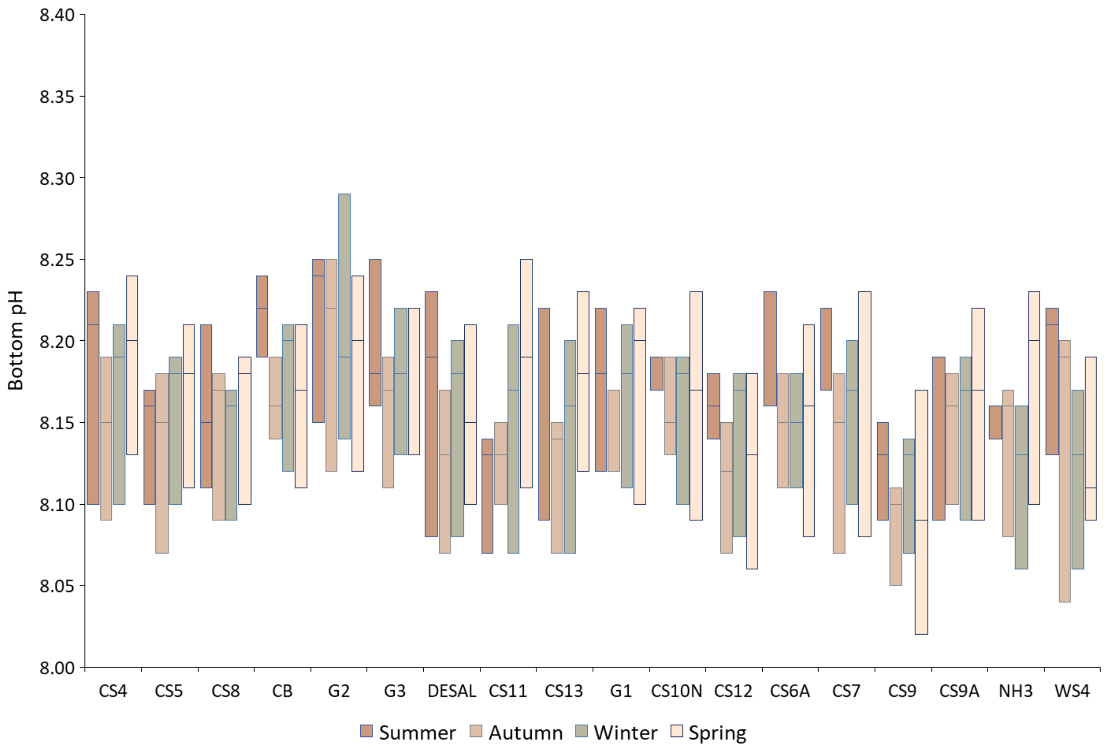

Figure G22: 2024 bottom water pH at 17 deep water sites compared with WS4 (deep water reference site).

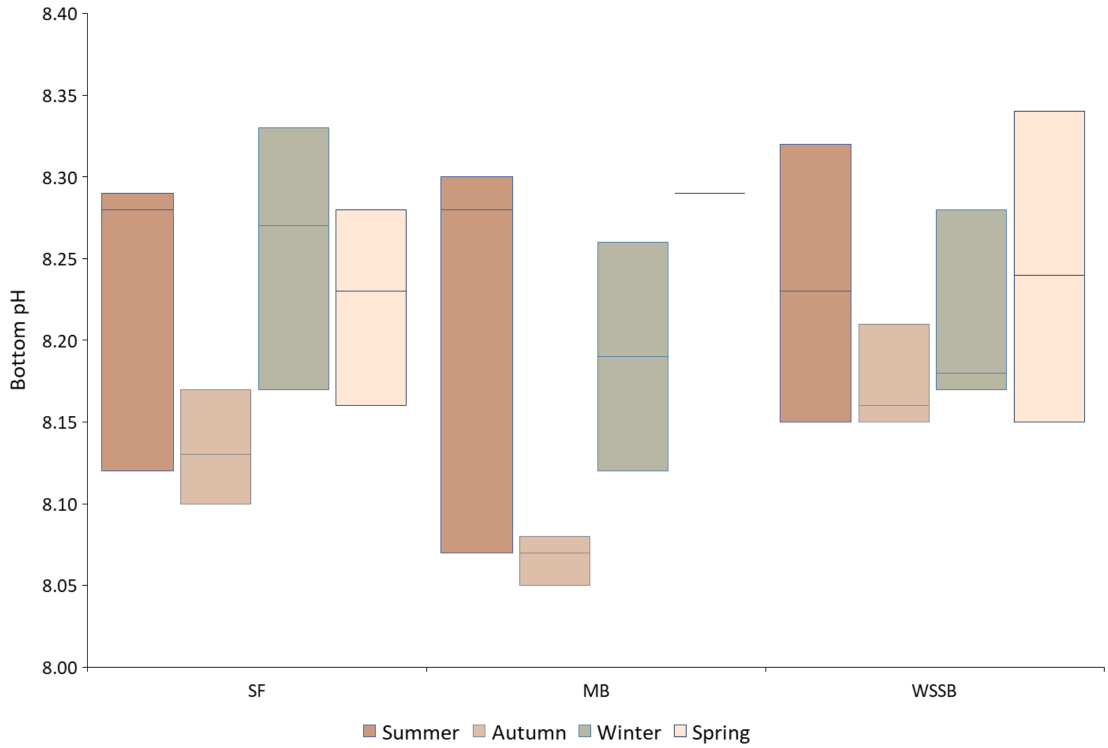

Figure G23: 2023 bottom water pH at two shallow water sites compared with WSSB (shallow water reference site).

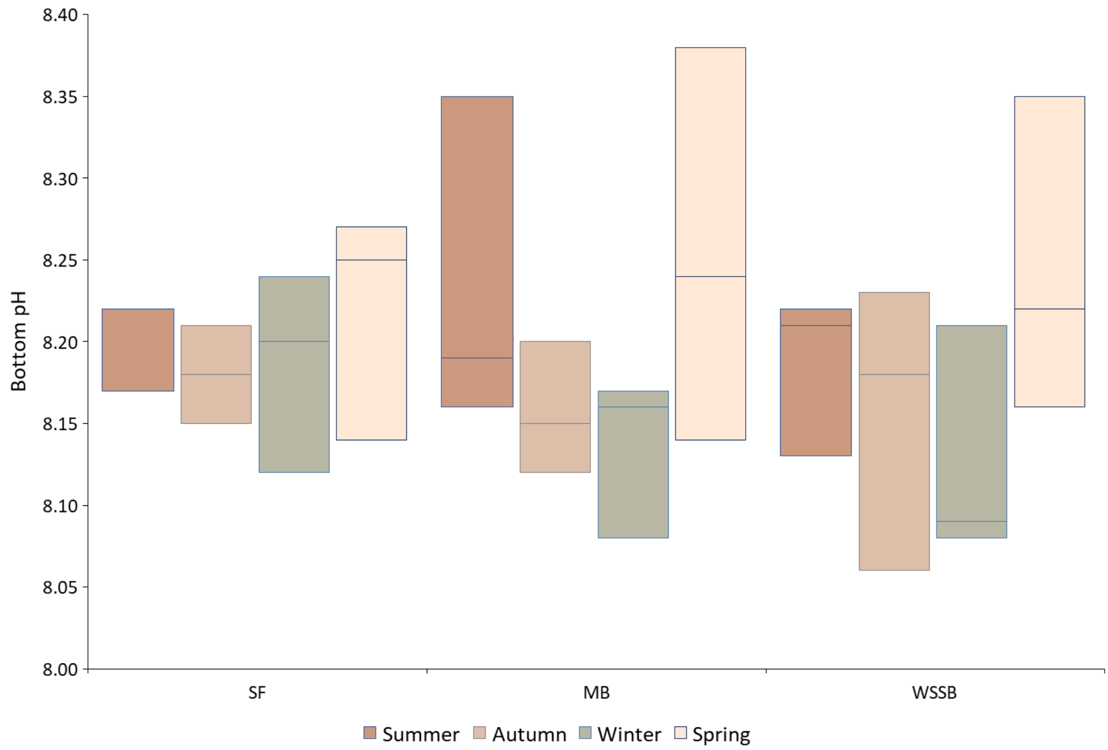

Figure G24: 2024 bottom water pH at two shallow water sites compared with WSSB (shallow water reference site).

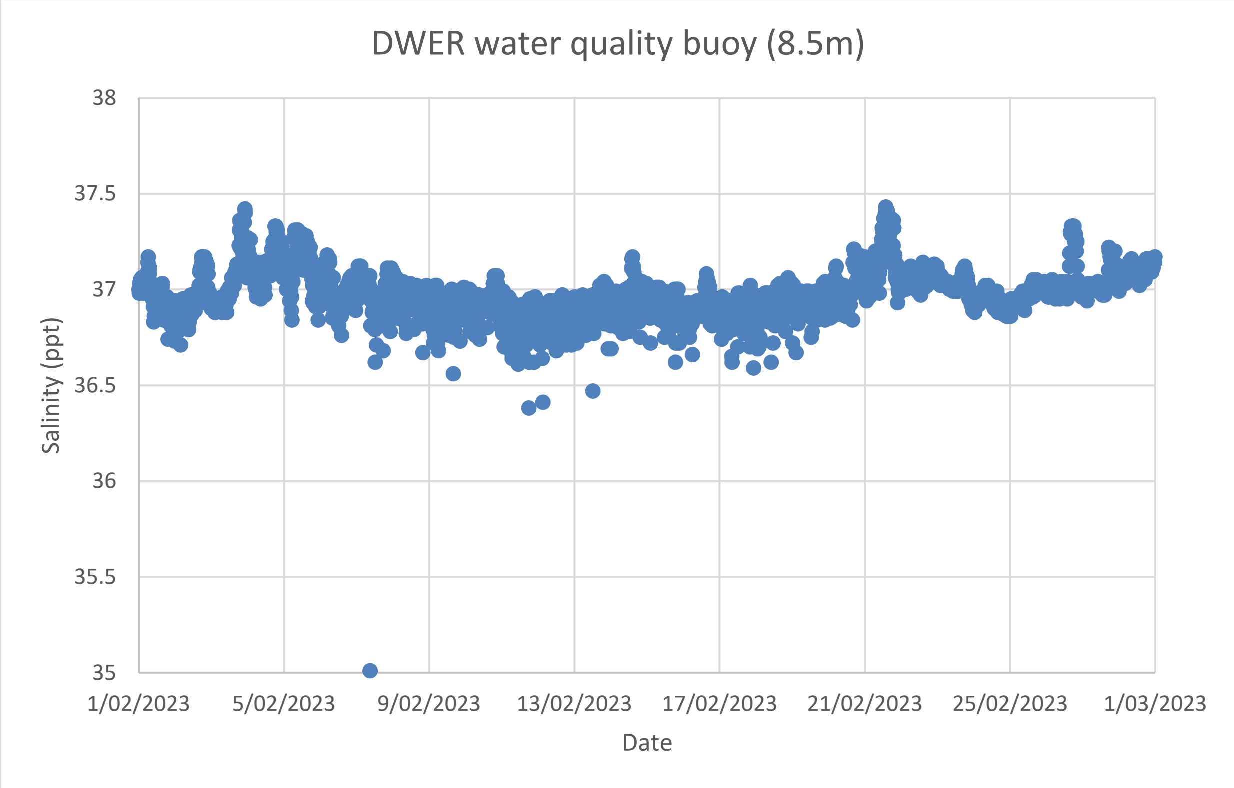

Figure G25: Salinity (ppt) in the bottom waters at DWER water quality buoy monitoring site on Kwinana Shelf (8.5 m depth) during February 2023.

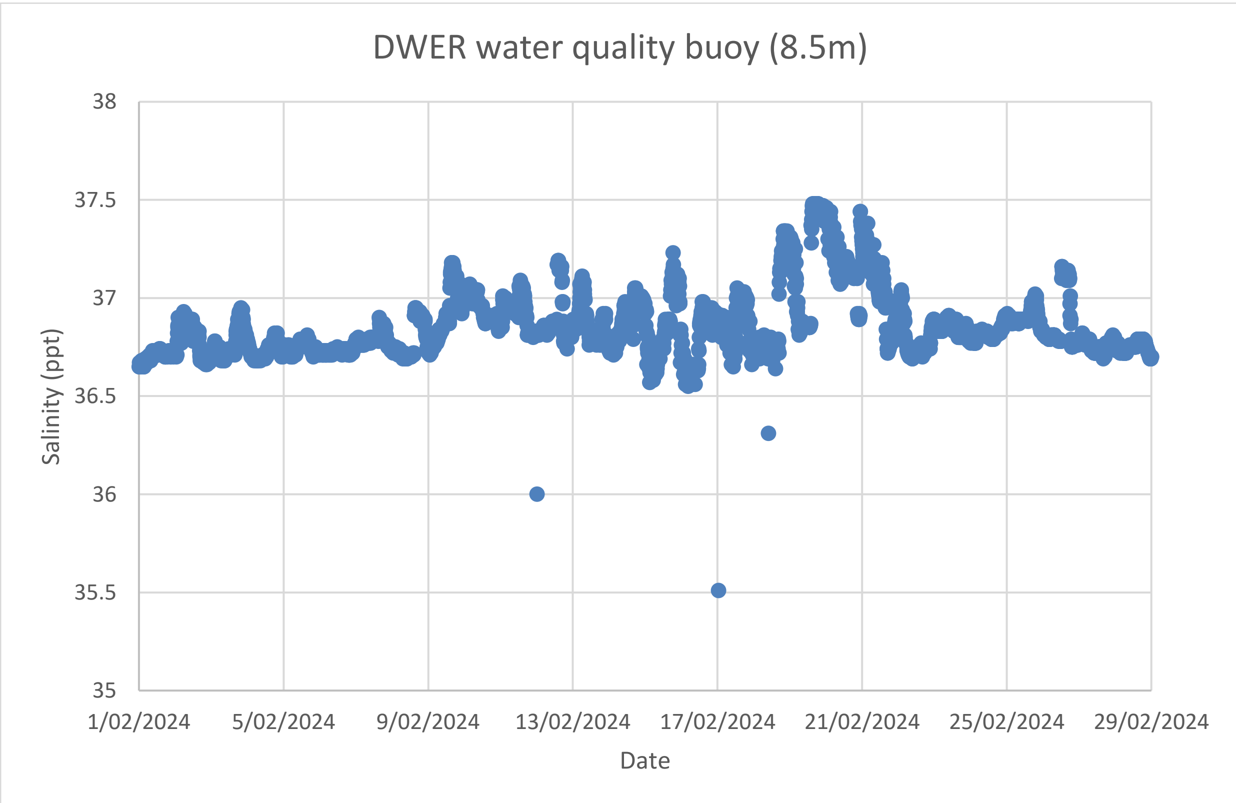

Figure G26: Salinity (ppt) in the bottom waters at DWER water quality buoy monitoring site on Kwinana Shelf (8.5 m depth) during February 2024.

Appendix H: Qualitative observations of indicators of aesthetic quality

Table H1: Qualitative (visual) observations of indicators of aesthetic quality at each of the 19 water quality monitoring sites in Cockburn Sound and the two reference sites in Warnbro Sound, between 1 December 2022 and 30 November 2024

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
Dec-22	CS6A ,CS7. CS12. CS9, CS9A, CS10N, MB, NH3 (slight algal bloom)		DESAL, CS13, CS11, WSSB, G1, G2, G3, CS4, CS6A, CS7, CS12, CS9, CS9A, CS10N and MB	DESAL, CS13, CS11, WSSB, G1, G2, G3, CS4, CS6A, CS7, CS12, CS9, CS9A, CS10N and MB (green)			CS13 (wheat debris), WSSB (seagrass fruit), CS4 (seagrass and algae), CS10N (wheat on surface) and MB (macros on surface)		
Jan-23			CS7, CS12, CS9, CS9A, CS10N and MB	CS7 and CS12 (brown), CS9, CS9A, CS10N and MB (green)			CS9, CS9A and MB (large, suspended particulate), CS8 (grain on surface), WSSB, WS4 and G2 (seagrass)		
Feb-23			CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, CS5, NH3, DESAL, CS13, CS11, G1, G2, G3 and CS4	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, CS5, NH3, DESAL, CS13, CS11, G1, G2, G3 and CS4 (green)		CS9, CS9A, DESAL, CS13, CS11	CS12, SF,WSSB and G2 (seagrass)		
Mar-23	CS12, CS9		CS12 and CS9	CS12 (green)		CS12, CS9	CS10N and		

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
	(algal)			and CS9 (brown)			MB (dust), SF, G2 and CS4 (seagrass), SC13 (wheat dust)		
Apr-23			WSSB, CS9A, CS10N and NH3	WSSB, CS9A, CS10N and NH3 (green)			CS11, WSSB, WS4, G1, G3, CS4, MB, CB, CS5 and NH3 (seagrass), CS9A, CS10N and CS8 (large particulates), G3 (brown seaweed), CS5 (dusty film)		CS12
May-23			CS12, CS9, MB and NH3	CS12, CS9, MB and NH3 (green)			MB, SF and CS8 (seagrass)		
Jun-23		CS10N (dead bird)	CS6A, CS7, CS12, CS9, CS9A, CS10N, CB, CS5, NH3, DESAL, CS13, CS11, WS4, G1, G2 and G3	CS6A, CS7, CS12, CS9, CS9A, CS10N, CB, CS5, NH3, DESAL, CS13, CS11, WS4, G1, G2 and G3 (green)			WSSB and G2 (seagrass), CS10N (wheat dust)		
Jul-23			CS7, CS11, G1, G2, G3 and CS4, MB and SF	CS7, CS11, G1, G2, G3 and CS4 (green), MB and SF (brown)			CS10N (wheat dust), WSSB (seagrass), CS4 (wrack)		CS6A

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
Aug-23			All sites	All sites (green)			CS7 (macroalgae) WSSB (seagrass) WSSB, G2, MB and CB (wrack)		
Sep-23	SF, WSSB (brown algae)		CS9, CS9A, CS10N, CS5, NH3, WSSB and WS4	CS9, CS9A, CS10N, CS5, NH3, WSSB and WS4 (green)			CS9, MB, WSSB and G2 (seagrass)		
Oct-23	CS12, CB and CS8 (brown algae)		CS6A, CS7, CS12, CS9, CS9A, CS10N, CS8, CB, CS5, NH3, DESAL, CS13, CS11, G1, G2, G3, CS4 and MB	CS6A, CS7, CS12, CS9, CS9A, CS10N, CS8, CB, CS5, NH3, DESAL, CS13, CS11, G1, G2, G3 and CS4 (green), MB (brown)			CS10N (wheat dust), MB, CF, CS8 and CS5 (seagrass), WSSB and G2 (wrack)		
Nov-23			CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, CS5, NH3, DESAL, CS13 and G1	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, CS5, NH3, DESAL, CS13 and G1 (green)			CS7, G2 and G3 (wrack)		
Dec-23	CB (brown algae), WSSB, G1, CS4 and CS7 (algae)		SF, CS8 and DESAL	SF, CS8 and DESAL (green)			CS10N (wheat dust, large particles), MB, SF, CS8, WSSB and CS7 and CB (seagrass)		

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
Jan-24	WSSB (macroalgae)		CS11, G1, G2, CS6A, CS7, CS9, CS9A, CS10N, MB, SF, CB and NH3	CS11, G1, G2, CS6A, CS7, CS9, CS9A, CS10N, MB, SF, CB and NH3 (green)			WSSB (seagrass)		
Feb-24	MB (algal bloom)		CS7, CS12, MB, SF, NH3, DESAL, CS13, CS11, WSSB, WS4, G1, G2, G3 and CS4	CS7, CS12, MB, SF, NH3, DESAL, CS13, CS11, WSSB, WS4, G1, G2, G3 and CS4 (green)			CS10N (wheat dust), SF, CS11, WSSB, G1, G2 and G3 (seagrass), WSSB and G1, G2 and G3 (macro wrack)		
Mar-24			CS7, CS12, CS9, CS9A, CS10N, MB, CB, NH3, DESAL, CS13, CS11, WSSB, WS4, G1 and G2	CS7, CS12, CS9, CS9A, CS10N, MB, CB, NH3, DESAL, CS13, CS11, WSSB, WS4, G1 and G2 (green)			MB, SF, CS8, WSSB and G2 (seagrass)		
Apr-24	G1, G3, SC4 (Trichodes-mium), G3 and CS4 (macroalgae)		CS6A, CS7, CS12, CS9, CS9A, CS10N, NH3, DESAL, CS13, CS11, WSSB, WS4, G1, G2 and G3	CS6A, CS7, CS12, CS9, CS9A, CS10N, NH3, DESAL, CS13, CS11, WSSB, WS4, G1, G2 and G3 (green)			CS10N (wheat dust), MB, CB, CS13, WSSB, WS4, G2 and G3 (seagrass),		
May-24	CS9A (macroalgae)		CS10N, NH3 and WSSB	CS10N, NH3 and WSSB (green)			MB, SF, CB, WSSB and G3 (seagrass)		

Sampling month	Nuisance organisms	Faunal deaths	Water clarity	Colour	Reflectance	Surface films	Surface debris	Submerged debris	Odours
Jun-24	MB, SF, CS8, CB, CS5 and NH3 (algae wrack)		All sites	All sites (green)			CS9 (wrack), CS9A, MB, SF, CS8, CB, CS5, NH3 WSSB, WS4, G1, G2, G3 and CS4 (seagrass)		
Jul-24	MB and CS11(algae)		All sites	All sites (green)			CS10N (wheat dust)		CS13 (burnt rubber)
Aug-24	DESAL, CS11, WS4, CS7, CS10N, MB and SF (macroalgae)		CS7, CS12, CS9, CS9A, CS10N, MB, CS5 and NH3	CS7, CS12, CS9, CS9A, CS10N, MB, CS5 and NH3 (green)			CB (seagrass)		
Sep-24	CS5 and G2 (macroalgae)		NH3	NH3 (green)					
Oct-24	CS6A, CS7, CS12, CS9, CB, CS5, G1 and G3 (macroalgae)		CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, CS5, NH3, DESAL, CS13, CS11, WSSB, WS4 and G1	CS6A, CS7, CS12, CS9, CS9A, CS10N, MB, SF, CS8, CB, CS5, NH3, DESAL, CS13, CS11, WSSB, WS4 and G1 (green)			CS10N (wheat dust), MB (seagrass wrack)		
Nov-24	CB (algae)		CS13, CS11, CS7, CS12, CS9, CS9A, CS10N, MB, CS8, CS, CS5 and NH3	CS13, CS11, CS7, CS12, CS9, CS9A, CS10N, MB, CS8, CS, CS5 and NH3 (green)			WSSB, G1, G2, G3, MB, SF, CS4, CS8 (seagrass), CS4 (seaweed), CS10N (wheat dust)		