Investigating the Environmental Drivers of Change in Pipe Clay Lagoon

Consultation and desktop review of available information

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Abbreviations

Abbreviation	Definition
ASI	Australian Seafood Industries
BEMP	Broadscale Environmental Monitoring Program
EPA	Environment Protection Authority Tasmania
IMAS	Institute of Marine and Antarctic Science
FRDC	Fisheries Research and Development Corporation
MAST	Marine and Safety Tasmania
MFDP	Marine Farming Development Plan
NRE Tas	Department of Natural Resources and Environment Tasmania
NRM	Natural Resource Management
PCL	Pipe Clay Lagoon
POMS	Pacific Oyster Mortality Syndrome
PST	Paralytic Shellfish Toxin
ShellMAP	Shellfish Market Access Program
TASQAP	Tasmanian Shellfish Quality Assurance Program
UTAS	University of Tasmania
UTS	University of Technology Sydney

Executive Summary

This report aims to investigate the drivers of environmental change in Pipe Clay Lagoon (PCL), southeast Lutruwita/Tasmania; particularly the simultaneous proliferation of seagrass and declines in farmed Pacific oysters (*Magallana gigas*) growth and survival observed since summer 2020. Marine Solutions conducted a desktop review and synthesis of existing information, in consultation with industry, community, research, and government representatives. The findings are intended to address current ecological and economic challenges and to inform sustainable management of PCL's aquaculture industry and ecosystems. In 2023, oyster growers with leases in PCL expressed concerns regarding the growth and survival of farmed Pacific oysters. Reports of environmental change including significant seagrass proliferation and sedimentation in the lagoon were communicated by growers and community members; however, the drivers of these changes had not been investigated. Further, there were concerns amongst stakeholders that similar issues may be occurring in other Tasmanian estuarine waters.

The aims for this project focussed on investigating the drivers behind the changing environment as well as the decline in oyster health. The objectives of this study were to: (1) characterise and quantify the environmental changes in PCL, providing an evidence base for anecdotal observations of these changes; (2) understand the drivers and interactions behind the observed environmental shifts; (3) identify management strategies to protect the values of PCL and other Tasmanian coastal lagoons, ensuring the sustainability of the aquaculture industry; and (4) propose mechanisms for capacity building and enhanced marine literacy within the community and industry to facilitate the observation and reporting of future changes.

The methods utilised in this investigation included extensive consultation with a broad range of stakeholders (including industry representatives, community members, research and government agencies) and the collation of relevant data (including scientific and grey literature, environmental and anecdotal data). In November 2024, stakeholders met in Hobart to discuss desired project outcomes and potential data sources.

This report suggests several key drivers of environmental change within PCL. The increased abundance of seagrass, driven by warmer temperatures and higher rainfall and runoff, has led to several ecological shifts in the lagoon. The proliferation of seagrass has likely increased

sedimentation in the lagoon by stabilising sediments, altering flow dynamics, and contributing to changes in the lagoon's physical properties. Additionally, the photosynthesis and respiration cycles of seagrass have created extreme daily fluctuations in dissolved oxygen and have likely influenced the pH in the lagoon. These fluctuations, coupled with the warmer temperatures, may have placed significant stress on oysters, affecting their overall health. Oysters in poor condition are susceptible to infection, particularly from *Vibrio* bacteria, exacerbating the already challenging conditions for oyster farming.

The report also highlights the complexity of the interactions between various environmental drivers and the difficulty of establishing a clear hierarchy of impacts without further investigation. These interactions, compounded by anthropogenic pressures and climate change, require more comprehensive field analysis and targeted data collection. It highlights the need for ongoing monitoring and testing to inform effective management and ensure the sustainability of PCL's ecological and aquaculture systems.

In mid-2025, all oyster farming leases in PCL have become functionally inactive due to oyster mortality, leading to significant economic loss for growers. The pressure on individual growers, particularly those with leases only in PCL, has intensified, creating an opportunity for government and industry to support and assist in solutions, relocation or closure efforts. The removal of tonnes of oysters from the system is expected to have further implications for the lagoon's ecology, particularly in terms of water filtration and nutrient cycling.

While the drivers of environmental change in PCL cannot be attributed to a single factor, the situation appears to be the result of a "perfect storm"— a convergence of a number of unfavourable factors and conditions resulting in a situation worse than the sum of its parts.. The insights gained from this report, however, can help direct future research and management strategies, not only for PCL but for other estuaries in Tasmania facing similar challenges. Moving forward, a more collaborative approach is necessary to ensure a cohesive and efficient strategy for addressing the ongoing issues in PCL.

To address challenges in PCL and guide future management and research, several recommendations have been outlined in this report. A reassessment of the lagoon's hydrodynamics, bathymetry, and tidal prism should be conducted using updated methodologies, including an accurate evaluation of seagrass extent. Continuous monitoring of temperature, dissolved oxygen, and pH is also recommended within and outside of seagrass beds to assess diel fluctuations in water quality and their potential effects on oyster health. While these recommendations are targeted to PCL, the findings highlight broader lessons for estuaries and oyster aquaculture across southeast Tasmania. Given the increasing frequency and intensity of climate-related stressors, it is important to extend monitoring and research efforts beyond PCL to other estuaries where early intervention may help mitigate negative impacts on oyster health before they reach critical levels. Approaches such as reassessing hydrodynamics, quantifying seagrass extent, and implementing continuous water quality monitoring should therefore be considered as part of a regional strategy to support the long-term resilience of oyster farming.

In terms of management, updates to the maintenance program for the Oyster Sensor Network are suggested, along with the creation of an open-access, central repository to store and maintain relevant information from each Tasmanian oyster-growing estuary, and a database to record environmental observations to help clarify and quantify anecdotal information. Furthermore, data collection should be initiated when declining oyster growth rates are noted, including key details of timing and location, and regular measurements of oyster growth and condition. Increased collaboration between industry, government, research, and community stakeholders is vital, and the creation of a working group could help coordinate these efforts. Ideally, the group would be comprised of industry representatives, managers, and specialist scientists such as seagrass experts and general ecologists, ensuring that oyster health is considered within the broader ecological context and that management approaches are holistic and responsive to the dynamic nature of the system.

Addressing knowledge gaps is also important for future research, for example the identification of preferred phytoplankton species for Pacific oysters, the contributing factors to oyster disease, and research into the localized effects of large-scale climate drivers like the El Niño-Southern Oscillation, should also be considered to better understand their potential role in the ecological changes observed in the lagoon.

Keywords

Pacific oyster, Pipe Clay Lagoon, estuary, Tasmania, *Magallana gigas,* environmental change

1 Introduction

Coastal lagoons are shallow, highly productive estuarine systems that provide critical ecosystem services, including biodiversity support, nutrient cycling, and flood protection (Danovaro & Pusceddu 2007; Kennish & Paerl 2010; Inácio et al. 2025). They also underpin socio-economic and cultural activities such as aquaculture, fishing, and recreation (Webster & Harris 2004; Pérez-Ruzafa et al. 2024). Positioned at the land–sea interface, lagoons are highly sensitive to terrestrial and marine stressors, including nutrient inputs, hydrodynamic changes, sea-level rise, warming, and extreme events. These pressures can alter water clarity, sedimentation, seagrass cover, and shellfish survival, with implications for aquaculture and ecosystem function (Webster & Harris 2004).

Pacific oysters (*Magallana gigas*) are one of the most widely farmed bivalves globally, valued for their resilience and rapid growth (Ruesink et al. 2005; Shatkin et al. 1997). Introduced to Tasmania in the 1950s to support aquaculture (English et al. 2000), they underpin an industry of significant economic and cultural importance. Pacific oysters are a hardy species with fast growth and high reproductive rates; they inhabit both intertidal and subtidal areas and can tolerate a wide range of temperature, salinity, and water quality conditions (Gerdes 1983). As filter-feeders, oysters improve water clarity and recycle nutrients, interacting closely with seagrass meadows in lagoon ecosystems (Peterson & Heck 2001; Vinther et al. 2008). However, their sessile lifestyle makes them vulnerable to multiple stressors, including disease outbreaks and warming seas (Gagnaire et al. 2006; Oliver et al. 2017).

Pipe Clay Lagoon (PCL) is a 530-ha coastal lagoon in southeastern Lutruwita/Tasmania, connected to Frederick Henry Bay by a narrow channel (Guiler 1950). The lagoon is bounded to the north by Cremorne and Rushy Lagoon; to the south by Clifton Beach village and a coastal reserve; to the east by the Pipe Clay Head peninsula; and to the west by rural residential subdivisions along South Arm and Clifton Beach roads, as well as village-zoned residences on Lumeah Point. The margins of the lagoon are comprised of rocky shoreline and saltmarsh habitat. The area surrounding PCL is light residential, with no significant industrial activity present, apart from aquaculture, specifically oyster farming. Management of PCL and the surrounding land is predominantly shared by Clarence City Council and the Department of Natural Resources and Environment Tasmania (NRE Tas).

PCL is a shallow lagoon, historically composed of sand flats (<2 m depth) and a deep channel.

The lagoon experiences delayed tides, warmer and more saline waters than the open sea, and sandy-mud substrates. It has no permanent freshwater inflow and is flushed daily by oceanic tides (Crawford et al. 1996). Since the early 1970s, PCL has supported shellfish aquaculture alongside recreational fishing, boating, and other community uses. Once Tasmania's most productive site for Pacific oyster farming, it has recently experienced oyster growth declines, increased mortality, and a marked proliferation of seagrass (NRE Tas, unpublished; community observations 2022–2024). The PCL catchment has been classified as 'severely impacted by anthropogenic activity' and the lagoon described as degraded and of low conservation significance, largely due to high population density and the presence of aquaculture within the system (Edgar et al. 1999).

Oyster farming in PCL has been central to the lagoon for over 50 years, and the lagoon was once one of Tasmania's most productive oyster growing areas, but industry performance has been severely affected in the past decade. Production had a major setback following the outbreak of Pacific Oyster Mortality Syndrome (POMS) in 2016. After a few years of stable production following POMS, by 2023 oyster harvests were reduced to around 30% of their historical average, with some growers reporting losses of up to 80% and several businesses closing by early 2025 (NRE Tas, *unpublished*). These industry challenges occur alongside environmental pressures, including expanding wild (not farmed, or invasive) Pacific oyster populations, seagrass proliferation, and altered lagoon dynamics. Climate change compounds these risks: Tasmanian waters are warming at three to four times the global average (Holbrook et al. 2019; Oliver et al. 2017), and marine heatwaves intensify mortality associated with POMS (Delisle et al. 2020).

The lagoon also supports a wide range of community uses, including recreational fishing, windsurfing, kayaking, and boating. There are 76 permanent vessel moorings in the lagoon, and beach access is used regularly for trailer boat launching (NRE 2008). Trailer boats are launched in the lagoon off the beach at the southern end of the Cremorne spit, where infrastructure includes a floating pontoon for boat mooring and fishing (Figure 1). Recreational users have reported changes in the lagoon, such as reduced access for swimming and watercraft due to seagrass proliferation, safety risks for windsurfers and other lagoon users associated with expanding wild Pacific oyster reefs, and increased siltation at the entrance channel restricting boat passage.

These impacts highlight the broader ecological, economic, and social values tied to the lagoon, and how environmental change affects multiple stakeholders.

Drivers of change in lagoons can include hydrodynamics, phytoplankton community shifts, harmful algal blooms, toxin exposure, disease outbreaks, groundwater inputs, and broader climate change. These factors, along with the influence of wild Pacific oysters and lagoon management practices, are of relevance to PCL. In recent years, declines in oyster growth and survival, combined with seagrass expansion and changing lagoon dynamics, have created uncertainty about the ecological drivers underpinning these changes. Understanding their role in shaping oyster health, seagrass expansion, and lagoon ecology is essential to support sustainable aquaculture, community use, and long-term environmental resilience.

This project responds to industry and community concerns by investigating the causes of environmental change in PCL and identifying solutions to maintain both ecological and economic values. Key components of the investigation included consultation and engagement with industry bodies, government agencies, and community stakeholders to inform the identification of potential drivers of change. The following sections synthesise existing information, stakeholder input, and scientific evidence to identify potential drivers of change and inform future management options.

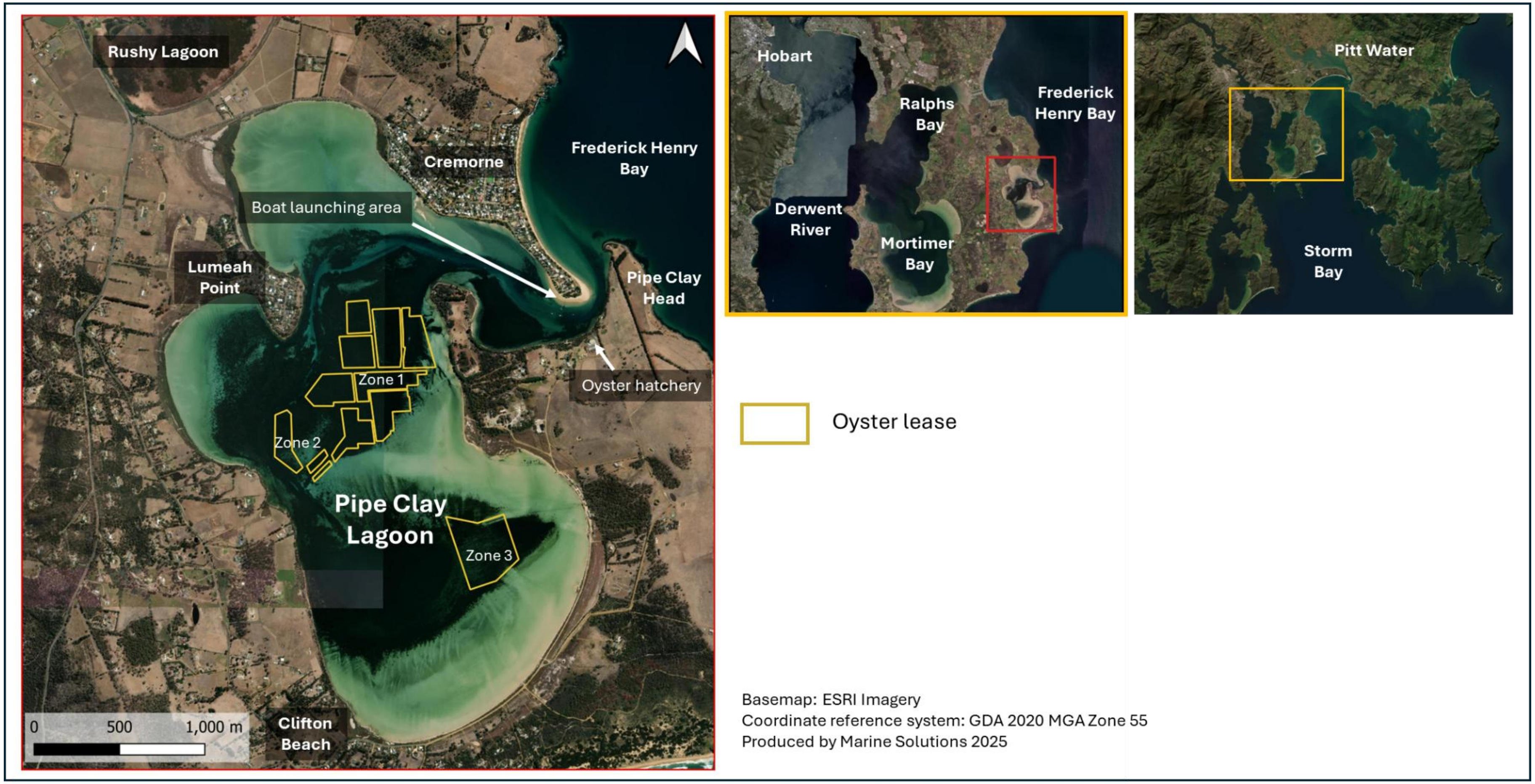

Figure 1. Map of Pipe Clay Lagoon and surrounding areas in southeastern Lutruwita/Tasmania, showing the oyster leases in three harvest zones, and location relative to Hobart and places referenced in this report (source ArcGIS Esri imagery with LISTmap marine lease overlay, image date: 12 Feb 2024).

2 Objectives and scope

This component of the project presents the findings of a desktop investigation into the drivers of changing environmental conditions in PCL and the subsequent decline in growth and survival of farmed oysters over the last five years. The investigation involved a review of existing scientific literature, analysis of available environmental data, and consultation with local stakeholders, including oyster farmers and community groups. The objectives of this project, as agreed upon between Marine Solutions and the Fisheries Research and Development Corporation (FRDC), are listed below:

1. Characterise and quantify environmental changes in PCL, providing an evidence base for anecdotal observations of change.

2. Understand the drivers and interactions behind observed environmental changes in PCL.

3. Identify management mechanisms to safeguard the values of PCL and other Tasmanian coastal lagoons, including sustainability of the aquaculture industry.

4. Propose mechanisms for capacity building and increased marine literacy within the community and industry to help observe and report change.

The scope of this project extends to identifying and evaluating the potential drivers of recent declining oyster growth and survival, and the environmental changes occurring in PCL, based on existing literature, environmental data, and stakeholder consultations. This project did not include new experimental manipulations, monitoring, or intervention in oyster farming operations.

3 Methods

This project adopted a desktop-based, integrative approach, combining stakeholder consultation with a review of available data and literature. The aim was to collate and synthesise information relevant to PCL, providing insights to highlight knowledge gaps, identify potential drivers of environmental change, and inform future management strategies.

3.1 Stakeholder Consultation and Engagement

A broad range of stakeholders were identified to inform and guide this project, including representatives from industry, community, research organisations, and local and state government (Table 1). Engagement was undertaken through a series of conversations, meetings, and email correspondence, as well as an in-person workshop held in November 2024. These interactions provided an opportunity to share observations, articulate values and concerns, and identify relevant information and potential data sources relating to PCL.

Consultation included oyster growers operating within the lagoon, the peak industry body Oysters Tasmania, and attendees at the annual Shellfish Futures Conference in September 2024 (Triabunna, Tasmania), where the project was introduced and feedback invited from the broader community[1]. Local and state government agencies engaged included Clarence City Council, the Department of Natural Resources and Environment Tasmania (NRE Tas), the Aquaculture Branch, Shellfish Market Access Program (ShellMAP), the Tasmanian Environmental Protection Agency (EPA), Biosecurity Tasmania, Animal Health Laboratory, Marine and Safety Tasmania (MAST), and the Department of State Growth. Additional perspectives were gathered from experts, organisations, and community groups, including Natural Resources Management South (NRM South), Friends of Lumeah Point Wildcare, Pipe Clay Coastcare, local residents, recreational and commercial fishers, and researchers from the University of Tasmania (UTas) and the Institute for Marine and Antarctic Studies (IMAS).

Consultations were conducted through individual discussions, small group meetings, and a single larger workshop session to ensure a comprehensive range of perspectives. Each organisation was represented by one or two individuals, and the process sought to maintain balanced input by

[1] Presentation available at: https://www.oysterstasmania.org/shellfishfutures2024.html

including multiple stakeholder groups and cross-checking information across participants. The qualitative input gathered helped shape the direction of the project, guided the identification of key themes, and provided context for the synthesis of existing data and literature.

The November 2024 workshop brought together these diverse stakeholders in a collective forum to discuss environmental change in PCL. The primary purpose of the workshop was to share knowledge, highlight stakeholder concerns, and identify information gaps to guide the desktop review. The workshop was structured as an open discussion, allowing participants to share experiences and perspectives across both recent and historical periods, capturing changes observed over the past decade as well as longer-term trends where known.

Table 1. Stakeholders engaged during consultation for the Pipe Clay Lagoon desktop investigation.

Sector	Entity
Oyster Industry	• Albatross Fishing • Amycus Pty Ltd • Australian Seafood Industries • Clifton Oysters • Freycinet Oysters • Oysters Tasmania • Pipe Clay Growers Association • Tasmanian Oyster Co. • Yumba Seafoods
Other Industry	• Pitt & Sherry • Salmon Tasmania • Petuna

Management / Government	• NRM South
	• Clarence City Council
	• NRE Tasmania
	  o Aquaculture Branch
	  o Biosecurity Tasmania
	  o Animal Health Lab
	• Department of State Growth Tasmania
	• Marine and Safety Tasmania (MAST)

Sector	Entity
Research	• IMAS (Fisheries and Aquaculture Centre, Fish Health, Biosecurity and Seafood Safety) • Nautilus Collaboration • UTAS School of Geography, Planning, and Spatial Sciences • University of Technology Sydney (Faculty of Science, Climate Change Cluster) • University of Sydney (School of Veterinary Science) • University of NSW (School of Civil and Environmental Engineering, Water Research Laboratory)

Community	• Local community groups
	  ○ Friends of Lumeah Point Wildcare
	  ○ Pipe Clay Coastcare
	• Local residents, recreational boaters, fishers, wind/kitesurfers

3.2 Information Gathering and Synthesis

Following stakeholder consultation, available information and environmental data pertaining to PCL were identified, collected, and reviewed. Sources included peer-reviewed studies, government monitoring programs, industry records, grey literature, historical accounts, aerial imagery, and anecdotal observations from lagoon users (Table 2).

Information was collated through a combination of searches of published and unpublished materials, requests to government and industry agencies, and consultation with local experts. Stakeholder input helped identify relevant datasets and contextual information, ensuring inclusion of both recent and historical observations. The relevance of each source was assessed based on its spatial and temporal coverage, connection to oyster health or lagoon ecology, and reliability of the data.

Key categories of information included:

- Water quality monitoring data– phytoplankton, biotoxin, microbiological, temperature, salinity, dissolved oxygen, and pH measurements from multiple monitoring programs (NRE Tas ShellMAP, ShellPOINT sensor network).
- Oyster health records – including production records, histopathology reports, and pathogen testing.

- Contaminants data – including sediment, groundwater, biotoxin and metals.
- Historical accounts, aerial imagery, and policy/management documents – including Marine Farming Development Plans, ShellMAP reports, and relevant municipal and academic reports.

Information from these diverse sources was integrated to provide a system-level understanding of PCL, identify potential drivers of environmental change, and highlight knowledge gaps. Where multiple datasets were available for the same parameter, cross-referencing was conducted to ensure consistency and reduce the risk of individual sources disproportionately influencing conclusions. Insights generated through this process can also inform monitoring and management strategies in other major oyster-producing regions.

Table 2 summarises the key datasets and information sources reviewed as part of this project. It includes both quantitative and qualitative data, ranging from environmental monitoring programs and oyster health records to historical accounts and stakeholder observations. Also indicated is the ownership or source of each dataset and a brief description of its contents, temporal coverage, and spatial extent. This compilation reflects the diversity of information integrated to develop a system-level understanding of PCL and to identify potential drivers of environmental change.

Table 2. List of information identified, accessed and reviewed as part of this project.

Data type	Ownership	Details
Anecdotal data	Individual oyster growers including: - Tasmanian Oyster Co. (Lease 12, 108, 198, 226) - Pipe Clay Oysters (Lease 15, 197, 270) - Amycus Pty Ltd (Lease 97, 13) - Clifton Oysters (Lease 98) - Albatross Fishing (Lease 91) Local residents, recreational boaters, fishers, wind/kitesurfers Local coast care groups: Lumeah Point and Pipe Clay	Observations of environmental change and oyster health.
Water quality data	ShellPOINT sensor network (Oysters Tasmania and NRM South)	Temperature and salinity measurements collected at 15-minute intervals at three locations in PCL from October 2022 to present. Dissolved oxygen and pH at from July 2023 to present (collected at two sites).
	NRE Tas (ShellMAP program)	Temperature, salinity, pathogen indicators collected at 9 sites ~ 4 to 10 times a year from 2008 to present.
	Australian Seafood Industries (ASI)	Nutrient data from five sites in PCL collected weekly for four weeks in March/April 2024 (data for 3 out of 4 weeks received).
	Department of State Growth	Physical parameters, nutrients, metal and pesticide toxicants collected at one site on two occasions in 2023.

Data type	Ownership	Details
	Salmon Tasmania	Water quality data collected monthly at three sites in Storm Bay from 2018 – 2024, including measurements of physical parameters and nutrients.
	Petuna	Water quality data collected monthly at two sites in Storm Bay from 2016 – 2024, including measurements of physical parameters, nutrients.
Phytoplankton data	NRE Tas (ShellMAP program)	Presence / absence and counts of phytoplankton collected monthly at one site in PCL from 2004 – 2024.
	Salmon Tasmania	Presence / absence and counts of phytoplankton collected monthly at three sites in Storm Bay from August 2019 – December 2023.
	ASI	Phytoplankton data from five sites in PCL collected weekly for four weeks in March/April 2024 (data for 3 out of 4 weeks received).
Biotoxin and oyster meat testing data	NRE Tas (ShellMAP program)	Monthly to weekly oyster meat testing for pathogen indicators (from 2018 - 2024) and biotoxins (2021 - 2024). Triennial meat testing for metal and chemical contaminants, from 1981 - 2018.
Oyster histopathology and microbiological testing	Animal Health Lab	Diagnostic results from PCL oyster meat sample testing for histopathology and microbiology, from 2020 – 2024.
Oyster production data	Oysters Tasmania	Confidentialised production data for PCL compared with the rest of the Tasmanian industry.
Groundwater data	Clarence City Council	Groundwater monitoring data including physical parameters, nutrients and faecal contamination indicators collected ~biannually from 13 bore sites from 2009 – 2018, and from six bore sites in Cremorne from 2019 – 2024.
Sediment data	MAST	Metal contaminants and likelihood of acid sulphate soils tested in sediment samples collected at four sites near the PCL mouth in May 2022.
Seagrass	IMAS	Ugalde and Ross (2023) ADVICE NOTE: Proliferation of seagrass in Pipe Clay Lagoon: the ecological role, understanding the drivers, and the consequences for oyster growers.
Seagrass	Various	Historical accounts of seagrass in PCL from Guiler (1950), DPIPWE (1998) and Mount et al. (2005)
Marine Farming Development Plan	NRE Tas	Pipe Clay Lagoon Marine Farming Development Plan (October 1998), reviewed in 2008, standardised to incorporate controls in 2024.

Data type	Ownership	Details
ShellMAP reports	NRE Tas (ShellMAP program)	- Annual and triennial reviews of water testing, triggers, harvest closures (1993 – present) - Area production overview (2020) - Sanitary survey (1991), - Shoreline surveys (2015 – 2024)
Benthic habitat and bathymetry	MAST	Bathymetric mapping and assessment of the seabed at the Cremorne boat launching site (mouth of PCL) in 2023.
Benthic habitat and bathymetry	Seamap Australia – benthic habitat mapping	Lucieer V, Walsh P, Flukes E, Butler C, Proctor R, Johnson C (2017). *Seamap Australia - a national seafloor habitat classification scheme.*
Hydrodynamics	CSIRO	CSIRO Storm Bay Modelling & Information System, TAS (2018-present) https://stormbaymodelling.csiro.au/quick-storm-bay
Hydrodynamics **Aerial / satellite imagery**	IMAS	Crawford et al. (1996) FRDC Grant 92/54 - Predictive modelling of carrying capacities of oyster (*Crassostrea gigas*) farming areas in Tasmania. July, 1996.
	IMAS Google Earth	Crawford & Mitchell (1999) Physical and chemical parameters of several oyster growing areas in Tasmania. Technical Report Series, Marine Research Laboratories, Tasmanian Aquaculture & Fisheries Institute, University of Tasmania.
		Google Earth Pro (2025) Pipe Clay Lagoon. 55G 544504 m E, 5242568 m S, elevation 0m. 2D map. Time scale 2016 – 2024.
Aerial / satellite imagery	Digital Earth Australia	National Intertidal Digital Elevation Model (NIDEM, Bishop-Taylor et al. 2019)
General Pipe Clay Lagoon documents	ArcGIS	ArcGIS World Imagery & Esri Wayback archive, time scale 2014 – 2025.
	NRE Tas	NRE Tas Pipe Clay Lagoon Environmental Information, *unpublished*

Data type	Ownership	Details
General Pipe Clay Lagoon documents	UTAS	Prahalad (2016) Clifton Saltmarshes, Pipe Clay Lagoon: Baseline Condition Assessment and Management Recommendations Consultation Report, August 2016
	Clarence City Council	Enviro-dynamics (2019) Reserve Activity Plan 2019 – 2029, Cremorne Coastal Reserve, October 2019
	Clarence City Council	Clarence City Council (2009) Climate Change Impacts on Clarence coastal areas – Final Report, prepared by SGS Economics and Planning & UNSW water Research laboratory, April 2009

3.3 Limitations

This project relied on a desktop-based approach, synthesising existing data, literature, and stakeholder input to provide an overview of environmental change in PCL. As such, no new empirical fieldwork was undertaken. The sources of information varied in type, quality, and coverage, including published and unpublished reports, monitoring programs, industry records, grey literature, and anecdotal observations. Differences in data collection methods, temporal and spatial coverage, and consistency across oyster farms and monitoring programs mean that trends cannot always be directly compared. Stakeholder input reflected personal observations and experiences, which, while highly valuable, may not be fully representative or objective. Finally, the review was exploratory in nature, aiming to identify potential drivers of change and knowledge gaps, rather than conducting formal statistical analyses or structured consensus-building exercises. These limitations should be considered when interpreting the findings and applying them to management decisions.

4 Results and Discussion

4.1 Stakeholder Consultation and Engagement

Stakeholders voiced a wide range of responses, opinions, values, and concerns both across and within stakeholder groups. A summary of the main issues identified by each of the different sectors, and a summary of each sector's values and concerns can be found in Table 3 and Table 4, respectively.

Across all sectors there was an overwhelming consensus that PCL is experiencing substantial environmental change, and this has resulted in concerns and challenges for a range of stakeholders. Additionally, there was agreement across sectors that PCL requires further investigation to understand the drivers of change, and for increased collaboration between industry, community, and government organisations to address the issues.

Consultation revealed gaps in collaboration between industry and government on the issues and observations of change in the lagoon when first reported. This was particularly highlighted by local growers, who expressed that their early concerns were not promptly addressed by government or industry. Local residents also raised concerns about the long-term management of aquaculture infrastructure in PCL, particularly in the event that farming activities decline. This was in reference to the large area of shellfish aquaculture infrastructure in PCL. Growers emphasized their significant economic loss in recent years, and that financial assistance may be required to assist in the decommissioning of oyster farms in PCL.

It was also clear that there is no clearly defined framework or plan to adequately manage or document unexpected environmental change and production loss, such as that observed at PCL within oyster production areas.

During consultation it was suggested that other Tasmanian estuarine systems have recently experienced reduction in oyster growth and increase in mortality, along with seagrass proliferation, although this has not been verified. This raised the question of whether investigations should focus only on PCL or also consider broader Tasmanian estuarine systems. Stakeholders noted that some of these may be driven by large-scale environmental factors, such as climate change, in which case attribution may not be possible with PCL data alone. This underscores the importance of implementing long-term monitoring of key environmental variables, including physical water quality parameters, phytoplankton and other parameters relevant to oyster health and lagoon condition.

4.1.1 Stakeholder observations

Anecdotal descriptions of environmental change in PCL included a number of observations for which there is no available scientific data. These observations were recorded to assist with defining environmental change in the lagoon since 2020:

- Proliferation of seagrass in the lagoon.
- Increased siltation, particularly around the mouth of the lagoon
- Change in marine species, including macroalgae, urchins, seastars
- Reduction in biofouling on farming equipment

There were mixed views in relation to wild Pacific oysters within the lagoon, with reports of both increase and a stable long-term trend in biomass. Community stakeholders and oyster growers expressed their concerns regarding the wild Pacific oyster population which included:

- Concern that wild Pacific oyster reefs reduce the amenity of the area and are a danger to recreational users (including windsurfers and paddleboarders).
- Concern that wild Pacific oysters compete for limiting resources with farmed oyster stock in the lagoon and are a risk to farmed stock health and biosecurity.

4.1.2 Information from oyster growers

Information regarding the deterioration of farmed Pacific oysters was collected from growers which included:

- Reduction in oyster growth and increased mortality, therefore loss in production.
- Affected oysters appeared translucent in meat colour, with darkened shell, dark mantle, and weakened adductor muscle.
- Deterioration started near the mouth of PCL before eventually impacting the entire lagoon.
- At first only small oysters (>2 mm) were impacted (unable to grow a young oyster, but able to maintain condition of a large adult oyster).
- Eventually all oysters (regardless of age and size) were impacted.
- Some PCL oyster growers had early success in keeping oysters alive after the start of oyster health issues by raising their racks higher in the water, keeping oysters clear of the seagrass.
- Speculation that the seagrass proliferation in the lagoon, which occurred over roughly the same time frame as the oyster productivity decline, has led to altered water flow to oyster leases in the lagoon and possible harbouring of disease agents that affect oyster health.

The possibility that similar issues to those seen in PCL may be evident in other estuaries in Tasmania and in other oyster-growing regions in Australia was identified during consultation, and conversations with the broader industry were initiated.

4.1.3 Pipe Clay Lagoon Stakeholder Engagement Workshop, November 2024:

This workshop assisted in knowledge sharing between industry, government and community which assisting in highlighting and bridging knowledge gaps applicable to this project. Outputs including social, economic and environmental values and concerns for stakeholders are outlined in Table 4.

Table 3. A summary of the main issues identified by each sector during stakeholder consultation.

Sector	Main Issues Identified
Oyster Industry	• Low growth and survival of Pacific oysters in PCL since 2020. Timeline and location of effects established. • Timing of oyster health impacts aligned with seagrass increase. • Reduced flow in lagoon from sedimentation and seagrass proliferation. • Impact of wild Pacific oysters – competition, biosecurity. • Possible change in composition of plankton communities. • Knowledge gap identified in relation to interactions between plankton species and oyster health. • Impacts of salmon farming on PCL water quality.
Management / Government	• Concern that industry did not report mortality (as per licence holder reporting requirements), or submit samples to Animal Health Lab for analysis when moribund oysters were first recorded, limiting the ability of the laboratory to provide useful diagnostic services. • Reliance on anecdotal information of issues, or on production reports (delayed indicator). • Identification of main land run-off points, no concerns in relation to pollution from septic tanks • Review of groundwater testing in area • Interest from Department to support efforts towards wild Pacific oyster removal • Department acknowledgement of delay in management plan review • Plans for excavation and redistribution of sandbanks at lagoon mouth to reduce recreational boating hazards • Plan for live-bearing seastar insurance population to be moved from Pittwater to PCL as part of the Midway Point and Sorell Causeways upgrade.
Research	• Interest in further investigations in relation to physiology and histology investigations in oysters at PCL. • Interest in improving management of surrounding saltmarsh habitat. • General information about oyster physiology and histology provided. • Discussions and comparison with oyster health and environmental drivers in other oyster growing estuaries (St Helens, Port Stephens, Hawkesbury River). • Change in coastal processes and inundation.
Community	• Concerns around overall health of lagoon. • Concerns around wild oysters – safety and accessibility.

Table 4. Values and concerns of stakeholders in relation to environmental changes in Pipe Clay Lagoon.

Sector	Values	Concerns
Oyster Industry	• A healthy ecosystem that assists in providing productive waters • A productive and sustainable industry	• Loss of productivity – viability of owning and operating a business in PCL. • Potential for pollution from land runoff • Lack of resilience in a changing climate • Issues occurring in PCL will arise in other areas • Lack of spatial planning e.g., land runoff into productive zones • Lack of up-to-date information with Marine Farming Plans • Lack of support from government for further testing of oysters
Management / Government	• A productive and sustainable industry • Safe boating opportunities • Working group on nearby saltmarsh restoration proposal	• Many factors likely to contribute to decline in PCL
Research	• A healthy ecosystem that assists in providing productive waters • A productive and sustainable industry • The natural environment and its contribution to social values • Saltmarsh communities • Lack of continual testing and ongoing collection of data	• Lack of resilience in a changing climate • Issues occurring in PCL could be more widespread • Lack of spatial planning e.g., land runoff into productive zones
Community	• The natural environment and its contribution to social values • Saltmarsh communities	• Impact on amenity and safety from wild Pacific oyster populations • Potential for pollution from land runoff and aquaculture (marine debris) • Lack of resilience in a changing climate • Monitoring and control of fringing land including sensitive salt marsh areas • PCL area will be left be left with the remnants of a failed industrial operation that will not be adequately and appropriately be cleaned up.

4.2 Information Gathering and Synthesis

This section summarises the topics raised during consultation with stakeholders, a review of available literature, and the empirical and anecdotal data on the potential drivers leading to environmental change in PCL.

4.2.1 Observed Changes in Pipe Clay Lagoon

4.2.1.1 Changing conditions in Pipe Clay Lagoon and impacts on use

Historically, the land surrounding PCL was used for farming, growing fruit that was shipped to Hobart on sailing barges or steamers that accessed the lagoon via a deep channel that was maintained for shipping (Clarence City Council 2019a). Several commercial fishing vessels have operated out of PCL, with most permanently moored in the lagoon. Commercial fishing activity has steadily declined and there has been a progressive shallowing of the entrance channel. While some of this reduction may reflect broader changes in the fishing industry, altered lagoon topography has clearly affected usability.

Recreational users have reported noticeable changes in the lagoon's condition over recent years. These include shifts in the presence and abundance of recreational fish species, restricted access for swimmers and watercraft due to widespread seagrass proliferation, and safety concerns for windsurfers navigating increasingly extensive wild Pacific oyster (*Magallana gigas*) reefs. Siltation at the lagoon's entrance has further restricted safe boating access, highlighting the cumulative effect of geomorphological and ecological changes on both commercial and community use.

4.2.1.2 Aquaculture history and recent decline

Since the early 1970s, PCL has been a major site for intertidal Pacific oyster farming, with approximately 50 hectares historically under cultivation (DPIWE 2008). The lagoon has been divided into three aquaculture zones: Zone 1 (North PCL), Zone 2 (Nursery), and Zone 3 (South PCL), with existing marine farming operations occupying around 9% of the lagoon's total surface area (see Figure 1). In the 1990s, PCL was recognised as one of Tasmania's most productive regions for Pacific oyster production (DPIWE 1998).

However, industry viability has been significantly affected by multiple events over the past decade. A gradual drop in production has been noted since 2012, followed by the confirmed presence of Pacific Oyster Mortality Syndrome (POMS) in the lagoon in early 2016 (see Figure 2).

Although Tasmanian oyster production stabilised in the years following the POMS outbreak (Nogrady 2019), a new sharp decline in the growth and survival of mature oysters was reported in PCL in 2021. By 2023, total oyster production had dropped significantly from the lagoon's previous average output (Figure 2).

It is important to note that official production data reflects only mature oyster harvests and does not account for the movement of juvenile stock, nursery use, or on-growing activities. Due to lag times in reporting and variability in time to market, full impacts may yet be underrepresented.

Nevertheless, anecdotal reports from growers in the region describe production losses of up to 80%, with significant economic and employment impacts. In 2024 and early 2025, several long-standing oyster businesses in PCL ceased operation. Those with leases in other estuaries have relocated stock, while those relying solely on PCL are either in the process of winding down or actively considering closure due to ongoing uncertainty around growth rates, mortality, and environmental conditions.

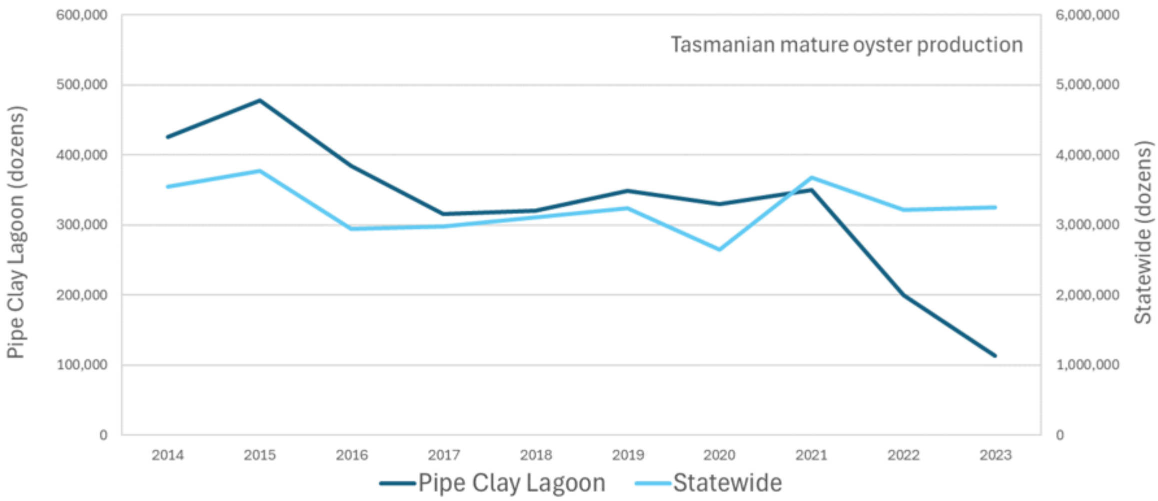

Figure 2. Tasmanian mature oyster annual production in Pipe Clay Lagoon and statewide (source: Oysters Tasmania 2024).

4.2.2 Oyster Health

Disease in oysters is defined as any harmful deviation from normal structure or function, typically involving symptoms such as poor condition, slow growth, and infection. While no known pathogens have been confirmed as the primary cause of recent oyster health issues in PCL, the term 'disease' is used here to describe the observed decline in oyster health, growth, and survival.

The change to farmed oyster health, growth and condition was first noted in 2020 by PCL growers. Juvenile oysters were in poor condition and slow to grow, with dark shell and mantle, and mantle that appeared to not be able to grow to the edge of the shell. Poor condition and slow growth were first noted in some leases (central and southern) in Zone 1. Similar issues were noted on the southeastern side of Zone 3 in 2021, and by 2023 the entire lagoon was impacted. Originally, only growing oysters were affected, with larger animals able to maintain condition. Over time the disease impacted all oysters in the lagoon and by 2023 there was mortality in both juvenile and adult oysters. At some leases, the effects of the disease appeared to worsen in the warmer months.

As a condition of their marine farming licence, oyster growers are required to immediately notify the General Manager of Marine Resources and the Chief Veterinary Officer of NRE Tas of any significant illness, mortality or disease in the shellfish within their lease area. Growers can be asked to submit samples to the Animal Health Laboratory (Department of NRE Tas, located in Prospect, Tasmania) as part of the General Biosecurity Duty (Biosecurity Act 2019, see ShellMAP 2023a). Over 90 separate submissions of Pacific oyster samples were sent to the Animal Health Laboratory from PCL oyster growers between February 2020 and July 2024. Sample sizes ranged from one individual to 6000 spat, and a range of size classes. On at least eight occasions samples were submitted for testing following sudden oyster mortality or observation of disease. It is not clear whether samples of moribund oysters were submitted for analysis when oyster health issues were first noted (presenting signs of disease were not often recorded by the sample submitter), which limited the capacity for useful diagnosis by the laboratory.

4.2.2.1 Pacific Oyster Mortality Syndrome and known oyster disease agents

Pacific Oyster Mortality Syndrome (POMS), caused by virus ostreid herpesvirus-1 microvariant (OsHV-1), was first detected in Tasmania in January 2016 and caused high mortalities of oysters in lower Pitt Water. The presence of POMS was confirmed in PCL in February 2016. PCL is currently one of five growing areas in Tasmania still classified as 'infected', i.e., where POMS is known to occur[2]. After recovering from the POMS outbreak, PCL oyster growers had a few years of consistent production before again noting disease (as detailed above) in juvenile oysters early in 2020.

All samples submitted to the Animal Health Laboratory during the 2020 – 2024 period tested negative to OsHV-1 and other known disease agents, including (when tested) to *Bonamia sp*., *Perkinsus olseni*, *Mikrocytos mackini, Marteilia sp., Marteilioides sp., Xenohaliotis sp*. and Iridovirus. Samples submitted following oyster mortality were cleared of known disease, no significant lesions were observable (lesions are a symptom of OsHV-1 infection), and bacterial infection (tested by gram stain, reported in some cases) was ruled out as a cause of mortality.

4.2.2.2 Unknown Disease in PCL

The specific histology case notes from the Animal Health Lab for some oyster mortality samples examined included:

- Brown granules and haemocytes detected in the interstitium, stomachs contained filtered feed material, and focal myositis detected in the adductor muscle of oysters tested in November 2022 (see below).
- *Vibrio* sp. were isolated from the haemolymph of two oysters in December 2023 (see below).
- Histology was consistent with atrophy due to starvation or salinity stress in January 2024.
- Ingested material in oyster oesophagus and gills was similar to algal organisms in water samples submitted with the oyster samples in July 2024.

PCL oysters were cleared of biosecurity risk early in 2024 and some oysters were moved to other estuaries. PCL oysters moved to other areas either eventually died (Pitt Water) or took many months to recover (Little Swanport).

The histopathological findings reported from moribund oysters tested in November 2022 were assessed by an independent histopathologist (E. Contador, Nautilus Collaboration, *pers. comm.*

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[2] Biosecurity Tasmania, Pacific Oyster Mortality Syndrome (POMS) https://nre.tas.gov.au/biosecurity-tasmania/aquatic-pests-and-diseases/aquatic-biosecurity-threats/poms

February 2024). It was concluded that the oysters in this sample were actively ingesting and absorbing feed, however there was an ongoing issue likely diverting the oysters' energy towards an inflammatory response as evidenced by the presence of brown granules and haemocytes. Haemocytes are specialised cells that serve many functions in bivalves, particularly in immune defence mechanisms. They protect tissues by engulfing living pathogens, and repair tissue damage caused by injury, poisoning, and infections through inflammatory processes (Lassudrie et al. 2020). The diversion of energy to an inflammatory response would likely disrupt the balance between feeding and energy expenditure. The observed poor size and gonad condition further supported this assessment. The findings of brown cells and adductor muscle inflammation suggested that the oyster health issue in PCL is likely related to water quality (e.g., change in environment, presence of environmental pollutants or noxious chemicals) rather than a pathogen issue.

4.2.2.3 Presence of Vibrio sp. in PCL

Vibrio bacteria occur naturally in marine environments and several species are pathogens, causing illness in human consumers (Potasman et al. 2002) and disease in fish and shellfish (Siboni et al. 2024). Oysters, as filter feeders that pump large volumes of water across their gills, can accumulate large quantities of *Vibrio* in their digestive glands and are particularly susceptible to disease. PCL has been identified as having an elevated *Vibrio* risk profile (ShellMAP 2023a).

It is unclear whether testing for bacteria (e.g., presence of *Vibrio* sp.) was carried out routinely in the analysis of samples sent to the Animal Health Lab, but testing for bacterial infection by gram stain was reported for some submitted samples and, in these cases, bacterial infection was ruled out as a cause of mortality. *Vibrio* was isolated from the haemolymph of two oysters in January 2024.

Also early in 2024, samples of PCL oyster meats were sent to the University of Technology Sydney's Ocean Microbiology laboratory for quantitative polymerase chain reaction (qPCR) and DNA sequencing to test for potential presence of *Vibrio* species. Two groups of samples were sent: one from an area of high (80%) oyster mortality and one from an area of lower (10%) mortality. The health status of test oysters (healthy, poor condition, moribund) at the time of sampling is not clear. It was found that there was high correlation between *Vibrio* sp. load and mortality, with oysters from the high mortality group having very high *Vibrio* sp. loads, and significantly higher loads than oyster samples from the Hawkesbury River with no mortality (Figure 3). These results are interesting but must be interpreted with caution.

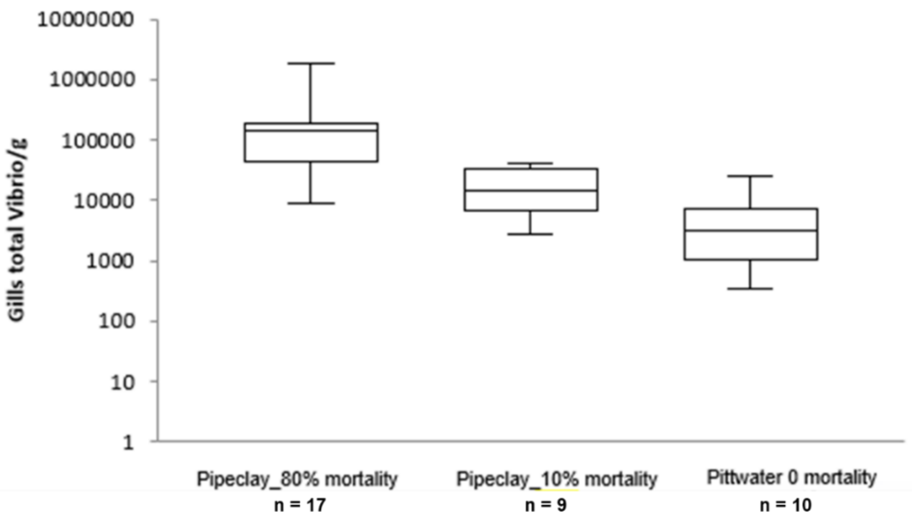

Figure 3. Comparison of *Vibrio* sp. load in oyster samples from Pipe Clay Lagoon (high mortality and low mortality group) compared with a zero-mortality group. Note log scale of y axis. (source: UTS Ocean Microbiology laboratory results provided by ASI).

Shifting environmental conditions are important triggers of oyster diseases. *Vibrio* bacteria increase in number with warmer temperatures (Vezzulli et al. 2015) and oyster mortality has been shown to correlate with both an increase in water temperature and *Vibrio* abundance (Siboni et al. 2024). However, it is difficult to separate the cause and effect of bacterial infection and oyster condition on oyster disease: *Vibrio* species are part of the marine environment in all oyster farming areas and are frequently detected along with OsHV-1 virus and considered a contributing factor to oyster mortality (Green et al. 2016). Oysters that are in poor condition are susceptible to infection by *Vibrio* sp. and this would contribute to mortality. Therefore, *Vibrio* are unlikely to be a cause of oyster health issues in PCL but rather a consequence of disease in oysters.

Multiple factors contribute to or expand the disease process, and many oyster diseases appear to be associated with a change in the interaction between environmental (e.g., temperature, pH, dissolved oxygen) and biological factors (e.g., oyster fitness, microbiome, pathogens and their vectors, such as phytoplankton) (King et al. 2019). Oyster disease in PCL clearly warrants further study. It was highlighted by both University of Technology Sydney (UTS) and Nautilus

Collaboration that further sampling in PCL is required to rule out potential contributors and drivers of oyster disease. Nautilus Collaboration has designed a sampling plan that supports further investigation, included as part of the original Marine Solutions project proposal. UTS are currently holding PCL oyster samples for further testing.

There is a current study by IMAS underway in PCL that includes histopathology and testing of the microbiome of oyster samples from PCL, along with regular monitoring of water quality and phytoplankton. Additionally, a proposed study by the University of Sydney Institute for Infectious Diseases (application submitted to FRDC in February 2025) plans to use PCL as a case study to develop a coordinated framework for investigating unexplained oyster mortality events using epidemiology and diagnostics (metatranscriptomics).

4.2.3 Broadscale Climate Drivers

Many of the environmental changes observed in PCL, including shifts in seagrass, sedimentation, and water quality, are influenced by large-scale climate variability. One of the most important drivers for Australia is the El Niño–Southern Oscillation (ENSO), which involves changes in Pacific Ocean temperatures and trade winds that affect global weather patterns (National Oceanic and Atmospheric Administration [NOAA], 2025). ENSO cycles between three phases: El Niño, La Niña, and neutral. In Australia, El Niño events are generally linked to hotter and drier conditions, whereas La Niña events are associated with above-average rainfall, cooler air temperatures, elevated sea levels, and stronger coastal processes (Tozer et al. 2023).

Between 2020 and 2023, Australia experienced a rare triple-year La Niña event, the first in more than fifty years. This prolonged sequence brought sustained wet conditions, flooding, elevated sea levels, and warmer ocean states (Huang et al. 2024). Such conditions can influence lagoon ecosystems by altering freshwater inflows, sediment and nutrient delivery, and erosion processes.

While ENSO is a dominant influence, it interacts with other ongoing aspects of climate change, including long-term warming trends and changing rainfall patterns. Together, these large-scale drivers may be contributing to recent ecological shifts in PCL. Continued monitoring will be important to better separate the influence of climate drivers from local stressors.

4.2.4 Seagrass

The size and density of seagrass beds in PCL has significantly increased in recent years, and consultation with oyster growers, NRE Tas and the local community identified this increase as one of the major recent changes in the lagoon.

Increase in seagrass density is not particularly uncommon, seagrass beds have expanded and increased in density in many estuaries and sheltered bays on the east coast of Tasmania in recent years. However, the extent and biomass of seagrass in PCL has resulted in dramatic changes to the ecology of the lagoon, not seen on the same scale in other areas.

Like oyster reefs, seagrass beds are considered to be ecosystem engineers, modifying the environment around them and forming important habitat which supports biodiversity. Seagrass provides a range of regulating, provisioning, cultural and supporting ecosystem services including coastal protection, erosion control, water purification, food provision, habitat provision including nursery habitat for juvenile fish, nutrient removal, and carbon sequestration (Valdez et al. 2020). Seagrass beds are known to alter water flows (through reducing water velocity, influencing erosion and deposition, changing tidal circulation) and stabilise sediments which consequentially bring about other changes such as alterations to resident estuarine communities.

These changes have been anecdotally reported in PCL: users of the lagoon have described changes to water flow, sediment type (increase in silty, muddy sediment from previously sandy substrate), and resident fish and invertebrate communities. Other observations relating to seagrass presence in the lagoon include large amounts of algal growth in the seagrass beds and epiphytic growth on the seagrass blades.

Satellite imagery from recent years clearly demonstrates a change in available habitat in PCL: from open sand flats in 2016 to extensive dark cover of the sand flats in 2024 (Figure 4). This dark cover is assumed to be seagrass, based on direct observation and observations by residents and oyster growers. The first occurrence associated with the recent proliferation of seagrass appears at the mouth of the lagoon in January 2019, with dark patches visible in aerial imagery at the lagoon mouth, along the channel and under the oyster leases in the northern zone (Zone 1). Over time, these dark patches become increasingly extensive, and by October 2022, much of the seabed in the lagoon had a dense cover, including all the oyster farming zones (Figure 4).

Historically, there has been variation in seagrass distribution, biomass, and potentially the seagrass species present in PCL, demonstrating the natural fluctuation of seagrass communities. Seagrass was first documented in the lagoon in 1948 (Guiler 1950) when several small beds of *Zostera* sp. were reported. The Marine Farming Management Plan for PCL (DPIWE 2008) described periods of growth and reduction in seagrass presence, including a notable increase in coverage between 1993 and 1997 (based on aerial photographs dating back to 1981). At the time of the management plan, the patches of seagrass were established opposite the Cremorne Spit, and southwest of the lagoon entrance. Surveys conducted in 2004 – 2005 found an "almost complete lack of seagrass" except for a few small beds near the entrance channel (Mount et al. 2005 pp. 41). Seamap Australia depicts the benthic habitat of PCL as sand and silty sand, with very small patches of seagrass at the entrance channel (Lucieer et al. 2017).

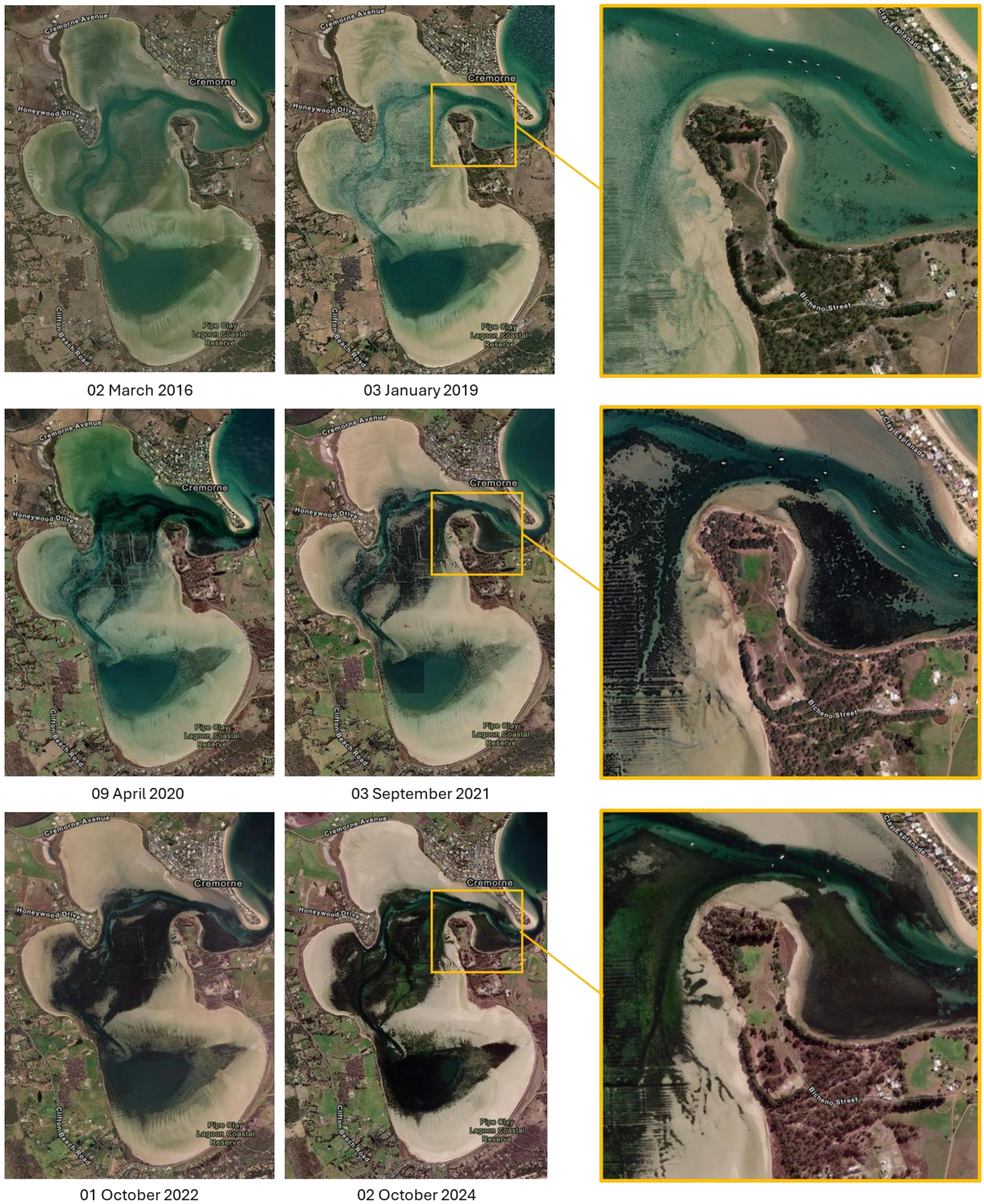

Figure 4. Satellite images of Pipe Clay Lagoon showing the change in benthic habitat from 2016 to 2024, with insets to show detail of substrate around the lagoon entrance. The substrate in the lagoon in 2016 was predominately sand flats. Dark patches on the sandy substrate (likely seagrass beds) were noted in small patches in January 2019 and increased progressively over the years (basemaps: Esri World Imagery wayback digital archive).

More recently, IMAS conducted a survey and issued an advice note to NRE Tas on the current proliferation of seagrass in PCL, the potential causes of the proliferation and the impact on oyster farming in the lagoon (Ugalde and Ross 2023). The need for the study was brought to the attention of NRE Tas when a permit application was submitted to trial mowing the seagrass in the lagoon. The trial proposed to test if removing the seagrass in PCL would restore favourable oyster growing conditions, but the application was withdrawn due to the cost of scientific monitoring required to measure the effect of the proposed trial. Ugalde & Ross (2023) confirmed that the seagrass species currently present in the lagoon is *Heterozostera nigricaulis* (an opportunistic native species that can reproduce quickly to colonise new areas) and confirmed the recent increase in seagrass abundance based on direct observations and aerial imagery and comparison with historical records. The report did not quantify the increase in seagrass extent or compare seagrass in PCL with other Tasmanian estuaries or perform ground truthing of aerial imagery. The increase in seagrass in PCL was attributed to large-scale climate factors such as higher-than-average rainfall and temperatures over the last few years (see section 4.2.3). Increased nutrients from land-based run-off or leaching from the water table may have provided conditions for seagrass to become established (Ugalde & Ross 2023).

The relationship between seagrass beds and oysters is complex and can be beneficial under the right conditions. As filter-feeders, oysters promote water clarity, which facilitates increased photosynthesis which in turn increases seagrass growth. Faeces and pseudofaeces released by oysters may also support the establishment of seagrass beds by providing optimal nutrient conditions. Furthermore, seagrass has the capacity to modify the carbonate chemistry and pH of the local environment, benefiting oysters by improving shell growth (Pacella et al. 2018; Ricart et al. 2021). This relationship between the seagrass and oysters becomes less predictable in waters that are warmer and more acidic (Garner et al. 2021; DuBois et al. 2024).

Seagrass beds are also known to harbour bacteria that inhibit the growth or kill phytoplankton (known as algicidal bacteria; Imai et al. 2017, Inaba 2024), which may impact on the available food for oysters in PCL (see Section 4.2.7). Seagrasses can also inhibit the growth of toxic algal species and act as a microbial filter to remove pathogens from the water column, significantly reducing threats to oysters (Lamb et al. 2017). Given the complex nature of the relationship between seagrass, oysters, and the broader ecology of the lagoon, coupled with the lack of local data available, it is not possible to assess the roles and interactions of these species within PCL at this time. However, given the current observations in relation to oyster mortality and condition, and changes to seagrass communities in the lagoon, it is recommended that further investigations are conducted.

While the concurrent increase in seagrass and decline in oyster performance is notable, these trends may be unrelated or only indirectly connected. Multiple interacting stressors, including climate variability, water quality, and disease, are also likely to play a role, and further research is needed to disentangle these drivers.

4.2.5 Sedimentation and Hydrodynamics

Consultation with the local community and oyster growers has highlighted two potential drivers of change in hydrodynamics within PCL: a change in sedimentation particularly an increase at the mouth of the lagoon, and the proliferation of seagrass reducing waterflow. Considering that water flow is directly related to the supply of food for oysters (and other flora and fauna), variation in hydrodynamics may impact carrying capacity for shellfish aquaculture in PCL. Oysters also grow best in conditions with faster flows, higher quality suspended food, and reduced sediment deposition, further emphasising the importance of hydrodynamic conditions for aquaculture (Lenihan 1999).

The only known hydrodynamics study conducted in PCL was carried out between 1991 – 1993 as part of the survey of Pacific oyster farming areas of Tasmania to provide predictive modelling of carrying capacities for these areas (Crawford et al. 1996, with details in Crawford & Mitchell 1999). This established that the lagoon is very shallow with only a small area deeper than 2 m. At this time the water in PCL was generally exchanged at least once a day, with an average flushing time of 1.4 tidal cycles. This was a high rate of water exchange and rapid flushing rate compared with other Tasmanian estuaries. During the flood tide, water entered the lagoon through the narrow main channel and spread out over the intertidal flats with circulation in and around the deeper hole near the head of the lagoon (Zone 3 farming area, see Figure 1). During the ebb tide the water drained from the intertidal flats at the head, into the deeper hole and then out through the main channel. There was a distinct increase in flow rate through the length of the lagoon, from slow flow across the extensive shallow intertidal area at the head of the lagoon to faster flow through the narrow entrance channel (Crawford & Mitchell 1999).

While these data provide an early baseline, subsequent observations indicate that conditions at the lagoon mouth and within the system have shifted considerably. The entrance to PCL is an area of dynamic sediment movement with considerable change reported over time. In the early 1900s trading ketches would enter PCL from Frederick Henry Bay to collect timber from the lagoon shoreline, and fruit from local orchards was transported by ketches and later steamers from small jetties along the shore (local resident *pers. comm.* Nov 2024; Clarence City Council 2019a), suggesting that the channel was deep at this time. Photographs from the 1930s and 1958 show a wide, deep channel (reported in DPIWE 2008). The sediment around the lagoon entrance has accreted and eroded throughout recent times, which is well documented in aerial photographs from the 1960s and 70s (Pyke 1996, cited in DPIWE 2008), the 1980s and 90s (DPIWE 2008), and from 2003 to 2022 (Google Earth, Esri World Imagery). Local knowledge further supports these records: through the 1980s there was at least 8 ft of water (2.4 m) from the lagoon mouth to Honeywood Drive, with ample water in the channel at all tides. The change to shallower conditions became evident in the mid to late 1990s (local fisher *pers. comm.* Nov 2024).

The type of system at the mouth of PCL (spit, channel and bar) is unstable, and will change over time from natural processes and human influences. Possible human influences on the change to sedimentation around the lagoon mouth include the modification of the spit (housing construction and foreshore reclamation), stabilisation of the foredunes along Cremorne and Clifton Beach, and the development of marine farming in the lagoon (DPIWE 2008). More recent satellite imagery adds further evidence, showing that since 2016 the sand bar along Cremorne beach has extended (see Appendix 1, Figure 14), so that water entering PCL from Frederick Henry Bay has further to travel, likely impacting the velocity of water exchange and possibly the replenishment of phytoplankton (see Section 4.2.7). High current velocities are desirable for farming oysters as they increase delivery of food to oysters, improve water quality, and increase dispersal of biodeposits (pseudofaeces) (summarised in Campbell & Hall 2019). Oyster growth is known to improve with increased flow velocity (Lenihan et al. 1996), and reduced flow likely has a detrimental effect. Consultation with PCL oyster growers also raised the possibility that the reefs of wild Pacific oyster in the lagoon have altered the hydrodynamics over time (see Section 4.2.11.1).

In addition to natural processes, human infrastructure has also contributed to hydrodynamic change. PCL is a very popular with recreational boaters and fishers. A floating pontoon was installed at the Cremorne spit in 2012, and local residents have noted that the formation of sand islands near the boat launching area have been accelerated by eddies created by the pontoon on an incoming tide. The boat launching area, floating pontoon in the mouth of the lagoon and moorings in the channel are managed by Marine and Safety Tasmania (MAST). Sandy sediments in the launching area area highly mobile, historically forming dynamic shoals that are characteristic of high flows. These shoals have recently been colonised by seagrass and have become progressively shallower, with some moorings in the channel deemed unusable due to shallow channel depth (Marine Solutions 2023). MAST have recently undertaken a project to excavate and redistribute sand from shoals near the Cremorne spit to retain some of the vessel launching area and improve vessel access and navigation.

Remote sensing data corroborate these local and observational accounts. Observation of the change to the exposed intertidal zone of PCL from 2016 to 2023 using the National Intertidal Digital Elevation Model (NIDEM, Bishop-Taylor et al. 2019) shows the middle of the lagoon (area amongst the Zone 1 leases, see Figure 1) becoming progressively shallower over time (Figure 5), with the timing aligning with the increase in seagrass coverage (Figure 4). This apparent shallowing of the lagoon (organic material and/or sediment above the lowest low water level in the lagoon) could be the result of seagrass reaching the water surface, or sedimentation due to the impact of seagrass. Either way, shallowing of the lagoon impacts on water flow by changing circulation patterns and reducing flow speed and energy via the shallowing of channels, which is likely the case at PCL.

The increased biomass of seagrass has high potential to alter and reduce water flow to parts of the lagoon (see Section 4.2.4). Whether the change in sedimentation and slowing of flow in the lagoon provided the opportunity for seagrass to become established, or the change to sedimentation and hydrodynamics is due to the impacts of seagrass is unknown. It is likely that both sedimentation and seagrass proliferation have had an impact on hydrodynamic patterns within PCL and that both drivers may result in a cumulative effect. Detailed 3D modelling of PCL at low tide using photogrammetry and geo-referenced LiDAR to establish the depth of the lagoon and calculate the tidal prism, as well as measure the extent of the seagrass, would be very valuable to understanding the current daily water exchange rate for comparison with the available information from the early 1990s.

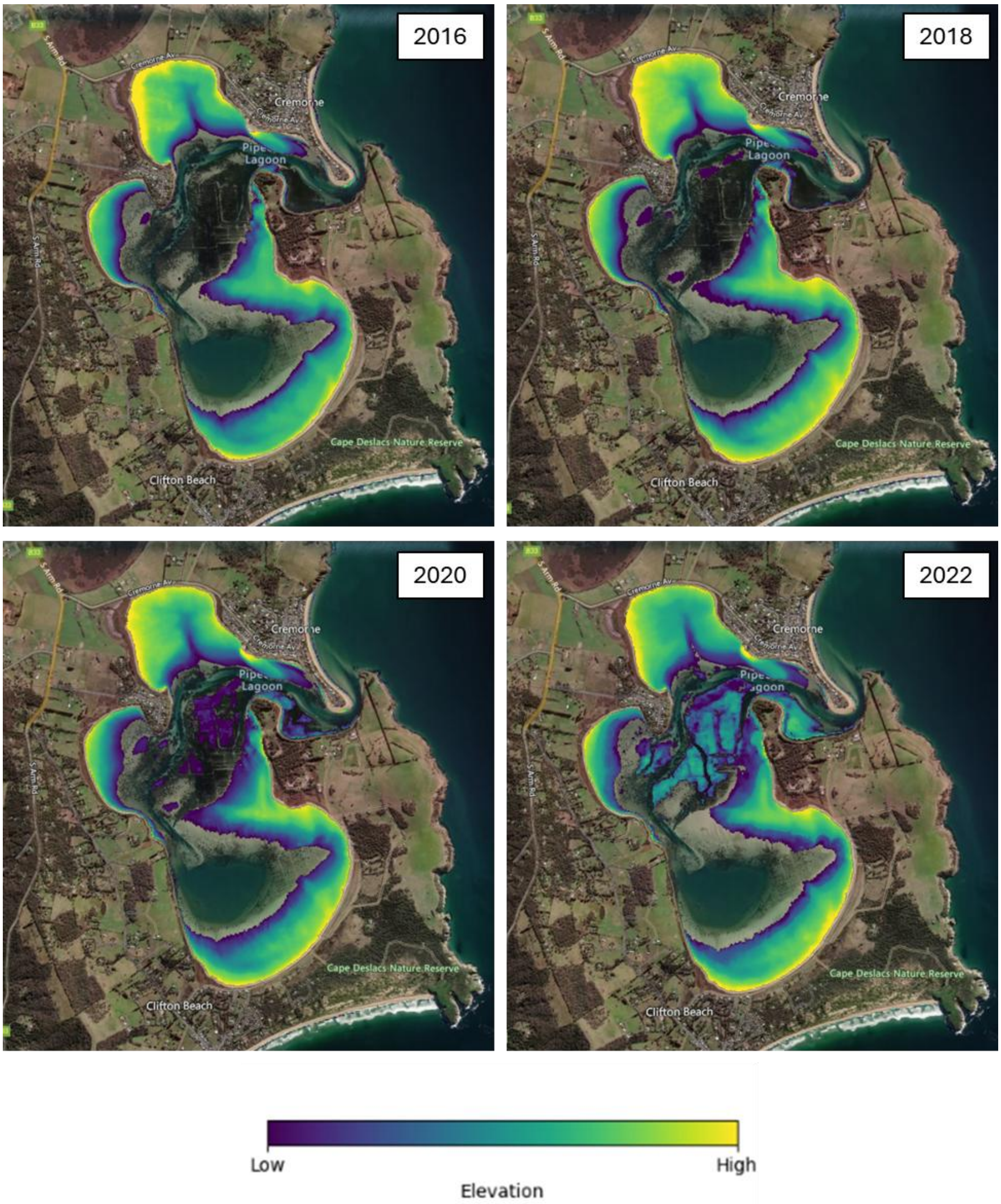

Figure 5. Estimate of the change in intertidal zone in Pipe Clay Lagoon between 2016 and 2022, generated by combining global tidal modelling with a 30-year time series archive of spatially and spectrally calibrated Landsat satellite data (Source: National Intertidal Digital Elevation Model (NIDEM): a continental-scale elevation dataset for Australia's exposed intertidal zone, Digital Earth Australia[3]).

[3] Digital Earth Australia https://maps.dea.ga.gov.au/story/DEAIntertidal

4.2.6 Water Quality

Water quality in PCL is influenced by multiple drivers, including (1) land use and wastewater management in surrounding suburbs, (2) ecological processes such as seagrass proliferation, (3) local monitoring data collected by ShellMAP and the Oyster Sensor Network (OSN), and (4) potential external inputs from salmon aquaculture in Storm Bay. Concerns about these factors were raised by both the oyster industry and local growers, particularly in relation to contamination, nutrient dynamics, and the impacts of seagrass expansion.

4.2.6.1 Land Use and Wastewater Management

Land usage around PCL consists of grazed pastures and residential area. The surrounding suburbs (Sandford, Cremorne and Clifton Beach) have grown in recent years, with a combined population increase of 8% between 2016 and 2021[4]. Furthermore, there has been an associated increase in road surfacing and stormwater management works in recent years. These suburbs are unserviced by mains sewage and rely on on-site wastewater systems such as septic tanks. Although any development close to the water is controlled by strict council environmental and planning requirements, aging infrastructure may not always function as intended. Clarence City Council conducts inspections on all wastewater systems when a development application is submitted or a property is sold, and development applications require septic systems to be upgraded as needed. This means that systems are continually modernised, reducing the potential for contamination of PCL from human domestic waste. Additional contamination pressures may come from agriculture and abundant birdlife, both recognised sources of faecal indicator bacteria.

4.2.6.2 Water Quality Monitoring Program

Two complementary monitoring programs provide water quality data in PCL: (1) The NRE Tas Shellfish Market Access Program (ShellMAP), which has monitored nine sites in the lagoon since 2008 (Figure 6), and (2) The Oyster Sensor Network (OSN), which has collected continuous high-frequency data from three sites since 2022.

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[4] Australian Bureau of Statistics https://www.abs.gov.au/census/find-census-data/search-by-area

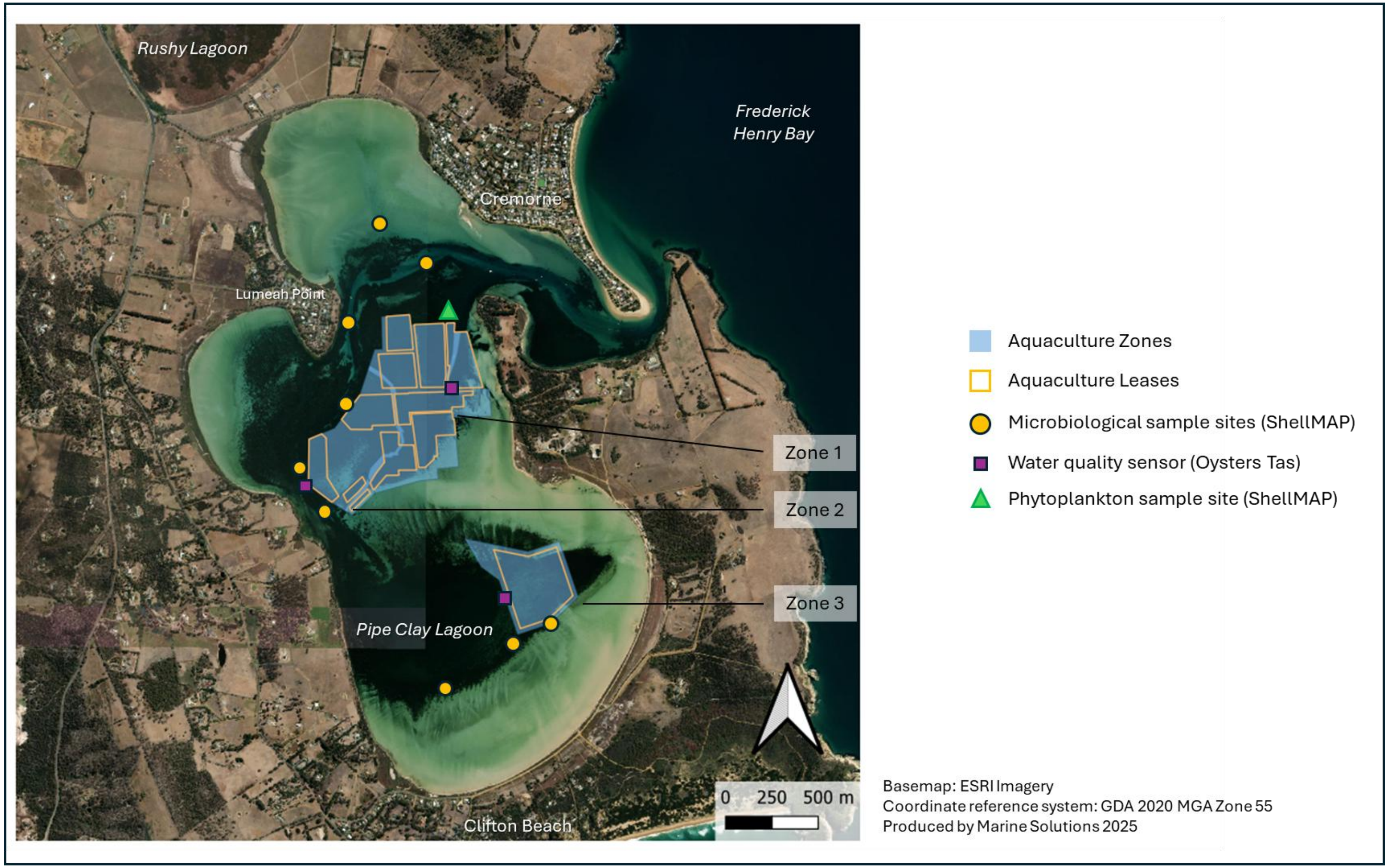

Figure 6. Location of sampling sites (ShellMAP monitoring sites and stationary sensors) relative to oyster leases and harvest zones in Pipe Clay Lagoon.

The Shellfish Market Access Program (ShellMAP) maintains regular bacteriological, biotoxin, chemical residue, and water quality monitoring to ensure shellfish are safe to consume. The environmental management criteria for PCL harvest area closures is salinity (<31 psu) and rainfall (⩾17 mm in one day, or ⩾60 mm over 7 days measured at Hobart airport; ShellMAP 2024).

ShellMAP conducts biotoxin testing on shellfish meat, representative of harvested stock, and phytoplankton counts in water samples collected from their algal sample site (Figure 6; these data are addressed in Section 4.2.7). Bacteriological samples are collected at nine sites (Figure 6) and tested for *Escherichia coli* and thermotolerant coliforms. Temperature and salinity are measured in the field at the time of sampling, with data available from 2008. Sampling is conducted at least six times per year, usually aligned with events that have the potential to result in adverse pollution conditions (e.g., high rainfall). ShellMAP sampling sites in PCL have been selected to best capture inputs to the lagoon, such as near residential areas, the boat mooring area, and downstream of the piggery in the northwest corner of the lagoon (with a water quality site added in 2019).

Long-term ShellMAP temperature and salinity datasets show seasonal variation in water temperature, similar across Zone 1 and Zone 3 and consistent over time (Figure 7). Salinity has shown greater variability since 2021, likely due to increased temperatures (enhancing evaporation in the shallow lagoon) and higher rainfall (increasing runoff). Temporary harvest closures for rainfall occurred between one and six times annually from 2013–2019, but ten times in 2021–2022 (ShellMAP 2022).

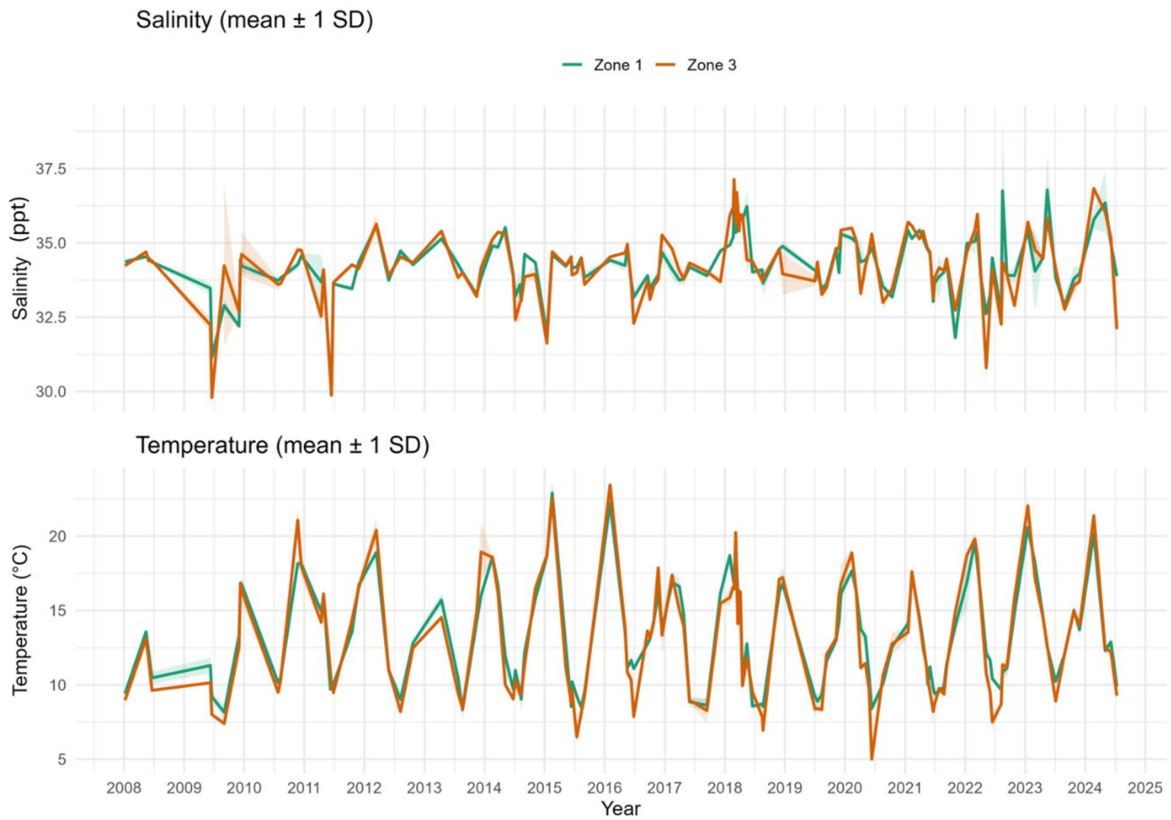

Figure 7. Temperature (°C) and salinity (PSU) in Pipe Clay Lagoon Zone 1 and Zone 3 from 2008 (data provided by ShellMAP).

E. coli and thermotolerant coliforms indicate faecal contamination, which may originate from agriculture, bird life, or human domestic waste. PCL is a significant roosting site for migratory wading birds (DPIPWE 2008; noted in ShellMAP annual reviews from 2018 onwards). The frequency and concentration of *E. coli* and thermotolerant coliforms detected in ShellMAP water samples increased from 2021 (Zone 1) and 2022 (Zone 3) (Figure 8). Rainfall is the factor most commonly associated with faecal indicator bacteria (Campos et al. 2013), and recent increases in PCL may be due to increased rainfall and runoff (see Section 4.2.3). Elevated *E. coli* in in oyster meat accounted for only one out of 13 temporary harvest closures in 2021−22 (Zone 1), and two out of nine closures in 2022−23 (Zone 1; one out of nine in Zone 3; ShellMAP 2023b, 2024).

Faecal indictor bacteria indicate the potential presence of pathogens that can impact the health of human consumers (ShellMAP 2023a), but do not directly impact on oysters. There is little evidence that other bacterial communities co-occur with faecal indicator bacteria (Brake et al.

2014; Leight et al. 2018), so the recent increases in *E. coli* and thermotolerant coliforms in PCL do not necessarily indicate an increase in the bacterial load in the lagoon.

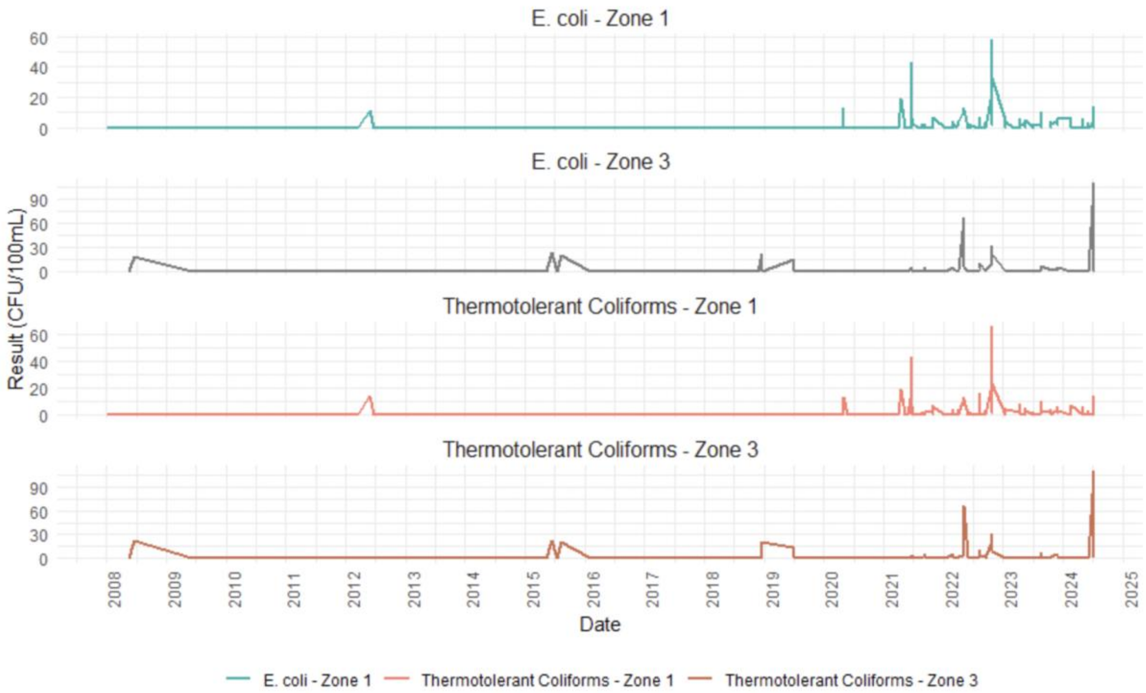

Figure 8. Indicators of faecal contamination (*E. coli* and thermotolerant coliforms) from regular monitoring in Pipe Clay Lagoon Zone 1 and Zone 3 (data provided by ShellMAP).

4.2.6.3 Oyster Sensor Network (OSN) Monitoring

The OSN has three sensors in PCL, one in each harvest zone (Figure 6). Sensors are set up to continuously measure environmental parameters, temperature and salinity, at ~20 cm below the water surface. They are cleaned and calibrated on a 90-day schedule (Tasmanian Shellfish Grower Handbook 2023), with measurements are recorded at 15-minute intervals and are accessed remotely via the ShellPOINT dashboard. Temperature and salinity data have been collected at all three sites since October 2022. A dissolved oxygen (DO) probe was added in Zone 1 and readings were collected from July 2023 to October 2024, and pH measurements since May 2024. In Zone 3, DO and pH data have been collected since August 2024. It was noted by Oysters Tasmania (*pers. comm*. May 2024) that the DO probe was not calibrated prior to installation and values may be an overestimation. Further, large amounts of biofouling have been observed on the sensors in PCL (*pers. obs.*), which is also likely to impact the accuracy of measurements.

Generally, sensors recorded a temperature increase over summer with a concurrent reduction in DO (Appendix 2, Figure 15). Average daily pH was highly variable but showed no clear seasonal pattern (Appendix 2, Figure 16). Gaps in data and spurious readings highlight the need for regular sensor maintenance, including cleaning and calibration.

Inspection of daily DO patterns during typical summer conditions (January 2025) revealed high daily variation (Figure 9). Diel-cycling hypoxia, in which DO cycles between low levels before dawn and higher levels during the day, frequently occurs in shallow waters due to photosynthetic and respiration cycles of phytoplankton, algae, and seagrass (Tyler et al. 2009). In PCL, DO rises rapidly after sunrise, peaks mid-morning, exhibits minor fluctuations consistent with tidal changes during the day, declines through the afternoon and evening, and reaches near-hypoxic (no oxygen) levels in the early morning. High DO during the day is consistent with oxygen produced by plants, particularly seagrass, during photosynthesis. Daily temperature and pH fluctuations correspond to day/night cycles and tidal influences (Appendix 3, Figure 17, Figure 18). Although daily DO and pH data from before the proliferation of seagrass are not available, seagrass proliferation likely amplifies these diel fluctuations.

Seagrass photosynthesis and respiration also drive daily CO_2 and pH changes: CO_2 decreases during photosynthesis, raising pH, and increases during respiration, lowering pH. These fluctuations can be particularly pronounced in dense seagrass beds under high summer irradiance (Berg et al. 2019; Wooten et al. 2008).

The combined effects of warming and diel-cycling DO and pH can strongly affect the fitness and survival of coastal organisms, including molluscs such as oysters (*Crassostrea virginica*), scallops (*Argopecten irradians irradians*), and abalone (*Haliotis discus hannai*) (Donelan et al. 2021; Tomasetti et al. 2021; Shen et al. 2022). Invertebrate species that live in the intertidal zone, and particularly sedentary species like oysters, have developed mechanisms for surviving twice-daily oxygen deprivation at low tide. Slowing of metabolic rate is one of the most important adaptations for hypoxia endurance (Larade and Storey 2002). Even brief hypoxic episodes can affect growth, survival, and susceptibility to disease (Davidson et al. 2016; Tyler et al. 2009; Keppel et al. 2015). Large diel fluctuations in DO, as seen in shallow estuaries, have been shown to present greater challenges to aquatic life than persistent hypoxia (Jarvis et al. 2023). Oysters are highly sensitive to pH changes: shifts as small as 0.1 units can reduce available calcium carbonate for shell formation, resulting in thinner shells, slower growth, and increased mortality (Gazeau et al. 2013; Lemasson et al. 2017). Early-life exposure to diel-cycling hypoxia can influence oyster fitness later in life by affecting tissue-to-shell growth when re-exposed to hypoxic conditions (Donelan et al. 2021).

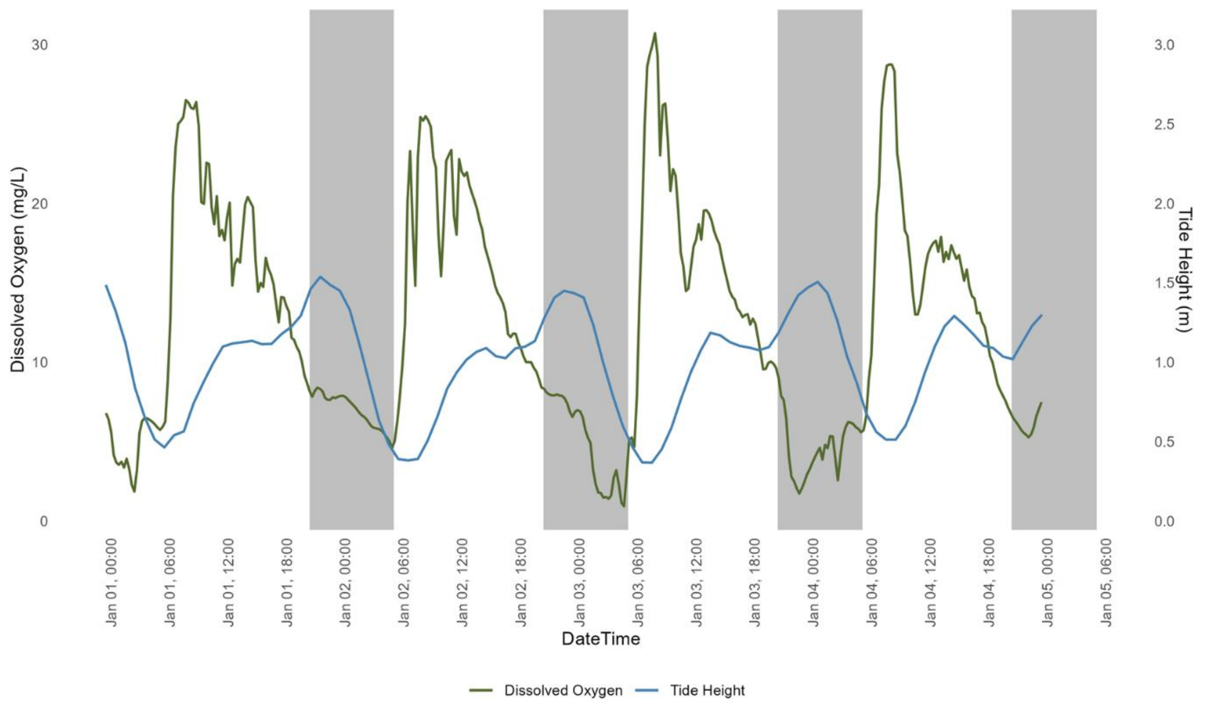

Figure 9. Daily fluctuation in dissolved oxygen (mg/L) in Zone 3 in Pipe Clay Lagoon relative to tide height and day/night (night time is shaded) (source: Oyster Sensor Network data).

4.2.6.4 Potential Influences of Salmon Aquaculture

The closest salmon aquaculture leases to PCL are in Storm Bay: Huon Aquaculture's Yellow Bluff lease (off north Bruny Island) and Tassal's West of Wedge lease (off the western Tasman Peninsula), both ~22 km south of the mouth of PCL (Figure 10). Yellow Bluff has been stocked since August 2019, and West of Wedge partially since April 2020. Salmon aquaculture introduces nutrients into the marine environment, which are monitored monthly at compliance sites by the EPA and as part of the Storm Bay Broadscale Environmental Monitoring Program (BEMP). Annual

BEMP reports (2019–2023) indicate no evidence of system-wide impacts from salmon aquaculture on water quality, soft-sediment, inshore reef, or deep reef habitats (Aquenal 2024).

Analysis of BEMP sites closest to PCL (SB9, SB17, SB22; now monitored by Salmon Tasmania Figure 10) shows generally stable nutrient concentrations over time (Appendix 4, Figure 19). At SB9, organic carbon (NPOC) has increased since 2020, with occasional high ammonia, total nitrogen, and phosphorus records in 2024. However, there is little evidence of nutrient increases affecting PCL. Minimal nutrient data are available for PCL itself. BEMP nutrient ranges are similar to early 1990s PCL data (Crawford et al. 1996). A four-week water quality study by ASI in March–April 2024 reported ammonia and nitrogen species below laboratory detection limits throughout PCL, while dissolved reactive phosphorus was measurable but at or below EPA guideline values (80th percentile of 9.0 μg/L) for well-flushed Tasmanian estuaries (EPA 2021).

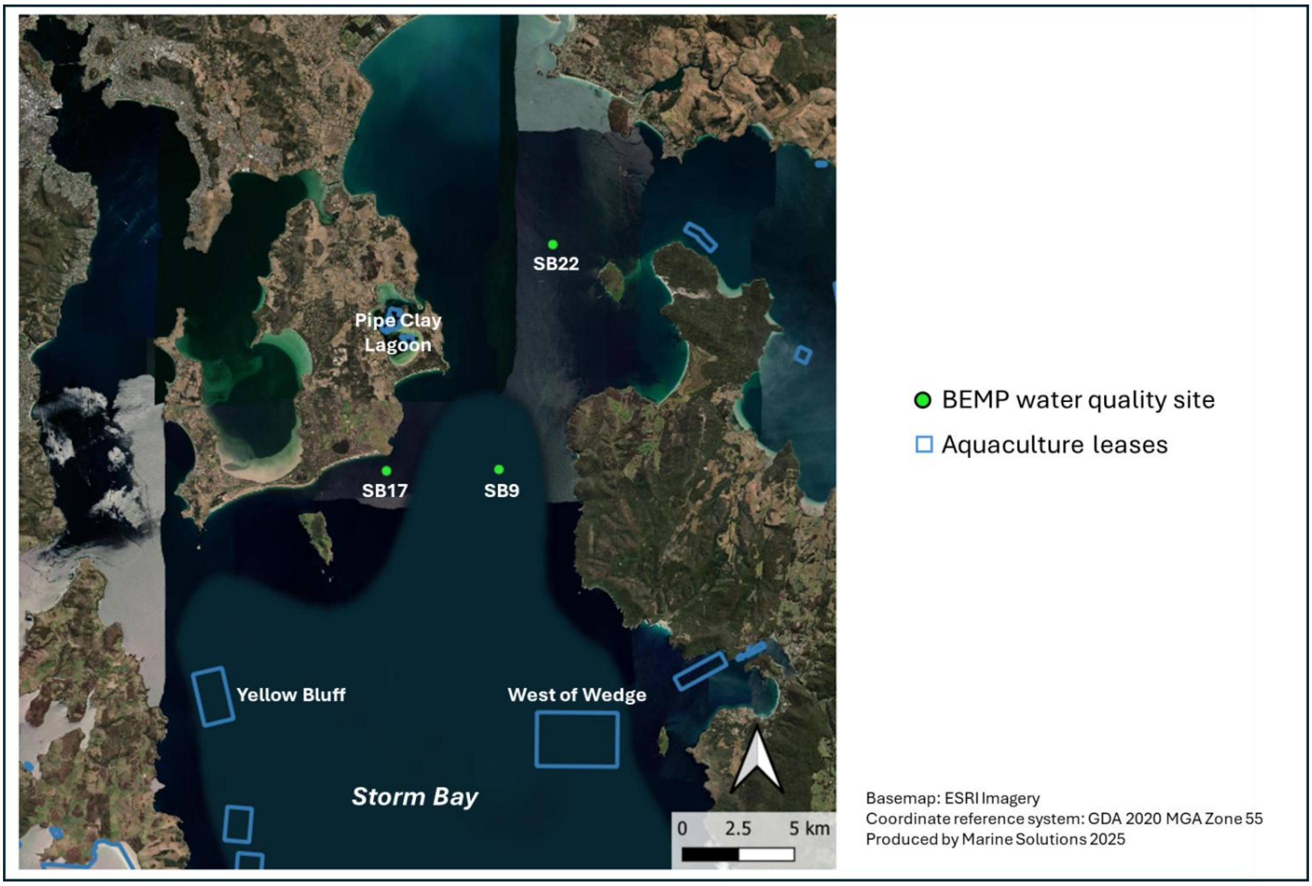

Figure 10. Location of salmon aquaculture leases in Storm Bay (Yellow Bluff and West of Wedge) and relevant Storm Bay Broadscale Environmental Monitoring Program (BEMP) sites, relative to the location of Pipe Clay Lagoon.

Overall, water quality in PCL reflects the combined influence of local land use, ecological processes such as seagrass proliferation, and monitoring observations, with little apparent effect from distant salmon aquaculture. Long-term ShellMAP and recent OSN datasets show stable seasonal patterns in temperature and salinity, although salinity variability has increased in recent years due to rainfall and evaporation. Faecal indicator bacteria show episodic increases linked to rainfall and runoff, and nutrient levels in the lagoon remain low and comparable to historical records. Diel-cycling hypoxia and associated pH fluctuations, driven by photosynthesis and respiration of seagrass and algae, represent the most dynamic water quality feature, with potential implications for aquatic organisms. Continued monitoring is important to track these natural and anthropogenic influences over time.

4.2.7 Phytoplankton

During consultation, growers expressed concerns regarding the potentially evolving community composition of planktonic plant species (microscopic algae, or phytoplankton) within PCL. Potential drivers behind the shift in phytoplankton communities include changes in large-scale currents (such as the strengthening of the East Australian Current), rising water temperatures that support different species, and alterations in flora (e.g., seagrass) that influence local physical parameters, possibly resulting in change to phytoplankton community structure.

The change in sand bar at the entrance to PCL and shallowing of the channel into the lagoon (see Section 4.2.5) may influence the abundance, biomass and the species of phytoplankton that are able to enter the lagoon. The replenishment of phytoplankton in PCL and the velocity at which food is delivered to oysters within the farming leases may be slowed by the change to water flow and hydrodynamics within the lagoon.

The most productive areas of oyster lease in PCL prior to 2020 were along the northern boundary and northwest corner of Zone 1 extending towards the main channel (DPIWE 2008, Figure 1). This location (close to the lagoon mouth) suggested that the water with most phytoplankton suitable for oyster ingestion was found on an incoming tide into PCL. These areas of previous productivity were also the areas that experienced the first change in oyster health and condition, and the possible change in the phytoplankton community composition was bought forward as a concern during consultation with oyster growers.

From a food perspective and the availability of suitable phytoplankton, it is understood that oysters will ingest anything in the water column that can fit through their gills. Generally, oysters consume plankton and detritus between 2 and 20 µm size, but can consume particles <1 µm (Bayne 2017). Oyster growing capacity could be impacted by the type and size of available phytoplankton and the preferred phytoplankton is likely to change throughout the lifecycle of the oyster due to size and nutritional properties (Bayne 2017, Ruth & Pattern 2018). Of the ingested material, oysters will only digest a partial component to meet their metabolic needs and will excrete the remainder as pseudofaeces (Galimany et al. 2017). When under stress, oysters can partition their energy into survival and will shut down other metabolic processes. Oysters will stop feeding to reduce energy expenditure on digestion and metabolic activity and can survive this way for short periods through times of environmental stress (Lannig et al. 2010). Therefore, diseased oysters may appear to be starving even when there is plentiful available food and analysis of phytoplankton species will not necessarily provide information on consumption by oysters.

Early work on the phytoplankton and productivity of PCL used the measurement of chlorophyll *a* as a proxy for phytoplankton biomass (CSIRO *unpublished data*, reported in DPIWE 2008). Chlorophyll *a* concentrations were relatively low in PCL (compared with other Tasmanian estuaries) and it was considered a less productive area, despite the high production of oysters per hectare. The high oyster production was attributed to the rapid flushing of the lagoon and good water exchange bringing a regular supply of food from Frederick Henry Bay. It was also noted that a high concentration of non-edible species (but high biomass of phytoplankton and high chlorophyll) would provide little benefit to filter-feeding animals.

Phytoplankton samples have been collected monthly by ShellMAP at a single site in PCL since 2004 (Figure 6). Full species counts have been analysed from samples since July 2022, but prior to this the identification of species has varied (Table 5) therefore it is difficult to look at a detailed change in phytoplankton species over time. ShellMAP phytoplankton data were compared with full species counts of phytoplankton collected monthly at three sites in Frederick Henry and Storm Bay by Salmon Tasmania since 2019.

Table 5. Detail of phytoplankton sample analysis by ShellMAP.

Date	Details of sampling
Jan 2004 to Nov 2012	Full species counts
Dec 2012 to Jan 2015	Toxic and food species only
Feb 2015 – June 2022	Toxic species only
July 2022 to current	Full species counts

Comparison of full phytoplankton species counts showed little change over time in the biomass of phytoplankton available in PCL. Algal abundance fluctuates seasonally, but recent counts were not substantially different to the 2004 – 2012 period in terms of biomass (Figure 11). Prior to 2013 (when full species counts were previously recorded), phytoplankton communities in PCL were made up largely of diatoms, with periodic increases in dinoflagellates prior to 2009 and regular occurrence of nanoflagellates from 2009 onwards (Figure 11). The recent phytoplankton assemblage in PCL (since 2022) is still dominated by diatoms, dinoflagellates and nanoflagellates with the notable inclusion of cyanobacteria (blue-green algae) species on three sampling occasions in 2023 and 2024 (Figure 11).

Further analysis of the cyanobacteria species present in PCL showed individual occurrences of nine different species, with *Phormidium* sp. occurring in greatest abundance on two occasions (Appendix 5, Figure 20). *Phormidium* sp. is a mat-forming bacteria which produces a range of neurotoxins (shown to be toxic to vertebrates, Wood et al. 2016).

Diatoms, dinoflagellates and cyanobacteria have the potential to accumulate as 'Harmful Algal Blooms' (HABs) under favourable conditions of increased nutrients and temperature. These blooms can be toxic (depending on the species), can compete with other phytoplankton for nutrients and light, can cause physical damage to the gills and tissues of animals, and can remove oxygen from the water column when they breakdown and decompose, impacting both the functional and structural properties of an ecosystem (Paerl and Huisman 2009; Zhao et al. 2022).

4.2.7.1 Harmful Algal Blooms

HABs are a natural phenomenon, but the frequency of HABs appears to have increased worldwide in recent decades (Glibert 2017), with recent devastating effects on marine organisms in South Australia[5]. The best-known HABs are those of species containing biotoxins associated with symptoms in human consumers of contaminated seafood (see review in Berdalet et al. 2015). These include a variety of shellfish toxins (most notably saxitoxins in Tasmania, produced by species of *Alexandrium*, *Gymnodinium* and *Pyrodinium* and causing paralytic shellfish poisoning, discussed further in Section 4.2.8.1).

Oysters are often thought to be the 'symptomless carriers' of phytoplankton toxins that are harmful to human consumers, but there are harmful algae with toxins that can be detrimental to filter feeders themselves (Lassudrie et al. 2020). The harmful mechanism of phytoplankton that can be toxic to oysters is associated with hypoxia from high bloom density, or through mechanical irritation (spines and spikes), or through toxic compounds that damage or kill cells causing disease. There is evidence to suggest that marine HABs are involved in bivalve disease outbreaks, particularly affecting bivalve immunity and defence against disease (Lassudrie et al. 2020). Several studies have reported that bivalves will modify their haemocyte variables in response to HAB exposure (reviewed in Lassudrie et al. 2020; and see Section 4.2.2.2 for notes on haemocytes in PCL oyster samples). The immune response of oysters to HAB exposure is reported in several studies, and this suggests that harmful phytoplankton may affect the susceptibility of oysters to disease.

The available phytoplankton data (from PCL, Frederick Henry Bay and Storm Bay) was interrogated for change in the presence and abundance of potentially toxic and HAB species (see Appendix 5, Table 7.). Detection of known harmful algal species was rare. Four species (*Dinophysis acuminata*, *Gymnodinium catenatum*, *Pseudo-nitzschia delicatissima* and *Scrippsiella trochoidea*) were detected regularly, but there was no evidence of recent elevations of these species to coincide with oyster health impacts (see Appendix 5, Figure 21).

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[5] Government of South Australia's Dept of Primary Industries and Regions *Algal bloom situation update* https://pir.sa.gov.au/sardi/aquatic_sciences/marine_ecosystems/algal_bloom

Without full phytoplankton species data from the time of the onset of recent oyster disease in PCL it is difficult to attribute change in phytoplankton assemblage as an environmental driver of change in PCL, but from the available data it appears unlikely. The biomass changes in specific species of phytoplankton flagged by oyster growers have been interrogated and no noteworthy change over time were noted based on the available data.

Without knowing the edible or preferred phytoplankton species for Pacific oysters, primary productivity and oyster production cannot consistently be linked. Preferred phytoplankton species by oysters has been identified as an industry knowledge gap, and a consideration for future research is that new phytoplankton counts are assessed now that farmed oysters have been removed from PCL to establish which species they may have been feeding on.

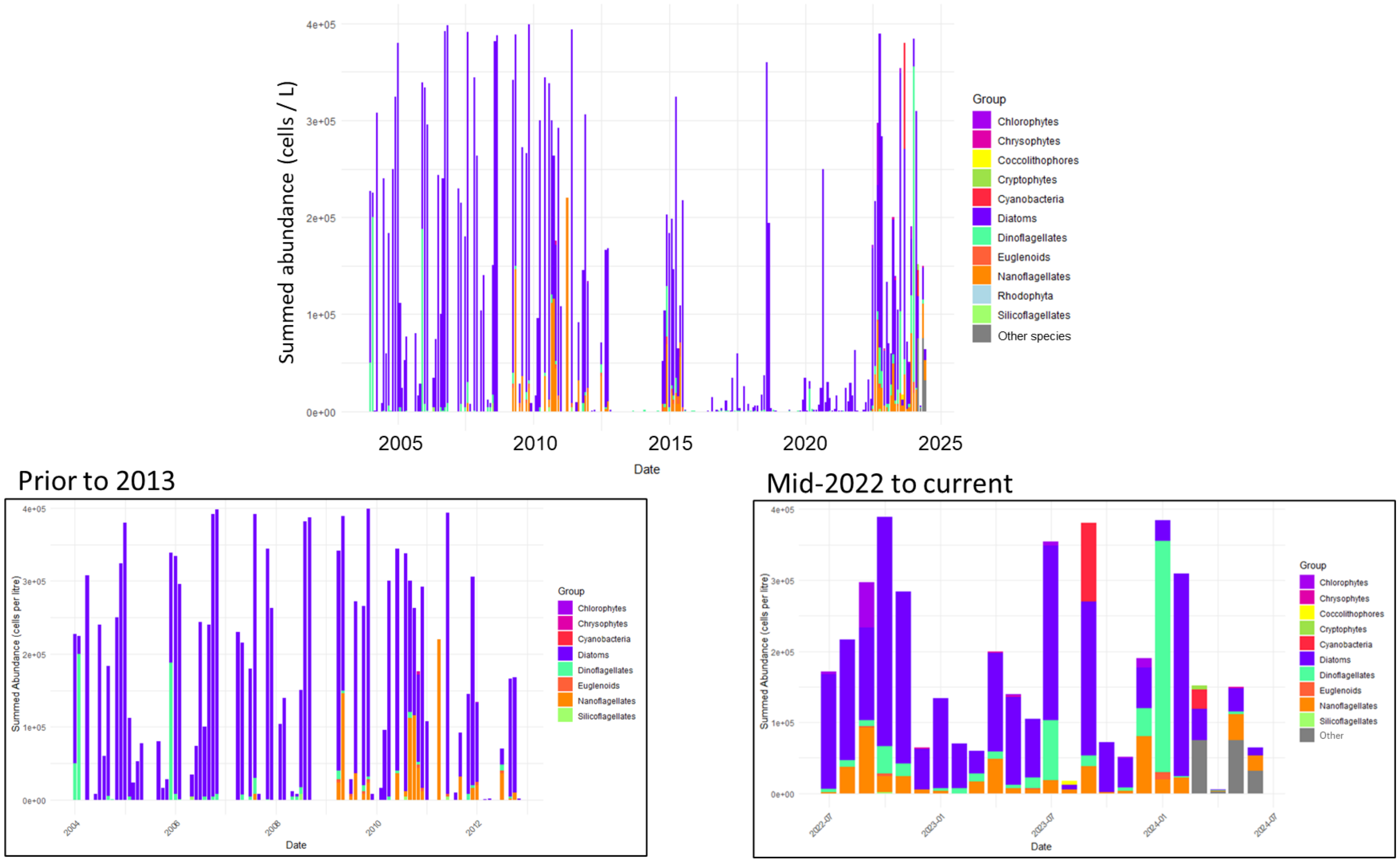

Figure 11. Phytoplankton counts from monthly ShellMAP monitoring in Pipe Clay Lagoon (see Table 5 for limits to data). TOP: phytoplankton abundance from 2004 to current. BOTTOM (L): summed abundance of full species counts from 2004 – 2013. BOTTOM (R): summed abundance of full species counts from July 2022 – current.

4.2.8 Toxins and Contaminants

As filter feeders, Pacific oysters take up metals, biotoxins (toxic substances such as shellfish poisons produced by certain species of phytoplankton), and other contaminants from the water column and these toxins accumulate in oyster tissue. Testing of oyster meat is used as an indicator of environmental contaminant loads (Jahan & Strezov 2019), and the accumulation of biotoxins can be a risk to human consumers (Turnbull et al. 2013).

Oysters have long been considered immune to the biotoxins and contaminants they consume and accumulate, but there is much evidence to suggest that biotoxins impact oyster health by increasing their susceptibility to disease (e.g., POMS, Jenkins et al. 2013; and *Vibrio* sp., Abi-Khalil et al. 2016). Heavy metal accumulation in oyster tissue has been shown to impact on oyster reproductive condition and immune response (Guzmán-García et al. 2009; Taylor et al. 2013; Weng & Wang 2019).

ShellMAP conducts biotoxin testing on shellfish meat (representative of harvested stock) from weekly samples of oyster meat collected in PCL by growers from Zone 1 and Zone 3. Chemical and heavy metal residue testing of shellfish is conducted by ShellMAP on a triennial basis.

4.2.8.1 Biotoxins

Blooms of toxic phytoplankton in Tasmanian waters (dinoflagellates *Gymnodinium catenatum* in the south since the 1980s, and *Alexandrium catenella* on the east coast since 2012) have resulted in the implementation of a Biotoxin Management Plan (ShellMAP 2019) and harvest closures during high-risk periods. Both *G. catenatum* and *A. catenella* produce paralytic shellfish toxin (PST) which results in paralytic shellfish poisoning in human consumers.

PCL was considered a low biotoxin risk area until 2015 when toxin-producing species were detected in oyster meats and lagoon water. The biotoxin risk rating for PCL has since been classified as high, with a weekly biotoxin and monthly phytoplankton sample testing required. Testing has confirmed the presence of paralytic shellfish toxin (PST) in oyster meats in at least low levels in PCL since 2015 (ShellMAP 2024) which aligns with other similar estuaries.

Inspection of weekly test results of total PST levels in oyster meats from PCL (available from 2021) showed that PST was generally low (<0.1 STX eq. mg/kg), with elevations in toxin levels in

May 2021 and between June and September 2022 (>0.4 STX eq. mg/kg, but only >0.8 mg/kg[6] on one occasion in September 2022). Similar elevations in PST in oyster meats were not recorded in other Tasmanian estuaries at the same time (Little Swanport and Boomer Bay). Although notable and may impact on oyster susceptibility to disease, these elevations were isolated and unlikely to have impacted on the overall oyster health issues in PCL.

4.2.8.2 Metals and Chemicals

ShellMAP testing is carried out for regulated heavy metals based on food standards, and chemicals (pesticides and herbicides) based on regional usage, and data is available from 1981.

The pesticide and herbicide lists for testing are reviewed every three years, with the last review taking place in 2022. In the most recent round of testing (2022), PCL oyster samples were below detection limits for all chemical contaminants and below Food Safety Australia & New Zealand (FSANZ) food standards[7] for regulated heavy metals, except for zinc. It is important to consider when interpreting these results that FSANZ food standard guidelines have been established to define maximum levels of contaminants for human health purposes only. These guidelines do not consider the implications of metal contamination to animal health or environmental processes.

Historically, concentrations of heavy metals were generally elevated in PCL oyster meats tested in the 1980s and 90s when compared with Little Swanport, Cloudy Bay Lagoon and Boomer Bay (ShellMAP data, 1981 - 2024). While concentrations of these metals have reduced in oyster meat from the early 1990s onwards, cadmium, copper, lead and zinc levels in PCL oyster meats are still notably greater than those in other Tasmanian estuaries.

Further, testing for metal contaminants in oyster meat samples from wild Pacific oyster samples in PCL in August 2022 reported high concentrations of metal analytes when compared with samples from Little Swanport, with the concentration of arsenic, cadmium, chromium, copper, manganese and lead at least double that of Little Swanport, and zinc concentration nearly 10-

[6] Guideline for concentration of paralytic shellfish poison (PSP) in edible shellfish, Australian Marine Biotoxin Management Plan for Shellfish Farming (2001)
[7] Food Safety Australia & New Zealand (FSANZ) Chemicals in Food https://www.foodstandards.gov.au/consumer/chemicals

fold greater in PCL (Table 6). Accumulation of metal contaminants by oysters can impact on oyster health (see above), but it is unlikely that this is a cause of recent oyster impacts given the long-term trend in PCL.

Table 6. Comparison of heavy metal concentrations in Pipe Clay Lagoon oyster meats with oyster meats from other Tasmanian estuaries.

(Data sources: ShellMAP heavy metals in oyster meats 1981 – 2024 (PCL, Little Swanport, Boomer Bay and Cloudy Bay); and lab results of wild Pacific oyster meat from PCL and Little Swanport tested in August 2022, Analytical Services Tasmania report provided by Tasmanian Oyster Co.)

Metal analyte	**Concentration in PCL oyster meats 1980 - 2024**	**Concentration in PCL oyster meats compared with sample from Little Swanport (mg/kgWMB)**	
		PCL	**Little Swanport**
Arsenic	Variable, no clear pattern	3.5	1.6
Cadmium	Significantly elevated in PCL oyster meat up to early 1990s compared to samples from other Tasmanian estuaries. Lower since then, but still greater than other sites.	0.3	0.1
Chromium	Variable, no clear pattern	0.3	0.1
Copper	Significantly elevated in PCL oyster meat up to early 1990s compared samples from other Tasmanian estuaries. Lower since then, but still greater than other sites.	13.7	5.0
Iron	Similar to other Tasmanian estuaries prior to 2014, but elevated since.	84.6	75.5
Lead	Significantly elevated in PCL oyster meat up to early 1990s. Lower since then, but still greater than in other Tasmanian estuaries.	0.5	<0.1
Manganese	Variable, no clear pattern	4.4	2.0
Zinc	Significantly elevated in PCL oyster meat up to early 1990s. Lower since then, but still greater than in other Tasmanian estuaries.	427.0	48.2

It appears there has historically been a local source of metals input to PCL that has stabilised since the early 1990s. Although metal levels in PCL oyster meats have reduced in recent years, they are still elevated in comparison to other Tasmanian estuaries and this warrants consideration. To understand local environmental drivers in PCL, identification of the source of contaminant input. Two possible sources of metal contaminant pollution of PCL via groundwater have been identified: the old Lauderdale waste transfer station (9 ha disused tip site 4 km north of PCL, see Figure 12) and the Nyrstar Hobart smelter (Lutana, 6 km north of Hobart).

The Lauderdale waste depot (tip) was developed in 1970, but by 1990 council concerns about the lack of leachate containment, inadequate covering of refuse and insufficient drainage lead to its closure in the early 2000s. The land has since been vacant with minimal management input (Clarence City Council 2019b). Groundwater monitoring at the site after closure recorded elevated ammonia, and metals, hydrocarbon and nutrients listed as potential pollutants (Ezzy 2002). It is possible that the waste depot site impacted the water quality of PCL historically, and it should be considered that the composition of tip leachate may change over time. Groundwater monitoring is discussed further in Section 4.2.9.

Nyrstar Hobart manufactures zinc, copper and lead and produces a large volume of cadmium as a by-product, all of which have historically high levels in PCL. Metals from Nyrstar have the capacity to enter into the environment via atmospheric emissions and waterways (Nyrstar 2017). The Derwent Estuary program has conducted a metal tracking experiment using Pacific oysters deployed in the Derwent Estuary and found exceedances of metal guidelines in oyster meat throughout the estuary, up to 4.5 km from the Nyrstar smelter and including in Ralphs Bay, 3.5 km north of PCL (DEP 2021).

PCL is connected to Ralphs Bay and the old Lauderdale waste depot site by a series of shallow ephemeral lagoons that become inundated after rainfall and high tides. Considering the sandy soil and shallow water table in the area (see Section 4.2.9), it is not unreasonable to consider input to PCL water quality and environmental conditions from the broader region. Input pollutants from Nyrstar, leachate from the waste depot and the wider region should be considered when evaluating potential contaminants within PCL.

4.2.9 Groundwater

Clarence City Council has monitored the water quality in groundwater bores in the PCL area since 2009, with efforts (location and frequency of sampling) adjusted to respond to concerns about stormwater and sewage contamination of groundwater.

There are ten groundwater monitoring bores around the edge of PCL and three bores to the north of the lagoon (one in Cremorne, two at Rushy Lagoon, Figure 12). Bores were monitored biannually from 2009 to 2018, and there is ongoing biannual monitoring of the six sites along the northern shore of PCL in Cremorne to assess impacts on groundwater quality from onsite wastewater treatment systems in the township (Sloane Geoscience 2023, data available to July 2024). Physical parameters including temperature, conductivity and pH are measured, along with nutrients (ammonia, total nitrogen, total phosphorus, nitrate, nitrite) and faecal contamination indicators (*E. coli*, thermotolerant coliforms, and including enterococci for recent Cremorne monitoring).

The PCL area has a shallow, unconfined sand aquifer with groundwater levels generally 0.5 – 1.2 m from the ground surface (Sloane Geoscience 2023). Faecal contamination indicators (*E. coli* and enterococci) were generally very low in groundwater (except for some isolated enterococci elevations at the western-most (saltmarsh) lagoon site in 2019, 2020 and 2024). Analysis of groundwater records revealed isolated high ammonia (>10 mg/L) at some sites, particularly at two of the Cremorne township sites, but there was no spatial pattern in increases or an increasing trend. There was no evidence of an increase in nutrient enrichment of the groundwater surrounding PCL. Without nutrient analysis of water samples from PCL at a similar time period, it is not possible to know whether groundwater influences the quality of surface water in PCL.

The dynamics of groundwater in the area surrounding PCL is unknown, but it is likely that PCL is connected to Ralphs Bay via the fresh groundwater aquifer south of Lauderdale (Derwent Estuary Program 2012).

Figure 12. (LEFT) Map of part of the South Arm peninsula, showing the location of a series of shallow lagoons connecting Pipe Clay Lagoon with Ralphs Bay and the old Lauderdale waste depot site, and (RIGHT) Location of groundwater sampling sites (source: Clarence City Council).

4.2.10 Genetics

Oyster growers expressed concerns that the oyster health issues in PCL may be related to oyster genetics. The Pacific oysters impacted in PCL were grown from spat sourced from two different Tasmanian oyster hatcheries. These hatcheries supply spat to growers throughout Tasmania, South Australia and New South Wales, and it is unlikely that oyster genetics is a contributing factor to the growth and mortality issues in PCL.

It is our understanding that Tasmanian diploid oyster brood stock originates from Australian Seafood Industries (ASI) family lines. ASI runs a Pacific oyster selective breeding program, originally focused on creating large, uniform, robust oysters but pivoted to focus on POMS resistance following the outbreak in 2016. ASI ran a trial in PCL in 2024 measuring growth and survival of different Pacific oyster family lines, in response to growth and mortality issues of oyster stock in the lagoon. The results of this trial would indicate if there has been any unintended selection for traits resulting in oysters more vulnerable to the adverse conditions in PCL. The data from this trial were requested but not received.

4.2.11 Changes in Other Populations and Species in PCL

There have been changes to other species diversity and abundance in PCL over recent years, some of which coincide with the increase in seagrass and the decline in farmed oysters, and others (wild Pacific oysters and live-bearing seastars) that are a result of human intervention. Changes to species listed here highlight anecdotal observations, and some of the other projects concurrently taking place in the lagoon.

Consultation with oyster growers and recreational lagoon users highlighted several observed changes to other species in PCL, that appeared to coincide with the increase in seagrass in the lagoon. The abundance of different species fluctuates in the lagoon, and many of the species currently present in high numbers in PCL have been recorded in the past (historical environmental studies conducted in PCL, e.g., Mount et al. 2005). Of note are:

- Anecdotal observation of change in the recreational fish species. Sand flathead and flounder were recorded in the Marine Farming Development Plan for PCL as the most common fish species (DPIPWE 1998). Numbers of flathead and flounder have anecdotally reduced in recent years, with an increase in calamari and bream (Ugalde & Ross 2023).

- Recent abundance of mock oysters (*Electroma papilionacea*) settled on the seagrass.

- A large number (100+) of black swans (*Cygnus atratus*) have recently become permanent residents in PCL. The abundance of resident cormorants (*Phalacrocorax* sp.) has increased notably in recent years.

- The previously-abundant heart urchins (*Echinocardium cordatum*) are rarely seen, and short-spined urchins (*Heliocidaris erythrogramma*) are numerous. Short-spined sea urchins have been observed in abundance in at least two areas of PCL, resulting in areas of sparser seagrass coverage due to urchin grazing.

- Populations of the invasive Northern Pacific seastar (*Asterias amurensis*) are frequently removed by community group clean ups and numbers have greatly reduced in recent years.

- The native eleven-armed seastar (*Coscinasterias muricata*) is currently abundant in PCL.

- Anecdotal observation by some growers of a significant change to biofouling on lease rack and rail structures. Growers noted a change in the abundance of cunjevoi (seasquirts, *Pyura stolonifera*) and orange sponge, usually prolific in clumps on lease structures but became absent at the same time as the arrival of dense seagrass and the decline in oyster health.

- The shells of native flat oyster (*Ostrea angasi*) are a common feature of the PCL shoreline and were recorded in sediment in many parts of PCL in samples taken in 1998 (Mitchell & Macleod 1998, reported in DPIWE 1998). It has been observed that populations of native flat oysters are beginning to re-emerge in PCL following the reduction in wild populations of Pacific oysters (most likely due to POMS) (observation by Biosecurity Tasmania, reported in NRE Tas, unpublished).

4.2.11.1 Wild Pacific Oysters

Pacific oysters were deliberately introduced to the estuaries of Tasmania by the CSIRO in the late 1940s and early 1950s, and the state-wide spread of wild (i.e., non-farmed, or invasive) Pacific oysters has been primarily credited to artificial relocations that occurred in the 1950s and 1960s (Mitchell et al. 2000). In PCL, wild Pacific oysters have colonised the rocky shoreline and have formed dense reefs in at least three offshore areas of the lagoon. Wild Pacific oysters were noted as a potential driver of change in PCL by growers and residents during consultation, and there were mixed anecdotal observations of the increase or decrease in biomass of wild Pacific oysters in recent years.

Wild Pacific oysters compete for food resources with farmed oysters, and there have been concerns raised about the potential barricade created by the northern wild Pacific oyster reef reducing incoming water flow to the northern oyster leases in PCL. Further, the ongoing presence of the POMS virus in the Tasmanian oyster population has a significantly higher prevalence in wild Pacific oysters and it has been concluded that wild oyster populations are a significant reservoir of POMS infection in PCL (NRE Tas *unpublished*). Wild Pacific oyster reefs in PCL have also long been a concern to residents and recreational users of the lagoon from an amenity and safety perspective.

For many years, the oyster growers in PCL have voluntarily assisted the local community group with regular wild Pacific oyster clean ups and many tonnes of oyster have been removed from the lagoon shoreline and offshore reefs. Although removal stopped for a period of time following POMS detection in PCL, regular clean ups occurred during 2018 and 2019, and again in 2022 and 2023. In 2023, NRM South supported growers and the local community to remove a portion of the wild Pacific oysters from the lagoon shoreline via the Tasmanian Smart Seafood Partnership project (Australian Government Smart Farms Partnership Program 2018-2023). Also at this time, an application for a license to commercially harvest wild Pacific oysters from PCL was initiated by one of the local growers.

4.2.11.2 Tasmanian Live-Bearing Seastar

A trial of rocky habitat conducted between 2021 – 2023 identified two sites on the western shore of PCL as suitable to host a population of endangered Tasmanian live-bearing seastar (*Parvulastra vivipara*) during construction of the new causeways in Pitt Water. As part of the planning by the Department of State Growth for the duplication of the Midway Point and Sorell causeways, the resident live-bearing seastar will be moved from habitats along the causeway prior to construction works, and relocated to augmented habitat in PCL. PCL was chosen as an ideal supplementary habitat augmentation location because it contains several areas of 'bare' rock platform suited to habitat augmentation, it currently supports native populations of live-bearing seastar, and has suitable baseline environmental conditions (tested in 2023).

The habitat augmentation works took place in April 2024 and involved the introduction and placement of small (5-20 cm) virgin rocks sourced from quarries to two areas of the shoreline. The relocation of live-bearing seastar individuals is scheduled to take place during 2025, depending on approvals and permitting.

IMAS has recently received a grant to remove wild (invasive) Pacific oysters and New Zealand porcelain crabs (*Petrolisthes elongatus*) from the PCL shoreline, to mitigate risks to the live-bearing seastar. Oysters and crabs compete for resources with the seastar and degrade habitat quality, which alters seastar behaviour and may reduce its chances of survival. IMAS have applied for permits and propose to conduct this work at sites along the western PCL shoreline during 2025.

4.2.12 Aquaculture Management

Marine farming practices in Tasmania (including in PCL) are regulated by NRE Tasmania's Aquaculture and Emerging Industries Branch. Safe harvesting of shellfish for human consumption is managed by ShellMAP, a program of NRE Tas. The Animal Health Laboratory, a department within Biosecurity Tasmania, are responsible for testing and pathology in relation to the impact to human health. The peak body for the oyster industry in Tasmania is Oysters Tasmania.

The PCL Marine Farming Development Plan (MFDP) October 1998 defines three zones for marine farming to maximise productivity and sustainability of shellfish culture in the lagoon (Figure 1). The Plan allows for flow channels (where no racking is permitted) between leases to assist water circulation through the zone area and the lagoon as a whole.

The Plan was reviewed in 2008 and modified in 2024 to incorporate approved standardized marine farming management controls (NRE Tas 2024).

NRE Tas has acknowledged the need to review the PCL MFDP. In particular, no update has been made between versions of the PCL Plan in relation to number of leases, and to *Environmental controls relating to management* or *environmental controls relating to carrying capacity*, despite issues in oyster growth and survival arising from 2020 and a significant drop in oyster production from 2021. The updated 2024 PCL MFDP includes the environmental monitoring requirement: "*Lessees must measure the growth of samples of shellfish and report to the Secretary in relation thereto (as required by the Secretary) in areas where the growth rates of shellfish have declined, and the Secretary is concerned that the carrying capacity of the area is being exceeded.*" (NRE Tas 2024, p.p 22). Growth rate of shellfish has not been collected in PCL as the current issues were considered to be more likely associated with environmental change than carrying capacity. To change the management control relating to carrying capacity there would need to be scientific evidence that stock density was the cause of the production decline, or in the lack of evidence, support from industry to change these controls. NRE Tas does not currently have this evidence. Further, if the issue in PCL was related to carrying capacity, as production has dropped and less oysters are growing in PCL, oyster growth should have (in theory) improved on the remaining leases in recent years.

The information used to inform the management plan for shellfish farming in PCL is over 25 years old, and distinct changes have occurred both in PCL and other Tasmanian estuaries. As change in environmental conditions is highly likely to result in change to carrying capacity, it is recommended that a more active and adaptive approach is adopted for management of shellfish farming in Tasmanian estuaries.

Oyster farmers in PCL employ different approaches to monitoring changes within their production systems, which has led to inconsistent data collection across the lagoon. In some cases, data were recorded and shared in an ad hoc manner, limiting the ability to build a comprehensive picture of environmental or stock-related changes. As a result, there is no consistent long-term dataset that can be used to track trends across farms or to understand how different factors may be influencing oyster production. Development of consistent management strategies would help to identify these issues sooner and inform monitoring and management practices in other major oyster-producing regions, supporting long-term industry sustainability.

5 Conclusion

5.1 Key findings

From the results of collation of the available data for PCL we can conclude that:

- Oyster health: Mortality of juvenile and adult oysters escalated after 2020–21. While POMS virus and other diseases tested negative, oysters showed inflammation, haemocyte activity, and high *Vibrio* loads.
- Environmental shifts: The recent triple-year La Niña increased rainfall and runoff, leading to variable salinity, elevated faecal indicator bacteria, and blue-green algae presence.
- Habitat change: Seagrass has expanded from patchy beds at the lagoon mouth to covering most of the benthic habitat. This shift has altered water flows, increased sedimentation, and changed community composition.
- Biogeochemical cycling: Continuous records (since 2023) revealed large diel fluctuations in dissolved oxygen and pH, driven by seagrass photosynthesis and respiration. These cycles can induce hypoxia and acidification, reducing oyster survival and increasing disease susceptibility.
- Food and contaminants: Phytoplankton biomass and harmful algal bloom species remained consistent with historical records, but some isolated elevations in Paralytic Shellfish Toxin (PST) were detected in oyster meat in 2021–22. Heavy metals remain elevated compared with other Tasmanian estuaries despite long-term declines.
- Connectivity: PCL is likely linked hydrologically to Ralphs Bay and the Derwent Estuary via shallow ephemeral lagoons, suggesting broader regional inputs to water quality.
- Outdated baseline: The management plan for shellfish farming in PCL relies on information over 25 years old.

5.2 Synthesis

In summary, the ecosystem in PCL is undergoing significant change, characterised by rapid seagrass proliferation and a concurrent decrease in farmed oyster production. The increased abundance of seagrass in PCL has likely reshaped PCL dynamics by stabilising sediments, increasing sedimentation, and altering flow dynamics. Its photosynthetic and respiratory cycles have created pronounced diel fluctuations in oxygen and pH, conditions known to stress oysters and increase their susceptibility to disease, increasing the risk of declining oyster health and mortality. Warm temperatures exacerbate these stressors, contributing to reduced metabolic processes, poor oyster condition, reduced feeding, and increasingly susceptibility to infection by *Vibrio*.

While harmful algal blooms have not increased, toxin levels and heavy metals remain concerns. Rainfall-driven runoff, coupled with altered hydrodynamics, adds further complexity to lagoon processes. Together, these interacting drivers have produced a cascade of physical and biological changes that are difficult to disentangle. Given the complex nature of ecological interactions coupled with anthropogenic pressure and a changing climate there is a considerable amount of overlap in the concerns discussed in this report (Figure 13). Multiple feedback loops (both positive and negative) exist between flora, fauna and physical properties that cannot be investigated without thorough field analysis and the targeted collection of environmental data. These ecological changes were further compounded by inconsistent monitoring and fragmented data collection, which limited the industry's ability to detect emerging issues and adapt management practices.

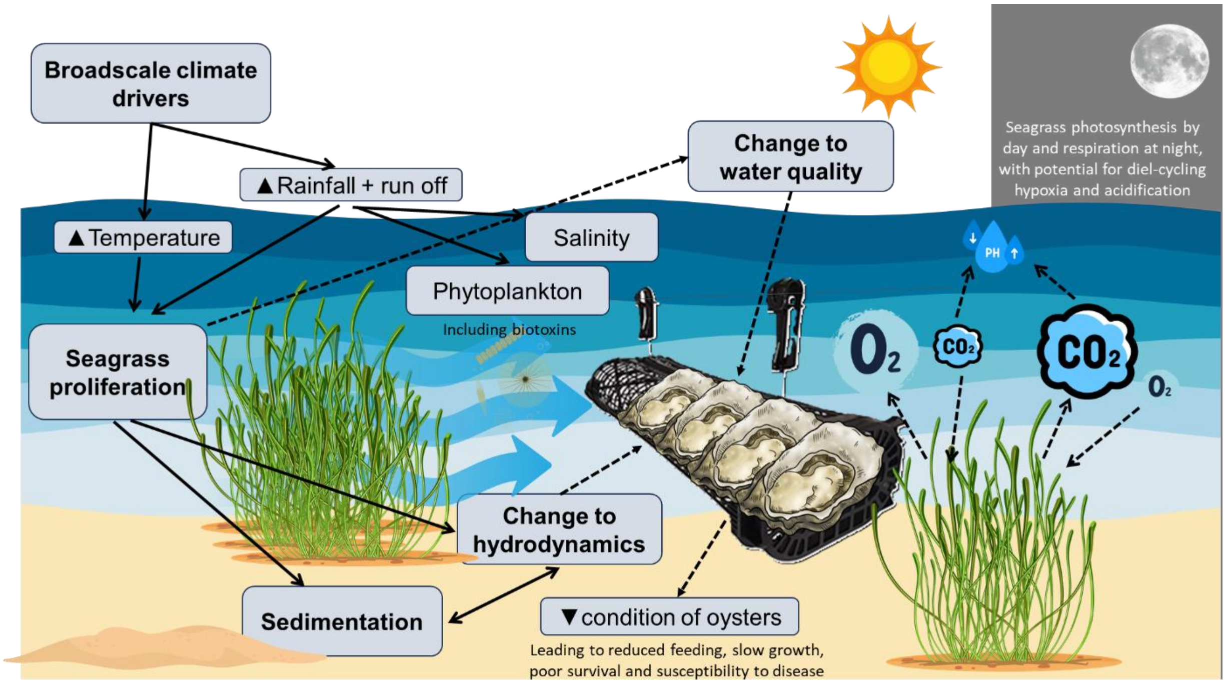

Figure 13. Conceptual diagram of interacting drivers of change in Pipe Clay Lagoon (PCL).

Solid arrows indicate known impacts; dashed arrows indicate proposed impacts in PCL. Expansion of seagrass beds has stabilised sediments, increased sedimentation, and altered hydrodynamics, leading to changes in water quality and lagoon depth. These shifts, combined with La Niña-driven rainfall and runoff, have created diel fluctuations in dissolved oxygen and pH, as well as variable salinity. Oysters have shown poor condition, reduced feeding, and increased susceptibility to *Vibrio* infection, while additional stressors include elevated paralytic shellfish toxins (PSTs) and heavy metals. Together these processes illustrate the "perfect storm" of interacting ecological and environmental pressures that led to widespread oyster mortality and the collapse of aquaculture in PCL.

6 Implications

By early 2025, all oyster leases in PCL were functionally inactive due to disease-related mortality and the consequential financial loss of income for growers. The sudden removal of millions of filter feeders from the system, is itself likely to result in further changes to PCL ecology. This is an important consideration for the development of new research or data collection in PCL. Given the multiple overlapping stressors, it is likely too late to attribute change to a single driver; instead the current situation in PCL represents "a perfect storm" – a convergence of a number of unfavourable factors and conditions resulting in a situation worse than the sum of its parts. However, the insights gained from this project are valuable for aquaculture management and estuarine ecosystem health in Tasmania more broadly. These findings should highlight the need for updated field data and targeted monitoring, both to understand continuing changed within PCL and to prevent similar outcomes in other Tasmanian estuaries, particularly as there are indications that such issues may already be emerging in other areas.

7 Recommendations

Field-based data collection

- Reassessment of PCL hydrodynamics, bathymetry and tidal prism using new, detailed methodology to update the information collected in 1996 (Crawford et al. 1998) and update the MFDP accordingly. Accurate assessment of the full extent of the seagrass in PCL could be achieved in this same study.
- Collection of continuous temperature, dissolved oxygen and pH measurements within and outside of seagrass beds to assess the impact of seagrass on these parameters and compare diel fluctuations among habitats.
- Establish standardised long-term data collection methods to ensure consistency so that data is comparable over time. This is particularly important for biological or ecological data collection where methods frequently differ between organisations.

Management

- A regular cleaning, maintenance and calibration program for the water quality sensors (Oyster Sensor Network) in PCL. The current 90-day interval is not sufficient for maintenance, especially over the warmer months.
- Increased collaboration between industry, government, research and community stakeholders, potentially through the implementation of a working group.
- Support for 'zero regret' management (i.e., beneficial regardless of future uncertainty). For example, support for the establishment of a native vegetation and saltmarsh buffer zone around lagoon.
- Repository of all relevant information for each Tasmanian oyster-growing estuary, ideally gathered and maintained by Oysters Tasmania. When studies are initiated, data is collected, results are published - it is sent to OT and stored on file for quick access. It is important that this repository is open access.
- Grower access to a database to record and document observations, including date, time, environmental observation and photo documentation. This would assist in quantifying and clarifying important anecdotal information.
- Collection of data when declining growth rates of oysters is noted, time, location, size and regular measurements of shell length and oyster condition.

Knowledge gaps

- The contributing factors to oyster disease in PCL are unknown, but may include planktonic microbiota (including, but not limited to, *Vibrio* sp.), and the presence/abundance of certain harmful algal species.
- Without knowing the edible or preferred phytoplankton species for Pacific oysters, primary productivity and oyster production cannot consistently be linked. The preferred phytoplankton species for oysters at various life stages was identified as an industry knowledge gap. A consideration for future research is that new phytoplankton counts are assessed now that farmed oysters have been removed from PCL to establish which species they may have been feeding on.

8 Extension and Adoption

This project has been presented to stakeholders and interested parties at the following forums:

- Shellfish Futures Conference 2024, Triabunna - 13 September 2024.
- Pipe Clay Lagoon Stakeholder Engagement Workshop, Hobart - 13 November 2024.
- Tasmanian Research Advisory Committee (TasRAC) - 26 March 2025.
- Shellfish Futures Conference 2025, Hobart - 11 September 2025.

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Appendices

Appendix 1. Change to sedimentation at Pipe Clay Lagoon entrance

September 2016 | October 2017 | May 2021 | April 2025

With assumed change to flow at the channel at the lagoon entrance indicated:

September 2016 | October 2017 | May 2021 | April 2025

Figure 14. Documented change to sedimentation at the entrance to Pipe Clay Lagoon since 2016. Images show the formation of a sand bar at the lagoon entrance (basemaps: Esri World Imagery wayback digital archive).

Appendix 2. Subset of water quality data (temperature, dissolved oxygen and pH) from the Oyster Sensor Network stationary sensors in Pipe Clay Lagoon, accessed via the SHELLPOINT portal

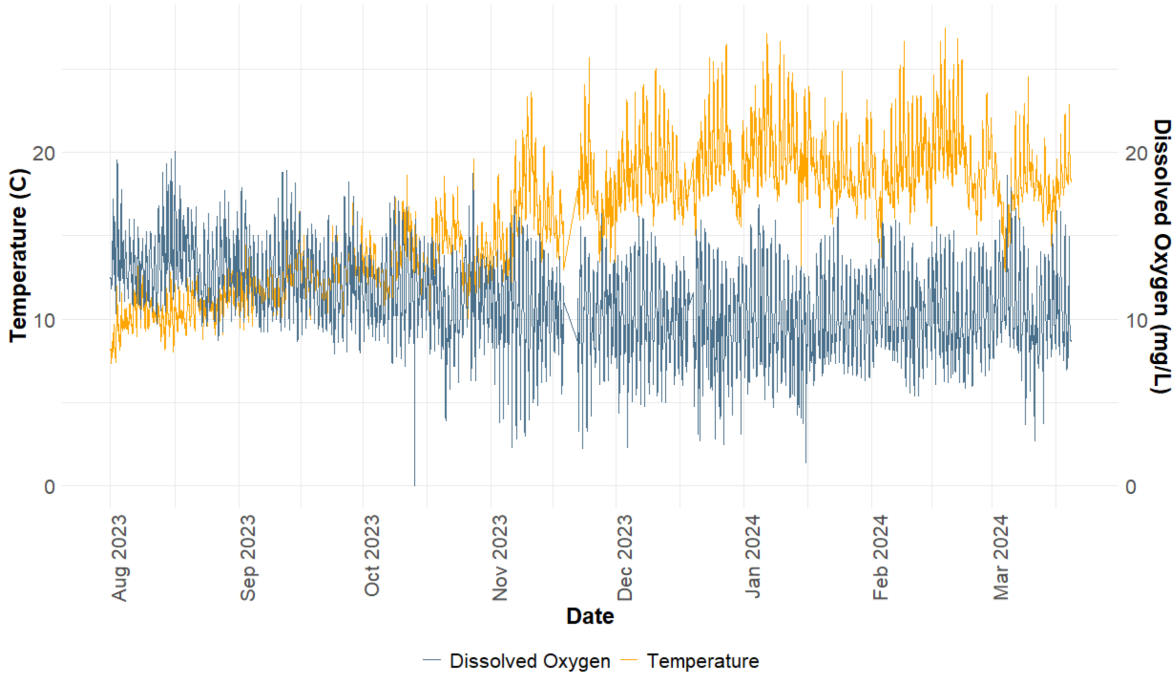


Figure 15. Subset of available data for dissolved oxygen and temperature at stationary sensor (Zone 1) in Pipe Clay Lagoon. Time period reflects the availability of consistent data.

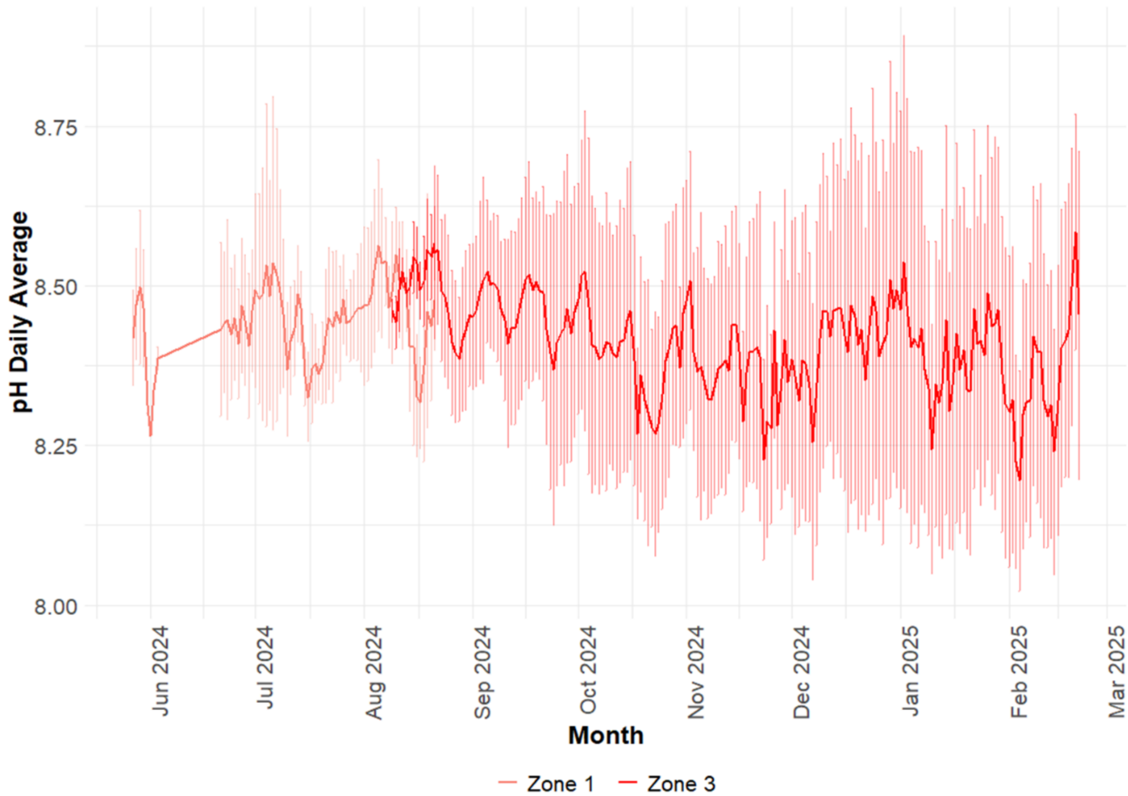


Figure 16. Available data for daily average pH measured at two stationary sensors (Zone 1, Zone 3) in Pipe Clay Lagoon over a nine-month period in 2024-25.

Appendix 3. Daily fluctuation in temperature and pH from Oyster Sensor Network stationary sensors in Pipe Clay Lagoon

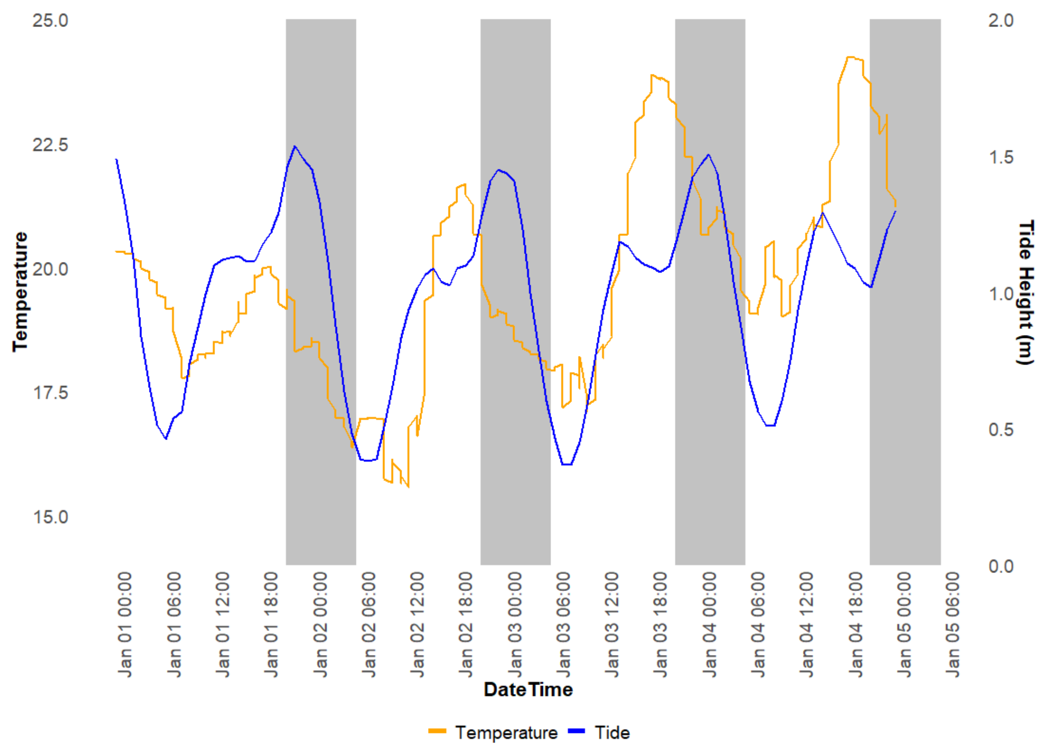


Figure 17. Typical daily fluctuation in temperature in Pipe Clay Lagoon in summer (January 2025) in Zone 3 in Pipe Clay Lagoon relative to tide height and day/night (night time is shaded).

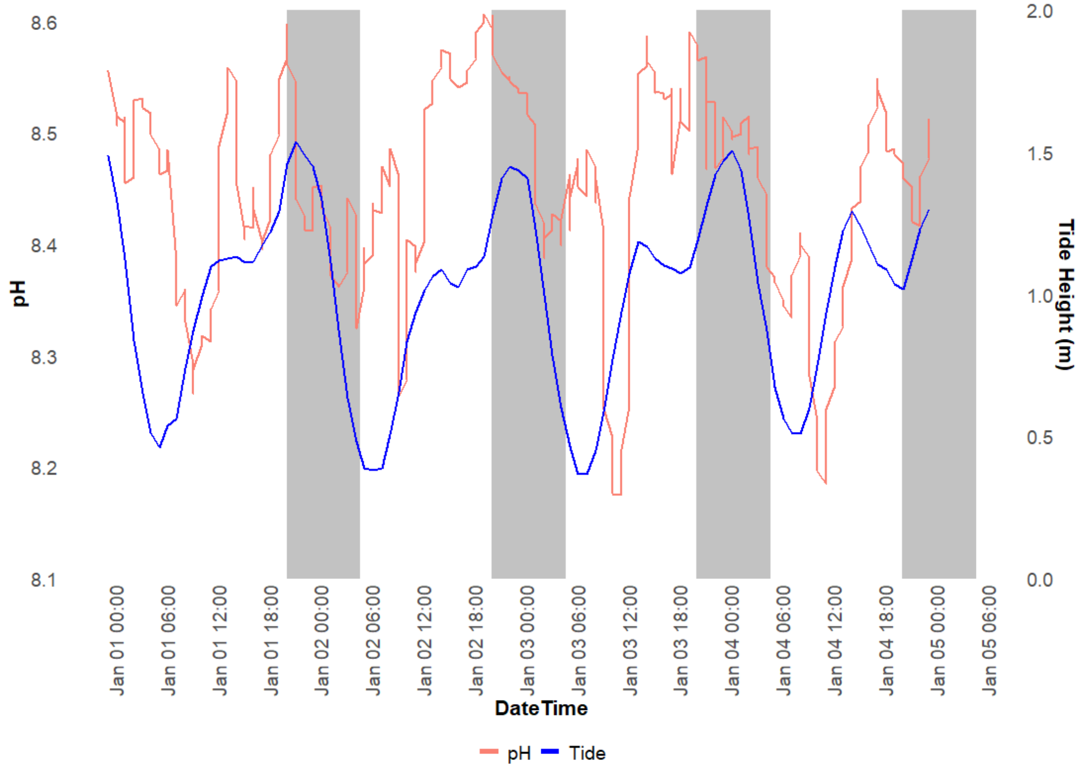
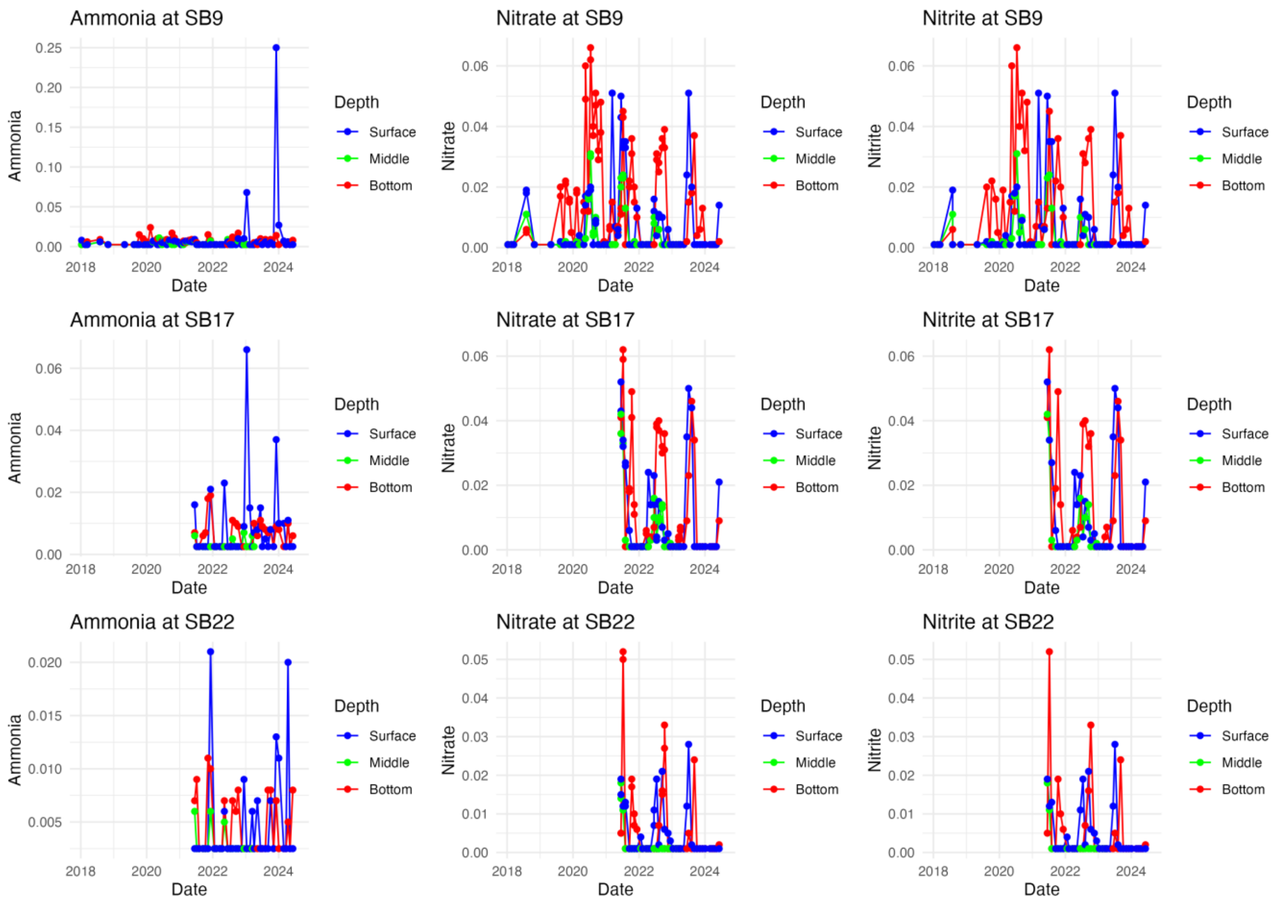
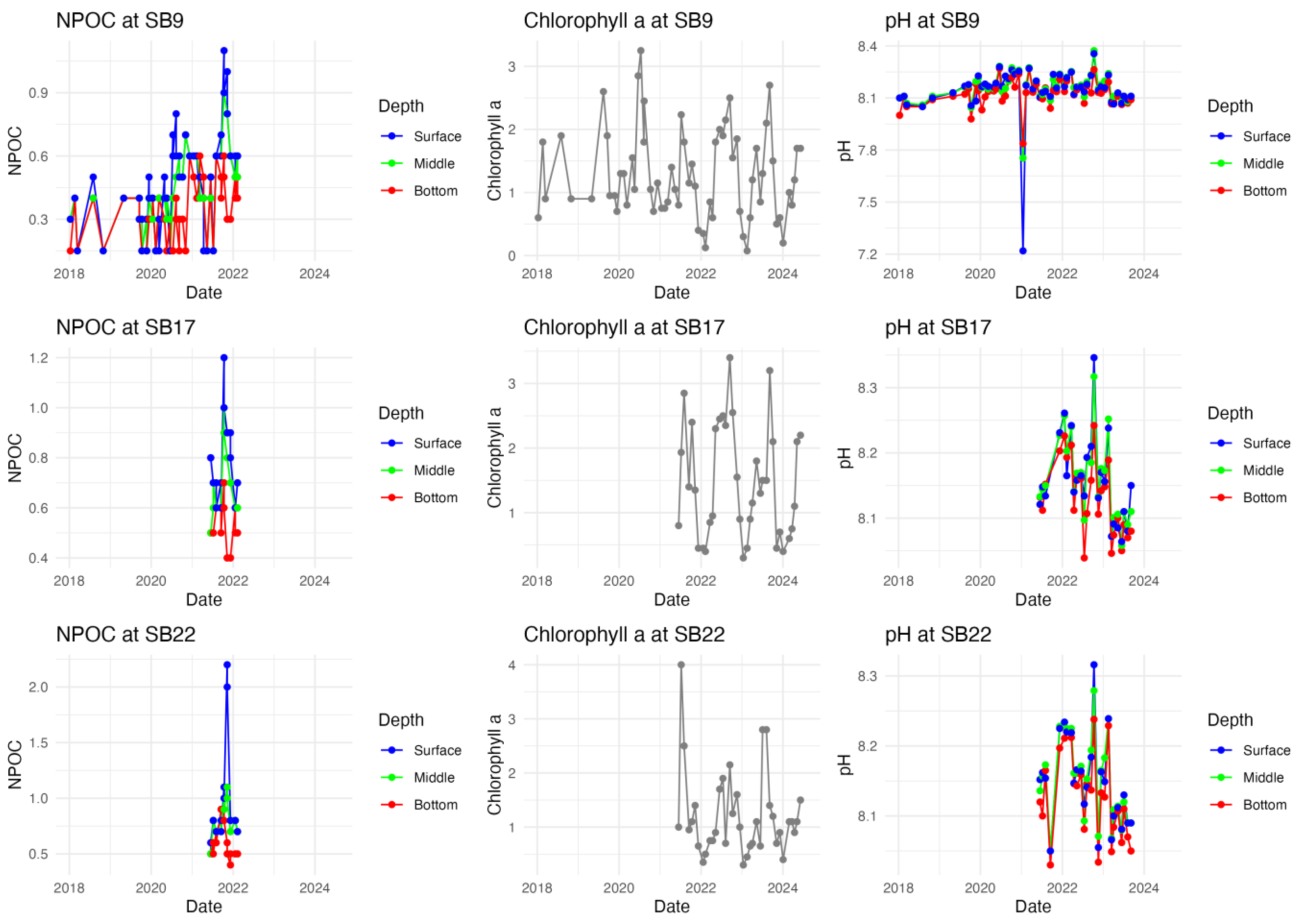


Figure 18. Typical daily fluctuation in pH in Pipe Clay Lagoon in summer (January 2025) in Zone 3 in Pipe Clay Lagoon relative to tide height and day/night (night time is shaded).

Appendix 4. Summary of water quality results for salmon aquaculture monitoring in Frederick Henry and Storm Bay




NPOC at SB9
Chlorophyll a at SB9
pH at SB9
NPOC at SB17
Chlorophyll a at SB17
pH at SB17
NPOC at SB22
Chlorophyll a at SB22
pH at SB22
NPOC
Chlorophyll a
pH
Date
2018
2020
2022
2024
Depth
Surface
Middle
Bottom

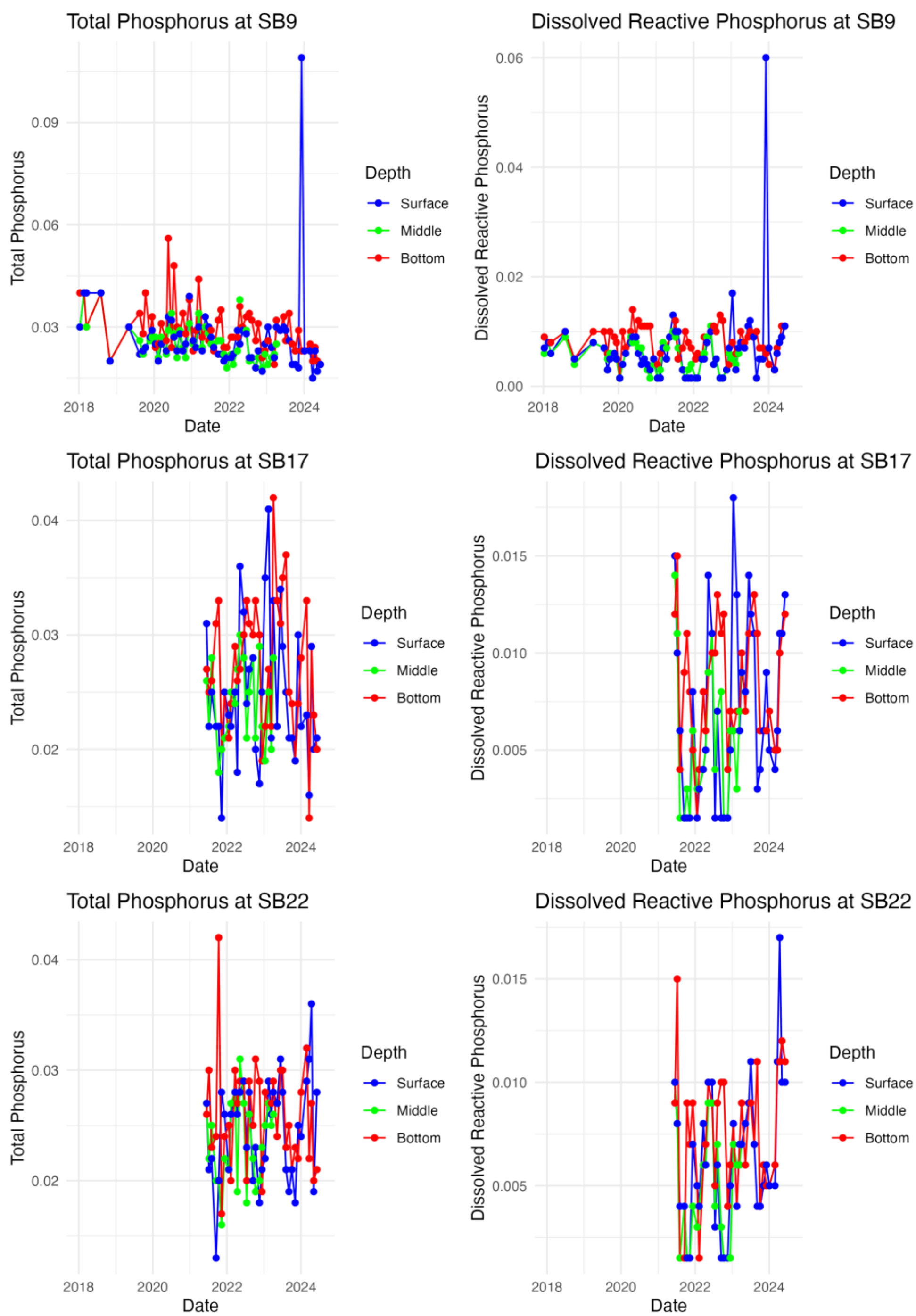


Figure 19. Monthly values in surface, mid and bottom waters for total ammonia, nitrate, nitrite (mg-N/L); NPOC (mg-C/L); dissolved reactive phosphorus (mg-P/L); total phosphorus (mg-P/L) and chlorophyll a (mg/m^3) and pH at the three sites closest to Pipe Clay Lagoon (SB9, SB17, SB22) from the Storm Bay Broadscale Environmental Monitoring Program (data provided by Salmon Tasmania).

Appendix 5. Change to presence and abundance of known harmful phytoplankton species from available phytoplankton data for Pipe Clay Lagoon, Frederick Henry Bay and Storm Bay

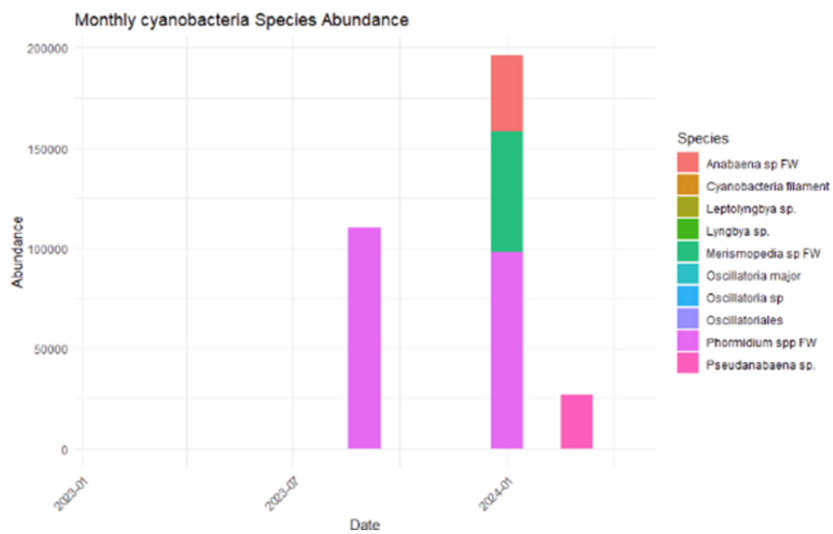


Figure 20. Detail of cyanobacteria species abundance in Pipe Clay Lagoon in 2023-24 (source: ShellMAP phytoplankton presence and counts)

Table 7. List of known harmful algal species in Australia, and their presence in Pipe Clay Lagoon and the broader region

Harmful Algae Species Name^	**Toxin Type or Impact**	**Presence in Pipe Clay Lagoon (ShellMAP data)**	**Presence in Frederick Henry Bay and Storm Bay (Salmon Tas data)**
Alexandrium catenella	Paralytic shellfish toxins (PST)	Detected regularly, but not in counts	Not detected
Alexandrium minutum	PST	Detected regularly, only counted in Nov 2023	Not detected
Alexandrium ostenfeldii	PST	Detected regularly, only counted in Feb 2014, Aug 2017, June 2018	Detected in Aug 2019
Alexandrium pacificum	PST	Not detected	Not detected
Chattonella marina	Ichthyotoxin (fish-killing)	Detected once (Nov 2013)	Not detected
Dinophysis acuminata	Diarrhetic shellfish toxins (DST)	Detected regularly and counted on several occasions*	Often present
Dinophysis acuta	DST	Detected regularly, only counted in Nov 2022	Detected in June 2023
Dinophysis fortii	DST	Detected regularly, counted in 2012, 2007	Not detected
Dinophysis tripos	DST	Detected, counted in Feb 2006, Apr 2010	Present on multiple occasions from April 2020
Fukuyoa spp. (e.g. *F. paulensis*)	Ciguatera fish toxins (CFP)	Not detected	Not detected
Gambierdiscus (incl. *G. toxicus* species complex)	CFP	Detected once (Nov 2013)	Not detected
Gymnodinium catenatum	PST	Detected regularly and counted on several occasions*	Present on multiple occasions from July 2020
Heterosigma akashiwo	Ichthyotoxin (fish-killing)	Detected once (Nov 2013)	Not specified. *Heterosigma* sp. detected on multiple occasions from Dec 2019
Karenia brevisulcata	NSP/Fish kill	Not detected	Not specified. *Karenia* sp. - present once in 2022 (Jan) and four times in 2023

Harmful Algae Species Name^	Toxin Type or Impact	Presence in Pipe Clay Lagoon (ShellMAP data)	Presence in Frederick Henry Bay and Storm Bay (Salmon Tas data)
Karenia cf. mikimotoi	Neurotoxic shellfish poisoning (NSP)	Detected once (Nov 2013)	Not specified. *Karenia* sp. - present once in 2022 (Jan) and four times in 2023
Karenia selliformis	NSP/Fish kill	Not detected	Not specified. *Karenia* sp. - present once in 2022 (Jan) and four times in 2023
Nodularia spumigena	Cyanotoxin (hepatotoxin)	Not detected	Not detected
Pseudochattonella verruculosa	Ichthyotoxin (fish-killing)	Not detected	Not detected
Pseudo-nitzschia australis	Amnesic shellfish toxin (AST)	Detected once (Nov 2013)	Not detected
Pseudo-nitzschia cuspidata	AST	Not detected	Not detected
Other *Pseudo-nitzschia* spp. (e.g. *P. multistriata, P. pungens, P. delicatissima*)	AST	*P.delicatissima* group detected and counted frequently since 2004*	*P.delicatissima* groups detected every month
Scrippsiella cf. *acuminata*	Blooms (non-toxic)	Not detected, but *S. trochoidea* (harmful to fish) detected and counted regularly since 2004*	Not detected, but *S. trochoidea* detected every month
Trichodesmium erythraeum	Blooms (cyanobacterium)	Not detected	Not detected

^ List of harmful algal species from Hallegraeff et al. 2021

* Patterns in abundance shown in Figure 21 below

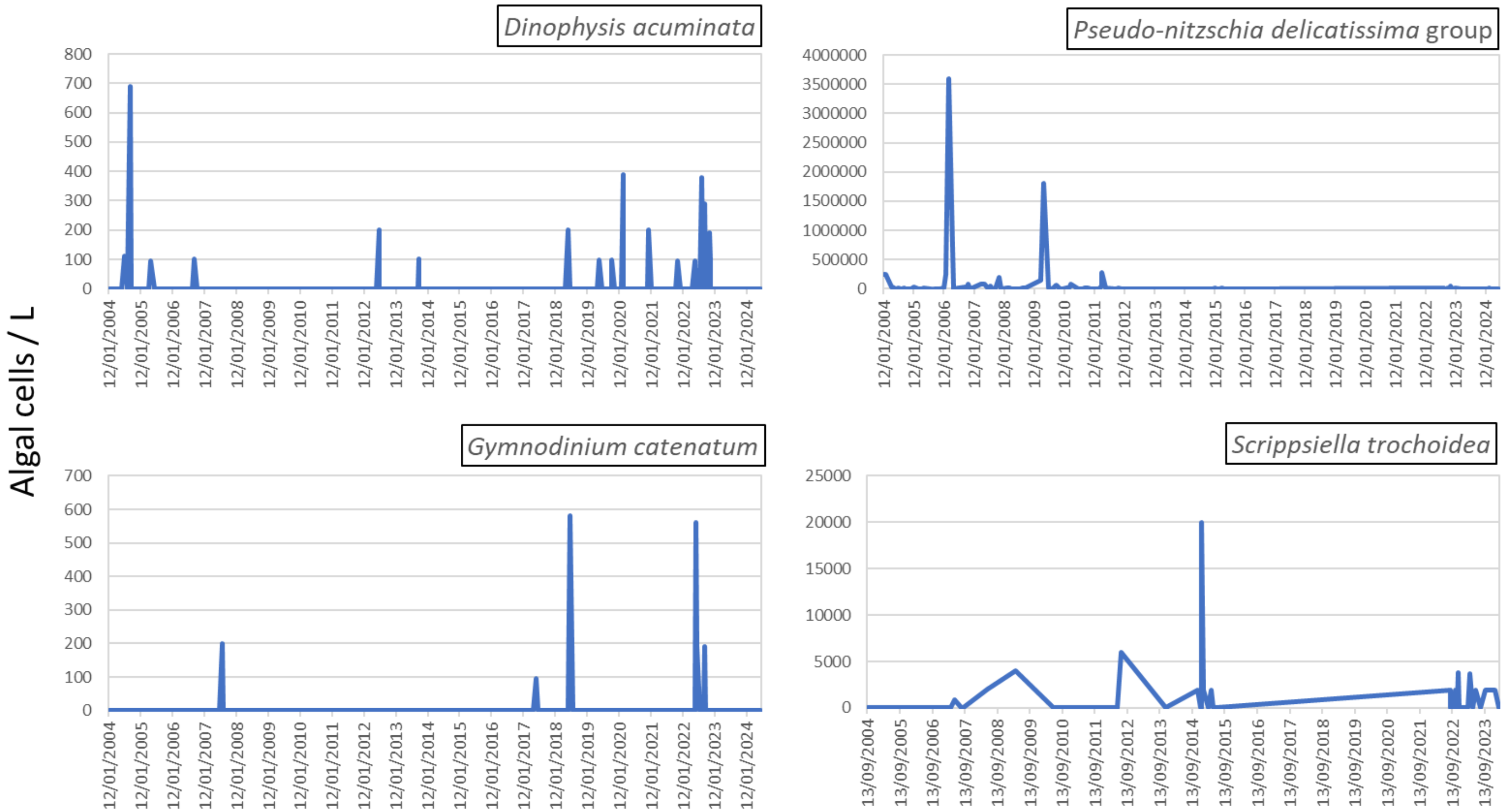


Figure 21. Harmful algal species of note in Pipe Clay Lagoon. Note that species on the right (*P. delicatissima* group and *S. trochoidea*) were not counted between 2015 and 2022, see Table 5 (source: ShellMAP phytoplankton presence and counts).