# Circumstances for Consideration Under S42(T)(5)

## Introduction

Additional circumstances for consideration are provided below. These circumstances are a summary of the current scientific knowledge of Macquarie Harbour, the interactions regarding anthropogenic stressors (primarily salmon farming) to the harbour and the response of water quality and the benthic ecosystem response. The circumstances also extend to the current knowledge of the Maugean Skate in the harbour and updated state and commonwealth advice regarding the conservation status of the Maugean Skate.

It should be noted that the vast amounts of research that have been undertaken in Macquarie Harbour have been done so by independent scientific organisations including the Institute for Marine and Antarctic Studies and also the Commonwealth Scientific and Industrial Research Organisation. In addition to independent scientific studies, there has also been a plethora of environmental monitoring undertaken in the Harbour since 1993. The EPA started conducting water quality monitoring in the Harbour in 1993 with continuous datasets collected since then. In addition, the aquaculture industry has been responsible for conducting broadscale environmental monitoring in the harbour since 2011.

In addition, to this more recent monitoring, other historical studies have been undertaken in the harbour to understand the oceanographic environment and the status of the benthic environment in response to hydroelectric installations on the west-coast of Tasmania and also the ongoing impact of legacy mining in the harbour.

Whilst the below is a summary of an immense amount of work undertaken in Macquarie Harbour to understand its dynamics and how it response to anthropogenic stressors, there are ongoing research projects in the harbour to further our understanding of this ecosystem and the many interactions that influence its ecological status.

## Water Quality

### *EPA Monitoring*

The EPA has been monitoring water quality within Macquarie Harbour since 1993. The monitoring has been undertaken on a near quarterly basis and has included physico-chemical parameters, nutrients and metals. In 2013 data logger instrumentation was deployed on the boundary of the World Heritage Area (WHA). Dissolved oxygen readings were taken at 10, 25 and 35 metres from the surface at intervals of 15 to 20 minutes. Logging of data continued until December 2022 and was re-established in September 2023.

The data from the logger instrumentation and water quality samples has allowed for the characterisation of water quality within the harbour and has provided information on the influence of catchment inflows, primarily from the Gordon and King Rivers and on the exchange of marine and harbour water through Kelly Channel.

The data has aided EPA in determination of biomass levels and more recently Total Permissible Dissolved Nitrogen Output (TPDNO) limits. The data has also been used by IMAS as part of the MHEMP Review and FRDC project 2016/067 "Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour", by CSIRO as part of FRDC project 2016/067 "Macquarie Harbour Oxygen Process model" and by the Macquarie Harbour Dissolved Oxygen Working Group (MHDOWG).

In September 2023, the EPA installed five new Dissolved Oxygen loggers, to replace old equipment, throughout Macquarie Harbour, including at the WHA boundary site where data had previously been

collected. In 2024, the EPA intends to deploy more logger instrumentation at additional sites within Macquarie Harbour to further characterise the dynamics of dissolved oxygen in the harbour. This is in addition to dissolved oxygen loggers installed and operated by industry and research institutions.

The EPA also continues to undertake quarterly monitoring of physico-chemical parameters, nutrients and metals at 15 sites throughout Macquarie Harbour. This is in addition to the 17 sites monitored by salmon companies under the Broadscale Environmental Monitoring Program (BEMP) requirements of the environmental licences.

All available data is compared to long term datasets (these include data since 2013 for oxygen logger data and since 1993 for quarterly water sampling data) by the EPA.

***Analysis of EPA Dissolved Oxygen Monitoring.***

A review of the long-term monitoring data indicates that the dissolved oxygen in most of the harbour continues to be significantly below pre-2010 levels, supporting a weight of evidence case for a declined ecosystem health status compared to pre-2010.

While dissolved oxygen levels in the harbour vary due to the circulation pattern hydrodynamics, which are influenced by riverine and marine inputs, the dissolved oxygen drawdown due to finfish aquaculture in the middle and bottom water is significant.

The equilibrium state for surface waters (recorded at 10 m depth) has shifted from a normoxic historic range of 5-8 mg/L to a state where the median more frequently occupies a level around the long-term 20$^{th}$ percentile or below.

In deeper waters, median dissolved oxygen levels have moved from the historic 20$^{th}$-80$^{th}$ percentile range of 3-5 mg/L to the severely hypoxic range of 1-2 mg/L. Levels remain below the long-term 20$^{th}$ percentile.

Over the past 12 months dissolved oxygen values measured at the WHA boundary have remained critically below the long-term averages. Since October 2022 surface water levels (recorded at 10 m depth) have sharply declined to values not previously recorded. Dissolved oxygen values have dropped below 1 mg/L on occasions, with the balance oscillating around 2 mg/L, compared to the long-term average for this depth of ~5 mg/L. It appears that reduced freshwater flow through the harbour is allowing tidal incursions of marine waters to displace bottom (recorded at 35 m) waters upwards into the mid-depth (recorded at 25 m) and subsequently surface (recorded at 10 m) depths. Dissolved oxygen values in bottom and mid-depth water have also declined over this period with bottom waters between 1 mg/L and 2 mg/L, compared to the long-term average ~4.2 mg/L, and mid-depth water in the vicinity of 1 mg/L, compared to a long-term average ~4 mg/L.

A report of these data is available in the EPA Macquarie Harbour Dissolved Oxygen - February 2023 report.

## *Industry Monitoring*

### *Environmental Licence Water Quality Monitoring*

Under the conditions of the Environmental Licences, licence holders are required to participate in the Macquarie Harbour Broadscale Environmental Monitoring Program (MHBEMP). The MHBEMP gathers a suite of nutrient, physico-chemical and phytoplankton data throughout Macquarie Harbour and the major tributaries, to try to determine whether aquaculture operations within the harbour are influencing the dynamics of the broader system.

Monthly ammonia, nitrate and dissolved oxygen data collected at compliance sites under the MHBEMP requirements demonstrate compliance with the water quality limits outlined in each Environmental Licence. The most recent dataset submitted included data collected up to and including October 2023.

Median rolling annual values for each specified parameter and water depth are compared against the relevant limits. Median values for ammonia and nitrate have remained stable in recent years and have continued to show improvement compared to earlier reporting periods (e.g. 2016). All values remain well below the respective limits.

Dissolved oxygen at 2 m depth has remained steadily above the limit, indicating well oxygenated surface waters with dissolved oxygen levels in the range of 8 to 10 mg/L.

Following an improvement in dissolved oxygen levels at 20 metres depth in 2021, concentrations in 2022 returned to lower levels, similar to those observed in 2016-17. More recent datasets however indicate improved dissolved oxygen concentrations at this depth. The last two assessment periods have shown levels around 2.7 mg/L.

#### *Dissolved Oxygen Logger Strings*

Dissolved oxygen logger strings continue to collect real time data collected through logger strings deployed at three locations across Macquarie Harbour (Franklin, Strahan and Table Head Central). Strings deployed at these locations measure key water quality parameters, including dissolved oxygen, temperature and salinity, at several depth intervals. Logged data can be accessed remotely.

## *A Summary of Research Monitoring in the Harbour*

### *CSIRO Logger Strings*

CSIRO maintains a sensor station in Macquarie Harbour which delivers datasets of hourly profiles of temperature, salinity, dissolved oxygen, chlorophyll and fluorescence in near real-time. The instruments have been operating in a location in the north of the harbour since June 2019. This sensor data has been used to generate near real-time and short-term forecast model results in the harbour and will feed into the Sustained Operation of the CSIRO Model and Information Systems for Macquarie Harbour by CSIRO – a commitment by the Tasmanian Government Salmon Plan.

#### *IMAS/CSIRO Dissolved Oxygen Reports & Modelling*

As has been demonstrated in earlier studies by Cresswell, Edwards and Barker (1989) and others, water column profiles conducted in Macquarie Harbour by Ross et al. 2015 have further demonstrated the highly stratified nature of Macquarie Harbour showing that the system is characterised by low salinities and high dissolved oxygen conditions in the surface waters compared with higher salinities and low dissolved oxygen conditions in the bottom waters. Surface salinity declined through the winter (May 2013) and spring (September 2013) surveys, consistent with the large step change increase in Gordon River flow that occurred in early 2013 due to increased power generation. Most notably, despite reasonably stable bottom water temperatures and salinities across the four surveys, dissolved oxygen of bottom waters declined significantly in winter and spring 2013, reaching 0.2 - 0.9 mg/L in the spring survey. More recent modelling studies within the harbour have demonstrated that the replenishment of oxygen in Macquarie harbour is reliant on oceanic and wind-driven recharge events through late spring to autumn when river conditions result in low flows to the harbour together with a complex interplay of anthropogenic nutrient loads from sources including towns and finfish aquaculture (Ross et al. 2021).

The topography of Macquarie Harbour is such that it is conceivable that while surface water may have a relatively short residence time the strong halocline and shallow sill may conspire to retain much of the mid water for a significant period of time. Oxygen diffusion is a very slow process such that a body of water sandwiched between oxygenated fresh water at the surface and occasional intrusions of oxygenated water at the bottom is essentially "isolated" with no opportunity for horizontal exchange with the ocean and therefore may be considered a closed system leading to a slow decline in dissolved oxygen. In this situation it may only require consumption of relatively small quantities of organic matter to drive dissolved oxygen down to the levels that have been measured. The strong seasonal cycle in dissolved oxygen makes it clear that processes consuming oxygen dominate from spring to autumn with significant resupply typically occurring during winter. The multiyear pattern of seasonal decline in dissolved oxygen below the halocline implies a consistent seasonal change in the balance of oxygen consumption and resupply (Revill et al. 2016).

Declines in dissolved oxygen are occurring throughout the world's oceans due to increased stratification. In the open ocean this is most often associated with warming. In coastal seas it has also been associated with more precipitation, freshwater runoff and eutrophication. All of these external factors are likely to be important in Macquarie Harbour as it is a highly stratified system with limited exchange with the ocean. In

addition, an increase in oxygen consumption is a reasonable expectation given the direct respiration of the substantial increase in farmed fish and the increased input of associated organic matter and ammonium (Revill et al. 2016).

A further major finding by Revill et al. 2016 was that gross pelagic biological oxygen demand is greatest at 3 m but net oxygen consumption is greatest at about 15 m. This highlights the role that surface exchange of oxygen (probably wind driven) plays in maintaining dissolved oxygen levels above the halocline, while below this depth, exchange is limited. It also highlights the capacity of surface waters above the halocline to decline rapidly when exchange processes become limited over an extended period as has recently been observed.

Through the FRDC funded project – Macquarie Harbour Oxygen Process Model (2016-067) CSIRO has developed and implemented a biochemical and water quality model for Macquarie Harbour based on data observed in 2017 and 2018. The model reproduces the hydrodynamics, biochemical cycling, and dissolved oxygen conditions in the Harbour. The modelling scenarios identified the key role of river flow and anthropogenic loads in modulating the oxygen status of Macquarie Harbour, with key microbial communities driving the biogeochemical cycling of nutrients, the remineralisation of organic matter and the ecological drawdown of oxygen (Wild-Allen et al. 2020). Recommendations from the report include provisions for further scenario simulations to better characterise the impact of contrasting anthropogenic loads. There is also evidence that variation in seasonal Hydro Tasmania dam releases can impact flushing and harbour oxygen status. This modelling tool has been provided in principle support by the Tasmanian Government to feed into the Sustained Operation of the CSIRO Model and Information Systems for Macquarie Harbour by CSIRO – a commitment by the Tasmanian Government Salmon Plan.

### **Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour - March 2021 (FRDC Project 2016-067)**

The final report in a series of reports, including the before mention CSIRO Macquarie Harbour Oxygen Process Model - June 2020. This report summerises the research undertaken by IMAS and CSIRO for the purpose of investigating deteriorating benthic conditions in Macquarie Harbour observed in the middle and bottom and waters in spring 2016. A major output of the FRDC project 2016-067 was the provision of advice to the EPA and industry on benthic and water column condition in the Harbour and how it related to ongoing management actions both operationally and of a regulatory nature. This took the form of eight IMAS reports on the status of dissolved oxygen and benthic conditions in the harbour based on the latest research observations. The Director, EPA utilised this information to inform their determinations for biomass in the harbour.

The research identified seasonal deterioration of benthic condition and decline in dissolved oxygen concentrations during spring followed by an improvement in benthic conditions in autumn-winter during replenishment of oxygen due to oceanic and wind driven recharge through late spring to autumn. The research identified the impacts that weather plays both directly and indirectly in influencing the magnitude and extent of seasonal decline in the harbour and therefore the capacity for dissolved oxygen to reach levels that may lead to deterioration with benthic conditions.

Key challenges facing finfish farmers and regulators are understanding the capacity of Macquarie Harbour to support finfish aquaculture and predicting the length of fallowing required for benthic recovery. It is clear that dissolved oxygen concentrations have been, and will be, a major determinant of the benthic response and this has major implications for management of finfish farming operations and environmental regulation in the harbour. The research undertaken by IMAS, and the model produced by CSIRO during FRDC project 2016-067 provides clarity on the drivers of oxygen dynamics, the influence of dissolved oxygen concentrations on benthic conditions and the effectiveness and duration of fallowing and remediation strategies (Strategies that are implemented by industry to allow recovery of benthic habitats during signs of organic enrichment and non-compliance with environmental licence conditions). The outputs from FRDC Project 2016-067 provides information that is essential for both operational management of farming activities and contemporaneous environmental regulation of aquaculture in Macquarie Harbour over the longer term.

### *Addition of new Environmental Licence conditions*

Despite promising signs of improving dissolved oxygen levels in Macquarie Harbour, dissolved oxygen still remains at levels lower than those observed historically and may produce ecological affects contributing to an increased extinction risk, most notably for the Maugean Skate.

Where the Director decides to renew licences, Dissolved Oxygen Management Requirements should be included in environmental licences to ensure that each of the marine finfish farming companies are working towards improving the water quality of the Harbour.

The conditions should require each licence holder in Macquarie Harbour to provide an estimate of oxygen consumption resulting from the farming activity on their lease, and to develop a mitigation plan for the 2024-25 finfish farming production period. The plan should also outline how the dissolved oxygen consumption generated can be offset or reduced and must make reference to the achievement of interim Default Guideline Values (DGVs) determined by the EPA for Macquarie Harbour..

In tandem with the mitigation plan, licence holders should also develop and implement a water quality monitoring plan. The monitoring plan should outline a program to measure changes to water quality as a result of the dissolved oxygen mitigation measures at and beyond the lease boundary.

### *Interim Default Guideline Values (DGVs)*

Water quality data collected by EPA from 1993 to 2009 has been used in the derivation of interim DGVs for aquatic ecosystems for Macquarie Harbour. The interim DGVs provide annual and seasonal information on key parameters for freshwater dominated surface waters, at the halocline (boundary between fresh and marine waters), for mid-depth and marine dominated bottom waters. The interim DGVs can be used for comparison against current conditions within the harbour and where warranted provide targets for water quality improvement. The interim DGVs are available as part of the environmental licence consideration packages and will be made available on EPA website once the decisions of the director have been finalised.

### *Total Permissible Dissolved Nitrogen Output (TPDNO) Determination*

On 31 August 2022 the Director made a determination regarding Total Permissible Dissolved Nitrogen Output (TPDNO) for Macquarie Harbour, setting the total apportionment for Macquarie Harbour at 500.1 tonnes and attributing each licence holder a share of that overall amount. This determination is currently in force and is valid to 31 August 2027.

In setting the TPDNO, the Director had regard to environmental conditions within Macquarie Harbour and the monitoring information available at that time. The 2022 TPDNO represents a modest reduction (10%) in nitrogen outputs compared to the 2021 calendar year.

TPDNO is applicable for any 12-month period going forward from the date of determination. Compliance assessments undertaken by EPA for the 1 September 2022 – 31 August 2023 and 1 October 2022 – 30 September 2023 periods concluded that all licence holders were compliant with their respective TPDNO apportionments.

To enable a comprehensive and measurable assessment of the new TPDNO determination it is essential that the current determination be maintained for at least another 12 months. Success of the determination will be measured by comparing measured water quality parameters against the interim DVG's and level of benthic recovery and compliance in the harbour.

## Status of the Maugean Skate (Zearaja maugeana)

The Maugean Skate (*Zearaja maugeana*) is endemic to Tasmania. This species has only been known to inhabit the estuaries of Macquarie Harbour and to a lesser extent Bathurst Harbour, demonstrating its restricted distribution and specific habitat requirements. The Maugean Skate is currently listed as endangered under both Tasmania's *Threatened Species Protection Act 1995* and the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). It is also a priority under the Australian Government's Threatened Species Action Plan 2022-2032.

The Department of Climate Change, Energy, the Environment and Water (DCCEEW) recently issued updated Conservation Advice for the Maugean Skate that is in effect under the EPBC Act from 6 September 2023. Based on this Conservation Advice, current major threats to the Maugean Skate are:

- Reduced water quality due to salmonid aquaculture operations in Macquarie Harbour – organic matter inputs and associated reduction in dissolved oxygen concentrations;
- Reduced water quality due to hydroelectric damning that alters the flow of the King and Gordon Rivers – steady river flows in naturally low-flow periods and periodic dam releases impact on complex hydrological dynamics linked to dissolved oxygen concentrations replenishment;
- Increased water temperatures and changes in rainfall due to climate change;
- Metal pollution and sediment contamination from upstream historical mining operations; and
- Recreational and commercial gillnet fishing and recreational line fishing.

This conservation advice also provides guidance for conservation planning, actions and research for the Maugean Skate while the Tasmanian Government's Conservation Action Plan and the Commonwealth's EPBC Act listing assessment are finalised. The conservation and management priorities include actions that address habitat loss and degradation, captive breeding program, survey and monitoring priorities, stakeholder and community engagement, information and research priorities, fishing, and climate change, extreme events and environmental changes.

Recent research and monitoring conducted by the Institute of Marine and Antarctic Studies (IMAS), University of Tasmania, indicates that the only known population of this species is in Macquarie Harbour (Moreno et al. 2022). A comprehensive study by Moreno et al. (2020) provides increased knowledge of the ecology and life history of the Maugean Skate, as well as the behavioural and physiological changes of this species to adapt to some degree to the challenging environmental conditions of Macquarie Harbour, in particular wide fluctuations in dissolved oxygen concentrations, temperature and salinity. However, the results of this study highlighted the vulnerability of the Maugean Skate in Macquarie Harbour based on the vulnerability of early life stages to changing environmental conditions, long-term changes in the size structure of the population, and the mortality of some individuals following environmental events. Further, Moreno and Semmens (2023) showed that there is a lack of recruitment of the Maugean Skate, since the median size of females had significantly increased and the proportion of juveniles captured had significantly decreased, based on data collected between 2012 and 2021. They also demonstrated a substantial decline of 47% in catch per unit effort, a measure of relative abundance, between 2014 and 2021.

In response to the increasing concerns for the conservation of the Maugean Skate, the Department of Natural Resources and Environment (NRE Tas) and the Department of Climate Change, Energy, the Environment and Water (DCCEEW) formed the National Recovery Team for the Maugean Skate in July 2023. This National Recovery Team provides a representative, collaborative and transparent framework for coordinated conservation management of the species. EPA representatives have participated in the collaborative processes of the National Recovery Team, including a number of working groups.

One of these working groups, the Environmental Remediation Working Group, has considered a variety of engineering mechanisms to introduce additional oxygen into the waters of Macquarie Harbour, with assistance from national and international experts. The EPA has also noted the willingness of Hydro Tasmania to prepare detailed catchment runoff models that could be used in tandem with the CSIRO's oxygen process modelling to manage water releases from hydro power stations in such a manner as to promote the likelihood of oceanic trickle recharge events through the mouth of Macquarie Harbour.

Through this collaborative process, the EPA has also repeatedly heard concerns from community and Local Council representatives about the potential loss of employment that is likely to accompany removal or reduction of salmon farming in the harbour, which could in turn lead to loss of critical services such as schools and doctors. NGO participants in the National Recovery Team process have repeatedly stated their view that the urgency of the threat to the Maugean Skate is such that rapid removal or reduction of salmon farming is a necessary measure.

The EPA is aware of a recently approved application to the Fisheries Research and Development Corporation (FRDC) for funding of a project to trial the injection of oxygen into the middle and deeper waters of Macquarie Harbour. The project team brings together salmon industry equipment and expertise

related to oxygenation of finfish pens with state, national and international expertise in science related to oxygen injection and associated environmental interactions. Examples of successful oxygenation of estuaries in Perth, in Scandinavian fjords, and in Chile provide confidence that similar approaches can be adapted to, and scaled up for, the Macquarie Harbour situation with detailed design and monitoring to guard against potential perverse environmental impacts.

Should the proposed oxygen injection trial not result in suitable improvements to dissolved oxygen concentrations in the harbour, the Director has the power to further reduce the Total Permissible Dissolved Nitrogen Output (TPDNO) in Macquarie Harbour. This would reduce the amount of nitrogen (associated with feed) that is discharged into Macquarie Harbour, thereby reducing salmon production and its associated oxygen demand.

Furthermore, the current work by Hydro Tasmania is promising. It is of note that Hydro Tasmania already has successful management regimes in place to protect threatened fish species within its impoundments. As such, it is recommended that the salmon companies be provided an opportunity to demonstrate that oxygen injection can shift dissolved oxygen levels across Macquarie Harbour over the next 6 months before the Director considers a further TPDNO reduction.

In November 2023, up-to-date advice regarding the Maugean Skate was also sought from NRE Tas for consideration in this Environmental Licence renewal process. The EPA was advised that the Tasmanian Threatened Species Listing Statement – Maugean Skate provides contemporary species and population data, as well as advice on research, conservation and management needs. In addition, a Population Viability Analysis (PVA) report by IMAS for DCCEEW has been completed which shows the extinction risk for the Maugean Skate under multiple scenarios. A copy of this report was provided by NRE Tas. This is currently not publicly available and was provided in confidence.

NRE Tas also advised of the internal and confidential draft Conservation Action Plan (CAP) for the Maugean Skate which has been developed with specific and targeted local, national and international input from scientists and engineers, industry, community and government representatives. It has guided actions that will prioritise coordinated recovery and management actions for the species. Many of these actions are already being implemented to mitigate the risk of further impacts. A copy of the draft CAP has been provided to the Director EPA, and the final version will be published as soon as possible, following consultation with the National Recovery Team. NRE Tas further noted the appropriateness to consider all actions proposed in the CAP and how these will complement the reductions in biomass in recent years as well as last year's determination limiting TPDNO in Macquarie Harbour. Further, NRE Tas considers a measured approach that conveys "the importance of collective commitment to the CAP and allow time for more robust evidence to be collected that will inform any future adaptive changes to licences and for industry to further adjust, if that is in fact what is required."

## Benthic Condition

As mentioned earlier in the water quality section, the structure of Macquarie Harbour with a narrow and shallow sill, coupled with multiple deep basins and freshwater inflows from a number of rivers results in an environment that is naturally stratified with limited vertical mixing and naturally low dissolved oxygen conditions in bottom and middle waters. Replenishment of Oxygen in Macquarie harbour is reliant on oceanic and wind-driven recharge events through late spring to autumn when river conditions result in low flows to the harbour. The interactions between dissolved oxygen levels in the middle and bottom waters, proximity to salmon farming, and the benthic condition of the harbour has been extensively studied in an FRDC funded project to IMAS in 2016 (FRDC Project no: 2016/067) and also in other related studies including Ross et al. 2015, Revill et al. 2016, Ross and Macleod 2017, Ross et al. 2021 and Ross et al. 2022.

Macquarie Harbour, like most estuarine systems on the west coast of Tasmania has a depauperate macrofauna community with low species diversity and abundance. The depauperate nature of the macrofauna community is attributed to low concentration of dissolved nutrients in rivers and dark-tannin-stained waters, which greatly restricts algal photosynthesis and primary productivity (Review by Ross et al. 2022). Heavy metal pollution and acid leaching from tailing dams into Macquarie Harbour from historical mining activities may also contribute to the depauperate nature of macrofaunal communities in Macquarie Harbour (Review by Ross et al. 2022).

Despite low primary productivity and mining impacts, the macrofaunal community has responded to organic enrichment from salmon aquaculture with benthic communities changing in the Harbour since the inception of farming (Ross et al. 2016 and reviewed by Ross et al. 2022). Faunal responses to finfish farm organic enrichment is evident out to 250-500m from farmed cages (Ross et al. 2016, 2017 and 2021), with footprint sizes larger and more pervasive for sites that have been farmed for longer (i.e. 15 yrs vs 2 yrs) and delineated by the feed volumes used. Closer to the cages surface deposit feeders (Dorvilleids) were able to take advantage of the organic enrichment, and filter feeding sabellids and terebellids dominate the macrofauna communities at distances farther from the cages. Farm management practices play a key role in Benthic condition and recovery dynamics, and this is evident looking at benthic compliance history. With the reduction in allowable standing biomass limits and the proactive farm management practices initiated by each of the 5 lease holders in Macquarie Harbour, there has been significant improvements in the number of non-compliances recorded against the individual environmental licences since the EPA started regulating the salmon farming industry.

Species richness, abundance and structure of faunal communities show a negative correlation with oxygen concentrations. Between 2016 and 2020, there have been multiple observations of improvements in benthic condition across the harbour in autumn-winter of each year and subsequent declines during the following spring. These response patterns coincided with a decline in oxygen concentrations in the middle and bottom waters each spring and subsequent replenishment of oxygen due to oceanic and wind-driven recharge events through late spring to autumn. The level of faunal and dissolved oxygen recovery is site dependent within the harbour, varying along the north/south axis of the harbour. The results presented by Ross et al. (2021) have shown improvements in benthic conditions in Macquarie Harbour over more recent years, with a recovery of harbour wide sites to well within previously reported ranges (i.e., before the decline in benthic conditions late 2016/early 2017). At the lease scale, the research has highlighted the capacity of fauna recovery via recruitment from the shallower reaches of the harbour.

In conclusion, the main findings of the research undertaken within Macquarie Harbour highlights the critical role and interplay of bottom water dissolved oxygen conditions experienced harbour wide and the role of organic enrichment and farm management practices in driving lease level faunal responses.

*Table 1: FRDC 2016-067 Report details and hyperlink to final report on FRDC website.*

| Report Name | Date | Authors | Hyperlink |
|---|---|---|---|
| Environmental Research in Macquarie Harbour Progress Report | September 2017 | Ross, Wild-Allen, Macleod | 2016-067 IMAS Progress Report on Macquarie Harbour September 2017.pdf (frdc.com.au) |
| Environmental Research in Macquarie Harbour Progress Report | February 2018 | Ross, Macleod | 2016-067 IMAS Progress Report on Macquarie Harbour February 2018.pdf (frdc.com.au) |
| Environmental Research in Macquarie Harbour Progress Report | June 2018 | Ross, Wild-Allen, Andrewartha, Macleod | 2016-067 IMAS Progress Report on Macquarie Harbour June 2018.pdf (frdc.com.au) |
| Environmental Research in Macquarie Harbour Progress Report | December 2018 | Ross, Wild-Allen, Andrewartha, Stehfest, Macleod | Microsoft Word - IMAS Progress Report on Macquarie Harbour _ Dec 20182.docx (frdc.com.au) |
| Environmental Research in Macquarie Harbour Progress Report | July 2019 | Ross, Wild-Allen, Andrewartha, Beard, Moreno, Macleod | 2016-067 IMAS Progress Report on Macquarie Harbour July 2019.pdf (frdc.com.au) |
| Environmental Research in Macquarie Harbour Progress Report | February 2020 | Ross, Wild-Allen, Andrewartha, Beard, Moreno | 2016-067 IMAS Progress Report on Macquarie Harbour February 2020.pdf (frdc.com.au) |
| Macquarie Harbour Oxygen Process model | June 2020 | Wild-Allen, Andrewartha, Baird, Bodrossy, Brewer, Erikesen, Skerratt, Revill, Sherrin, Wild | CSIRO report template (frdc.com.au) |
| Environmental Research in Macquarie Harbour Progress Report | October 2020 | Ross, Beard, Moreno | Microsoft Word - IMAS Progress Report on Macquarie Harbour _ October 2020.docx (frdc.com.au) |
| Understanding the oxygen dynamics and the importance for benthic recovery in Macquarie Harbour | March 2021 | Ross, Beard, Wild-Allen, Andrewartha, Stehfest, Durand, Semmens, Davey, Hortle, Pender, Quigley, Macleod, Moreno | 2016-067 MH FRDC final V4 |

*Table 2: Other relevant Macquarie Harbour reports*

| Report Name | Date | Authors | Hyperlink |
|---|---|---|---|
| Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies | 2021 | Ross, Macleod, White, Hadley, Moreno, Bush, Barrett | 2015-024-DLD-compressed.pdf (utas.edu.au) |
| Assessment of the Macquarie Harbour Broadscale Environmental Monitoring Program (BEMP) data from 2011-2020 | March 2022 | Ross, Moreno, Bell, Mardones, Beard | Ross-et-al.-2022-Assessment-of-the-Macquarie-Harbour-BEMP-data-from-2011-to-2020.pdf (utas.edu.au) |
| Characterising benthic pelagic interactions in Macquarie Harbour – organic matter processing in sediments and the importance for nutrient dynamics | May 2015 | Ross, Hartstein, Macleod | FRDC Final Report Design Standard (utas.edu.au) |
| Movement, habitat utilisation and population status of the endangered Maugean Skate and implications for fishing and aquaculture operations in Macquarie Harbour | February 2016 | Bell, Lyle, Semmens, Awruch, Moreno, Currie, Morash, Ross, Barrett | FRDC Final Report Design Standard (utas.edu.au) |
| Investigating Dissolved Oxygen Drawdown in Macquarie Harbour | February 2016 | Revill, Ross, Thompson | Microsoft Word - MH Drawdown report-Final.docx (huonaqua.com.au) |
| Understanding the ecology of Dorvilleid polychaetes in Macquarie Harbour | 2016 | Ross, McCarthy, Davey, Pender, Macleod | 2014-038-DLD-Dorvs.pdf (utas.edu.au) |
| Environmental Research in Macquarie Harbour – Interim synopsis of benthic and water column conditions | 2017 | Ross, Macleod | IMAS-Technical-Report-on-Macquarie-Harbour-Condition.pdf (utas.edu.au) |
| Review of broad-scale environmental monitoring programs: Macquarie Harbour | 2022 | Black, Tett, Reinardy | SAMS International Macquarie Harbour BEMP Review.pdf (epa.tas.gov.au) |