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INVESTIGATING ENVIRONMENTAL DRIVERS OF CHANGE IN PIPE CLAY LAGOON

DESKTOP REVIEW OF AVAILABLE INFORMATION

SUMMARY DOCUMENT

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Cover photo: Pipe Clay Lagoon (Marine Solutions, 2025).

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Summary

This document provides a summary of key findings from Marine Solutions and FRDC project *Investigating drivers of environmental change in Pipe Clay Lagoon*. The full report is available online via the FRDC website (https://www.frdc.com.au/project/2023-176).

Any questions in relation to the information in this document can be forwarded to the following:

Carryn Manicom

Marine Solutions - Project Manager

e: carryn@marinesolutions.net.au

Ally King

Marine Solutions – Project Officer

e: ally@marinesolutions.net.au

1 Project Background

Pipe Clay Lagoon (PCL) in southeastern Tasmania has sustained a shellfish aquaculture industry since the 1970s and currently hosts 11 shellfish (Pacific oyster) leases. In addition to the existing marine farming operations, the lagoon provides a safe anchorage for recreational vessels, and is used for boat launching and maintenance, recreational fishing, wind- and kitesurfing, kayaking, swimming, walking, horse riding and bird watching. In recent years, our own observations and anecdotal reports from multiple stakeholders are that the lagoon is undergoing significant change, including an increase in seagrass, change in sedimentation and hydrodynamics, and declining growth rates of farmed oysters. There is an urgent need to better understand the extent and causal agents of stress and change in Tasmanian lagoon systems, for protection of both environmental and socioeconomic values.

In early 2024 Marine Solutions were contacted by PCL oyster growers with concerns regarding the suppressed growth and increased mortality of farmed oysters in the lagoon. Marine Solutions put forward a funding proposal for a project '*Investigating the drivers of change in Pipe Clay Lagoon, a response to the needs of industry and community*' which included both a desktop and field work component. The FRDC approved funding for Marine Solutions to complete the desktop component of this project (i.e., a review of the available information and collation of data), and this report is currently in its final stages.

Concurrently, the Institute of Marine and Antarctic Studies (IMAS) is conducting a field investigation within PCL and reference sites, looking at oyster growth and condition, water quality, microbial and histopathological aspects, under funding from NRE Tasmania.

2 Scope of Investigation

Marine Solutions contacted a range of stakeholders and collated information and data relevant to PCL to complete a desktop review. Stakeholders included oyster growers (from PCL and other areas), community members, relevant government agencies, research and industry bodies.

All available information and data were assessed to identify potential lines of investigation. All hypotheses put forward during the consultation period were considered and the available data was examined to assess whether it supported each theory. The data available for PCL includes:

- Long-term datasets of water quality, phytoplankton, biotoxins and oyster meats from the Department of Natural Resources and Environment Tasmania (NRE Tas) Shellfish Market Access Program (ShellMAP),
- Recent water quality data from three sensors in PCL (part of the Oysters Tasmania sensor network),
- NRE Tas Animal Health Laboratory records for oyster samples submitted from PCL since 2020,

- Local groundwater quality records from Clarence City Council,
- Publicly accessible satellite images, and
- Published reports and aquaculture management documents.

A full list of data sources used in the report is provided in Appendix 1.

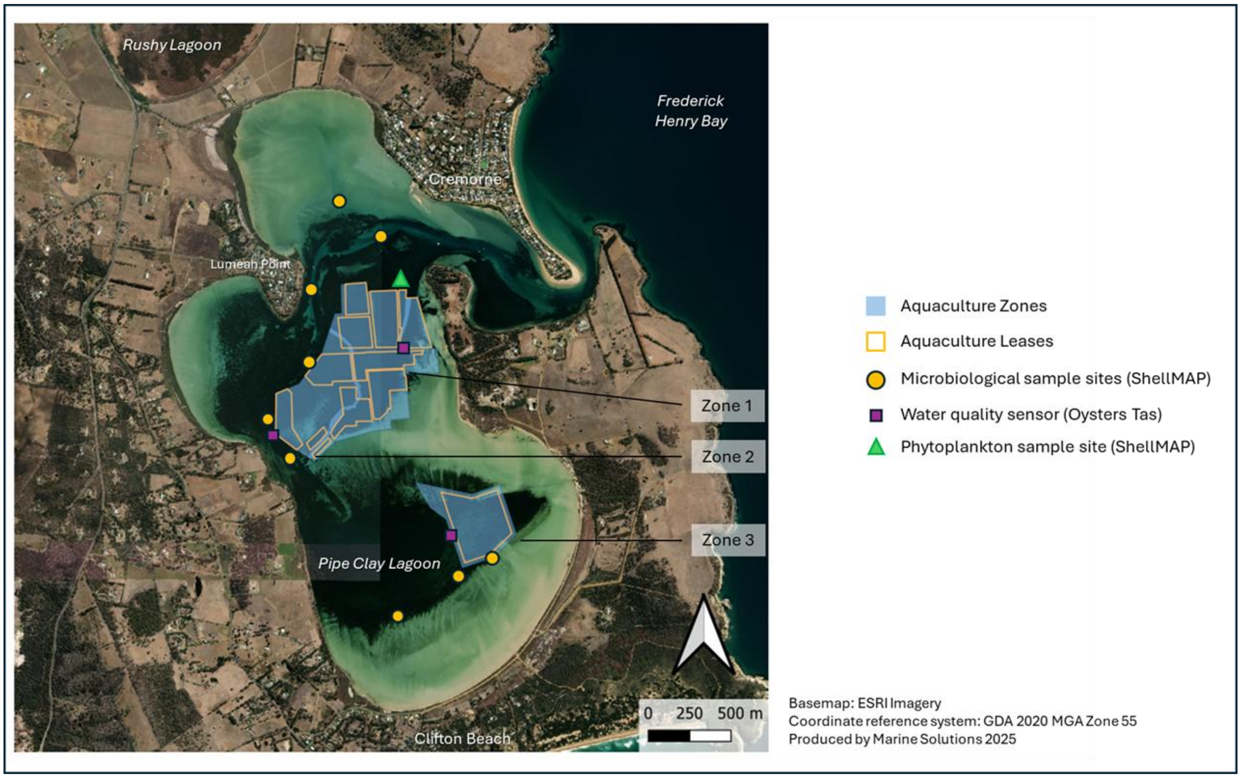


Figure 1. Map of Pipe Clay Lagoon (PCL) showing oyster leases, aquaculture zones, water quality and phytoplankton sampling sites.

3 Summary of Findings

The full report (FRDC report 2023-176) includes a summary of the consultation and data assimilation process. The results are discussed under themes that may contribute to the drivers of change in PCL. All themes covered in the full report are listed below, and a summary of the information available is presented in each section.

'Lagoon users' refers to the various people that use the lagoon, and includes the oyster growers and local community (including residents, recreational boaters, windsurfers, walkers, etc.).

3.1 Oyster Health

Data source	***Results***	***Conclusions***
Consultation with oyster growers	• Noted juvenile oysters had slow growth and poor condition, with dark shell and mantle, and mantle that appeared to not be able to grow to the edge of the shell. • First noted in leases in the north of the lagoon (Zone 1) before similar issues were seen in the south (Zone 3) in 2021 (Figure 1). • Initially only growing oysters were affected with larger animals able to maintain condition, but over time all oysters in the lagoon were impacted and by 2023 there was mortality in both juvenile and adult oysters. • In some leases, the oyster health impacts appeared to worsen in the warmer months.	

Data source	***Results***	***Conclusions***
Animal Health Laboratory - Over 90 separate submissions of Pacific oyster samples were sent from PCL oyster growers between February 2020 and July 2024.	• All samples tested negative to the Pacific Oyster Mortality Syndrome (POMS)-causing virus OsHV-1 and other known disease agents (including *Bonamia* sp., *Perkinsus olseni*, *Mikrocytos mackini*, *Marteilia* sp., *Marteilioides* sp., *Xenohaliotis* sp. and Iridovirus). • Some other observations included: - brown granules and haemocytes in oyster tissue (which indicates an inflammatory response), - inflammation of the adductor muscle, - some reports of stomachs containing filtered feed material (indicating that oysters were actively ingesting and absorbing feed). - some reports showing indications of starvation and salinity stress.	• Review by an independent histopathologist suggested that there was likely an ongoing issue diverting the oysters' energy towards an inflammatory response, and this diversion of energy would disrupt the balance between feeding and energy expenditure. • The inflammatory response suggests that the oyster health issue in PCL is likely related to water quality rather than a pathogen issue.
University of Technology Sydney's Ocean Microbiology laboratory - Early in 2024, samples of PCL oyster meats were sent for testing for the presence of *Vibrio* species.	• It was found that there was high correlation between *Vibrio* sp. load and mortality, with oysters from an area with high mortality group having very high *Vibrio* sp. loads, compared with oysters from a low mortality area.	• Oyster samples from PCL had significantly higher *Vibrio* loads. However, it is not possible to separate the cause and effect of bacterial infection and oyster condition on oyster disease (Oysters that are in poor condition are susceptible to infection by *Vibrio* sp. and this would contribute to mortality).

In summary, diseased oysters showed an inflammatory response likely due to issues in water quality. Infection of diseased oysters with *Vibrio* bacteria is likely a consequence of their poor condition, rather than the cause of oyster health issues in PCL. The current study by IMAS underway in PCL includes histopathology and testing of the microbiome of oyster samples, along with regular monitoring of water quality and algae.

3.2 Seagrass

Data source	***Results***	***Conclusions***
Consultation with lagoon users	• Noted proliferation of seagrass beds within the lagoon in recent years, becoming denser and more extensive with time. • Described changes to - water flow, - sediment type (increase in silty, muddy sediment from previously sandy substrate), and - resident fish and invertebrate communities.	• Seagrass beds are known to alter water flows (through reducing water velocity, influencing erosion and deposition, changing tidal circulation) and stabilise sediments. This then brings about other changes, such as a shift in resident estuarine communities.
Recent satellite imagery	• The habitat in PCL has shifted from open sand flats in 2016 to extensive dark cover of the sand flats in 2024 (see Appendix 2). This dark cover is assumed to be seagrass, based on direct observation and observations by residents and oyster growers.	• Increase in seagrass density is not uncommon, seagrass beds have expanded and increased in density in many estuaries and sheltered bays on the east coast of Tasmania in recent years. • The current extent and biomass of seagrass increase in PCL is significant and has resulted

Data source	*Results*	*Conclusions*
	• The first occurrence associated with the recent proliferation of seagrass appears at the mouth of the lagoon in January 2019 and becomes more extensive over time so that by October 2022 much of the seabed in the lagoon has a dense cover, including all three oyster farming zones.	in dramatic changes to the ecology of the lagoon, not seen on the same scale in other areas.
Historical reports and aerial imagery	• Seagrass was first documented in the lagoon in 1948 and had periods of growth and reduction in following years including a notable increase in coverage between 1993 and 1997, mostly near the entrance channel. Surveys conducted in 2004 – 2005 found very little seagrass (only small patches near the entrance channel).	• Seagrass presence and density has varied over time in PCL but has not previously been recorded in the same density and extent as current conditions.
Institute of Marine and Antarctic Science (IMAS) – Conducted a survey on the current proliferation of seagrass in PCL in 2023 (Ugalde and 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).	• 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. • Conditions for seagrass to become established may have been provided by increased nutrients from land-based run-off or leaching from the water table.

In summary, the timing of the proliferation of seagrass in PCL correlates closely with the observed impacts on oyster health in the lagoon. Seagrass has been recorded in PCL since the 1940s and the recent increase is likely due to large-scale climatic factors (as seen in other Tasmanian estuaries). Seagrass can impact water flow and sedimentation, as well as water quality conditions (through changes to O_2 and CO_2 through photosynthesis and respiration).

The relationship between seagrass beds and oysters is complex and can be beneficial or detrimental (depending on conditions) and could impact the broader ecology of the lagoon. Some of these impacts are discussed further in the Water Quality section.

3.3 Sediment and Hydrodynamics

Data source	*Results*	*Conclusions*
Consultation with lagoon users	• Users noted recent change to the hydrodynamics and sedimentation within PCL: - accumulation of sediment (at the lagoon entrance and boat launching area), - shallowing of the channel restricting navigation into PCL, and - reduced waterflow due to the proliferation of seagrass.	• 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. • Human influences that may have changed sedimentation around the lagoon mouth include - modification of the spit (housing construction, foreshore reclamation/protection and installation of the walkway to the pontoon),

Data source	*Results*	*Conclusions*
Aerial imagery	• There has been dynamic sediment movement at the lagoon entrance and within the channel over time. Erosion and accretion of the sediment around the entrance of PCL is documented in aerial photographs from as early as the 1930s.	- stabilisation of the foredunes along Cremorne and Clifton Beach, and - the development of marine farming in the lagoon. • The increased biomass of seagrass has high potential to reduce water depth and alter and reduce water flow to parts of the lagoon, but this has not been documented. • Considering that water flow is directly related to the supply of food for oysters (and other flora and fauna), variation in hydrodynamics would impact the carrying capacity for shellfish aquaculture in PCL.
Satellite imagery - National Intertidal Digital Elevation Model (NIDEM, Bishop-Taylor et al. 2019)	• The mouth (entrance) of PCL has clearly changed in recent years (see Appendix 3). • The intertidal zone of PCL has clearly shallowed in recent years (see Appendix 4).	
Hydrodynamics study - Crawford et al. (1996) survey of Tasmanian oyster farming areas to model carrying capacities	• Established that the lagoon is very shallow (only small area deeper than 2 m). • PCL had high rate of water exchange and rapid flushing rate (average flushing time of 1.4 tidal cycles) compared with other Tasmanian estuaries.	• This study (carried out between 1991 – 1993) is the only known hydrodynamics study in PCL. • It is likely that both sedimentation and seagrass proliferation have had an impact on the hydrodynamics of PCL in recent years, but this has not been documented. • A contemporary hydrodynamics study (e.g., 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.

In summary, 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. Variation in hydrodynamics may be impacting the carrying capacity for shellfish aquaculture in PCL.

3.4 Water Quality

Data source	***Results***	***Conclusions***
NRE Tas ShellMap monitoring - Water samples are collected at nine sites (see Figure 1) and tested for temperature and salinity in the field, with samples laboratory tested for faecal indicator bacteria (*Escherichia coli* and thermotolerant coliforms). Sampling is conducted at least six times per year.	• The long-term dataset shows seasonal variation in temperature, with no substantial change in the pattern over time. • Salinity was more variable from 2021 (see Figure 3 in Appendix 5). • Faecal indicator bacteria detected in water samples increased from 2021 (see Figure 4 in Appendix 5).	• Evidence of a greater variation in salinity in recent years can be attributed to warmer temperatures (increased evaporation in the shallow lagoon system) and increased rainfall (resulting in increased run off). • Rainfall is the factor most associated with faecal indicator bacteria, and recent increases in PCL may be due to increased rainfall and runoff. • Faecal indicator bacteria indicate the potential presence of pathogens that can impact the health of human consumers, but do not directly impact on oysters. There is little evidence that other bacterial communities co-occur with faecal indicator bacteria.

Data source	*Results*	*Conclusions*
Oyster Sensor Network – Three sensors in PCL, one in each zone (see Figure 1). Sensors are set up to continuously measure environmental parameters of the water at 15-minute intervals, at ~20 cm below the water surface.	• Sensors recorded a temperature increase over summer with a concurrent reduction in dissolved oxygen (DO) over the warmer months (see Figure 5 in Appendix 5). • Looking more closely at the daily water quality showed that DO levels vary significantly throughout the day (see Figure 6 in Appendix 5). • In PCL, DO levels are high during the day, consistent with oxygen produced by plants (seagrass) during photosynthesis. DO increased rapidly after sunrise and peaked mid-morning with a small drop during the day consistent with the turn of the tide. DO level dropped through the afternoon and evening, with near-hypoxic (no oxygen) conditions in the early hours of the morning consistent with oxygen used during respiration by plants in the dark. • Sensors recorded large fluctuations in daily pH, with greater variability in the warmer months (see Figure 7 in Appendix 5). Looking more closely at the daily water quality showed that pH varies by up to 0.4 units during the day (see Figure 8 in Appendix 5).	• Daily cycling hypoxia (very low oxygen) is a phenomenon that frequently occurs during the summer in shallow water because of variation in photosynthetic and respiration rates of plants (phytoplankton, algae and in the case of PCL, seagrass) that corresponds with the day/night cycle. • It is suggested that the presence of seagrass strongly impacts the incidence of daily hypoxia. • Large daily fluctuations in DO, as seen in shallow estuaries, present greater challenges to aquatic life than persistent hypoxia, and even brief hypoxic episodes can affect organisms' growth, survival, and susceptibility to disease. • 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.
Storm Bay Broadscale Environmental Monitoring Program - Salmon aquaculture introduces nutrients into	• 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	• Nutrient levels in the lagoon remain low and comparable to historical records with little

Data source	***Results***	***Conclusions***
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).	Wedge lease (off the western Tasman Peninsula), both ~22 km south of the mouth of PCL. • 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. • BEMP nutrient ranges are similar to early 1990s PCL data. A four-week water quality study in PCL (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 for well-flushed Tasmanian estuaries.	apparent effect from distant salmon aquaculture.

In summary, there are substantial daily fluctuations in dissolved oxygen, temperature and pH in PCL, most notably in the summer months. It is assumed that these daily water quality fluctuations would place significant stress on marine organisms, including Pacific oysters. Recent fluctuations in salinity and faecal indicator bacteria are likely due to increased rainfall and run-off. There is no apparent effect of distant salmon aquaculture on lagoon water quality.

3.5 Phytoplankton (algae)

Data source	*Results*	*Conclusions*
Consultation with growers	- Concerns regarding the potentially evolving planktonic community composition within PCL. - The change to the sand bar at the entrance to PCL (see Section 3.3) 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.	- Oysters consume plankton and detritus from the water column from <1 to 20 µm in size. - Little is known about the preferred and problematic phytoplankton for Pacific oysters.
DPIPWE 2008 – Marine Farming Development Plan	- 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.	- 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.
	- 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.

Data source	*Results*	*Conclusions*
ShellMAP – phytoplankton sampling in PCL (2004 – current with varying sampling analysis in that time) **Storm Bay Broadscale Environmental Monitoring Program** – species counts of phytoplankton at sites in Frederick Henry Bay and Storm Bay	• Comparison of full phytoplankton species counts showed little change over time in the biomass and types of phytoplankton available in PCL (recent counts were similar to 2004 – 2012 period). • Notable inclusion of cyanobacteria (blue-green algae) species on three sampling occasions in 2023 and 2024. • 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. Detection of known toxic or harmful algal species was rare.	• Diatoms, dinoflagellates and cyanobacteria have the potential to accumulate as 'Harmful Algal Blooms' (HABs) under favourable conditions of increased nutrients and temperature. • Phytoplankton toxins can be harmful to human consumers, but there are also algae with toxins that can be harmful to filter feeders (oysters) themselves. This can be from hypoxia (very low oxygen) from high bloom density, or through mechanical irritation (spines and spikes), or through toxic compounds that damage or kill cells causing disease. • 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.

In summary, all available phytoplankton data was interrogated to assess change over time (quantity and type) and increase in known toxic and/or harmful species (Harmful Algal Blooms). Besides detection of cyanobacteria (blue-green algae) in 2023-24 (attributed to increased rainfall and run-off), from the available data there was no evidence of a change to phytoplankton species and abundance in recent years.

3.6 Toxins and Contaminants

Data source	***Results***	***Conclusions***
ShellMap – weekly biotoxin testing on PCL oyster meat samples.	• Biotoxin risk rating for PCL has been classified as high since 2015, weekly testing is conducted. • Low level presence of paralytic shellfish toxin (PST) in oyster meats in PCL on isolated occasions in 2021 and 2022.	• No evidence to suggest recent significant contamination of oyster meats, and therefore it is unlikely that toxins and contaminants have caused the recent oyster health issues.
ShellMap – Chemical and heavy metal residue testing of shellfish is conducted on a triennial basis. **Lab results** - metals analysis from a PCL wild (invasive) Pacific oyster sample compared with a sample from Little Swanport in August 2022.	• Historically (1980s and 90s), heavy metals were elevated in PCL oyster meats compared with other Tasmanian estuaries. Levels have significantly reduced since the early 1990s, but still greater than other estuaries. • 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 for regulated heavy metals, except for zinc.	

Data source	*Results*	*Conclusions*
	• High concentrations of metal analytes in wild Pacific oyster meats when compared with samples from Little Swanport.	

In summary, there is no evidence of significant change to biotoxin, measured chemical contaminants or heavy metals in oyster meats in recent years.

3.7 Groundwater

Data source	*Results*	*Conclusions*
Clarence City Council – Has monitored groundwater bores for nutrients and faecal contaminants in the PCL area since 2009.	• 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). • Records of elevated ammonia (>10 mg/L) at some sites, with no spatial pattern or increasing trend.	• The dynamics of groundwater in the area surrounding PCL is unknown, but it is likely that PCL is connected to Ralphs Bay via the groundwater aquifer south of Lauderdale. • Without nutrient analysis of water samples from PCL at a similar time, it is not possible to know whether groundwater influences the quality of surface water in PCL.

In summary, there is no evidence of significant change to groundwater quality from the parameters tested in recent years.

3.8 Changes to other species and populations in PCL

Data source	***Results***	***Conclusions***
Consultation with lagoon users	• Observed declines in previously abundant species, including cunjevoi (*Pyura stolonifera*) and other biofouling organisms. • Observed increases in species, including mock oysters (*Electroma papilionacea*), short-spined urchins (*Heliocidaris erythrogramma),* black swans (*Cygnus atratus)* and cormorants (*Phalacrocorax* sp.). • Anecdotal change to recreational fish species.	• Observed changes in species appear to have coincided with the increase in seagrass in the lagoon.
	• Change to wild (invasive, non-farmed) Pacific oyster populations (both increase and decrease have been reported). • Oyster growers and local community (supported by NRM South) have removed a portion of wild oysters from the lagoon shoreline in recent years.	• Wild Pacific oysters in PCL may reduce available food for farmed oysters and alter local hydrodynamics.
Department of State Growth Relocation of live-bearing seastars (*Parvulastra vivipara*) from Midway Point and Sorell causeways to PCL	• Habitat on the western shoreline of PCL has been augmented with small rocks for the relocation of critically endangered live-bearing seastars from Pittwater. • In conjunction with relocation, IMAS plans to remove competitors for seastar resources, wild Pacific oysters and New Zealand porcelain crabs (*Petrolisthes elongatus*), from the PCL shoreline.	• Unrelated to the current seagrass proliferation and farmed oyster decline, but worth noting as a change to lagoon species.

In summary, there has been notable change in the presence and abundance of other species in PCL. Some of these changes may coincide with the increase in seagrass and decline in farmed oysters in PCL, however further investigations would be required to better understand these interactions.

3.9 Broadscale climate drivers

Data source	***Results***	***Conclusions***
Bureau of Meteorology (BOM) Monthly average temperature and rainfall for Hoabrt, 1960 to 2025	• The Pacific Ocean experienced a rare multi-year La Niña event from 2020 – 2023 (this has only happened three times in 50 years). • In Tasmania, this period is characterised by higher-than-average rainfall, greater average maximum temperatures and warmer ocean temperatures.	• Environmental changes observed in PCL including the proliferation of seagrass, increased sedimentation in the lagoon and the growth and mortality issues with farmed oysters align with this change in climate.

In summary, it is likely that the recent prolonged La Niña event is a driver of environmental change in PCL, resulting in the proliferation of seagrass and alteration to hydrodynamics, sedimentation and community structure in the lagoon.

4 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 in PCL.
- 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. 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 Conclusion: A Perfect Storm

The assessment of existing literature and data could not identify a single cause for the reduced growth and increased mortality of farmed Pacific oysters in Pipe Clay Lagoon. Instead, the issues appear to result from a combination of environmental factors acting together, with the resultant outcome worse than any single factor alone —a perfect storm.

Warmer temperatures and increased rainfall and run-off (the result of a multi-year La Niña event) has altered seagrass distribution around Tasmania, contributing to the increased seagrass proliferation in Pipe Clay Lagoon. At the same time, the lagoon has shallowed over recent years, possibly due to change in sedimentation at the lagoon entrance, sediment stabilization by seagrass, or both (Figure 2).

The combination of a shallower lagoon and the increased density of seagrass has likely changed the lagoon flow dynamics, reducing water flow to oysters and altering the replenishment of food supply, and the flushing of waste. In addition to reduced water flow and food supply, the lagoon's physiochemical water parameters have likely changed due to these same processes. Seagrass photosynthesizes during the day, producing oxygen, but respires at night, consuming oxygen. This leads to significant daily fluctuations in dissolved oxygen (DO), with high levels during daylight and near-hypoxic conditions at night (Figure 2). Large daily fluctuations in pH have also been observed, likely driven by changes in oxygen and carbon cycling.

While no DO or pH data exists from before the seagrass expansion, it is reasonable to conclude that seagrass proliferation is driving these daily hypoxic events. Daily fluctuating oxygen levels are likely to impose significant stress on oysters, particularly during warmer water temperatures. This mechanism may explain the progressive worsening of oyster health observed each summer, as seagrass coverage and water chemistry fluctuations intensify. It is likely that oysters are impacted due to the cumulative impact of these changes.

Overall, these findings highlight the need for a broader approach to monitoring, collaboration and management, aimed at understanding shared environmental stressors and building industry-wide resilience.

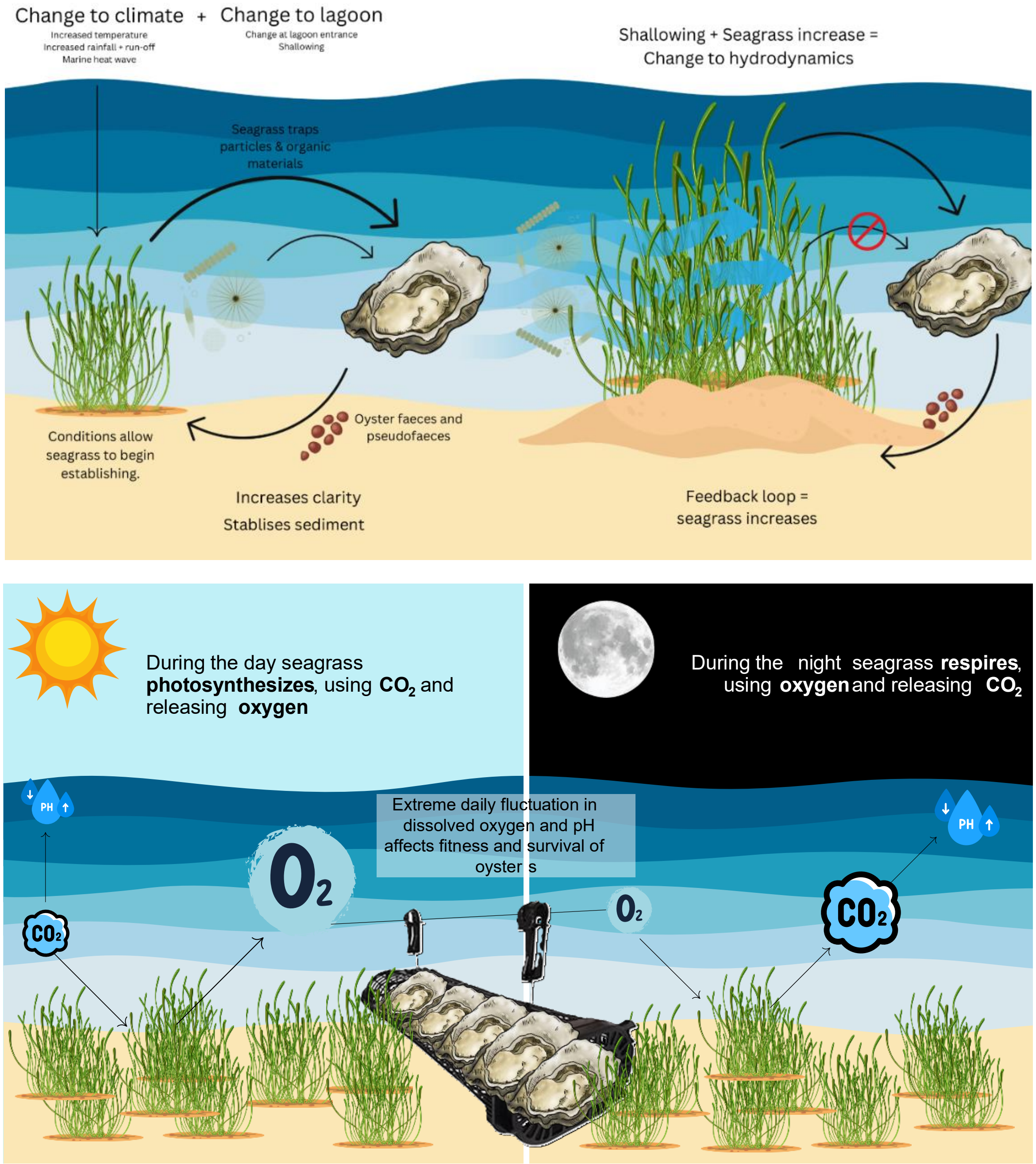


Figure 2. Conceptual diagrams showing interconnecting drivers of change in Pipe Clay Lagoon.

Expansion of seagrass beds has stabilised sediments, increased sedimentation, and altered hydrodynamics, leading to changes in water quality and lagoon depth. These shifts have changed water flow and created daily fluctuations in dissolved oxygen and pH. 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 Future considerations and recommendations

Given the complexity of ecosystem changes and the likely 'perfect storm' of environmental change affecting Pipe Clay Lagoon, identifying clear solutions for oyster growers remains challenging. However, in response, we have proposed a set of recommendations focused on addressing key knowledge gaps, future fieldwork and improved management approaches. These actions present valuable opportunities to strengthen the resilience of the broader oyster industry and enhance preparedness for future adverse events.

The full report lists recommendations including:

- 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 marine farming plan accordingly. Accurate assessment of the full current extent of the seagrass in PCL could be achieved in this same study.
- Collection of standardised data and parameters, so that records are consistent and comparable through time.
- Increased collaboration between industry, government, research and community stakeholders, potentially through the implementation of a working group.
- An open-access repository of all relevant information for all Tasmanian oyster-growing areas. When studies are initiated, data is collected, results are published - it is sent to a central repository and stored on file for quick access.
- Oyster grower access to a shared database to record and document observations, including date, time, environmental observation and photo documentation. This would assist in recording and quantifying important anecdotal information.
- Requirement for the collection of information from when declining oyster growth rates is first noted, including date, location, observations and regular measurements of shell length and oyster condition.

Appendix 1. Data accessed relating to Pipe Clay Lagoon

Data type	Ownership	Details
Anecdotal data	Individual oyster growers from PCL aquaculture leases, including: - Tasmanian Oyster Co. (Lease 12, 108, 198, 226) - Pipe Clay Oysters (Lease 15, 197, 270) - Amycus Pty Ltd (Lease 97, 13) - Clifton Pacific Oysters (Lease 98) - Albatross Fishing Pty Ltd (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.
	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.
	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
	IMAS	Crawford et al. (1996) FRDC Grant 92/54 - Predictive modelling of carrying capacities of oyster (*Crassostrea gigas*) farming areas in Tasmania. July, 1996.
		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.
Aerial / satellite imagery	Google Earth	Google Earth Pro (2025) Pipe Clay Lagoon. 55G 544504 m E, 5242568 m S, elevation 0m. 2D map. Time scale 2016 – 2024.
	Digital Earth Australia	National Intertidal Digital Elevation Model (NIDEM, Bishop-Taylor et al. 2019)
	ArcGIS	ArcGIS World Imagery & Esri Wayback archive, time scale 2014 – 2025.
General Pipe Clay Lagoon documents	NRE Tas	NRE Tas Pipe Clay Lagoon Environmental Information, *unpublished*
	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 (2009) Climate Change Impacts on Clarence coastal areas – Final Report, prepared by SGS Economics and Planning & UNSW water Research laboratory, April 2009

Appendix 2. Satellite images of Pipe Clay Lagoon between 2016 and 2024

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).

02 March 2016 03 January 2019

09 April 2020 03 September 2021

01 October 2022 02 October 2024

Appendix 3. Change to sedimentation at the entrance to Pipe Clay Lagoon since 2016.

Images show the formation of a sand bar at the Pipe Clay Lagoon entrance (basemaps: Esri World Imagery wayback digital archive).

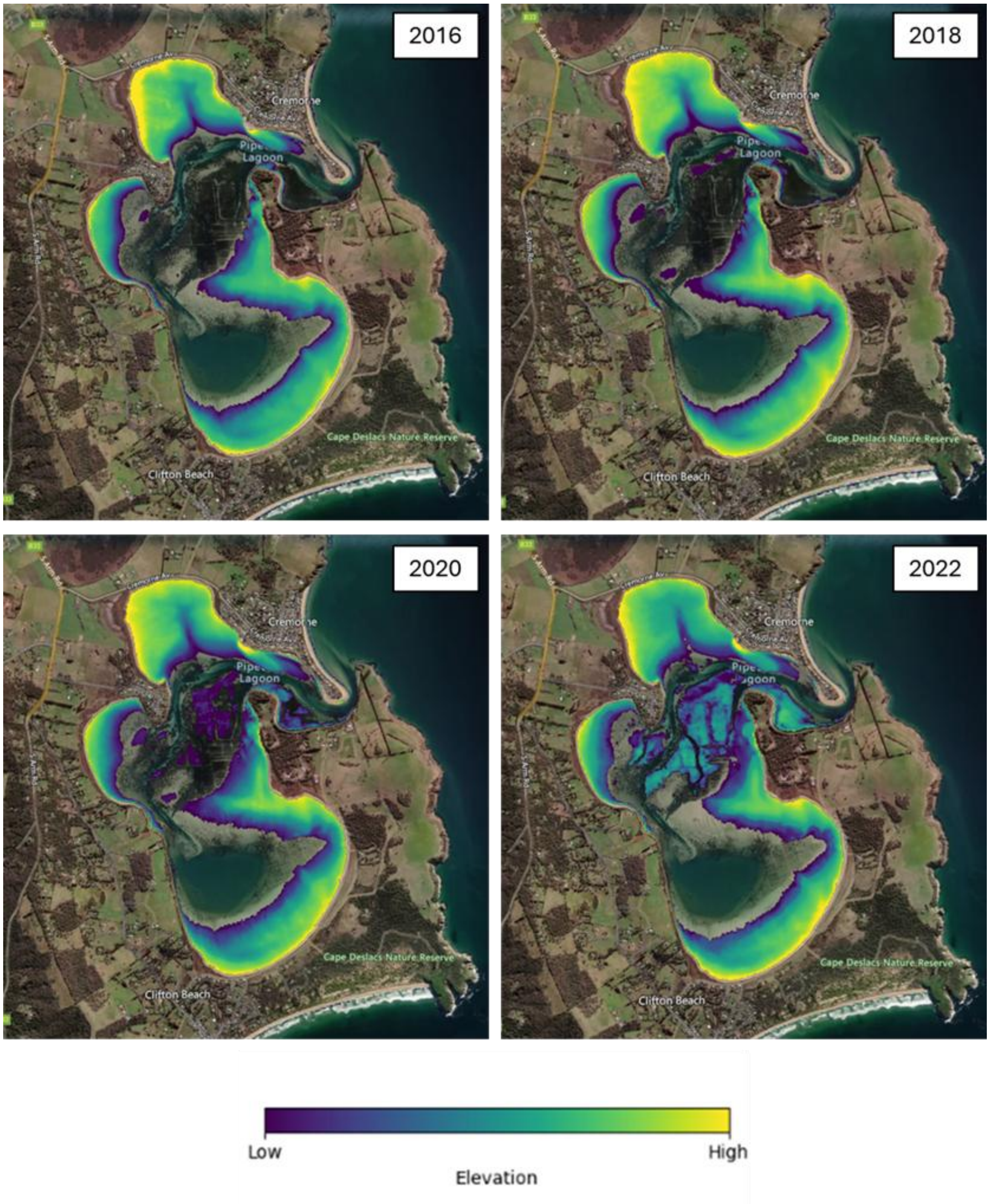
September 2016 October 2017 May 2021 April 2025

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

September 2016 October 2017 May 2021 April 2025

Appendix 4. 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: Digital Earth Australia, Geoscience Australia).



Appendix 5. Water quality results from recent sampling in Pipe Clay Lagoon

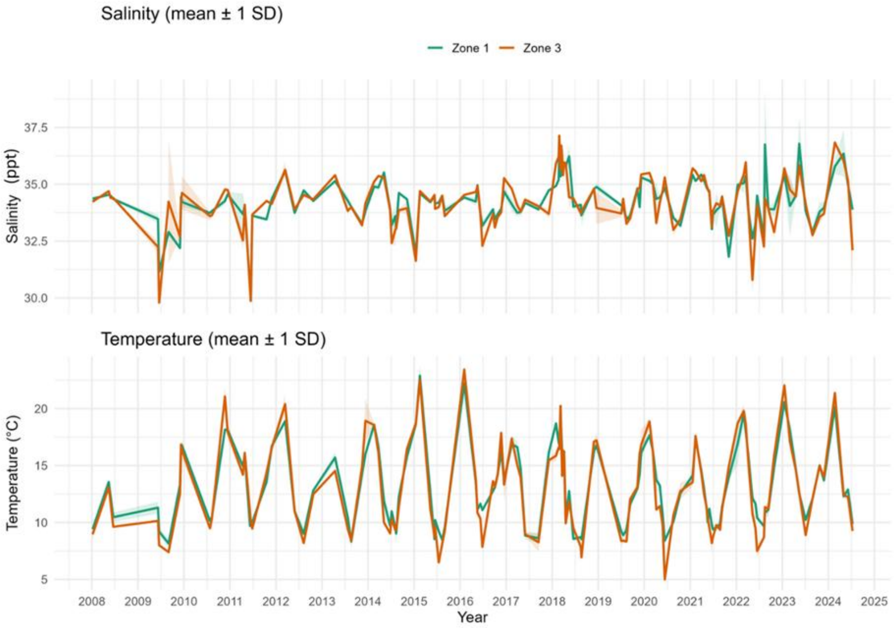


Figure 3. Temperature (°C) and salinity (ppt) in Pipe Clay Lagoon Zone 1 and Zone 3 from 2008 (data provided by ShellMAP).

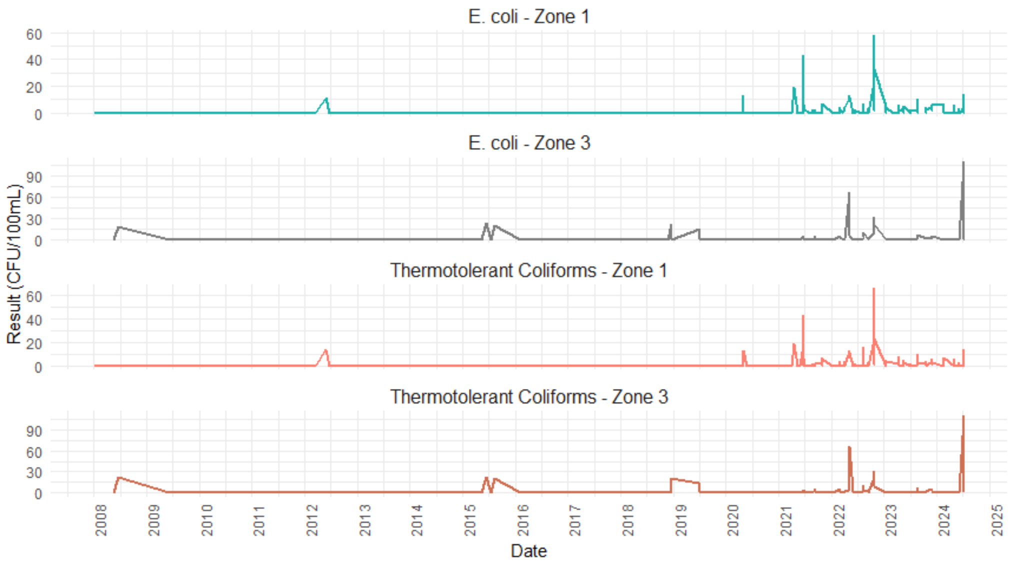


Figure 4. Indicators of faecal contamination (*E. coli* and thermotolerant coliforms) from regular monitoring in Pipe Clay Lagoon Zone 1 and Zone 3 (data provided by ShellMAP).

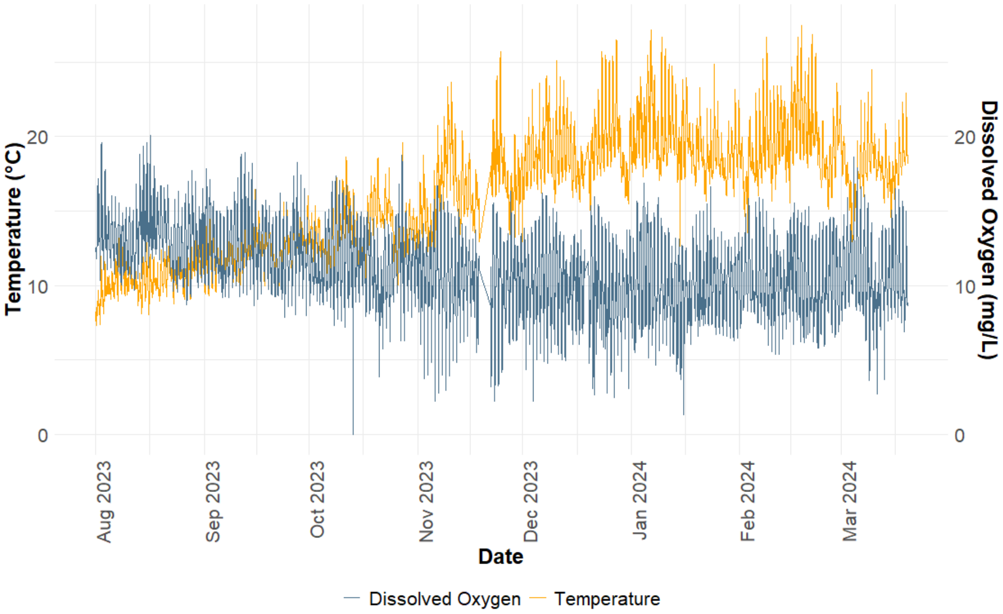


Figure 5. Annual variation in temperature (°C) and dissolved oxygen (mg/L) measured in Pipe Clay Lagoon Zone 1 between August 2023 and March 2024 (source: Oyster Sensor Network). Time period reflects the availability of consistent data.

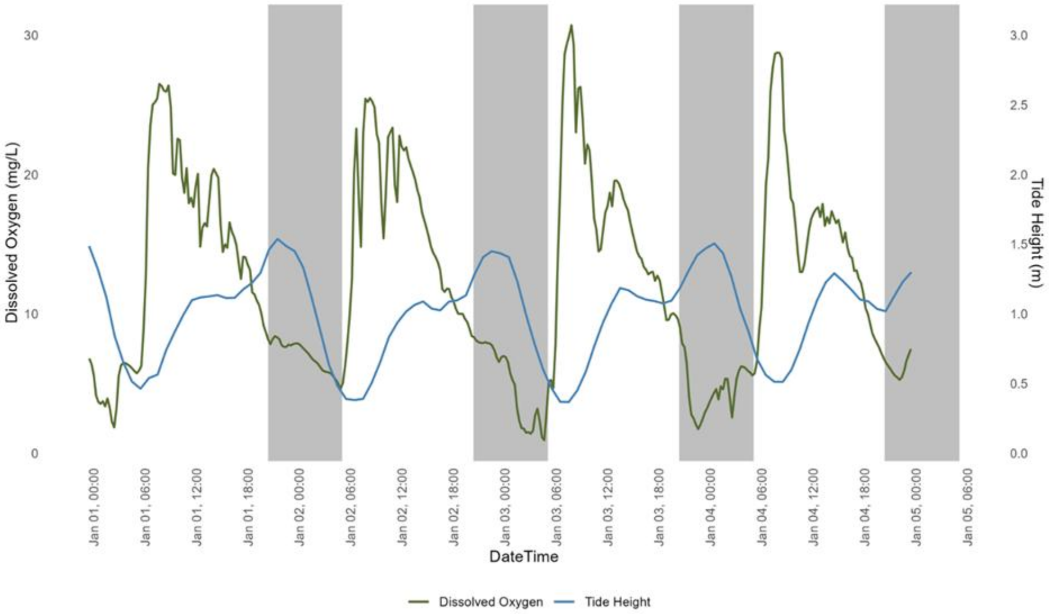


Figure 6. Daily fluctuation in dissolved oxygen (mg/L) in Zone 3 in Pipe Clay Lagoon relative to tide height and day/night (nighttime is shaded) for a small subset of the data, measured in January 2025 (source: Oyster Sensor Network data).

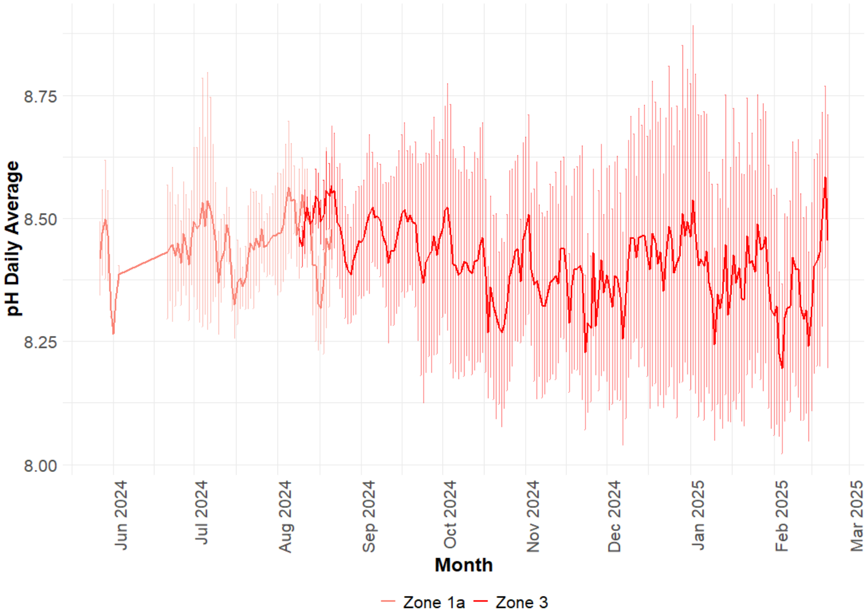


Figure 7. Average pH measured in Pipe Clay Lagoon Zone 1 and Zone 3 between June 2024 and March 2025 (source: Oyster Sensor Network). Time period reflects the available data.

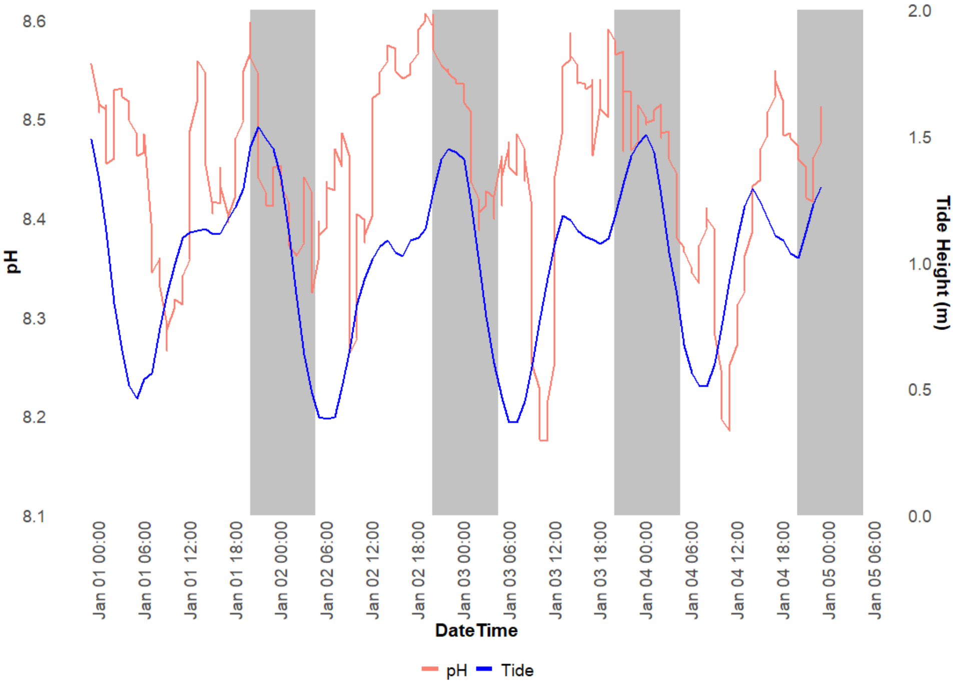


Figure 8. Daily fluctuation in pH in Zone 3 in Pipe Clay Lagoon relative to tide height and day/night (nighttime is shaded) for a small subset of the data, measured in January 2025 (source: Oyster Sensor Network data).