

2 February 2024

The Hon Tanya Plibersek MP
Minister for the Environment and Water
Parliament House
Canberra

By email: EPBC.VicTas@environment.gov.au

Dear Minister

Submission on Reconsideration Requests Marine Farming Expansion, Macquarie Harbour, Tasmania (EPBC 2012/6406)

- 1 We refer to the public notice, and correspondence received from the Department of Climate Change, Energy, the Environment and Water (the **Department**), inviting submissions on three requests for the reconsideration of the not a controlled action (particular manner) decision made by the Minister on 3 October 2012 under section 75 of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (the **EPBC Act**) in relation to EPBC referral 2012/6406 for the expansion of marine farming operations in the Macquarie Harbour (**Marine Farming Expansion**), the **NCA-PM Decision**.
- 2 This submission is a response to the reconsideration requests made by the Tasmanian branch of The Australia Institute (**The Australia Institute**), Fitzgerald and Browne Lawyers on behalf of the Bob Brown Foundation Inc (**BB Foundation**) and Environmental Defenders Office on behalf of the Australian Marine Conservation Society and Humane Society International Australia (together, **AMCS/HSI**), (**Reconsideration Requests**).
- 3 Salmon Tasmania, provides this submission on behalf and in addition to the submissions made by its member entities, Petuna Aquaculture, Tassal Operations and Huon Aquaculture. In submitting this document, we seek to present the collective perspective of our membership on the matters raised in the Reconsideration Requests.
- 4 The Reconsideration Requests assert that you should revoke and substitute the NCA-PM Decision, on the basis that there is substantial new information and an unforeseen, substantial change in circumstances in relation to the impacts of the Marine Farming Expansion on the Maugean Skate.
- 5 The BB Foundation further alleges that the Marine Farming Expansion is not being undertaken in accordance with the particular manner conditions.
- 6 It is Salmon Tasmania's position that none of the Reconsideration Requests establish the relevant statutory grounds required under section 78A(1) of the EPBC Act. The information in the reconsideration requests is insufficient to satisfy you that the revocation and substitution of the NCA-PM Decision is warranted.
- 7 Furthermore, Salmon Tasmania and its members reject the unfounded and unsubstantiated assertion made by the Bob Brown Foundation that the Macquarie Harbour Expansion is not being carried out in accordance with the NCA-PM conditions.

8 Salmon Tasmania welcomes the opportunity for further discussion with the Department regarding the contents of our submission.

Yours faithfully

A handwritten signature in black ink, consisting of several overlapping loops and a long horizontal stroke extending to the right.

Luke Martin

CEO

Salmon Tasmania

Salmon Tasmania Submission

**Requests for Reconsideration of Referral Decision:
Marine Farming Expansion, Macquarie Harbour, Tasmania
(EPBC 2012/6406)**

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1 Introduction

- (a) We refer to the public notice, and correspondence received from the Department of Climate Change, Energy, the Environment and Water (the **Department**), inviting submissions on three requests for the reconsideration of the decision made under section 75 of the *Environment Protection and Biodiversity Conservation Act 1999* (the **EPBC Act**) in relation to EPBC referral 2012/6406.
- (b) On 3 October 2012, the then Federal Minister decided that the proposed expansion of marine farming operations in Macquarie Harbour, on the west coast of Tasmania (as described in EPBC Act referral No 2012/6406) (**Marine Farming Expansion**), was not a controlled action provided it is taken in the particular manner specified in the decision (**NCA-PM Decision**).
- (c) The matters nominated in the NCA-PM Decision as relevant for the Marine Farming Expansion are:
- (i) World Heritage properties (sections 12 and 15A);
 - (ii) National Heritage places (sections 15B and 15C); and
 - (iii) Listed threatened species and communities (sections 18 and 18A).
- (d) The World Heritage property, National Heritage place and listed threatened species noted to be relevant to EPBC referral 2012/6406 were the Tasmanian Wilderness World Heritage Area (**TWWHA**) and Maugean Skate (*Zearaja maugeana*) respectively.
- (e) The entities named in the NCA-PM Decision, being Petuna Aquaculture, Tassal Operations and Huon Aquaculture (together, the **Operators**), have been carrying out their respective marine farming operations in Macquarie Harbour pursuant to the decision.
- (f) Three requests have been made for you to reconsider the NCA-PM Decision in accordance with the process provided by section 78A of the EPBC Act (**Reconsideration Requests**). These requests were submitted by:
- (i) the Tasmanian branch of The Australia Institute (**The Australia Institute**) by way of letters dated 8 June 2023 and 31 July 2023;
 - (ii) Fitzgerald and Browne Lawyers on behalf of the Bob Brown Foundation Inc (**BB Foundation**) by way of letter dated 25 July 2023; and
 - (iii) the Environmental Defenders Office on behalf of the Australian Marine Conservation Society and Humane Society International Australia (together, **AMCS/HSI**) by way of letters dated 23 August 2023 and 20 November 2023;
- (together, the **Requestors**).
- (g) The Reconsideration Requests are each made under section 78A of the EPBC Act and rely in part on common grounds under section 78 (further detail on differences as between the requests is addressed below). By way of summary, the primary submission common to the Reconsideration Requests is that you should be satisfied the revocation and substitution of the NCA-PM decision with a new decision that the Marine Farming Expansion is a controlled action is warranted because:
- (i) for the purposes of section 78(1)(a), it is alleged that there is substantial new information available about the impacts the Marine Farming Expansion is having (or will have or is likely to have) on the Maugean Skate (being a matter protected by Part 3 of the EPBC Act); and/or

Salmon Tasmania Submission on Requests for Reconsideration of Referral Decision

- (ii) for the purposes of section 78(1)(aa), it is alleged that there is a substantial change in circumstances that was not foreseen at the time of the NCA-PM decision and it relates to the impacts that the Marine Farming Expansion is having (or will have or is likely to have) on the Maugean Skate (being a matter protected by a provision of Part 3 of the EPBC Act).
- (h) In addition to the above grounds, the BB Foundation requests the revocation and substitution of the NCA-PM Decision under section 78(1)(b) on the basis of an allegation that the NCA-PM Decision requires the Operators not have a significant impact on the Maugean Skate and that the Operators are not complying with this particular manner requirement.
- (i) In accordance with section 78C of the EPBC Act, you are required to reconsider the NCA-PM Decision, and to either confirm that decision, or revoke the decision on one or more of the grounds under section 78(1) and to substitute it with a new decision.
- (j) This document provides Salmon Tasmania's response to the Reconsideration Requests and addresses the claims and concerns raised in the documentation that forms the basis of those requests.

2 Role of Salmon Tasmania

- (a) This submission has been prepared by Salmon Tasmania on behalf of our members, the major operators in Macquarie Harbour, being Petuna Aquaculture, Tassal Operations and Huon Aquaculture.
- (b) Salmon Tasmania is a peak industry body representing the interests of Tasmanian salmon farmers, within the Australian aquaculture sector. Salmon Tasmania's members are industry leaders dedicated to sustainable and responsible aquaculture practices within the local salmon farming community.
- (c) The Tasmanian salmon and trout farming industry currently creates 5,103 FTE (full-time equivalent) jobs¹, has a gross production value of \$888 million², and is the largest fishery by economic value and volume in Australia³.
- (d) The positive impact of the industry on the economy spreads well beyond direct employment with the salmon companies, and the flow-on impacts into the broader community are significant. There is a thriving ancillary sector providing imports to the industry such as vessels, pens, nets, feed, training, transport and logistics, and a range of contract and consultancy services.
- (e) The industry has a strong record of encouraging training and skills development, creating career paths to attract and retain skilled staff, especially in regional communities.
- (f) The Macquarie Harbour activities of the Operators sustain 395 FTE direct and indirect roles, with 1 in 3 residents of the town of Strahan being employed in the industry⁴. For the wider West Coast region of Tasmania, the salmon industry supports 17% of employment in the region⁵.
- (g) Salmon Tasmania, its members, and workforce are extremely concerned that the Reconsideration Requests be carefully scrutinised and the legislative requirements rigorously applied. A decision to revoke the NCA-PM Decision and make the Marine Farming Expansion a 'controlled action' will have immediate, dire consequences for the Operators and the broader West Coast community (see further in section 8).

¹ Deloitte Access Economics (2022), *Socio-economic contribution of the Tasmanian salmon industry*

² Tasmanian Agri-food Scorecard, <https://nre.tas.gov.au/Document2.s/Tasmanian%20Agri-Food%20ScoreCard%202019-20.pdf>

³ <https://nre.tas.gov.au/Documents/Tasmanian%20Salmon%20Industry%20Plan%202023.pdf>;
<https://www.imas.utas.edu.au/research/fisheries-and-aquaculture/aquaculture/atlantic-salmon-aquaculture-research>

⁴ Deloitte Access Economics (2022), *Socio-economic contribution of the Tasmanian salmon industry*

⁵ Deloitte Access Economics (2022), *Socio-economic contribution of the Tasmanian salmon industry*

3 Overview of Salmon Tasmania's response to the Reconsideration Requests

Summary

- (a) Salmon Tasmania submits the appropriate course is for you to confirm the existing NCA-PM Decision.
- (b) You should not be satisfied that it is warranted to revoke the NCA-PM Decision and to substitute a new decision that the Marine Farming Expansion is a controlled action, on the basis of any of the claimed grounds in section 78(1) of the EPBC Act.
- (c) None of the asserted grounds under sections 78(1)(a), (aa) or (b) that are relied upon by the Requestors are in fact made out by the information provided in, or referenced by, the Requests.

Any substantial new information about the impacts of the Marine Farming Expansion on the skate?

- (d) Central to each of the Reconsideration Requests is an Interim Report published by the Institute for Marine and Antarctic Studies (**IMAS**) '*Macquarie Harbour Maugean skate population status and monitoring*' on 2 May 2023 (**IMAS 2023 Report**).⁶
- (e) The IMAS 2023 Report is relied upon as the primary source of new information by the Reconsideration Requests for the purposes of section 78(1)(a) of the EPBC Act.
- (f) The IMAS 2023 Report is an interim report only, which presents newly gathered monitoring data on skate population changes (size composition and relative abundance). The collected data is expressly noted to be subject to further analysis, with the report stating that the analysis of the interim data is not definitive.
- (g) The IMAS 2023 Report does not present any information about the impacts of the Marine Farming Expansion on the skate, let alone any substantial new information about such impacts or their likelihood of occurring.⁷
- (h) The report recognises that there are numerous anthropogenic activities including mining, forestry, hydro-electricity generation and the general effects of climate change along with marine farming, that have all contributed to a change in the physicochemical conditions in Macquarie Harbour.
- (i) Where additional scientific reports are relied upon in the Reconsideration Requests (addressed in section 5 and Schedule 2), those reports do not establish a causal link between impacts of the Marine Farming Expansion and impacts on the skate population.
- (j) Moreover, the reports which contend that salmon farming has the impact of reducing levels of dissolved oxygen in the harbour and that this is likely to have an impact on the skate, fail to demonstrate these impacts are likely to happen with a high degree of certainty as is required by clause 4AA.01 of the *Environment Protection and Biodiversity Conservation Regulations 2000* (Cth) (**EPBC Regulation**).
- (k) The reports that do attempt to draw a causal link are based on flawed assumptions that do not reflect modern marine farming practices or outdated data (addressed in section 5 and Schedule 2).

A substantial change in circumstances that was not foreseen at the time the NCA-PM Decision was made, and relates to the impacts of the Marine Farming Expansion on the skate?

- (l) The IMAS 2023 Report and the other scientific literature relied upon by the Requestors do not identify a substantial change in circumstances that was not foreseen at the time of the

⁶ https://imas.utas.edu.au/_data/assets/pdf_file/0007/1655611/Maugean-skate-2021-interim-report-FINAL.pdf/ nocache

⁷ The IMAS 2023 Report and the scientific literature cited within that Report are addressed in greater detail in section 5.

NCA-PM Decision, and which relates to impacts that the Marine Farming Expansion has or is likely to have on the Maugean Skate.

- (m) The salmon farming industry accepts that the presence of salmon pens in Macquarie Harbour has an influence on levels of dissolved oxygen in the harbour. This influence was known at the time of the NCA-PM Decision and recognised in the express terms of the NCA-PM Decision notice through requirements imposing obligations for monitoring and management of water quality indicators including dissolved oxygen levels, benthic conditions and physio-chemical impacts.
- (n) As such, there is no unforeseen and substantial change in circumstances that relates to the impacts of the salmon farming on the skate.
- (o) Furthermore, the Requests fail to demonstrate that some change in the potential impacts of the salmon farming on the skate is likely to happen with a high degree of certainty, as is required by clause 4AA.01 of the EPBC Regulation.

Impacts on dissolved oxygen in Macquarie Harbour from salmon farming operations and implications for the skate?

- (p) Salmon farming is one of many anthropogenic factors identified as having an influence on the environmental conditions, including dissolved oxygen levels, in Macquarie Harbour.
- (q) The extent of the influence and observed impacts attributable to salmon farming is presented in section 5.4 of this submission, which details the findings of a technical memorandum prepared by Dr Ian Wallis in a 2024 technical memorandum (see Schedule 4) commissioned by Salmon Tasmania.
- (r) Salmon Tasmania submits that this expert evidence, which goes directly to the central concern raised by the Requestors, will give you comfort that the NCA-PM Decision remains appropriate and should be confirmed.
- (s) Dr Wallis's findings include:
 - (i) Oxygen is primarily introduced into Macquarie Harbour by river and ocean water inflows and surface re-aeration.
 - (ii) There is a high level of stratification in the harbour waters. The natural levels of dissolved oxygen in the lower layer are, and always have been, low because of the hydrological processes occurring in the harbour.
 - (iii) The majority of the oxygen demand on the lower layer comes from the river inflow, with organics settling from the top layer of the harbour into the lower layer. River inflows are continuous, with volumes varying seasonally and following releases from hydroelectric dams upstream in the Gordon and King Rivers.
 - (iv) River inflow is also the process that determines the extent of ocean water inflow to the harbour, and the oxygen content of the lower layer. High river flows cause less ocean inflow and less oxygen in the lower layer, whereas low river flows result in more ocean inflow and more oxygen in the lower layer.
 - (v) Natural processes are estimated to reduce the average dissolved oxygen in the lower layer to around 35% saturation. In the lower layer, the extra load from salmon farms reduces the average dissolved oxygen to around 25% saturation.
 - (vi) In the 4000 years since Macquarie Harbour changed from a freshwater lake to a stratified estuary, there have likely been many variations in river inflow. It is unlikely that present dissolved oxygen conditions have not been experienced in the past.

- (vii) Research shows that Skate mostly reside in the top layer of the harbour which has satisfactory levels of dissolved oxygen, and travel into the lower layer only where there is satisfactory dissolved oxygen.
- (viii) Salmon farms reduce the dissolved oxygen in the top layer by 4% or 0.3 mg/L. "This minor decrease would have negligible effect on the survival of the skates in their normal habitat in the top layer near Table Head".
- (ix) 'Uplift events', where waters with low dissolved oxygen move from the lower layer of the harbour into the top layer, are natural events driven largely by low river flows and, to a lesser extent, by tides, atmospheric pressure and winds. The uplift events are not caused by, or increased by, salmon farms.
- (x) There is ample dissolved oxygen (DO) in the top layer due to the supply from the rivers and the atmosphere. The estimated oxygen supply to the top layer of Macquarie Harbour is 134,000 t/yr which corresponds to an average DO concentration of about 7.4 mg/L. Measured oxygen levels in the top layer range from 5 to 8 mg/L, which matches the calculated average value.
- (xi) The situation is different in the lower layer, as it cannot receive oxygen from the rivers or the atmosphere. The only supply is from the periodic ocean inflows, which bring in an estimated 17,700 t/yr of oxygen. The residence time for the lower layer is about a year and the natural oxygen demand is around 7,500 t/yr. DO is naturally depleted in the lower layer.
- (xii) The biological activities that use oxygen seem to be concentrated at 20 to 35 m depth, and oxygen levels in this depth range are typically only 20 to 40 per cent of saturation.
- (t) Dr Wallis concludes that the drawdown of oxygen attributable to salmon farming occurs in a manner that would result in negligible impacts to the Maugean Skate in their observed habitat.
- (u) These findings highlight that the cessation of aquaculture in Macquarie Harbour alone without addressing other anthropogenic factors causing environmental degradation including changed river flows and the presence of heavy metals from historic mining activities, would be most unlikely to resolve current low levels of dissolved oxygen.
- (v) Dr Wallis also undertook a review of scientific literature relied upon in the Reconsideration Requests and found that data relied upon and assumptions made in the literature either did not support the conclusions drawn or overstated the impacts of salmon farming on environmental conditions (see section 5.4 and Schedule 4).

Whether the Marine Farming Expansion is not being, or will not be taken in accordance with the NCA-PM Decision?

- (w) Salmon Tasmania submits that the revocation and substitution of the NCA-PM Decision cannot be warranted on grounds contained in section 78(1)(b) of the EPBC Act. This is because you have not received a properly made request on these grounds.
- (x) Moreover, the Operators reject the allegation by the BB Foundation that they are not conducting the Marine Farming Expansion in accordance with the NCA-PM Decision requirements.
- (y) The BB Foundation submission provides no detail of a single instance nor any particulars of conduct by an operator that is said to be inconsistent with the measures stated in the NCA-PM Decision to support the allegation. This is contrary to the requirement in

clause 4AA.01(5) of the EPBC Regulation – in short, the BB Foundation request on this ground cannot be accepted as being validly made.

- (z) In any event, if you or your Department held such concerns, as matter of procedural fairness, it would be appropriate in the first instance for those matters to be put in writing to the relevant operator directly by the Department, for the operator's consideration and response. In the absence of any prima facie basis to accept such an allegation, it is submitted there is no lawful basis for you to accept that a ground is established under section 78(1)(b) to revoke the NCA-PM Decision.

Marine farming environmental requirements, monitoring and adaptive management

- (aa) In the event that you are satisfied that the information presented in the Reconsideration Requests does relevantly constitute substantial new information or an unforeseen and substantial change in circumstances, we nonetheless submit that the requirements imposed under the current NCA-PM Decision are the most appropriate protection measures and that Decision should be confirmed.
- (bb) The adaptive management principles integrated into the NCA-PM Decision, through requiring compliance with the Tasmanian Government's regulatory regime, including the Macquarie Harbour Marine Farming Development Plan and licencing conditions, are an effective and appropriate framework to identify and address any significant impacts of salmon farming to the Macquarie Harbour environment.
- (cc) The adaptive management framework is responsive to developments in technology and scientific research, with the Tasmanian Government amending the State regulatory regime that regulates finfish farming to incorporate international best practices.
- (dd) Monitoring, reporting and responding to environmental management conditions, including in relation to dissolved oxygen levels, are already required, and have been complied with, by the Operators since the NCA-PM Decision was made.
- (ee) Further, the industry has been proactive in addressing concerns relating to the environmental conditions of Macquarie Harbour and impacts on the Maugean Skate.
- (ff) Significant financial and technical contributions have been made by industry to support research and development of marine farming practices including taking a leadership role on research initiatives such as the Macquarie Harbour Oxygenation Project.
- (gg) Under the current Tasmanian environmental licencing regime, marine farming in Macquarie Harbour is conducted in a manner that exceeds the requirements contained in the 2012 NCA-PM Decision and at significantly lower levels of production than was intended in 2012. The graph at Schedule 1 demonstrates that production levels in Macquarie Harbour are now less than existed at the time of the NCA-PM Decision in 2012.
- (hh) The cessation of marine farming operations in Macquarie Harbour would represent a loss of the largest employer in the region and would result in irreparable damage to the community, both from direct job losses and impacts to businesses that support aquaculture operations.

Alternative submission – NCA-PM with updated requirements

- (ii) If you are satisfied that revocation and substitution of the NCA-PM Decision is warranted on any of the grounds under section 78(1), Salmon Tasmania provides an alternative submission for your consideration.
- (jj) Salmon Tasmania submits that if the existing NCA-PM Decision is to be substituted, it would be appropriate to take a new decision that the Marine Farming Expansion is not a controlled

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action if undertaken in a particular manner, and that those requirements of the particular manner be updated.

- (kk) Salmon Tasmania in conjunction with the Operators, has convened a technical advisory group to provide recommendations on steps that can be taken to further enhance environmental protection requirements for the Maugean Skate.
- (ll) Salmon Tasmania is ready and willing to facilitate engagement by your Department with the Operators, and wider industry stakeholders, in relation to any such proposed measures.

4 Basis of Reconsideration Requests

4.1 Outline

- (a) This section summarises the key claims relied upon by the Requestors as the basis of their respective Reconsideration Requests. The purpose of this section is to set out the key matters to which a response will be provided by Salmon Tasmania.
- (b) Salmon Tasmania's review and response to each of the claims is contained in section 5 and a technical review of scientific literature relied upon by the Requestors is set out at Schedule 2.

4.2 IMAS 2023 Report

- (a) Central to the submissions of each of the Requestors is an Interim Report published by the Institute for Marine and Antarctic Studies (**IMAS**) '*Macquarie Harbour Maugean skate population status and monitoring*' on 2 May 2023 (**IMAS 2023 Report**).⁸
- (b) The IMAS 2023 Report is relied upon as the primary basis of the reconsideration requests made under sections 78(1)(a) and 78(1)(aa) of the EPBC Act, by each Requestor.
- (c) Each of the Requestors state that this report constitutes:
 - (i) 'substantial new information' regarding the impacts of the Marine Farming Expansion on the Maugean Skate; and
 - (ii) identifies a 'substantial change in circumstances that was not foreseen at the time of the controlled action decision' that relates to the impacts of the Marine Farming Expansion on the Maugean Skate.
- (d) The report contains initial data and findings resulting from a survey monitoring program that sought to establish the current size and composition of the Maugean Skate population in Macquarie Harbour.
- (e) Results from the first year of the survey (2021) were stated to show:
 - (i) a decline of 47%, in catch per unit effort (**CPUE**) indicating a substantial decrease in relative abundance of the skate in the Harbour (since 2014); and
 - (ii) that the median size of females had increased (since 2012) while the proportion of juveniles captured had decreased, which was stated to be consistent with recruitment failure.
- (f) The report states that there is mounting evidence that low dissolved oxygen conditions are impacting the Maugean Skate population, but relies upon separate scientific literature for that premise.
- (g) Separate scientific literature is also used to allege a change in environmental conditions in the harbour, specifically reduced dissolved oxygen levels in deep water (>10m depth).
- (h) The report lists marine farming operations as one of various anthropogenic activities including mining, forestry, hydro-electricity generation, and the general effects of climate change, that have 'influenced' a change in the physicochemical conditions in Macquarie Harbour.
- (i) The IMAS 2023 Report relies on a 2022 study as the basis of the claim that 'vast majority, if not all, of the remaining Maugean skate live only in Macquarie Harbour' which is said to 'highlight the vulnerability of the species and the need for urgent conservation action'.

⁸ https://imas.utas.edu.au/_data/assets/pdf_file/0007/1655611/Maugean-skate-2021-interim-report-FINAL.pdf/_nocache

4.3 The Australia Institute Reconsideration Request

- (a) In addition to the IMAS 2023 Report, The Australia Institute relies on a number of additional scientific reports to assert that the Marine Farming Expansion is having a significant impact on the Maugean Skate, such that the NCA-PM decision should be revoked.
- (b) These reports include:
 - (i) *Understanding the Ecology of Dorvilleid Polychaetes in Macquarie Harbour (Ross 2016 Report)*;⁹
 - (ii) *Environmental Research in Macquarie Harbour Interim Synopsis of Benthic and Water Column Conditions (Ross 2017 Report)*;¹⁰
 - (iii) *Vulnerability of the endangered Maugean Skate population to degraded environmental conditions in Macquarie Harbour (Moreno 2020 Report)*;¹¹ and
 - (iv) *Macquarie Harbour Oxygen Process model (Wild-Allen 2020 Report)*.
- (c) The above reports are relied upon to support the conclusion drawn by The Australia Institute that the reduced dissolved oxygen levels in the harbour and therefore the impacts being experienced by the skate are attributable to the Marine Farming Expansion.
- (d) The Australia Institute states that each of the additional reports constitutes substantial new information and asserts that they establish a substantial change in circumstances relating to the impacts of the Marine Farming Expansion on the Skate.

4.4 AMCS/HSI Reconsideration Request

- (a) The AMCS/HSI request relies on similar scientific literature to The Australia Institute to allege a link between the reduced dissolved oxygen levels observed in the Macquarie Harbour and the Marine Farming Expansion.
- (b) Substantial new information is also said to consist of:
 - (i) a report which investigated the existence of Maugean Skate in locations other than Macquarie Harbour, which observed 'low traces of Maugean Skate DNA in Bathurst Harbour' (*Application of environmental DNA to survey Bathurst Harbour (Tasmania) for the Endangered Maugean Skate (Zearaja maugeana)*)¹² (**Moreno 2022 Report**); and
 - (ii) compliance monitoring data maintained by the Tasmanian Environment Protection Authority (**Tasmanian EPA**) that is stated to have documented 'cases of benthic bacterial matting spreading from Tassal's lease MF266'.
- (c) Additional research regarding projected increased coastal water temperatures in the coming summer and the impact of these higher temperatures on dissolved oxygen levels is also asserted to constitute evidence of a 'change in circumstances' that should be considered.¹³

⁹ *Understanding the Ecology of Dorvilleid Polychaetes in Macquarie Harbour*, Jeff Ross, Arlie McCarthy, Adam Davey, Andrew Pender and Catriona MacLeod (2016).

¹⁰ *Environmental Research in Macquarie Harbour Interim Synopsis of Benthic and Water Column Conditions*, Jeff Ross & Catriona MacLeod (2017).

¹¹ *Vulnerability of the endangered Maugean Skate population to degraded environmental conditions in Macquarie Harbour*, David Moreno, Jeremy Lyle, Jayson Semmens, Andrea Morash, Kilian Stehfest, Jaime McAllister, Bailee Bowen and Neville Barrett (2020);

¹² *Application of environmental DNA to survey Bathurst Harbour (Tasmania) for the Endangered Maugean Skate (Zearaja maugeana)*, David Moreno, Jawahar Patil, Bruce Deagle & Jayson Semmens (2022)

¹³ *Three decades of variability and warming of nearshore waters around Tasmania. Progress in Oceanography*, K.R Ridgway and S.D Ling (2023).

4.5 BB Foundation Reconsideration Request

- (a) In addition to relying on the IMAS 2023 Report to establish grounds for the reconsideration request under sections 78(1)(a) and 78(1)(aa) of the EPBC Act, the BB Foundation has additionally sought to rely on the report to seek reconsideration under section 78(1)(b) of the EPBC Act.
- (b) The BB Foundation:
 - (i) has interpreted the conditions of the NCA-PM Decision as requiring the Operators to ensure that their operations in the harbour do not have a significant impact on the Maugean Skate;
 - (ii) alleges that the results of the IMAS 2023 Report 'demonstrate... that significant impacts are being inflicted upon the Maugean Skate'; and
 - (iii) concludes that due to these observed impacts, the Marine Farming Expansion is not being conducted in the manner stipulated by the NCA-PM Decision.

5 Response to Reconsideration Requests

5.1 Outline

- (a) This section presents Salmon Tasmania's review and response to each of the claims as set out the preceding section 4.
- (b) Salmon Tasmania seeks to assist you in your assessment of the Reconsideration Requests in two modes:
 - (i) Providing an objective review and response to the Requestors' claims, checked against the actual methodology and findings reached in scientific literature cited by the Requestors; and
 - (ii) Providing you with expert technical opinion from Dr Ian Wallis in relation to the impact of salmon farming on the levels of dissolved oxygen in Macquarie Harbour as that may be relevant to the Maugean Skate.
- (c) A technical review of the scientific literature relied upon by the Requestors is set out at Schedule 2. Further, Nautilus Collaboration has been commissioned to undertake a scientific review of the literature relied upon by The Australia Institute (the **Nautilus Report**). The Nautilus Report is provided with this submission at Schedule 3.
- (d) Dr Wallis is a member of the Macquarie Harbour Oxygenation Project (**MHOP**) team and was engaged by Salmon Tasmania to prepare a technical memorandum to estimate the demand for oxygen by salmon farms in Macquarie Harbour and determine whether the resulting dissolved oxygen draw down impacts the Maugean Skate (**Wallis 2024 Report**).
- (e) The Wallis 2024 Report has drawn from and commented on the sources relied upon by the Requestors in section 4 above. A copy of the Wallis 2024 Report is attached as Schedule 4 to this submission.
- (f) In short, Salmon Tasmania's review highlights that:
 - (i) None of the scientific literature relied upon by the Reconsideration Requests establishes the requisite causal link demonstrating that the Marine Farming Expansion has caused reduced dissolved oxygen levels that have significantly negatively impacted the Maugean Skate, and does not provide substantiation of the relevant grounds under section 78(1) of the EPBC Act (as described in section 1);
 - (ii) Nautilus finds that:
 - (A) Causality of impacts of salmon farming on the skate has not been in fact demonstrated in any of the reference material cited by The Australia Institute; and
 - (B) The submission of The Australia Institute:
 - (1) inflates the impact of salmon farming;
 - (2) fails to discuss or recognise the diminutive attribution of salmon farming to oxygen use in the harbour; and
 - (3) fails to acknowledge that there is a crucial influence on organic load and enrichment from the river systems from organic deposition;
 - (iii) Dr Wallis finds that:
 - (A) For the top layer of harbour waters (surface to depth of approx. 15m) - the reduction of dissolved oxygen in the top layer of the harbour waters by 4% or

0.3 mg/L from salmon farming "would have negligible effect on the survival of the skates in their normal habitat..."; and

- (B) For the bottom layer of harbour waters (greater than approx. 15m) - salmon farms reduce dissolved oxygen in the lower layer of harbour waters by 10% to 16%, or 1 mg/L. Skates have been observed to avoid areas of low dissolved oxygen including when uplift events occur, by moving to the deeper ocean inflow regions where high dissolved oxygen water is entering (and causing the uplift event). Uplift events are not caused by, or increased by, salmon farming.

5.2 Response to IMAS 2023 Report

Summary

- (a) The salmon farming industry acknowledges the interim Macquarie Harbour data gathered for the IMAS 2023 Report.
- (b) The industry rejects however the interpretation of, and conclusions drawn from the report's findings by the Requestors, which can be summarised as:
- (i) the reduced environmental conditions, namely reduced dissolved oxygen levels, occurring in the harbour are predominantly caused by salmon aquaculture;
 - (ii) the reduced dissolved oxygen levels are negatively impacting the Maugean Skate; and
 - (iii) the sole manner to resolve the impacts identified in the report is the cessation of aquaculture and marine farming in Macquarie Harbour, as is called for in The Australia Institute and AMCS/HSI requests.
- (c) To the contrary, no such conclusions can be conclusively drawn from the data or resulting analysis contained in the IMAS 2023 Report, as this goes beyond the scope of the report.
- (d) The only novel information contained in the IMAS 2023 Report is data regarding the population size, composition and characteristics of the Skate.
- (e) The IMAS 2023 Report does not independently identify marine farming as the dominant cause of reduced dissolved oxygen levels in the harbour, nor does it establish any causal link between the declining CPUE, observed 'recruitment failure' and reduced dissolved oxygen levels in Macquarie Harbour.
- (f) Separate scientific literature is referred to throughout the IMAS 2023 Report to establish the changed environmental conditions in Macquarie Harbour, the source of these changes and in turn the impact on the Maugean Skate.
- (g) As such, the report does not itself establish any new evidence of Marine Farming Expansion having an impact on the Maugean Skate, as is required under section 78(1) of the Act.
- (h) Although the initially reported 47% decline in CPUE since 2014 is notable, as an interim report, data collection for the IMAS 2023 Report remains ongoing. The preliminary nature of the findings is acknowledged in the report, which states that the analysis is not definitive. Following the release of the IMAS 2023 Report, the IMAS researchers have verbally reported the capture of juvenile Maugean Skate in significant numbers compared to historical efforts. This highlights the challenges of basing significant decisions on interim reports, prior to finalisation of populations studies. It also demonstrates the importance of the independent review of the methodology used to estimate population size and distribution which is currently underway via the Maugean Skate recovery process.

- (i) Further, it is noted that the Moreno 2020 Report 'reported two environmental events in 2019 that resulted in high mortality (~44%) of [skate] being electronically tracked.' The IMAS 2023 Report attributes the cause of 'the observed declines in relative abundance' of the skate to 'high impact environmental events'.
- (j) This coincides with uplift events in the harbour as described by Dr Wallis (see Schedule 4 at page 12).
- (k) Notwithstanding, the mortality rate observed in the IMAS 2023 Report is consistent with the known natural mortality rate for skates, which was observed to be 40% per year (Grant et al, 2022) such that the findings of the report cannot be said to be evidence of excessive mortality.

Conclusion

- (l) In the absence of final data identifying any conclusive impact on the skate, the sections of the Reconsideration Requests that rely on the IMAS 2023 Report fail to satisfy the requirement under EPCB Regulation 4AA.01 that stipulates that the requests must demonstrate 'a change in the potential impacts of the action is likely to happen with a high degree of certainty.'
- (m) On the grounds stated above, Salmon Tasmania and its members reject that the IMAS 2023 Report constitutes:
 - (i) substantial new information about the impacts that the Marine Farming Expansion has, will have or is likely to have on the Maugean Skate; and/or
 - (ii) a substantial change in circumstances that was not foreseen at the time of the NCA-PM Decision and relates to the impacts that the Marine Farming Expansion has, will have or is likely to have on the Maugean Skate.
- (n) Salmon Tasmania submits that the revocation and substitution of the NCA-PM Decision cannot be warranted based on the information contained in the IMAS 2023 Report, as it does not meet the requisite thresholds under section 78(1)(a) or section 78(1)(aa) of the Act.

5.3 Review of Additional Scientific literature referred to The Australia Institute and AMCS/HMI Requests

- (a) A review of additional scientific literature cited by The Australia Institute and the AMCS/HMI Requests is set out in the Technical Review at Schedule 2 and is supplemented by the Nautilus Report provided at Schedule 3.
- (b) The authors of the Nautilus Report are Christine Huynh, Andrew Mackay and Elena Contador, being experts with specific experience in advising the aquaculture industry on animal welfare and operations modelling.
- (c) Key findings by the Nautilus include:
 - (i) The comments made by The Australia Institute in their reconsideration requests must be interpreted with caution as the data and information has been taken out of context and infers that there is causality.
 - (ii) Causality has not been in fact demonstrated in any of the referenced material and the influence of salmon farming is over-stated in each of The Australia Institute requests.
 - (iii) Wild-Allen (2020) in the FRDC report that found when modelling the removal of salmon farms "a 50 per cent reduction in hypoxic volume, and a 43 per cent increase in healthy water would result from elimination of salmonid farming". What the

modelling actually found, was a reduction from 27-28% hypoxic to 14-17% by volume and from 12% to 4-6% by area. The model also used hard definitions of hypoxic as between 1-30% oxygen saturation, which means if the removal of salmon farming increased saturation by 1% and a portion of the water was at 30%, that water volume would now be considered 'intermediate'.

- (iv) The Wild-Allen 2020 report findings and budget were based on modelling conditions and farming inputs from 2017 and 2018, which are no longer representative due to changes in salmon farming (decreased biomass limits and nitrogen budgets) and any changes in hydro-electric dam operational management (refer to Schedule 1 for HOG tonnes produced in the harbour).
- (v) The referenced material in The Australia Institute letter is considered 'old' evidence. The salmon industry has already considered these pieces of evidence in their adaptive management processes, and since their release, have changed biomass and nitrogen limits to suit the estimated carrying capacity of the harbour. (See discussion of the adaptive management regime under the Tasmanian licensing regime in section 7). This is a statement that applies to all the referenced material, as the models, assumptions and methods need to be updated to incorporate new scientific evidence.
- (d) In response to the claim concerning marine lease MF266, this is not new information. MF266 is the southern most lease in the harbour and is impacted by Gordon River flows and related organic matter. This lease sits at the edge of the organic gradient that IMAS research identified. It should be noted that the presence of *Beggiatoa sp.* at sites located well upstream in the TWH has been observed on a number of occasions and is not related to the impacts of salmon farming.

5.4 Wallis 2024 Report Findings

- (a) Key findings of the Wallis 2024 Report include:
 - (i) that oxygen is primarily introduced into Macquarie Harbour by river and ocean water inflows and surface re-aeration. River inflows are continuous, with volumes varying seasonally and following releases from hydroelectric dams upstream in the Gordon and King Rivers;
 - (ii) inflows of sea water are responsible for replenishing DO levels of water at the lower layer of the Harbour. The ability of ocean water to enter the harbour is determined by river inflows and is hampered by the large volume of freshwater that must be discharged during a tide cycle and the long channel (8km) from the ocean to the harbour. In periods of higher river flow (generally during winter-spring or following a dam release event) inflow of ocean water is restricted and periods of low DO in deep waters are also observed;
 - (iii) uplift events where waters with low DO come closer to the surface are natural events driven largely by low river flows and, to a lesser extent, by tides, atmospheric pressure and winds. The events are not caused by, or increased by, salmon farms;
 - (i) the current evidence is that the Maugean Skate generally live in the top layer of the Macquarie Harbour at a range of 8m to 15m which has satisfactory levels of dissolved oxygen and travel into the lower layer only where there is satisfactory dissolved oxygen.

- (ii) salmon pens are located at the surface of the harbour and extend down to approximately 13m depth, with the preferential depth of the fish within the pen varying with temperature changes and DO levels;
 - (iii) dissolved oxygen demands associated with marine farming operations are 2-fold, being demands from fish respiration and the biological processes associated with lost feed and salmon excreta. When respiration and the net drawdown of oxygen associated with biological processes is considered, 'salmon farms reduce the DO in the top layer [of the harbour] by 4% or 0.3mg/L'. This minor decrease is said to have negligible effect on the survival of the skates in their normal habitat in the top layer near Table Head;
 - (iv) the drawdown of DO levels associated with marine farming in deeper waters (at 15 to 30 m depth) is estimated to be between 10% and 16% of that supplied by ocean water into the lower layers of the harbour. The DO demand from fish respiration has no effect on dissolved oxygen levels in the bottom layer as salmon pens do not extend to this depth;
 - (v) the impact of biological processes at depth as a result of salmon farming are minor when considered in the context of the whole harbour. Dr Wallis finds that 'the majority of the oxygen demand on the lower layer' comes from organic material introduced into the harbour as a result of river inflows.
 - (vi) the natural processes associated with river inflow organics is 'estimated to reduce the DO in the lower layer to around 35 % saturation'. Salmon farming is said to reduce DO levels to around 25%;
- (b) Dr Wallis concludes that 'It is not obvious from the DO data analysed in this report that there has been "a marked decline in dissolved oxygen conditions in Macquarie Harbour which are likely to have a significant impact on many resident species, including the Maugean Skate". Dissolved oxygen was always low in the lower layer ... whether or not there is a long term trend of declining DO with time is still an open question...'

5.5 Response to BB Foundation Reconsideration Request

- (a) The allegation made by the BB Foundation that the impacts reported in the IMAS 2023 Report indicates that the Marine Farming Expansion is not being undertaken in accordance with the NCA-PM Decision fundamentally misinterprets the function of the decision requirements.
- (b) Moreover, the BB Foundation fails to establish, or refer to documentation that establishes, causality between the Marine Farming Expansion, the reported reduced environmental conditions in the harbour and the impacts on the Maugean Skate.
- (c) The NCA-PM Decision requires that the Marine Farming Expansion be undertaken in accordance with the Macquarie Harbour Marine Farming Development Plan October 2005 (**MHMFDP Plan**) and the measures stated in requirements 1-3 of the decision.
- (d) The allegation by the BB Foundation is not supported by any particulars of conduct by the Operators that has occurred in a manner inconsistent with the requirements of the NCA-PM. This is contrary to the requirement in clause 4AA.01(5) of the EPBC Regulation; accordingly the request on the basis of section 78(1)(b) of the EPBC Act is not valid and cannot not be accepted by you.
- (e) If you or your Department held any concerns as to compliance with the NCA-PM Decision, as matter of procedural fairness, it would be appropriate in the first instance for those

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matters to be put by the Department directly to the relevant operators, in confidence, for its consideration and response.

- (f) Even if the allegation made by the BB Foundation constituted a properly made reconsideration request, it is submitted there is no factual basis for you to reasonably accept that a ground is established under section 78(1)(b) to revoke the NCA-PM Decision.

6 Addressing environmental impacts, and improving knowledge of the Maugean Skate

6.1 State and Commonwealth Conservation Advice

- (a) On 6 September 2023 updated Conservation Advice for Maugean Skate was published by the Department of Climate Change, Energy, the Environment and Water under the EPBC Act (**Conservation Advice**).¹⁴
- (b) The Conservation Advice provides guidance and identifies actions required and research to be undertaken to ensure the conservation and recovery of the Maugean Skate and provides a summary of the current threats to the species.
- (c) Several key urgent actions are identified by the Conservation Advice that were recommended to be implemented prior to summer 2023 to ensure the species does not become extinct including:
 - (i) increasing the levels of dissolved oxygen in Macquarie Harbour, via a reduction in salmon aquaculture organic loads and/or utilisation of mechanical/engineering environmental remediation technologies;
 - (ii) initiation of a captive breeding program, including all appropriate Commonwealth and state permits for collection of Maugean skate adults and eggs; and
 - (iii) reinstating the CSIRO predictive monitoring modelling to inform modification of hydroelectric dam environmental flows.
- (d) In January 2024, the Department of Natural Resources and Environment Tasmania (**NRE Tas**) released the newly developed Maugean Skate Conservation Action Plan.
- (e) The Conservation Action Plan details 5 objectives and actions designed to minimise the extinction risk of the Maugean Skate and support recovery of the skate in the wild.
- (f) The first objective of the Conservation Action Plan is to 'ensure that viable habitat in Macquarie Harbour is available to meet the needs of the Maugean skate'. This objective will aim to be achieved through the undertaking of 'Priority Conservation Actions' which for Objective 1 include engineered oxygenation projects supported by the industry.
- (g) Both the Federal and State conservation materials identify the role that engineered solutions will need to play in addressing environment conditions within Macquarie Harbour.
- (h) The salmon farming industry acknowledges the sensitivities of operating within the unique Macquarie Harbour environment and are alive to the need to develop innovative and effective methods to reduce and mitigate impacts on the environment and to work closely with peak research bodies in order to achieve this.

6.2 Industry Involvement in Research Initiatives

- (a) Significant time and resources have been invested by the Operators into addressing these concerns, including providing funding and technical expertise for research and conservation initiatives.
- (b) Industry is engaged, consulted and actively participate in research undertaken by peak bodies including the Fisheries Research and Development Corporation (**FRDC**) and IMAS.
- (c) Much of the data that underlies the scientific reporting conducted by FRDC and IMAS is collected by the Operators throughout the harbour.

¹⁴ <https://www.environment.gov.au/biodiversity/threatened/species/pubs/83504-conservation-advice-06092023.pdf>.

- (d) Since 2012, the industry has provided financial support for research undertaken in relation to environmental impacts and environmental management relevant to salmon farming in Macquarie Harbour, through projects coordinated by the FRDC including:
 - (i) Atlantic Salmon Aquaculture Subprogram: characterising benthic pelagic interactions in Macquarie Harbour - organic matter processing in sediments and the importance for nutrient dynamics (FRDC Project no. 2012-047);
 - (ii) Movement, habitat utilisation and population status of the Endangered Maugean skate (FRDC Project no. 2013-008);
 - (iii) Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies (FRDC Project no. 2015-024);
 - (iv) Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour (FRDC Project no. 2016-067); and
 - (v) Vulnerability of the endangered Maugean skate population to degraded environmental conditions in Macquarie Harbour (FRDC Project no. 2016-068).
- (e) Given the high level of involvement of industry in these research efforts the findings arising from these projects are proactively integrated into industry management and operational practices often before the findings are made publicly available.
- (f) The most recent initiative is the MHOP – ie the "Macquarie Harbour oxygenation trial" (FRDC Project no. 2023-087) addressed in section 6.3 below.
- (g) Extensive technical research has been undertaken by IMAS, again financially and operationally supported by industry, in relation to Macquarie Harbour since 2012, which has informed the Operators' management and practices. This includes the following:
 - (i) IMAS Technical Report on Macquarie Harbour Condition, Jan 2017;
 - (ii) IMAS Progress Report on Macquarie Harbour, May 2017;
 - (iii) Macquarie Harbour TWWHA Environmental Status Report, EPA, May 2017;
 - (iv) Macquarie Harbour 2013-2016 Nutrient Review May 2017 (Internal Final Draft);
 - (v) IMAS Progress Report on Macquarie Harbour, September 2017;
 - (vi) IMAS Progress Report on Macquarie Harbour, February 2018;
 - (vii) IMAS Progress Report on Macquarie Harbour, December 2018;
 - (viii) IMAS Environmental Research Progress Report, July 2019;
 - (ix) IMAS Environmental Research Progress Report, February 2020; and
 - (x) IMAS Assessment of Macquarie Harbour BEMP data from 2011 to 2020, March 2022.

6.3 Macquarie Harbour Oxygenation Project

- (a) The MHOP is a \$6 million trial of engineering solutions to enhance oxygen levels in Macquarie Harbour. The project is being led by the salmon farming industry, in partnership with independent organisations - the Australian Government's FRDC, and the IMAS.
- (b) The MHOP will be instrumental in demonstrating the role that an engineered solution, being the mechanical oxygenation of bottom and mid waters, can play in improving and regulating the oxygen levels in Macquarie Harbour, as identified in both the State and Federal Conservation documents.

- (c) The MHOP will incorporate three packages:
 - (i) engineering and operation of the oxygenation plant and delivery system;
 - (ii) measuring the ecosystem response; and
 - (iii) modelling to predict plume diffusion and advection at local and broad scales.
- (d) The pilot trial will progress in a staged approach, with the volume, duration and method of injection progressively scaled based on plume dispersion modelling and detailed water quality and ecosystem observations to ensure that the oxygen is delivered and retained in the bottom waters with no adverse ecological effects.¹⁵
- (e) The MHOP will trial 2 dissolution systems to boost oxygen levels in dissolved-oxygen poor, middle and bottom waters over time:
 - (i) The first dissolution system works by generating oxygen which is subsequently mixed with water that has been pumped from a depth of 20m. The supersaturated water is then pumped to the high resident marine water that sits beneath the freshwater surface layer at approximately 30m-40m depth; and
 - (ii) The second employs nano-bubble and micro-bubble technology where oxygen gas will be piped directly to the desired depth where it is injected into the water.
- (f) These forms of generation were identified as the best oxygen delivery methods that simultaneously avoid any upwelling or mass water movements in the highly stratified waterway.
- (g) This type of technology is regularly used around the world for port and harbour remediation, river and estuarine systems to assist natural water exchange and oxygenation. There is a long serving installation that has been in the Swan River in Perth to assist this naturally low water exchange river and provide oxygen. Internationally, these systems are commercially available and used to boost deep water oxygen levels.
- (h) A two-year trial was commenced in Summer 2023/24 which will assess the delivery of oxygen to the deeper water sections of the harbour. These deeper waters of the Macquarie Harbour system have the longest residence time and is where biological oxygen demand from aquaculture, hydro and river systems occurs.
- (i) The trial will further determine whether this technology can provide a long-term solution to improve the Macquarie Harbour environment for the Maugean Skate, while responding to the challenge of warming waters.
- (j) The impacts of the trial oxygenation activities on the surrounding area will also be assessed to ensure there are no adverse ecological effects as a result of the MHOP project, during the trial period and long-term.
- (k) Real-time monitoring will be used to measure oxygen, temperature, salinity levels and turbidity and chlorophyll near the injection location during the trial period. Samples will additionally be collected to test for changes to metals, microbes and nutrients baselines.
- (l) The MHOP will be overseen by IMAS scientists, who will independently review and report on the results of the trial to all stakeholders, including the Tasmanian EPA and the Australian Government.
- (m) Reports providing updates on the oxygenation trials including a summary of key performance outcomes based on the water column and benthic observations, model outputs and any

¹⁵ FRDC funding application

other relevant findings, will be made publicly available on the FRDC and IMAS websites and in scientific literature publications.

- (n) The MHOP has been endorsed by the Maugean Skate National Recovery Task Force as one of the immediate priority actions to support the conservation and recovery of the Maugean Skate as is detailed in the Conservation Advice and Action Plan for the Maugean Skate.
- (o) The MHOP has received further endorsement from Senator for Tasmania, Senator Anne Urquhart, who has acknowledged the salmon farming industry's role in pursuing positive outcomes for the harbour.
- (p) While we acknowledge that salmon farming is one of many activities that impact upon the environmental conditions of Macquarie Harbour, the industry has voluntarily undertaken to reduce its own direct impact on oxygen levels in the harbour by supplementing the known DO drawdown with oxygenated water (super-saturated) pumped from the surface to depth in the water column.
- (q) Salmon Tasmania submits that the two-year trial should be allowed to run its course before any conclusions are reached about its efficacy.

7 Strengthened Tasmanian Government Regime for Marine Farming

7.1 Regulatory framework introduction

- (a) Separate to forming the basis of the Reconsideration Requests made under s78A, each of the requests allege that the data contained in the IMAS 2023 Report is evidence that the conditions in the NCA-PM Decision are not sufficient to ensure that the Marine Farming Expansion has no significant impact on the skate.
- (b) Salmon Tasmania and the industry reject this allegation as unsubstantiated. The criticisms fail to appreciate the requirements of the NCA-PM Decision and the manner in which they operate in conjunction with the evolution of practices within the industry and the changes to the Tasmanian regulatory regime over time.
- (c) The NCA-PM Decision requires that the Marine Farming Expansion be undertaken in accordance with MHMFD Plan and the measures stated in requirements 1-3 of the decision. The conditions require compliance by the Operators with monitoring and reporting requirements as prescribed by the relevant marine farming licence conditions.
- (d) Since sampling began in 2012, dissolved oxygen levels have always complied with the set trigger limit for 2 meters (6.82 mg/L). This compliance record for dissolved oxygen incorporates the data from over 100 sampling events (and applies a rolling median).
- (e) This evidence of compliance is the same for the other parameters, notably trigger levels set for ammonia at 2 and 20 meters (0.033 mg/L and 0.024 mg/L respectively) and the nitrate trigger set for 2 meters (0.053 mg/L). None of these triggers outlined in the 2012 decision have been breached.
- (f) Close supervision of the industry by the Tasmanian Government has resulted in amendments to the regulation of finfish farming and aquaculture at the State level since the NCA-PM Decision was made. A central component of this approach has been the adoption of adaptive management principles.
- (g) As a result of changes by the Tasmanian Government, the salmon farming industry is subject to materially more stringent monitoring, reporting and compliance requirements at the State level than were in effect at the time of the 2012 decision.
- (h) This is in addition to self-imposed changes by industry in operations and management of salmon farming arising from the results of scientific research and development initiatives.
- (i) Significantly, recent amendments to renewed Environmental Licences for Macquarie Harbour farming operations have introduced requirements to monitor and develop mitigation plans relating to dissolved oxygen levels.
- (j) The amended regulatory framework has been further bolstered by the State's adoption of modernised impact mitigation measures, introduction of legally enforceable environmental and technical standards and development of key policy documents.
- (k) These steps notably include halving the total maximum allowable biomass limits for the harbour, the introduction of Total Permissible Dissolved Nitrogen Output (*TPDNO*) as the metric for managing finfish production, the introduction of *Environmental Standards for Tasmanian Marine Finfish Farming in 2023* and the development of a dedicated Conservation Action Plan for the Maugean Skate.
- (l) The enhanced requirements under the State regime means that marine farming in Macquarie Harbour is conducted in a manner that exceeds the requirements contained in the 2012 NCA-PM Decision and at significantly lower levels of production than was intended in

2012. Indeed, as demonstrated in Schedule 1, production levels are now less than existed at the time of the NCA-PM Decision in 2012.

- (m) Compliance with environmental licence requirements under the State regime is enforced by the independent environment regulator, the Tasmanian EPA, and for the marine farming leases by the Tasmanian Department of Natural Resources and Environment (**NRE Tas**) - meaning there is further oversight over the industry to ensure compliance with the regulatory regime and appropriate management of environmental impacts.
- (n) The further development of the regulatory framework for managing environmental impacts to water quality and aquatic life continues, as evidenced by the release in July 2023 by the Tasmanian EPA of the Interim Default Guideline Values for Aquatic Ecosystems for part of Macquarie Harbour.

7.2 Limiting of Biomass and Introduction of Total Permissible Dissolved Nitrogen Output

- (a) Until 2022, biomass caps that determined the maximum allowable biomass of finfish (tonnes per hectare) were implemented under the MHMFD Plan to regulate the number of fish that may be stocked in Macquarie Harbour.
- (b) The Marine Farming Expansion included the reconfiguration of leases within Macquarie Harbour to increase the total allowable lease space from 564 ha to 926 ha. A considerable body of social, economic and environmental information was consolidated into an Environmental Impact Statement that supported the proposed increased production in Macquarie Harbour.
- (c) The maximum sustainable biomass determined for the harbour was initially modelled at 29,500 tonnes. Salmon production in the harbour reached a level of 19,200 tonnes in late 2014.
- (d) In April 2016, the biomass caps for each company were decreased to 21,500 tonnes for the 2016/2017 production year
- (e) In 2017 the Tasmanian EPA Director issued determinations to each of the Operators in the harbour, requiring that maximum permissible biomass limits be reduced by half (**2017 Determinations**).
- (f) The maximum permissible biomass allowed to be stocked in the Harbour has continued to be progressively lowered since 2017. The total allowable biomass cap for the Harbour was 14,000 tonnes from 14 February to 30 April 2017, 12,000 tonnes for the period 31 May 2017 to 31 May 2018 and 9,500 tonnes per annum between 1 June 2018 to 31 May 2022.
- (g) Amendments to the MHMFD Plan on 13 September 2016 conferred the Tasmanian EPA Director with power to determine the total permissible dissolved nitrogen output (**TPDNO**) attributable to licensed finfish marine farming operations in Macquarie for specified periods.
- (h) TPDNO limits have been introduced to replace biomass caps as the method for limiting finfish production in Macquarie Harbour.
- (i) The first TPDNO determination of 500.1 tonnes was made on 31 August 2022 and applies for the period 1 September 2022 until 31 August 2027.¹⁶ The TPDNO specified in the determination provided for a 10% reduction in production from 2021 production levels.
- (j) As a result, current production levels in the harbour are lower than they were at the time of the NCA-PM Decision in 2012.

¹⁶ [Determination And Apportionment of Total Permissible Dissolved Nitrogen Output](#)

- (k) The introduction of TPDNO is an example of how modern and improved practices are being implemented in the regulation of the salmon farming industry to provide more clarity, transparency and better outcomes for the environment.
- (l) The reduced production in Macquarie Harbour as a result of the biomass caps and TPDNO determinations is shown in Schedule 1 .

7.3 New Environmental Licence Conditions

- (a) Since the granting of the original licences in 2012, the Marine Licence Conditions (now Environmental Licences) have become more contemporary and includes increased sampling requirements (near and far field).
- (b) Industry has also established a real-time sensor network across the system to measure key environmental parameters including oxygen, salinity and temperature.
- (c) The strengthened licence conditions have been underpinned by the comprehensive research that has been conducted across Macquarie Harbour allowing the adaptive management of this unique waterway.
- (d) On 30 November 2023, following a historical compliance review, the Tasmanian EPA Director decided to renew all environmental licences for leases within Macquarie Harbour for a 2-year period.
- (e) This included leases held by Petuna Aquaculture, Tassal Operations and Huon Aquaculture.
- (f) In renewing these licences, the Director imposed additional conditions requiring each environmental licence holder to:
 - (i) provide the Director with the overall dissolved oxygen demand resulting from finfish activities on their lease;
 - (ii) provide and implement a Dissolved Oxygen Mitigation Plan to substantially offset or reduce dissolved oxygen demand from their lease; and
 - (iii) develop for approval and implement a Water Quality Monitoring Plan to measure the success of the dissolved oxygen mitigation measures against the interim default guideline values set by the EPA.
- (g) The Environmental Licence conditions now require the reporting of oxygen consumption for both fish respiration and biological oxygen demand.
- (h) There are also default guideline values that have been developed for 3 segmented zones as determined by EPA across the system. The broadscale water quality monitoring program has remained in place since 2011 and provides a world-class continuous dataset for system wide analysis.
- (i) These requirements represent additional measures, in addition to those stated in the NCA-PM Decision, that are undertaken by the Operators in order to address the concerns relating to diminished DO levels in the harbour.

7.4 New Environmental and Technical Standards

- (a) In 2023, new Environmental Standards for Tasmanian Marine Finfish Farming were made pursuant to the *Environment Management and Pollution Control Act 1994 (Tas)* (**EMPCA**) and came into effect on 18 October 2023 (**Environmental Standards**).

- (b) The standards were introduced as part of the Tasmanian Salmon Industry Plan in support of the regulation and management of the marine finfish farming industry in Tasmania¹⁷. The Environmental Standards will be enforced by the Tasmanian EPA.
- (c) The purpose of the Standards is to set out the environmental management conditions that will be imposed on environmental licences issued to marine finfish farmers, with non-compliance with the Standards being an offence under the EMPCA.
- (d) Under the Environmental Standards, the Tasmanian EPA Director is empowered to make determinations as to compliance thresholds, monitoring requirements for marine farming activities and impose conditions relating to environmental outcomes that must be complied with by licence holders.
- (e) The Standards also contain standard environmental management conditions that will be imposed on environmental licences issued to marine finfish farmers and are enforced by the Tasmanian EPA.
- (f) The Standards are reflective of international industry best practice, and have been developed following a review of international regulatory practices for monitoring the environmental impacts of farming salmonids in net pens by the Tasmania EPA. Input from peak research bodies including IMAS and the Commonwealth Scientific and Industrial Research Organisation (**CSIRO**) also informed the development of the Environmental Standards.
- (g) Technical Standards that will enable the Tasmanian EPA to implement the new Environmental Standards are currently under development. The Technical Standards will contain contemporary, scientifically sound, and auditable methods and are expected to be published by 1 January 2025.¹⁸
- (h) In carrying out the Marine Farming Expansion the Operators are required to comply with the Environmental Standards, and in turn with the forthcoming Technical Standards.

7.5 Conservation Action Plan

- (a) The MHOP will play a key role in achieving the first objective of the Maugean Skate Conservation Action Plan, being to 'ensure that viable habitat in Macquarie Harbour is available to meet the needs of the Maugean skate'.
- (b) The CAP will be deemed successful if, among other criteria, threats to the skate population and health of Macquarie Harbour generally are better understood and where feasible reduced, and there is an increased understanding of the species' response to anthropogenic impacts within 3 years of the introduction of the Conservation Action Plan.

7.6 Conclusion

- (a) The significant work undertaken by the Tasmanian Government and salmon farming industry means that the Marine Farming Expansion is carried out in accordance with international best practice.
- (b) Both the Tasmanian Government and the industry are responsive to developments in technology and actionable findings from scientific reports, and incorporate these developments into their licencing requirements and operational practices.

¹⁷ Environmental Standards for Marine Finfish Farming, Tasmanian EPA.

¹⁸ Environmental Standards for Marine Finfish Farming, Tasmanian EPA.

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- (c) Salmon Tasmania submits that you should take notice that the Tasmanian regulatory regime ensures that the Marine Farming Expansion is being proactively managed in an effective and transparent manner to achieve published standards.

8 Immediate, significant adverse impacts of any revocation of the NCA-PM decision

8.1 Immediate impact on aquaculture activities

- (a) Should the outcome of the reconsideration request process lead to a decision that the Marine Farming Expansion in Macquarie Harbour is a 'controlled action', this would result in the activities immediately being expressly prohibited by section 74AA of the EPBC Act until such time as an assessment has been completed and an approval issued.
- (b) As such, any revocation of the current NCA-PM Decision and substitution of a controlled action decision would immediately result in the activities being unlawful until approved. All salmon farming industry participants relying on the NCA-PM decision would be required to immediately cease all operations in the Macquarie Harbour, as quickly and practically as possible without compromising animal welfare.
- (c) Ceasing operations in Macquarie Harbour would result in major impacts to the local community including a near total reduction in the local workforce.
- (d) Should the industry be required to abruptly halt and relocate their activities, it would be highly challenging and cost prohibitive for the industry to restart salmon farming in Macquarie Harbour.
- (e) Furthermore, any decision around this matter must consider the immediate animal welfare of the stock of fish currently growing in the harbour. It is not logistically or commercially possible to relocate such large quantities of livestock to other parts of the State, nor is this permitted under the State's biosecurity regime.
- (f) The salmon industry considers that any decision that affects the lawfulness of current aquaculture operations in Macquarie Harbour must consider the practical need for fish stock within the harbour to be able to grow out to production size. The only alternative option would be to euthanise the stock.
- (g) The Tasmanian EPA Director recognised this constraint in the Statement of Reasons provided for the renewal of Environmental Licences relevant to the Marine Farming Expansion in late 2023. The Director acknowledged that Tasmania does not currently have the capacity to adequately manage the volume of waste that would result from the cessation of aquaculture in the harbour.¹⁹
- (h) Consideration would also need to be had to the handling of the next year class of finfish that are currently being held in freshwater hatcheries waiting to be put into the harbour. The practicality of prematurely destroying infant livestock that cannot be used for production is not something that industry has ever needed to contemplate.
- (i) The management of the mortalities from a biosecurity and waste management perspective would require a major undertaking by industry and the Tasmanian Government, with the potential to trigger significant new environmental challenges. Salmon Tasmania urges you to seek advice from your agency and the Tasmanian Government on the environmental risks of such an outcome.

8.2 Impact on member entities

- (a) Additionally, if the effect of a new controlled action decision is that the Marine Farming Expansion becomes immediately unlawful (until approved), or conditions imposed on any subsequent approval are unduly onerous and such that it becomes financially unviable, there will be significant flow on effects for Salmon Tasmania's members.

¹⁹ *Statement of Reasons for the Renewal of the Environmental Licences Issued to Petuna Aquaculture Pty Ltd for Finfish Farming Activities in Macquarie Harbour (2023)* page 7.

- (b) At a high level, expected likely adverse impacts in the above scenarios include:
 - (i) environmental considerations in relation to the suspending of operations and decommissioning of the project;
 - (ii) obligations under employment and remuneration contracts;
 - (iii) termination of supplier and customer agreements upstream and downstream along the logistics and value chain;
 - (iv) implications for breach of covenants in agreements with third parties including financiers and suppliers;
 - (v) risks to certifications held by Operators that affect operations outside of Macquarie Harbour; and
 - (vi) implications for insurance and inability to obtain further cover.
- (c) These effects represent a significant risk to the operating future of our member entities, who are significant employers in the region and would have immediate adverse impacts on our members' workers, their families and the wider community of the West Coast region.

8.3 Impact on the Community and Tasmanian economy

- (a) The principles of ecologically sustainable development that underpin the objects of the EPBC Act require the balancing of economic advancement and environmental preservation in order to achieve sustainable outcomes.
- (b) The EPBC Act requires that any decision-making process under the Act effectively integrate both long-term and short-term economic, environmental, social and equitable considerations.²⁰
- (c) The role of the salmon aquaculture industry in promoting the economic prosperity of the region and of Tasmania as a whole cannot be understated.
- (d) Deloitte Access Economics analysis in 2022 found:
 - (i) the Tasmanian salmon farming industry supported 5,103 FTE (full-time equivalent) jobs, and contributed \$770 million to the Tasmanian economy.²¹ This represents 2.1% of the Tasmanian economy;
 - (ii) importantly the economic benefit generated by the industry is not concentrated in metropolitan centres but rather in regional areas, where the salmon industry accounts for more than 1 in 4 jobs. In the West Coast region, where Macquarie Harbour is located, the salmon industry supports 17% of employment in the region;
 - (iii) Macquarie Harbour operations account for 395 FTE direct and indirect roles alone, with 1 in 3 residents of the town of Strahan being employed within the industry; and
 - (iv) the jobs created by the salmon industry are of high quality with average remuneration being more than double that of the average Tasmanian job and more than 74% of other jobs in the West Coast region. This is in part reflective of the highly technical and skilled nature of the roles involved in the salmon industry.
- (e) The positive impact of the salmon industry on the economy spreads well beyond direct employment with the salmon companies, and the flow-on impacts into the broader community are significant.

²⁰ Section 3A(a) EPBC Act.

²¹ Deloitte Access Economics (2022), *Socio-economic contribution of the Tasmanian salmon industry*

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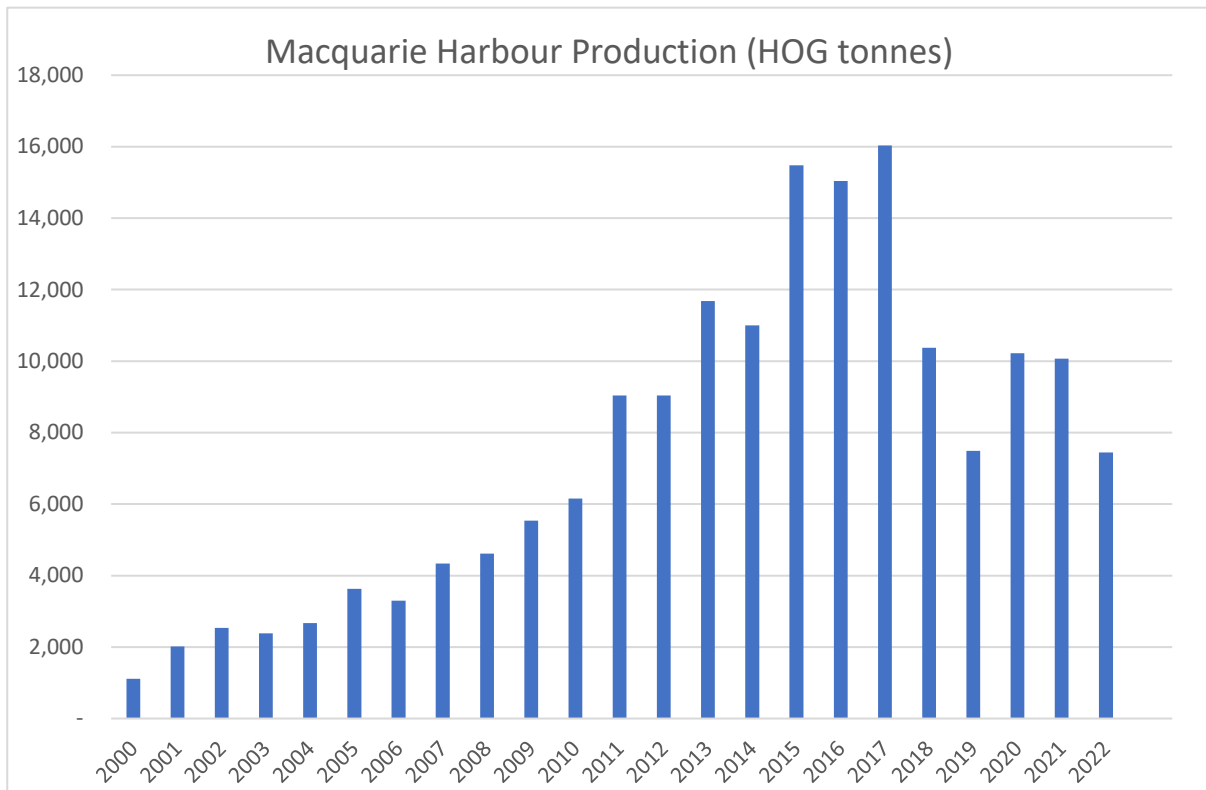
- (f) There is a thriving ancillary sector providing inputs to the industry such as vessels, pens, nets, feed, training, transport, fuel and logistics, and a range of contract and consultancy services.
- (g) Notably the salmon companies utilise vertically integrated business models, with operations spanning across the whole salmon production lifecycle from hatcheries to salmon processing and distribution. Therefore, any impacts on the aquaculture portion of the business will directly impact the other arms of the Operators' businesses.
- (h) The revocation of the NCA-PM decision would result in a devastating loss of jobs across a broad section of the Tasmanian Community.

9 NCA-PM with updated requirements

- (a) Should you be satisfied that revocation of the NCA-PM Decision is warranted on any of the grounds under section 78(1), and you are considering what new decision you may take in substitution for the NCA-PM Decision, then Salmon Tasmania makes an alternative submission for your consideration.
- (b) Salmon Tasmania submits that if the existing NCA-PM Decision is to be substituted, it would be appropriate to take a new decision that the Marine Farming Expansion is not a controlled action if undertaken in a particular manner, and that those requirements of the particular manner be updated.
- (c) Salmon Tasmania in conjunction with the Operators, has convened a technical advisory group to provide recommendations on steps that can be taken to further support environmental protections for the Maugean Skate.
- (d) With the benefit of that technical advice, and following consultation with the Operators, Salmon Tasmania is available to put forward for your consideration a set of proposed alternative particular manner restrictions, and requests you to seek technical advice from your Department and engage with industry and the Operators as to additional appropriate, practical and proportionate measures that will further support improved environmental conditions in Macquarie Harbour for the Maugean Skate.
- (e) Salmon Tasmania stands ready and willing to facilitate engagement by your Department with the Operators and wider industry stakeholders in relation to the development of any such measures.
- (f) Salmon Tasmania is confident that any discussions on updated particular manner requirements would properly inform a fresh decision that the Marine Farming Expansion is not a controlled action decision if undertaken in accordance with an updated set of particular manner restrictions.
- (g) If this alternative proposal is of interest to you and your Department, Salmon Tasmania would welcome the opportunity to engage on the scope and nature of any proposed amended 'particular manner' requirements, to ensure they align with your expectations and comprise a comprehensive set of practical steps to support the recovery of the Maugean Skate in conjunction with sustainable salmon farming in Macquarie Harbour.
- (h) In contrast to a fresh NCA-PM decision, any decision that would result in aquaculture in Macquarie Harbour ending without a scientific basis for doing so, that also failed to address other sources of environmental degradation including changed river flows from hydro-electricity generation and the presence of heavy metals from historic mining activities, would be most unlikely to resolve current low levels of dissolved oxygen and that decision made alone would be unlikely to achieve improved environmental conditions in the harbour to support the recovery of the Maugean Skate.

Salmon Tasmania welcomes any questions in relation to this submission and would be pleased to provide further submissions if that will assist your consideration of the matters raised above.

Schedule 1 – Macquarie Harbour salmon farming production



Source: Department of Natural Resources and Environment Tasmania – Aquaculture Branch (public document) Macquarie Harbour Production Data 2000-2022

Schedule 2 – Technical Review

Review of scientific reports and papers cited in the Requests from The Australia Institute and the AMCS/HSI

1 Overview

This document presents the findings of the objective review of the Reconsideration Requests and scientific literature referred to and relied upon by the requests. The technical review has been undertaken for Salmon Tasmania by a Technical Advisory Group comprising senior technicians drawn from the Operators, with independent review and findings incorporated from the Nautilus Report (Schedule 3) and the Wallis 2024 Report (Schedule 4). This document is to supplement the primary matters raised in the Submission.

2 Response to The Australia Institute Reconsideration Request

2.1 Salmon Tasmania Submissions

- (a) In addition to the IMAS 2023 Report, The Australia Institute relies on the scientific reports outlined in section 4.3 of the Submission in order to assert a causal link between marine farming operations and the observed impacts on the Skate arising from reduced dissolved oxygen levels in Macquarie Harbour.

Substantial new information

- (b) Salmon Tasmania submits that individually the reports cited by The Australia Institute fail to establish any causal link between the observed decline in skate population and marine farming operations.
- (c) The failure to draw a causal link means that the information relied upon does not demonstrate that a change in the potential impacts of the Marine Farming Expansion is likely to happen with a high degree of certainty, as is required under the EPBC Regulation.
- (d) Where cited reports do observe causal links, they overstate the impacts of marine farming operations on dissolved oxygen levels and incorrectly attribute the observed drawdown of oxygen solely or primarily to aquaculture, without considering the hydrological conditions of the harbour and the impacts of other anthropogenic inputs.
- (e) The Request by The Australia Institute also restates findings of cited reports in a manner that does not accurately reflect the conclusions of the relevant report.
- (f) Moreover, the alleged 'new evidence' extracted in The Australia Institute Letter dated 31 July 2023 (**31 July 2023 Letter**) relies on reports that have already been considered and acted upon by the salmon industry, relevant research partners and regulators.

Unforeseen substantial change in circumstances

- (g) The request includes scientific data and statements that support the arguments presented by The Australia Institute, without conducting a discussion of the data or considering the findings via a holistic approach in the context of the changing conditions in Macquarie Harbour or other types of anthropogenic change.

- (h) None of the reports relied upon identify circumstances that were not known by the Minister or the industry at the time of the NCA-PM Decision.
- (i) There have been significant additional monitoring information collected over time which has supported and improved the understanding of the complexities in managing impacts on the Macquarie Harbour system. However, this further information relating to impacts does not amount to a substantial change in circumstances that was unforeseen – to the contrary the monitoring was anticipated and required of the operators.

2.2 Tasmanian Threatened Species Listing Statement

Summary

- (a) The Tasmanian Threatened Species Listing Statement for the Maugean Skate notes that modelling and empirical studies have identified 'river flows and increased nutrient loadings from salmonid aquaculture operations' as playing a 'role in influencing the dissolved oxygen status of the harbour'. River flows were noted to have been altered by 'flows from hydroelectric production' which in turn have also had an impact on 'hydrodynamics and dissolved oxygen status of the harbour'.
- (b) These findings are taken from the Ross 2017 Report and the Wild-Allen 2020 Report, discussed below.

2.3 Ross 2016 Report

Summary

- (a) The Ross 2016 Report investigated the response of benthic invertebrate communities, specifically *Dorvilleid polychaetes*, to 'organic enrichment' from fish farming in Macquarie Harbour.
- (b) The presence of benthic invertebrate communities can be used as an indication of deteriorating environmental conditions. Such indicators have been incorporated in monitoring protocols for Macquarie Harbour and the environmental licence monitoring conditions.
- (c) Having identified a gap in the understanding of the ecology of the benthic communities present in Macquarie Harbour, the report sought to 'determine the reliability of this species as an indicator of sediment condition' and make 'recommendations as to the future use of *Dorvilleids Sp.* in regulatory monitoring of salmon aquaculture in Macquarie Harbour.'
- (d) The Report found that there was an increased presence of benthic communities, specifically 2 types of *Dorvilleid Sp.* in the areas immediately surrounding pens used for marine farming. This coincided with decreased dissolved oxygen (**DO**) saturation in the same areas when compared to background levels. DO saturation levels were reported to gradually increase with distance from the pens.
- (e) These impacts were more pronounced in lease areas that were further from the oceanic entrance of the harbour and that had been farmed more intensely and for longer periods and determined related background organic gradients across the system.
- (f) The Australia Institute relies on these findings as evidence of marine farming operations having an indirect, negative impact on DO levels within the harbour.

Technical Review

- (g) Data regarding DO levels taken from the Ross 2016 Report are drawn from periods prior to subsequent salmon biomass determinations which reduced the allowable stock in the harbour.
- (h) The production volume and nature of marine farming operations has therefore changed significantly since the data relied upon in the Ross 2016 Report was obtained. Changes to DO levels in the harbour since this time can be observed in Figure 1.
- (i) The presence of *Dorvellid Sp.* worms in the area under the salmon pens does not necessarily indicate that salmon farming is having a negative impact on environmental conditions. This conclusion cannot be reached based on the information in the Ross 2016 Report alone.
- (j) The presence of benthic communities of this kind are used as an indicator species, in combination with other indicators like benthic diversity and the presence of *Beggiatoa Sp.* mats as an assessment tool for lease management.
- (k) Research regarding benthic species has informed industry and regulators of specific indicator species and the role they play during different stages of organic enrichment within the system, which have been incorporated into management and regulatory practices.
- (l) Moreover, as sampling for the report was only conducted over one discrete period, the impact of temporal and seasonal cycles on the observed presence of benthic communities and reduced DO levels is stated to be unknown.
- (m) The findings contained in the Ross 2016 Report, informed the operation of individual lease areas and stocking practices for different sized fish.

2.4 Ross 2017 Report

Summary

- (a) The Ross 2017 Report provides an 'interim synopsis' of the scientific literature that considered the then 'current status of the benthic and water column environments' in Macquarie Harbour.
- (b) No causal connections are established by the report, which provides a 'summary of key research projects and their findings' and gaps analysis with recommendations for future research.
- (c) Paragraph 12 of 31 July 2023 Letter misattributes the source of the findings regarding potential indirect impacts of salmon farming on the Maugean Skate. This commentary is not contained in the Ross 2017 Report, but rather in a report that forms part of the literature review titled *Movement, habitat utilisation and population status of the endangered Maugean skate and implications for fishing and aquaculture operations in Macquarie Harbour*.¹
- (d) With support from the industry, this report primarily investigated population characteristics and the distribution of the skate within Macquarie Harbour and implications this may have for marine farming operations.

¹ *Movement, habitat utilisation and population status of the endangered Maugean skate and implications for fishing and aquaculture operations in Macquarie Harbour*, Justin Bell, Jeremy Lyle, Jayson Semmens, Cynthia Awruch, David Moreno, Suzie Currie, Andrea Morash, Jeff Ross and Neville Barrett (2016).

- (e) An array of acoustic receivers were used to determine the 'distribution, habitat utilisation and movement' of the Skate within the harbour and seasonal biological sampling was undertaken to determine key biological characteristics.
- (f) This data was used to establish the preferential habit of the Maugean Skate population within Macquarie Harbour.
- (g) Conclusions as to the potential impact of salmonid farming on the Maugean Skate were made by comparing the observed habitat preferences of the skate and the location of marine farming operations.
- (h) Paragraph 13 of the 31 July 2023 Letter, contains an extract that details a decline in DO levels in the harbour from 2009 to mid 2014, which continued to the period in which the report was published being 2017.
- (i) The section in Paragraph 14 of the 31 July 2023 Letter is extracted from a report entitled *Effect of hypoxia and anoxia on invertebrate behaviour: ecological perspectives from species to community level.*²
- (j) This report considered the impacts of hypoxia and anoxia on 'a representative spectrum of benthic macrofauna in the natural setting in the Northern Adriatic Sea' and was used to estimate the ecological effect of changing DO levels in Macquarie Harbour on the skate in the Ross 2017 Report, as research specific to the skate was not available.
- (k) The Ross 2017 Report states that this approximation was used as 'it is difficult to say for certain what the ecological effect of [variability in bottom water DO levels in Macquarie Harbour] might be' but that some 'insight' may be gained from other research.
- (l) 'Figure 28' contained in Paragraph 15 of the 31 July Letter, is also extracted from the same report.

Technical Review

- (m) Similar to Ross 2016, data regarding DO levels is taken from the period before salmon stock in the harbour was significantly reduced. The volume and nature of marine farming operations has therefore significantly changed since this data was recorded and the findings that result are unlikely to be reflective of current circumstances.
- (n) Recording using the acoustic receivers was only conducted once and not repeated again providing only a single set of data from a discrete time period.
- (o) Concerns regarding the size of the sensors used to record the acoustic data and the related mortality rates from the sensors with the related capture and attachment process were also raised in the report.
- (p) Salmon Tasmania submits that the usefulness of the extract in Paragraph 13 extract is limited as the cause or source of the reduced DO levels are not stated in the extract or the wider report, and the data regarding DO levels is now over 5 years old.
- (q) The report from which the information Paragraphs 14 and 15 is taken relates to a different species in an environment distinct to that of Macquarie Harbour. As such, the conclusions drawn from this data in relation to the Skate are not conclusive.

2.5 Moreno 2020 Report

Summary

² *Effect of hypoxia and anoxia on invertebrate behaviour: ecological perspectives from species to community level*, B. Riedel T. Pados, K. Pretterebner, L. Schiemer, A. Steckbauer, A. Haselmair, M. Zuschin, and M. Stachowitsch (2014).

- (a) The Moreno 2020 Report investigated the 'mechanistic links' between the environmental conditions in Macquarie Harbour and the impacts on the skate across multiple life stages. Field surveys, assessments and laboratory studies were conducted to establish findings for the report.
- (b) Skate were found to be capable of surviving 'chronic exposure to hypoxic conditions' through entering a depressed metabolic state. This state is noted to not be sustainable in the long term however, and it occurs 'at the cost of other energy intensive life... processes'.
- (c) DO levels in bottom waters are stated to 'represent a crucial factor' in the wellbeing of the Skate population.
- (d) 'Various' anthropogenic activities are identified as impacting the environmental conditions in Macquarie Harbour, with 'aquaculture, mining, hydro-electricity generation (fluctuating river flows) and coastal development - along with the effects of climate change' all stated to 'play a role in shaping the environmental conditions of this unique system'.

Technical Review

- (e) As is identified in the Wallis 2024 Report, the impact of salmon farming on waters in the lower layers of the harbour is minimal. As the nets used on pens in Macquarie Harbour only reach depths of approximately 13m, there is no observed impact on bottom water DO as a result of salmon respiration as no salmon are present at this depth.
- (f) Further, the DO draw down associated with biological processes arising from salmon excrement and feed loss on the harbour bed, was found by Wallis to be minimal.

2.6 Wild-Allen 2020 Report

Summary

- (a) The Wild-Allen 2020 Report used a biogeochemical and hydrodynamic model to simulate the effects of changes to rivers inflows and a reduction in anthropogenic activities on water quality in Macquarie Harbour.
- (b) The model was used to simulate a scenario in which finfish farming was ceased in Macquarie Harbour (by omitting the oxygen drawdown and dissolved and particulate waste attributable to the farms), and then used to predict levels of DO.
- (c) Paragraph 22 of the 31 July Letter states that farmed fish respiration accounts for 3% of DO loss in the harbour. In the same 2018 period to which this data relates, this contribution to DO loss is comparable to losses attributable to air sea flux and water column biogeochemistry losses. The greatest loss of DO (87%) for the period was the export of oxygen rich surface water to the ocean. Salmon biomass has decreased and is now regulated via a TPDNO that limits the release of nutrients from farming operations.
- (d) The Australia Institute relies upon the model predictions which presented a '50% reduction in hypoxic volume and a 40% reduction in hypoxic sediment area under reduced anthropogenic load' when compared to 2017-18 levels. The modelled reduced anthropogenic load represented the largest reduction in hypoxia when compared to all other modelled scenarios.

- (e) The report states that it is the combined effect of river inflows and anthropogenic load that 'ultimately defines the hypoxic condition of the harbour', with the primary source of DO depletion at depth being stratification and 'slow flushing of deep water into the harbour'.³
- (f) Variations in seasonal releases from hydro dams were also stated to 'impact flushing and harbour oxygen status'.

Technical Review

- (g) The central findings of the Wild-Allen 2020 Report, being the modelled removal of salmon farming from the harbour are problematic on a number of fronts:
 - (i) the key findings (see 2.6(b)) are presented in a manner that overstates the effect of the modelled reduced anthropogenic load. The model predicted a reduction in hypoxic conditions from 27-28% to 14-17% by volume and from 12% to 4-6% by area. When considered in the context of the harbour as a whole, this reduction is not as significant as is represented;
 - (ii) the ranges used to define the levels of oxygenation are broad and may not provide a true reflection of the relative water conditions in the harbour. For example, if the removal of salmon farming increased oxygen saturation by 1% and a portion of the water was at 30%, the oxygenation of that water volume would be considered 'intermediate'; and
 - (iii) the baseline data is obtained for the period 2017-2018 which is from the period prior to the biomass caps being implemented, and is therefore not reflective of current operations and stock levels in Macquarie Harbour.
- (h) The Wild-Allen 2020 Report estimates the DO load in the sediments due to the oxygen consumption required in biological process associated with the breakdown of salmon food and faeces to be 12,000 t/yr.
- (i) The Wallis 2024 Report similarly estimated the DO drawdown associated with these biological processes and determined that the total demand in the lower layer would be 1,770 t/yr.
- (j) The differences arise due to the assumptions used in Wild-Allen's modelling being incorrect and not representative of salmon farming practices. The Wild-Allen 2020 Report assumes a feed efficiency of 85%, which in turn assumes a 15% wastage. Currently the industry operations achieve approximately a 3% wastage rate. This difference in assumed wastage rates would significantly change the outputs of the Wild-Allen model and in turn the findings of the report.
- (k) The nitrogen content of feed as assumed in the Wild-Allen 2020 Report is also not reflective of current data from improved feed formulations, nor are the biomass figures used in the modelled scenarios.
- (l) The estimated average effect of the salmon farms is to reduce the DO in the lower layer by around 16 per cent or 1 mg/L. This estimate is lower than the prediction by CSIRO that DO in the lower layer would increase by around 1 to 2 mg/L at 25 to 35 m depth if the 12,000 t/yr salmon load (CSIRO estimate) was removed. The load estimated here of 1,770 t/yr is lower because salmon production in 2017 (the year for the CSIRO prediction) was about twice current levels.

³ Pg 6.

2.7 Conclusion

- (a) The findings and analysis contained in the Ross 2016 Report and Ross 2017 Report do not fully consider the impact of the Marine Farming Expansion on the Maugean Skate.
- (b) The Marine Farming Expansion resulted in the relocation of 59% of the previous marine farming lease area that occurred in less than 20m depth into the deeper central waters of the Harbour. This effectively reduced the lease area where the Maugean Skate preferred habitat occurred.
- (c) As noted above, the Ross 2016 Report findings are not 'new' to the industry and in accordance with the adaptive management principles, changes to how industry manages biomass and nitrogenous inputs, as well as in-field data (e.g. benthic surveys) and system-wide monitoring were made as a result of the findings.
- (d) Wallis notes in his 2024 Report at page 17 that:
 - (i) *'In response to harbour wide declines in DO levels and declines in benthic faunal abundance that was observed in the Ross 2017 Report, the total permissible biomass limits for the harbour were reduced. Present day feed inputs are now approximately half the earlier peak rate ...'*
 - (ii) *'Further modern marine farming practices achieve high rates of feed consumption (97%) with very minimal fallout of around 3%.'*
- (e) As discussed above, the Ross 2017 Report relies on related scientific literature to draw parallels to potential impacts of reduced DO levels on the Skate. The secondary or 'indirect' impacts stated in the report (and relied upon by The Australia Institute) are speculative and not based on data collected for the report.
- (f) Though the Moreno 2020 Report establishes that reduced DO levels in bottom waters may negatively impact the skate, aquaculture is one of many anthropogenic sources stated as having an impact in the conditions of the harbour, based on other research.
- (g) Salmon aquaculture was found in the Wallis 2024 Report to have a minor impact of DO levels in the bottom of the harbour, given the location of the salmon pens in the top layer of the harbour (to a depth of about 15 metres).
- (h) Great care should be taken when having regard to the Request by The Australia Institute, as it repeatedly extracts various report sections and restates conclusions of the of scientific reports in a manner that does accurately reflect the findings of the cited report.
- (i) Paragraph 9 of the Letter Dated 8 June 2023 states that Tasmanian Threatened Species Listing Statement 'concludes that the Maugean skate is at risk from the aquaculture industry'. This fundamentally overstates the conclusions drawn in the Statement as extracted in section 2.2(a). Further, as is discussed above, the reports relied upon by the Listing Statement to draw these conclusions are also flawed.
- (j) The recommendation extracted from Paragraph 10 of the Letter Dated 8 June 2023 does not form part of any recommendations from the Senate Environment and Communications References Committee and is actually contained in the Australian Greens' Dissenting Report.
- (k) Paragraph 15 of the 31 July Letter, states that aquaculture is a factor contributing to the environmental conditions contained in the harbour, however it is noted to be one of many anthropogenic factors that impacts Macquarie Harbour and no causal link that supports this claim is established in the Moreno 2020 Report.

- (l) For the reasons set out above, Salmon Tasmania submits that the literature relied upon in the Request by The Australia Institute does not constitute substantial new information or an substantial change in circumstances that was unforeseen at the time of the NCA-PM Decision in 2012 that relates to the impacts of the Marine Farming Expansion on the Maugean Skate.
- (m) As the information does not satisfy the criteria in section 78(1) of the EPBC Act it cannot warrant the revocation and substitution of the NCA-PM Decision.

3 Response to AMCS/HSI Reconsideration Request

3.1 Salmon Tasmania Submission

- (a) We have considered the additional material relied upon in the AMCS/HSI Reconsideration Request and in conjunction with the Wallis Report.

Substantial new information

- (b) Salmon Tasmania asserts that the information presented in the reports does not establish any causal link between the declining skate population and reduced dissolved oxygen conditions attributable to marine farming operations. Therefore the stated impacts cannot be said to be likely to occur with a high degree of certainty.
- (c) The reports that do try to establish a causation, overstate the impacts of marine farming operations on dissolved oxygen levels.

Unforeseen substantial change in circumstances

- (d) The alleged unforeseen changes in circumstances do not specifically relate to impacts the Marine Farming Expansion will have on the Maugean Skate, as is required under section 78(1)(aa). Rather the findings relate to broader circumstances such as climatic changes separate to salmon aquaculture, that may impact the environmental conditions in the harbour or the viability of the skate population.
- (e) As such the information relied upon fails to satisfy the criteria in section 78(1)(a) or 78(1)(aa) of the EPBC Act and therefore cannot warrant the revocation and substitution of the NCA-PM Decision on either grounds.

3.1 Moreno 2022 Report

Summary

- (a) Using eDNA the Moreno 2022 Report conducted surveys to determine the presence of Maugean Skate in Bathurst Harbour.
- (b) Insufficient concentrations of Maugean Skate DNA were found in Bathurst Harbour to allow for positive identification alone. The report concludes that this data suggests 'the vast majority, if not all' of Maugean Skate live in Macquarie Harbour.
- (c) The AMCS/HSI submit that the as the Macquarie Harbour population of skate are likely the last population of skate any risks to the population must receive heightened attention.

Technical Review

- (d) Hydrological processes will affect the dispersal and persistence of eDNA, especially water flow and in general, temperature.
- (e) As such, additional temporal sampling points should be considered to account for the impacts of hydrological processes to the DNA material.
- (f) Monitoring at additional depths would also improve the likelihood of capturing the presence of the Maugean Skate in both Bathurst harbour and Macquarie Harbour.
- (g) Populations of Maugean Skate may not necessarily be constrained solely to Macquarie Harbour. This species was first identified in Tasmanian waters in Port Davey in 1980's (a waterway where salmon farming or any other anthropogenic activity has occurred). Previous survey work to detect Maugean Skate eDNA in Bathurst Harbour has proved inconclusive. Sampling in Macquarie Harbour in November 2021 (Moreno *et al.* 2022),

also failed to detect the species (where a resident population exists) but was successful in February 2022. This suggests movement of the Skate population may be seasonal and indicates that more scientific assessment work needs to be done in this space.

3.2 Wild-Allen 2020 Report

- (a) AMCS/HSI relies upon the same data as the Australia institute from the Wild-Allen 2020 Report to support their claim, namely that the modelled absence of fish farming resulted in a ' 50% reduction in hypoxic volume and a 40% reduction in hypoxic sediment area under reduced anthropogenic load'.
- (b) The summary and technical review in section 2.6 apply.

3.3 Ridgway Report 2023

Summary

- (a) The AMCS/HSI request relies upon the Ridgway Report 2023 which finds inshore bays including Macquarie Harbour 'unequivocally... show heightened seasonal changes (warmer in summer and cooler in winter).'
- (b) This information considered in conjunction with other climatic data suggests higher than normal water temperatures will be experienced in Macquarie Harbour this summer which will impact DO levels due to reduced dissolvability and increases to BOD processes.

Technical Review

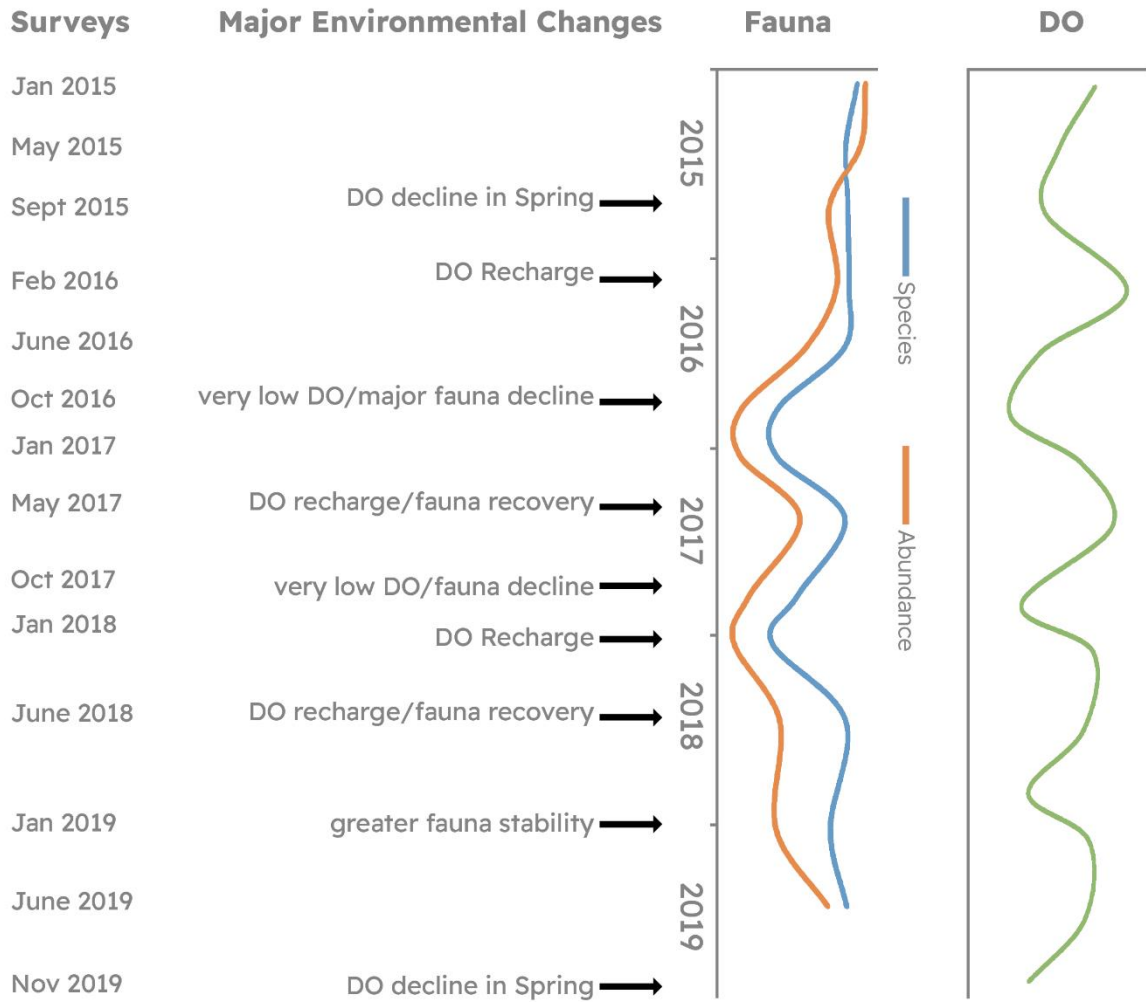
- (c) The potential impacts of a warming climate have been known for over 30 years.
- (d) The IMAS Assessment of Macquarie Harbour BEMP data from 2011 to 2022 highlights a climate driven increase in bottom water temperatures of 1.5-2°C over the past 30 years.
- (e) A warming climate is considered to be one of the many influences on the observed decline in population abundance of the Maugean Skate through decreased oxygen solubility and increased metabolic rates.
- (f) This climatic information is not new to environmental managers and does not present an unforeseen change in circumstances in relation to the impacts of the action on the skate. This impact on DO is not related to marine farming operations and cannot be controlled by the Operators.

3.4 Conclusion

- (a) For the reasons set out above, Salmon Tasmania submits that the information relied upon in the AMCS/HSI Reconsideration Request does not constitute substantial new information or a substantial change in circumstances that was unforeseen at the time of the NCA-PM Decision in 2012 that relates to the impacts of the Marine Farming Expansion on the Maugean Skate.
- (b) The AMCS/HSI Reconsideration Request states that the Moreno 2022 Report constitutes 'substantial new information', however the findings of the report only provide new information in regard to the uncertainty about Maugean Skate still residing in Bathurst Harbour and not the impacts of marine farming on the skate.

- (c) There is again a failure by the cited scientific reports to draw conclusions as to the casual linkages by which the impacts of Marine Farming Expansion on the Maugean Skate will occur with a high degree of certainty.
- (d) The criticisms of the Wild-Allen 2020 Report assumptions detailed above again apply.
- (e) The AMCS/HSI Reconsideration Request states that the information provided in Ridgway Report 2023 amounts to an unforeseen change in circumstances.
- (f) The findings relate to climatic changes and therefore do not relate to the impacts of the Marine Farming Expansion on the skate, moreover the circumstances referred to are outside of the control of the Operators.
- (g) As the information does not satisfy the criteria in section 78(1) of the EPBC Act it cannot warrant the revocation and substitution of the NCA-PM Decision.

Figure 1



Source: FRDC 2016/067: Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour (Progress Report)

Schedule 3 – Nautilus Collaboration (2024)

Scientific opinion– Australian Institute reconsideration request

The Australian Institute (AI) reconsideration request has selected information which is outdated, to support their arguments against aquaculture in Macquarie Harbour (MH). All of the information/data that the Australian Institute references, were reports that were supported by the salmon industry. The salmon industry commissioned these important research projects, to improve scientific knowledge and understanding, and to incorporate any new evidence/findings into adaptive management techniques to better manage farming practices in the harbour (refer to the 'Acknowledgement' section in these reports).

The comments made by the AI in their reconsideration requests must be interpreted with caution as the data and information has been taken out of context and infers that there is causality. Causality has not been in fact demonstrated in any of the referenced material and the influence of salmon farming is over-stated in all AI submissions.

In reference to the letter from the Australian Institute dated 31 July 2023:

In a previous letter dated 8 June 2023, there was recognition from the Australian Institute that the conditions in the harbour have changed markedly, with the influence of anthropogenic activities (including mining, forestry, hydro-electricity generation, and marine farming operations). AI have since, left out these references and scientific discussions in their updated letter.

Firstly, the referenced material in the AI letter is considered old evidence. The salmon industry has already considered these pieces of evidence in their adaptive management processes, and since their release, have changed biomass and nitrogen limits to suit the estimated carrying capacity of the harbour. This is a statement that applies to all of the referenced material, as the models, assumptions and methods need to be updated to incorporate new scientific evidence.

The AI letter inflates the impact of salmon farming and fails to discuss or recognise the diminutive attribution of salmon farming to oxygen use in the harbour. There is a need to assess the impacts holistically, in terms of an updated oxygen budget and balance (Wallis 2024).

Science is a field that requires input from many different perspectives, and it is encouraged to ensure that critical thinking is exercised to maximise research quality. Therefore, the comments received from AI are acknowledged. It is acknowledged that not all research is made available in real-time, and therefore, unless there is active involvement in these projects, most evidence will be read and considered retrospectively.

(8-10) Ross 2016:

AI rely on this report to support their argument that salmon farming in the harbour is causing detrimental effects, but in fact, the dorvilleid species that are described, were being assessed as an environmental indicator and the report was commissioned by the salmon industry to further understand the significance of the dorvilleid worms and their response to the level of organic enrichment. It was found that there were two species of worms, and their respective presence reflected different levels of organic enrichment. The dorvilleid worms, could then be incorporated into monitoring programs (alongside *Beggiatoa*), to further the industry's understanding of harbour-wide changes and direct effects within a

farming lease. The AI letter fails to acknowledge that there is a crucial influence on organic load and enrichment, from the river systems from organic deposition.

It is also noted that the benthic and environmental conditions when the surveys occurred, have changed dramatically due to the adaptive management strategies employed by the salmon industry and EPA. Additionally, the survey was performed in a single period and does not take into account seasonal/temporal changes.

The report played a crucial role in the industry's stocking strategy, following periods and modifying operations within an individual lease. The salmon industry, after commissioning and supporting the research in-kind, used the results to improve environmental management practices across the harbour.

(11-16) Ross 2017:

The report provided a summary of the available research (until October 2016) which assisted at the time, to interpret benthic and water column observations. This report was helpful as a discussion document to understand knowledge gaps and further research opportunities. The authors highlighted a number of key questions/issues on page 33-36 which provided recommendations and work packages for the salmon industry to consider.

The discussion of "current status" where the AI draws its conclusions, is out-dated as it uses data that is over 7 years old. Biomass and nitrogen limits have since been changed, and the AI have not taken this into account in their letter. The report does not conclude that there is any causal relationship between the population dynamics of the skate; or dissolved oxygen draw-down and salmon farming.

(17-21) Moreno 2020:

There are large gaps in our knowledge of skate reproductive behaviour and physiology. Due to the scarce amount of research available it is difficult to understand the cumulative influences of:

- Exposure of chronic low dissolved oxygen to reproductive capacity
- Influence of available heavy metals to reproductive capacity – including gamete quality and quantity and egg/larval survival (which are present from mining activity and erosion)
- Fluctuation in water chemistry and quality from seasonal weather patterns, rainfall, hydro-electric dam release, and mining

It is evident from the research conducted that the skate can modify its metabolic state to survive in environments with hypoxic conditions. The AI letter suggests that salmon farming may affect the available dissolved oxygen where the skate reproduce/reside. Salmon school in the upper layers of MH, where there is ample dissolved oxygen from river inflow and brackish water outflow. The Wild-Allen 2020 oxygen balance/budget calculations detailed that the reduction associated with salmon respiration in the upper and mid- water column was replenished by surface gas exchange and water exchange in the harbour.

The bottom waters of MH will not only be influenced by the biological oxygen demand from salmon farming, but also river inflow, and organic deposition. Salmon farming accounts for approximately 10% of the dissolved oxygen use in bottom waters (Wallis 2024).

It is important to recognise that there are other environmental processes that can influence the reproductive outcomes of the skate; as well as egg and larval development- and there is not enough information and knowledge about the species to be able to definitively state causality.

(22-26) Wild-Allen 2020:

Wild-Allen (2020) in the FRDC report that found when modelling the removal of salmon farms " a 50 per cent reduction in hypoxic volume, and a 43 per cent increase in healthy water would result from elimination of salmonid farming". What the modelling actually found, was a reduction from 27-28% hypoxic to 14-17% by volume and from 12% to 4-6% by area. The model also used hard definitions of hypoxic as between 1-30% oxygen saturation, which means if the removal of salmon farming increased saturation by 1% and a portion of the water was at 30%, that water volume would now be considered intermediate.

Wild-allen 2020 also states that the "...oxygen budget analysis found the largest influx of oxygen to the harbour was from rivers (66%), marine input (10%) and air-sea flux (6%); the greatest loss terms were from export to the ocean (87%), biogeochemical remineralisation processes in the sediment (8%) and estimated farmed fish respiration (3%)." And "... around 60% of fish farm nitrogen is exported to the ocean and this likely enhances local algal blooms (evident in remotely sensed images of Macquarie Harbour plumes)".

The Australian Institute's request for reconsideration claims the Interim report – Macquarie Harbour Maugean skate population status and monitoring attributes the decline in dissolved oxygen is caused by "anthropogenic inputs' being the large-scale development of salmonid aquaculture.". In this case, anthropogenic is defined as '(chiefly of pollution or environmental change) originating in human activity.'. These statements must be explored further with context.

"While anthropogenic activities since European colonisation have long impacted the harbour, in the past 15 years altered river flows (growing reliance on hydroelectric generation and production demand) and large-scale development of salmonid aquaculture have resulted in considerable changes to the environment.". The report does not claim that the salmonid farming is the only cause of lower dissolved oxygen. There are other reports that discuss the state of the harbour, such as the MHDOWG (2014) which also should be considered in their assessment. The MHDOWG 2014 states, "There have been a number of significant changes over the period from 2009-present. River flow was historically low between 2009-12 and historically high in 2013. This period also coincides with a major expansion of salmon aquaculture". Additionally, there significant influences in total organic carbon load which is associated with river discharge into MH 'around 100 times that of salmon production in the harbour' – these statements were made in the MHDOWG 2014 report, with data from when salmon farming biomasses were higher than they are today.

The MHDOWG 2014 report states that "...based on the data available from recent in situ measurements aquaculture is estimated to be responsible for between 3 and 12% of the benthic BOD in Macquarie Harbour (for sediments deeper than 15 m). The remaining benthic BOD is presumably associated with particulates in river discharge and detritus derived from biological production within the harbour. "- These percentages have further reduce since this report was written due to the reduction in farming biomass.

Additionally, it was found that "...representing 2.3% of the benthic area (> 15 m), the cage and buffer area account for approximately 5% of the total benthic BOD".

The Wild-Allen 2020 report findings and budget were based on modelling conditions and farming inputs from 2017 and 2018, which is no longer representative due to changes in salmon farming (decreased biomass limits and nitrogen budgets) and any changes in hydro-electric dam operational management (refer to Figure 1 for HOG tonnes produced in the harbour).

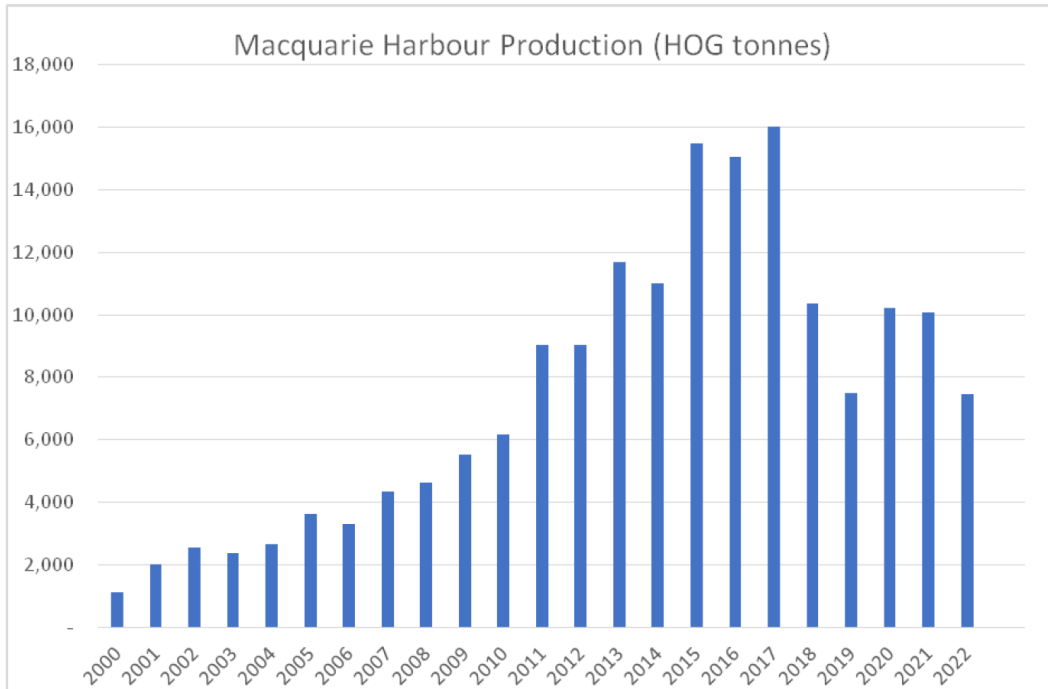


Figure 1: Macquarie harbour production tonnage (HOG tonnes) - noting that from 2018 onwards, there has been a significant reduction in harvested biomass from the harbour

Additionally, there are newer references which have been published Wang 2013 and Wang and Olsen 2023 which are both required to update the oxygen balance and budget.

The following updates need to be made, and are used in Wallis’s oxygen budget memo (2024):

Nitrogen	Wang Et al 2012	Wang Et al 2013
DIN (%)		
Dissolved inorganic nitrogen	0.45	0.39
DON (%)		
Dissolved organic nitrogen	0.0225	0.03
PON (%)		
Particulate organic nitrogen	0.153	0.15
Fish Gain	0.38	0.43

Carbon	Wang Et al 2012	Wang Et al 2013
Respired (%)	0.48	0.4

DOC (%)		
Dissolved organic carbon	0.03	0.03
POC (%)		
Particulate organic carbon	0.19	0.19
Fish Gain	0.3	0.38

This changes totals by 5.92% reduction in overall total oxygen demand.

Author biographies



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Christine completed a Bachelor of Veterinary Science at the University of Sydney. She has been working in the aquaculture industry since, and consults internationally, offering technical management services that support global best practice.

Specialises in: production medicine, aquatic animal welfare, biosecurity management, technical strategy, technical due diligence



Andrew Mackay

Data Scientist

Andrew holds a Bachelor of Science degree from Monash University majoring in Mathematics with minors in Computational Science and Mathematical Statistics. Andrew

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Aquatic animal health consultant

Elena, a Chilean veterinarian, holds a Master's in Fish Pathology from Canada's Ontario Veterinary College. With 16 years of expertise in diagnosing fish diseases, her experience ranges from fish farms to wild (native) and exotic species in Canada. In Chile, she served as a laboratory manager and fish histopathologist for 3 years. She then spent 3 years in Malta, contributing to fish stock health in RAS settings.

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Schedule 4 – Dr Ian Wallis (2024)



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Foreword

The purpose of this technical memo is to estimate the demand for oxygen imposed by salmon farms in Macquarie Harbour, Tasmania.

The author, Dr Ian Wallis, is part of the team with the responsibility to trial oxygenation of the deeper waters of Macquarie Harbour, to counter very low levels of dissolved oxygen in the water column.

The Fisheries Research and Development Corporation (FRDC) is funding the project to trial the injection of oxygen into the middle and deeper waters of Macquarie Harbour. The project team includes salmon industry personnel with equipment and experience related to oxygenation of finfish pens and engineers and scientists with State, National and international expertise related to oxygen injection and associated environmental interactions.

There are examples of successful oxygenation of estuaries in Perth, in Scandinavian fjords, and in Chile. Oxygenation at shallower depths is routinely used in wastewater treatment lagoons and water storages throughout Tasmania and elsewhere.

It would assist the team if they had an estimate of the amount of oxygen input that is required to balance the oxygen demand from the salmon farms in Macquarie Harbour and the best locations to add that oxygen.

Salmon farms were first established in Macquarie Harbour in the 1980s. The early farms were acquired by the three major companies, and Tassal established farms there in 2003, Huon Aquaculture in 2008 and Petuna around 2011. Production increased from 2,000 t/yr in 2010 to around 16,000 t/yr in 2015-2017, but has decreased since then and averaged 9,500 t/yr in 2018-2023.

The main concerns regarding low dissolved oxygen in Macquarie Harbour are:

1. The risk to the survival of the Maugean Skate, which is a threatened species that apparently survives in low numbers only in Macquarie Harbour;
2. The risk to other ecological processes and systems in Macquarie Harbour; and
3. Anoxic or near-anoxic conditions would encourage the movement of metals from the sediments into solution. The metals exist from past mining activities in the catchment and from natural erosion processes.

There is extensive and ongoing research into the hydrodynamics, water quality, benthic chemistry and biological conditions in the harbour by researchers from the University of Tasmania (UTAS), EPA, CSIRO and other institutions. The research is supported by the FRDC and by the State government through the EPA and Department of Primary Industries, Parks, Water and Environment (DPIPWE). The program includes a trial of re-oxygenation of deeper waters at a rate of approximately 1 t/d of oxygen in 2024.

Macquarie Harbour Stratification

Macquarie Harbour is a large estuary on the west coast of Tasmania, 33 km long by 9 km wide, with a surface area of 280 sq km. The main freshwater supply is from the Gordon River which flows into the south of the estuary. The entrance to the sea is an 8 km long, shallow channel in the north-west of the estuary.

The freshwater inflow from the Gordon River, and other smaller rivers and creeks, forms a surface layer that is 5 m to 10 m deep. The depth depends on the river flow, with the surface layer becoming deeper at times of high river flow and shallower at times of low river flow.

Wind mixes the surface layer into the underlying more saline layer. This results in relatively uniform salinity over the top 2 m, and often down to 6 m depth.

There is a strong salinity gradient from 6 m to 11 m depth. From 12 m depth down to the bottom, at around 45 m depth, there is relatively uniform salinity, generally of 30 to 32 parts per thousand (ppt), only about 10 per cent lower than ocean water.

Mixing of incoming ocean water with harbour water just inside the entrance where the dense seawater cascades down the slope into the harbour means that the salinity of the lowest harbour waters is always less than ocean salinity.

Figure 1 shows the monthly salinity profiles at a central station in Macquarie Harbour for 2013-2014 (data provided by IMAS). Lowest salinity is 2 ppt (at the surface) but the salinity in the surface layer (0 to 4 m) ranged seasonally from 2 ppt to 14 ppt. There is a strong salinity gradient between 5 m and 11 m depth. Below 15 m depth there is a very weak salinity gradient from around 28 ppt at 15 m depth to 31 ppt at the bed. The gradient indicates weak vertical mixing (and hence weak currents) in the lower layer of the harbour.

Figure 1. Vertical Salinity Profiles in Macquarie Harbour in 2013-2014

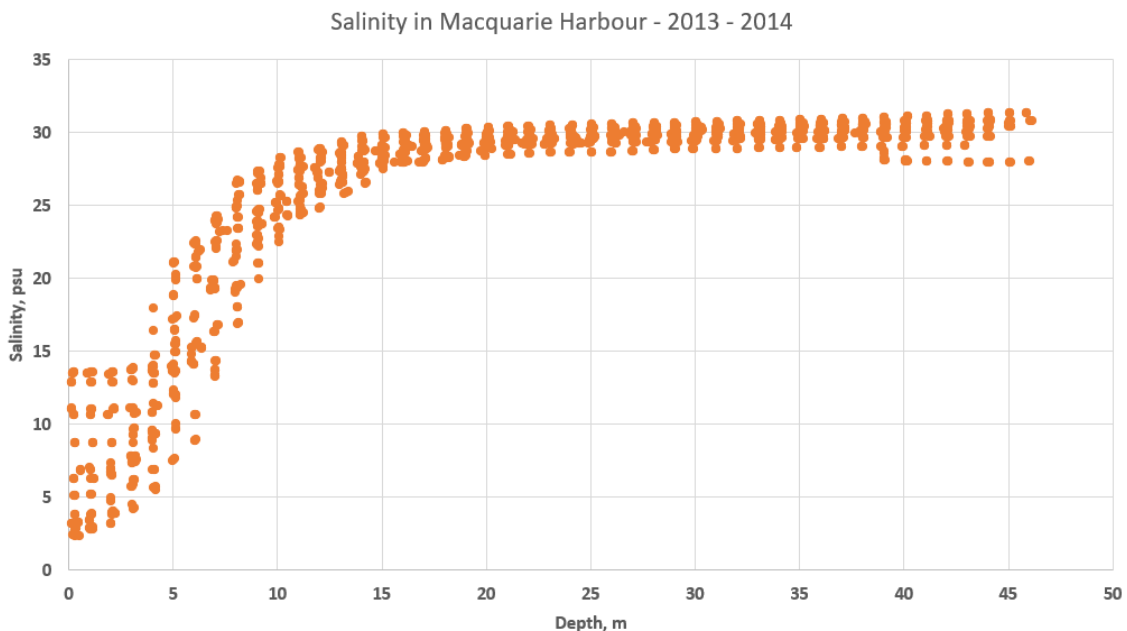


Figure 2 shows the monthly salinity profiles at a central station in Macquarie Harbour for 2018-2019 (data provided by IMAS). There is a single reading of zero surface salinity. The salinity in the surface layer (0 to 4 m) ranged seasonally from 3 ppt to 17 ppt. There is a strong salinity gradient between 5 m and 11 m depth. Below 15 m depth, there is a very weak salinity gradient from around 29 ppt at 15 m depth to 32 ppt at the bed.

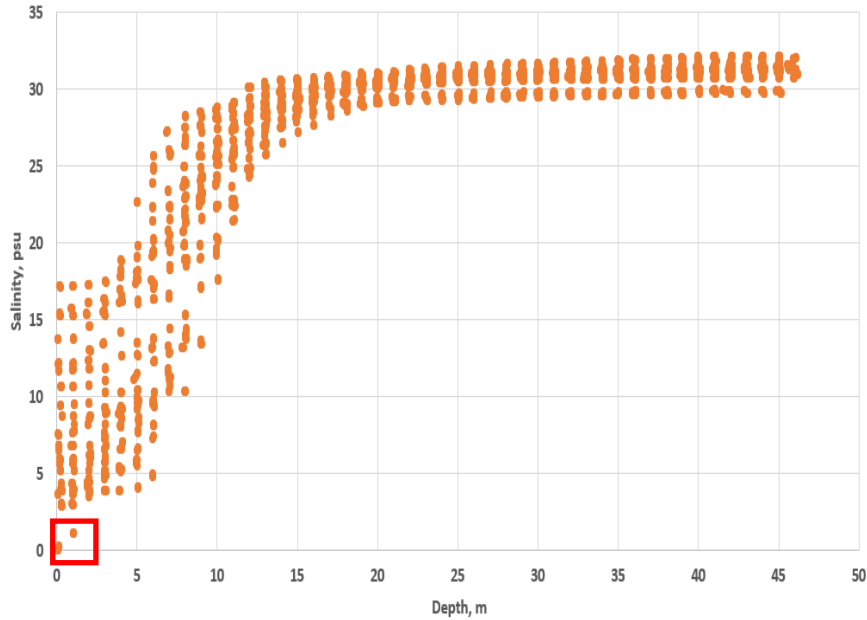
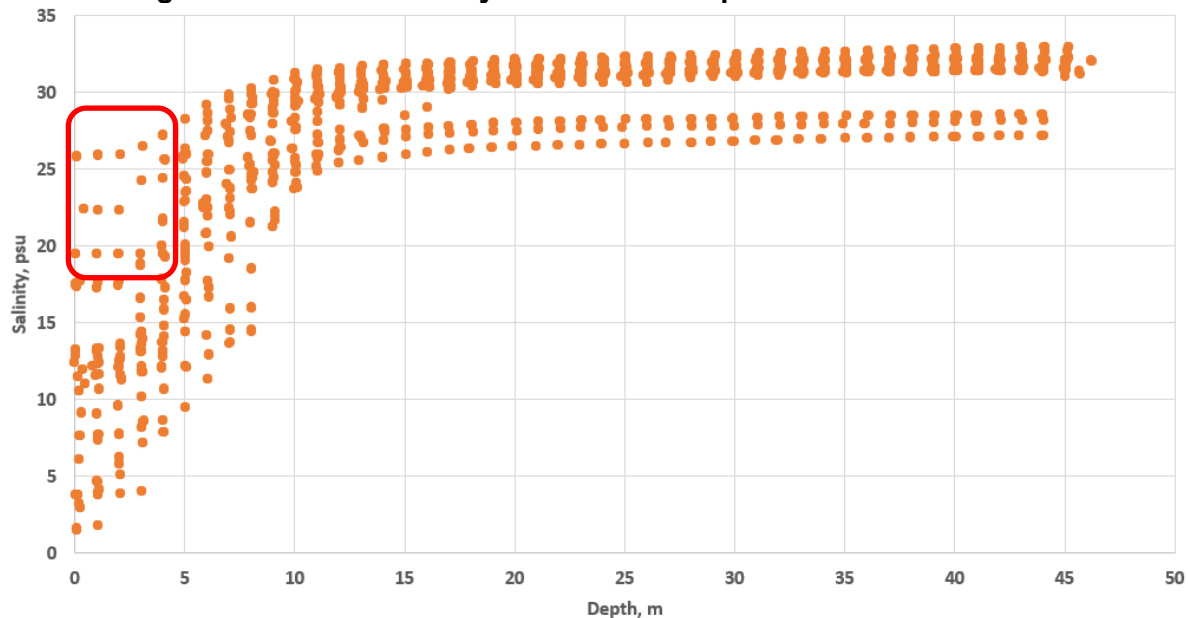
Figure 2. Vertical Salinity Profiles in Macquarie Harbour in 2018-2019

Figure 3 shows the monthly salinity profiles at a central station in Macquarie Harbour for 2022-2023 (data provided by IMAS). This period shows a different pattern, with much higher average and peak salinity in the surface layer (highlighted in the red box). The strong salinity gradient is higher in the water column from 4 m to 9 m depth. Below 11 m depth, there are two lines both showing a very weak salinity gradient from around 26 to 30 ppt at 11 m depth to around 27 to 32.5 ppt at the bed.

Figure 3. Vertical Salinity Profiles in Macquarie Harbour in 2022-2023

The vertical salinity pattern in 2022-2023 is different from the earlier years, with much higher salinity at and near the surface, which indicates a reduction in the river flow during that period, perhaps accompanied by stronger wind mixing. The lower salinity water was deeper in 2022-2023 than in previous years, indicating more ocean water inflow and uplifting of the saline layer.

River Inflow

The major process driving the stratification and circulation in the harbour is the freshwater inflow from the rivers. Koehnken (2005) reported the average annual flow from the Gordon River was 265 m³/s and the average flow from the King River was 55 m³/s. Adding minor tributaries such as the Sorell River and Birchs River makes a total freshwater input of around 330 m³/s. This is sufficient to create a surface layer 0.1 m deep in a day or 4 m deep in a month. (*Note: Mean river inflow for 2017-2018 was 352 m³/s, Wild-Allen et al, CSIRO, 2020.*)

The inflow is, of course, seasonal, and mean monthly flows vary from less than 100 m³/s in summer and early autumn to 500 m³/s in late autumn, winter, and spring (Hartstein et al., 2016). Variations in annual rainfall produce higher inflows in wet years and lower inflows during droughts. (*Note: Range of inflow for 2017-2018 was 50 to 2,700 m³/s, Wild-Allen et al, CSIRO, 2020, p 31.*)

There is another important source of variation in the freshwater input to Macquarie Harbour. River flows from the catchments of the Gordon River and King River have been regulated by hydroelectric dams operated by Hydro Tasmania since 1983. Periodic dam releases on the Gordon River make discharges into Macquarie Harbour more variable, and can double the average flow conditions for short periods of time (Hydro Tasmania, 2016).

The freshwater escapes from Macquarie Harbour through the 8 km long entrance at Hells Gates. The mean depth at the narrowest section along the Hells Gates inlet is 4 m (and the entrance channel is approximately 120 m wide). To release the average freshwater input of 330 m³/s at an average salinity of 8 ppt requires an ebb tide current averaging 1.8 m/s through this constriction.

The mean tidal range in Macquarie Harbour is around 0.5 m (0.2 m for neap tides and 0.9 m for spring tides). The inflow of ocean water to the harbour is restricted by two processes: (1) the large volume of freshwater that must be discharged each tide cycle, limiting the duration of seawater inflow; and (2) the long entrance channel, so that only the seawater that reaches the harbour end of the channel can stay in the harbour – the contents of the channel return to the ocean with the reverse in the current direction.

As an approximation, the seawater input each day corresponds to a net input of about 0.2 to 0.3 m depth of ocean water. As the lower saline layer extends over a depth range of around 40 m, the tidal inflow of seawater takes around 150 to 300 days to replace the water in the lower layer.

Because of this long residence time, a small organic load each day can have a substantial impact on the dissolved oxygen concentration in the lower layer. Low dissolved oxygen concentration in the lower layer should be expected because of the long residence time of water in that layer and the strong stratification which inhibits the transfer of oxygen from the surface to the lower layer.

There are a range of other hydrodynamic processes that influence dissolved oxygen levels, including mixing in the river estuaries, mixing where the incoming seawater cascades down the side of the harbour, seiching and internal waves, wind-driven mixing, surface and halocline slope due to persistent winds and long term variations in ocean water levels. These complicate the prediction of currents, stratification and dissolved oxygen.

According to Hartstein et al, 2019, the tidal water level amplitude is approximately 0.25 m and tides explain only 27% of the water level variation whereas variations in barometric air pressure explained 41% of the observed changes in water level.

Macquarie Harbour Dissolved Oxygen

Oxygen enters Macquarie Harbour continuously with river inflows (which are generally saturated with dissolved oxygen) and surface re-aeration. The ocean water entering the harbour also is generally saturated with dissolved oxygen. Inflows of ocean water are episodic, with regular small inputs at times of spring tides and low river flow, and occasional larger inputs (typically once a year) when the combination of persistent wind and low atmospheric pressure cause a large inflow of ocean water (known as deep layer recharge events).

The waters of Macquarie Harbour are strongly coloured by tannin, so there is low light penetration. Nonetheless, there are phytoplankton living in the harbour (measured chlorophyll-a is around $1 \mu\text{g}/\text{m}^3$) regularly adding to the oxygen supply. The input of oxygen from macrophytes is very small.

Oxygen is consumed by the decomposition of organic compounds entering the harbour in rivers, local runoff and ocean waters, and by respiration of marine organisms in the water and in the bed. The salmon farms are a source of additional organic material as well as ammonia discharges, which require oxygen for conversion to organic material as well as nitrification to nitrate. Some oxygen is returned by denitrification. The focus of this Technical Memo is to estimate the oxygen demand of the salmon farms.

Figure 4 shows the monthly dissolved oxygen (DO) profiles at a central station in Macquarie Harbour for 2013-2019 (data provided by IMAS). The DO in the top 3 m is always more than 80 % saturated (depicted by the blue colour). Minimum DO occurs at around 30 m depth, and low DO can extend to the bed of the harbour. DO of less than 30 % saturation is depicted by the orange colour. A feature of the DO pattern is the strong gradient, with DO decreasing with depth to around 30 m depth. Periods of low DO in the deep waters correspond to higher river flow in winter-spring, when less seawater comes into the harbour.

Figure 4. Vertical Dissolved Oxygen Pattern in Macquarie Harbour in 2013-2018

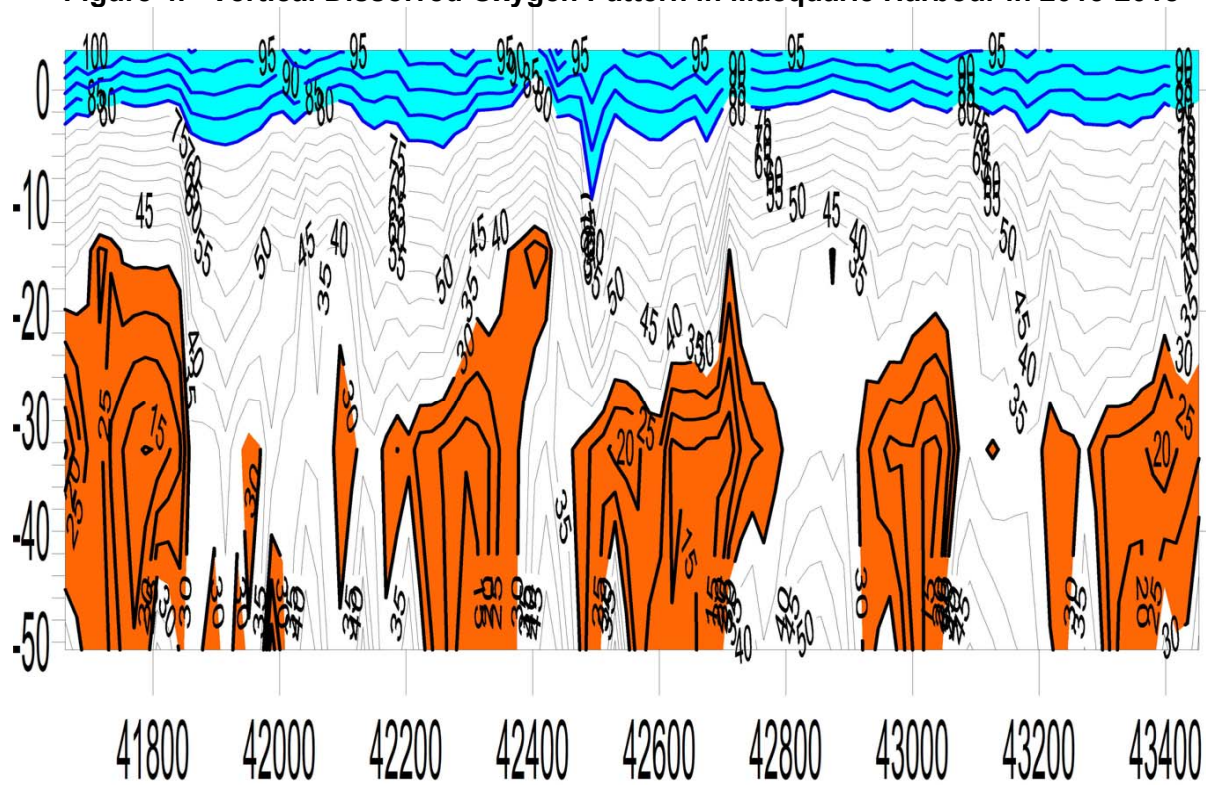


Figure 5 shows the monthly DO profiles at a central station in Macquarie Harbour for 2013-2014 (data provided by IMAS). The well-mixed surface layer extends down to 4 m depth, with the DO level being 95 % to 100 % saturation in this surface layer.

There is a strong gradient of declining dissolved oxygen from around 85 % saturation at 5 m depth to around 20 % saturation at 20 m depth.

Very low DO occurs at times at 25 m to 30 m depth, close to anoxic conditions. From 30 m depth to the bed at 45 m depth, there is a gradual increase in DO. The DO at the bed ranges from 15 % to 45 % saturation, so conditions at the bed are not anoxic.

Figure 5. Vertical Salinity Profiles in Macquarie Harbour in 2013-2014

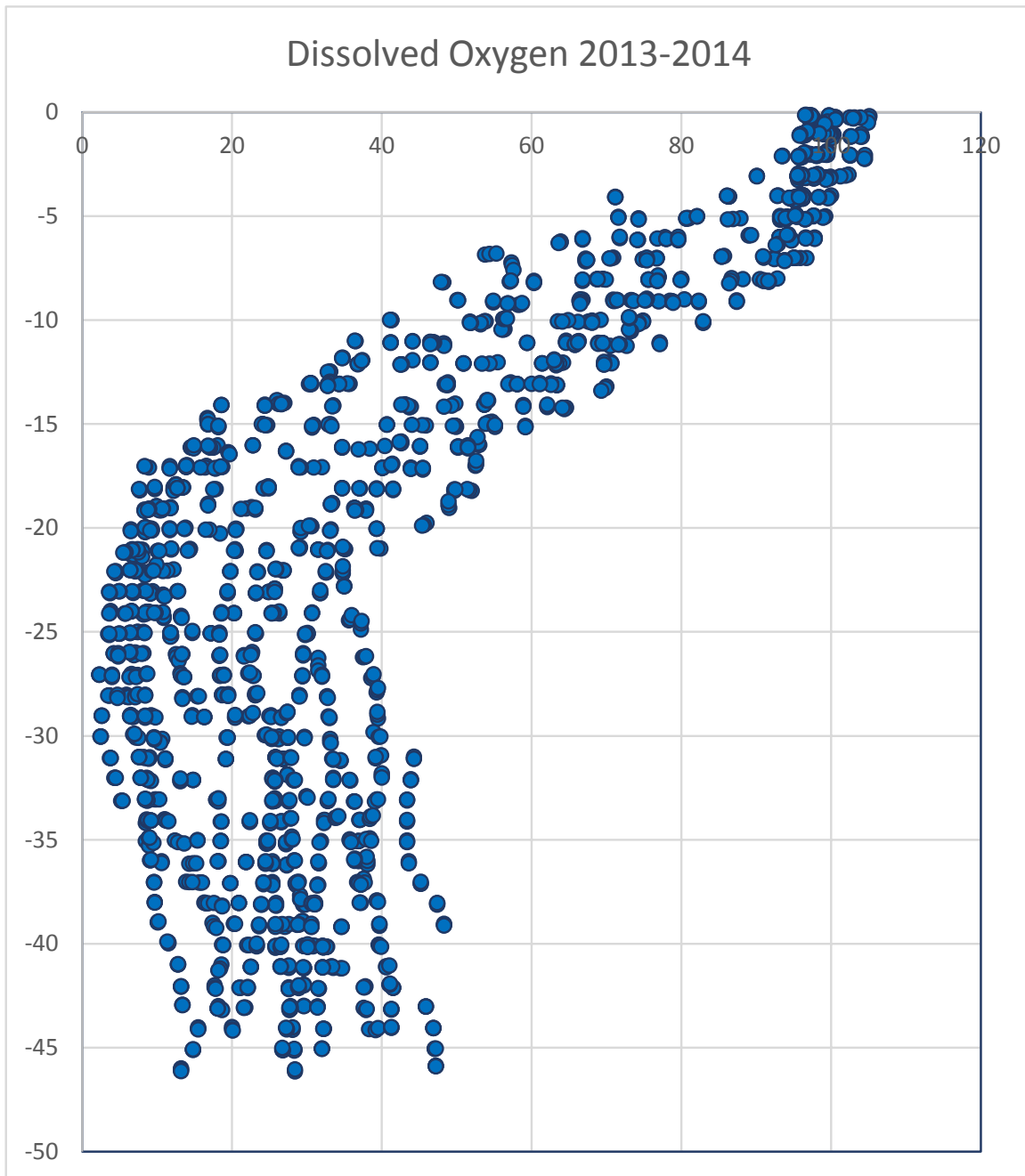


Figure 6 shows the monthly DO profiles at a central station in Macquarie Harbour for 2018-2019. The well-mixed surface layer extends down to 5 m depth, with the DO level being 92 % to 100 % saturation in the surface layer.

There is a strong gradient of declining dissolved oxygen from around 85 % saturation at 6 m depth to around 20 % saturation at 20 m depth. There was one month (January 2019) with lower than usual DO from 6 m to 12 m depth (highlighted with the red box).

Lowest DO occurs at times at 25 m depth, generally in the range of 15 % to 30 % saturation. From 25 m depth to the bed at 45 m depth, there is a gradual increase in DO so that DO at the bed ranges from 18 % to 45 % saturation. There was a smaller range in DO at each depth during 2018-2019 than in the earlier period.

Figure 6. Vertical DO Profiles in Macquarie Harbour in 2018-2019
Dissolved Oxygen - 2018-2019

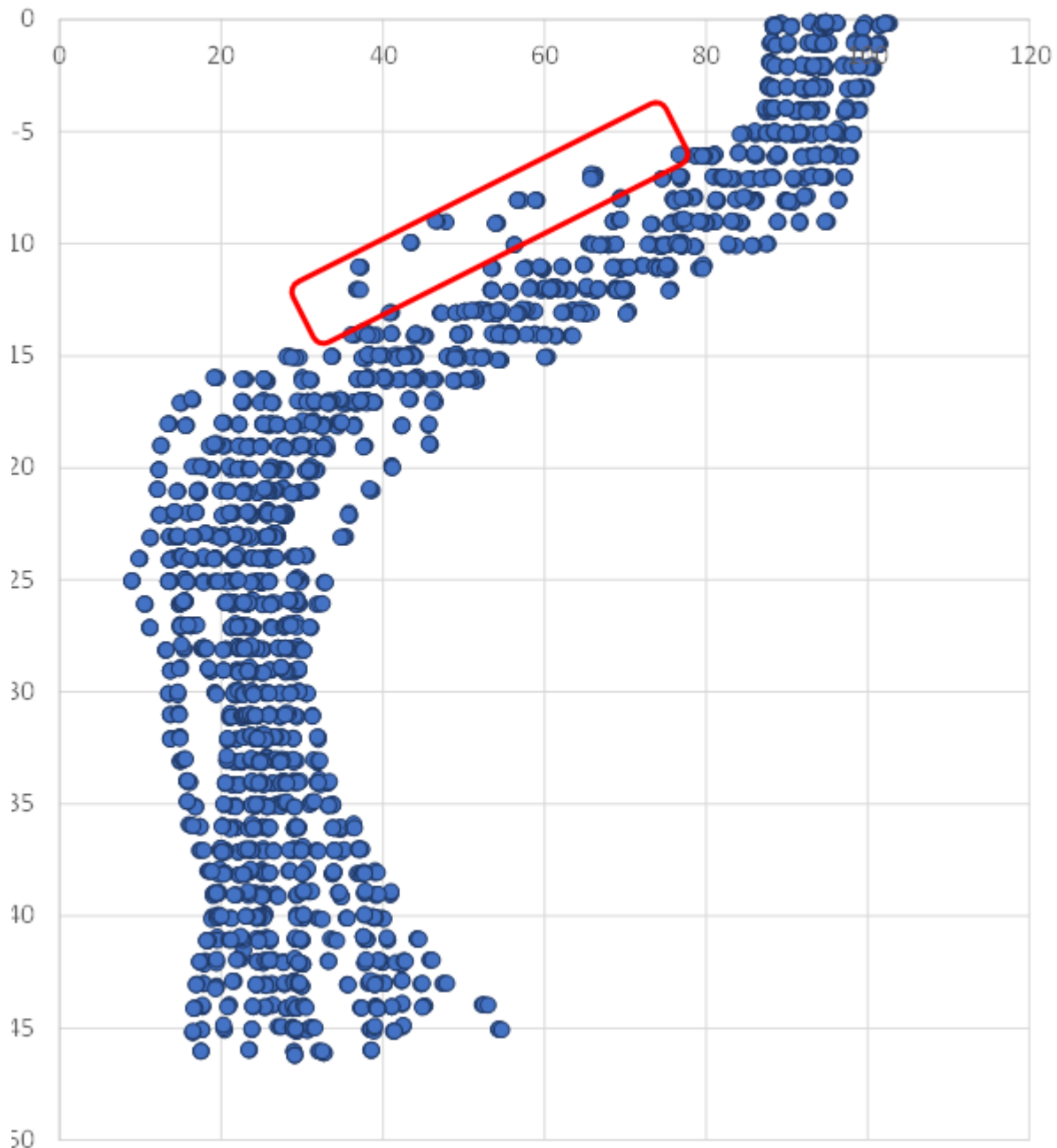
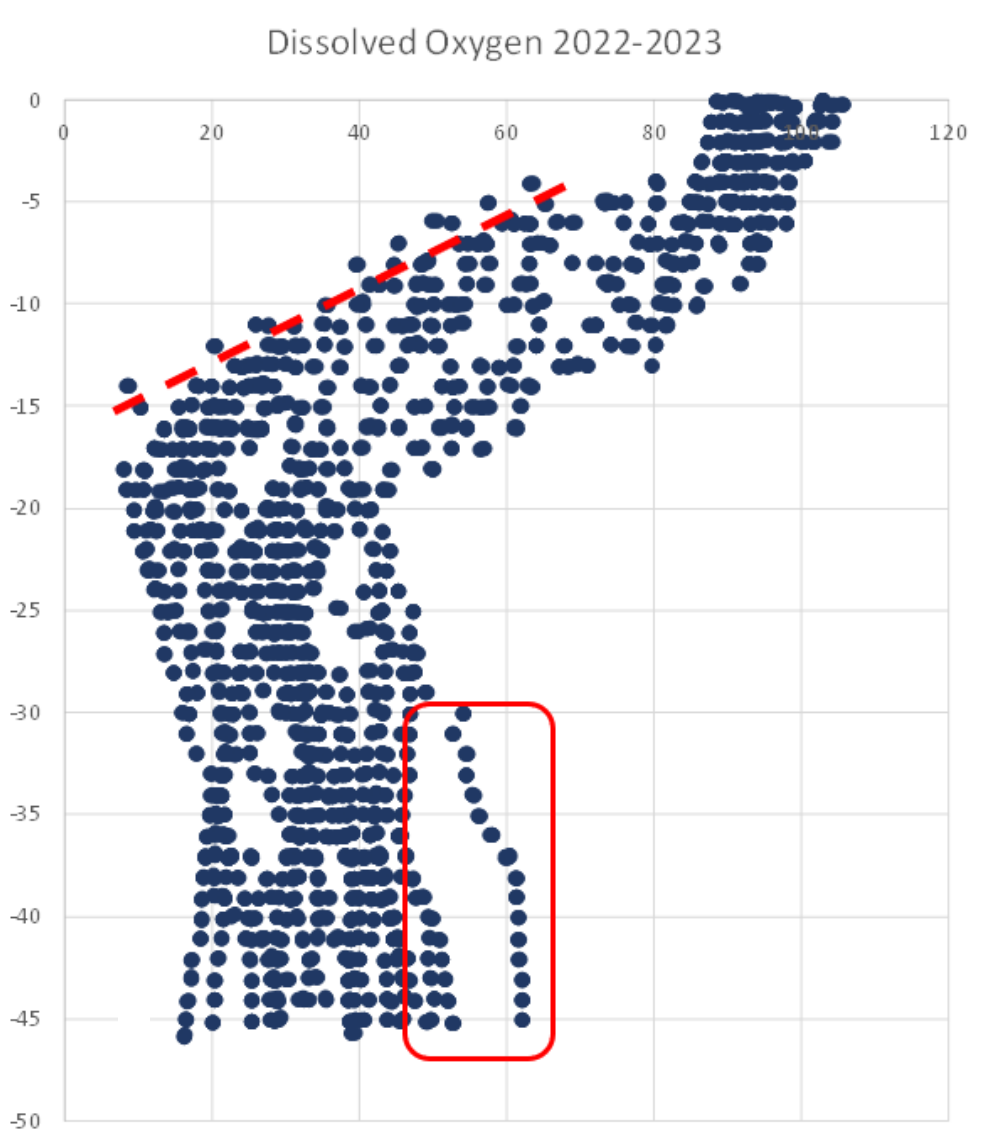


Figure 7 shows the monthly DO profiles at a central station in Macquarie Harbour for 2022-2023. The well-mixed surface layer extends down to 5 m depth, with the DO level being 86 % to 105 % saturation in this surface layer.

DO levels at 5 to 15 m depth were much lower in 2022-2023 than in 2018-2019, showing the water from lower levels had been uplifted in the latter two years. The higher salinity of the surface layer in 2022-2023 corresponds to a reduction in dissolved oxygen in the layer from 5 m to 15 m depth. However, there is not a significant reduction in the surface layer, indicating that surface re-aeration is a dominant process for maintaining high DO levels in the surface layer.

There is a strong gradient of declining dissolved oxygen from 5 m depth to less than 10 % saturation at 15 to 20 m depth. The DO increases slightly from 20 m depth to the bed, evidence that the incoming seawater is an important source of dissolved oxygen to the lower layer. A period when DO in the lower layer exceeded 60 % saturation is highlighted by the red box, indicating an event with a large seawater inflow in January 2022.

Figure 7. Vertical DO Profiles in Macquarie Harbour in 2022-2023



Mortality of Salmon in 2015 and 2019

In May 2015, Petuna reported a mortality event for 3.7 % of their salmon due to low dissolved oxygen near the bottom of the fish pens in Macquarie Harbour (ABC rural, 2015). Other salmon farms in the harbour lost fish as well. The mortality was attributed to a storm lifting low DO water into the shallower waters where the fish are located.

Salmon have a known temperature preference and tolerance, and a known dissolved oxygen tolerance. Salmon actively avoid water warmer than 17 to 18 °C and move to lower depths when the water temperature in the surface layer exceeds 18 °C.

Unfortunately for the salmon, there was a large intrusion of seawater into the harbour in May 2015. Seawater is more dense than the waters in the harbour and moves to the bottom. This displaces the existing bottom layer of water upward and hence each layer in the harbour is uplifted. As a result, water with low dissolved oxygen moves towards the surface.

Uplifting is a hydrodynamic process that occurs throughout the summer low-river-flow period each year. Various combinations of spring tides, onshore winds, low atmospheric pressure and low river flows encourage seawater to enter the harbour. As shown in Figures 1 to 3, the surface layer has an average salinity of 8 ppt. Thus, about 25 % of the outflow from the harbour originates from seawater intruding into the bottom layer. As the river inflow averages 330 m³/s, the seawater inflow averages 80 m³/s and the average outflow averages 410 m³/s.

Salmon are active swimmers and require 50 to 55 % dissolved oxygen in the water to survive. Mortality of salmon occurs when there is a combination of high temperature in the surface layer (so the salmon move down in the water column) and an event of high seawater inflow (which uplifts water with low dissolved oxygen upwards into the bottom of the farm cages).

An event with high seawater inflow occurred in May 2015. Other events occurred in March-April 2019 and January 2022.

*A note on terminology. As discussed above, the process that brings waters with low dissolved oxygen closer to the surface is **uplift**. It occurs when a higher-than-usual volume of seawater enters the harbour, cascades down to the bed of the harbour and replaces the bottom layer of water, causing the layers of water above it to move upwards. The process is incorrectly referred to as **inversion** by Moreno et al (IMAS, 2020) but there is no inversion of the top and bottom layers. An examination of the vertical density profile (see Figure 8) shows that Macquarie Harbour always has a stable density structure with no evidence of an inversion.*

These uplift events are natural occurrences. The influencing parameters are (1) large tidal range; (2) low atmospheric pressure; (3) strong wind conditions; and (4) low river flow (influenced by wet/drought cycles). The operation of hydro-electric storages is another factor that can influence uplift events. Inflow events are reduced when there is higher river inflow.

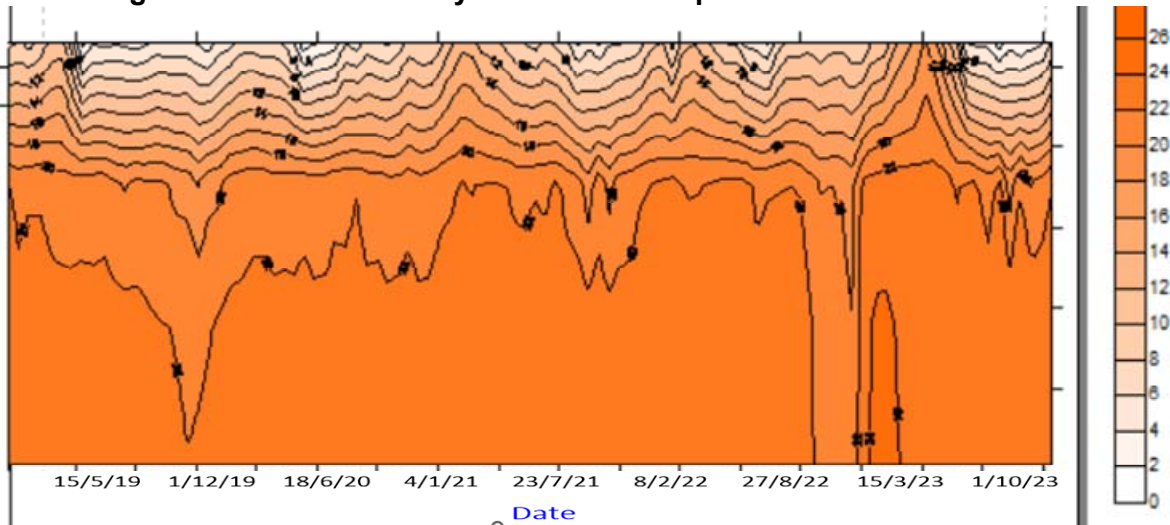
The presence of the salmon farms does not affect the inflow events.

Density Profile of Macquarie Harbour

Figure 8 shows the vertical density profile of Macquarie Harbour (plotted as sigma-T) for 2019 to 2023. The density (sigma-T) of surface waters ranges from near zero (at times of high river inflow) to around 12 kg/m^3 (at times of low river inflow). There is a seasonal pattern, but infrequent floods dominate the surface density.

The vertical profile shows strong stratification from the surface to 20 m depth, with weak stratification at the lower depths. The density stratification is strongly stable, showing that large scale inversions cannot occur. The density near the bed is mostly around 22 kg/m^3 , consistent with seawater slightly diluted with freshwater as the ocean inflow cascades down the side of the harbour to the bed.

Figure 8. Vertical Density Profiles in Macquarie Harbour in 2019-2023



The more saline seawater mixes upward into the less saline layers. Thus, over a year, the seawater entering the harbour and settling to the bed slowly mixes upward through the water column, eventually leaves the harbour as part of the brackish surface outflow.

Dissolved oxygen (DO) enters the lowest layer with the seawater (which would normally be 100 % saturated with DO). DO also enters the surface layer with the river inflows (which would also normally be 100 % saturated with DO).

The stratification inhibits the vertical mixing of DO, which is why the lowest DO concentration occurs at 15 to 25 m depth, in the middle of the water column.

It is not obvious from the DO data analysed in this report that there has been “a marked decline in dissolved oxygen conditions in Macquarie Harbour which are likely to have a significant impact on many resident species, including the Maugean Skate” Dissolved oxygen was always low in the lower layer. There are certainly significant variations in DO in Macquarie Harbour from month-to-month and year-to-year. Whether or not there is a long term trend of declining DO with time is still an open question, as any trend is difficult to separate from variations in annual and longer term river flows, and events with a large inflow of seawater, due to a coincidence of environmental conditions that encourage such events.

Long period cycles are also likely to be important. As an example, there appears to be a 50-year cycle in the extent of seagrass in Port Phillip Bay, responding to decade-long variations in rainfall (Jenkins, et al, 2015) and similar long cycles may occur in Macquarie Harbour.

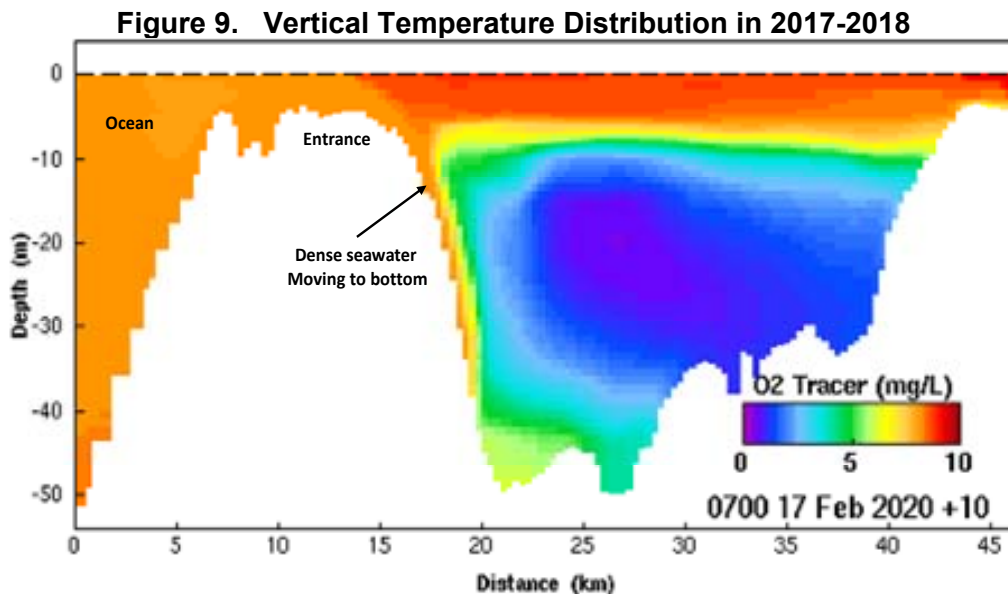
Moving from 2-D to 3-D

The analysis of vertical profiles of salinity, dissolved oxygen and density is based on a string of monitoring sensors in the middle of the harbour. IMAS maintains the sensors and reported that salinity and density conditions are very similar along the main NW-SE axis of the harbour, based on the correspondence of results for several vertical strings of sensors. The changes over the depth, and with time, are much greater than the changes with distance along the axis of the harbour. Thus, the analysis can be described as a 2-D depiction of conditions.

Conditions near the inlet of the rivers and in the channel connecting the harbour to the ocean differ from the conditions in the bulk of Macquarie Harbour. Near the mouth of the rivers, the freshwater salinity and temperature dominate conditions locally. In the ocean entrance channel, conditions vary over the tide cycle (although river flow rather than tide height dominate the direction of water movement).

In summer, when there is mostly lower river flow, more seawater enters the harbour, and descends down the side to the bed of the estuary. The effect of this plume on temperature is apparent in the summer profiles in Figure 9.

In winter, when there is generally higher river input, the outflow of the surface layer dominates flow in the channel, and there is a smaller inflow of seawater (but some occurs when there is a coincidence of conditions favouring seawater inflow).



Source: Wild Allen et al, Macquarie Harbour Oxygen Process model, Fig 2-10, CSIRO, 2020

Uplifting of lower DO waters can occur in suitable conditions, such as persistent strong westerly winds when river inflow is low and the surface layer is shallow (perhaps with higher than usual salinity). The haloclines are tilted and there is an intrusion of marine water causing an uplift of mid layer water with low DO to near the surface at the northwest end of the harbour. In such an event in March 2018, there were large oscillations in the haloclines along the length of the harbour with higher surface salinity and lower dissolved oxygen at sites close to the harbour entrance. After the event, dissolved oxygen was reported to have increased by more than 50 % in the bottom water.

When the wind is aligned along the major axis of the harbour, it sets up oscillations in sea-level that raise and lower the halocline at opposite ends of the harbour. Conditions around the edges of Macquarie Harbour are more variable than in the middle.

Salinity and Temperature Preference of Skates

Moreno and Semmens (IMAS, 2023) reported on the distribution of Maugean Skate eggs in Macquarie Harbour, with particular reference to depth and DO. The distribution of Skates was assessed from multiple net trawls, diver surveys, and tracking of 25 adult Maugean Skates fitted with multi-sensor acoustic tags by 52 acoustic receivers in the Table Head/Liberty Point region of Macquarie Harbour over a 12-month period from Nov 2018 to Nov 2019.

The 25 tagged Maugean Skate were mature individuals ranging from 620 and 820 mm in size. Two of the tagged skate exited the array within a few days of release and were not detected again during the study period. Five individuals exited the array area at 2 to 8 months after release and were not detected again.

Eleven skate (eight males and three females) were assumed to have died during the study period. Seven individuals stayed within the array area for the duration of the study and survived for 12 months. The mortality rate (11 of 25 skates in a year) matches the typical mortality rate for skates (40 % per year, Grant et al, 2022) which predicts the loss of 10 skates per year.

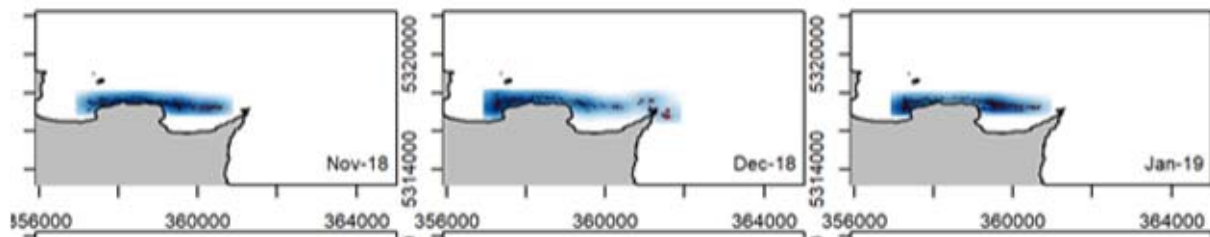
The uplift event in January 2019 has been highlighted earlier in this Technical Memo. The vertical profile for 24 January 2019 showed the DO was at 60 % saturation at 8 m and 50 % saturation at 9 m depth. The salinity at these depths was elevated at 28 ppt at 8 m depth and 28.5 ppt at 9 m depth. This is evidence of a strong salinity uplift event.

The conditions in April 2019 showed a weaker uplift event, with the DO at 60 % saturation at 12 m depth and 50 % saturation at 16 m depth. The salinity at these depths was elevated at 27 ppt at 12 m depth and 30 ppt at 16 m depth.

The location of the mortality events mostly occurred in shallow water (less than 5 m deep) where there was high dissolved oxygen (see Figure 14 of Moreno and Semmens, 2023).

Overall, the skates had small home ranges (< 4 km travel distance, mostly along the depth contours) through which they moved in a consistent manner (see Figure 10). However, at different times of the year, most individuals displayed a change in behaviour where they briefly travelled to sites away from the home range in short excursions (< one week). This travelling was short lived and followed by a return to normal home ranging behaviour.

Figure 10. Travel Paths of Skates at Table Head in 2018-19



The skates had a strong preference for temperatures between 13 to 15°C. During the summer months, when ambient temperatures high in the water column were above that range, individuals spent most of their time at the cooler available sites. The opposite was true during winter, when individuals favoured sites within the preferred range over other much cooler areas.

Figure 11 shows vertical temperature profiles in the 12 months of 2019 with the skates preferred range of 13 to 15°C highlighted. It appears that the temperature in the surface layer (zero to 5 m depth) is too hot in summer and too cold in winter, but just right in spring and autumn. The seasonal variation encourages the skates to move to the 8 m to 15 m depth layer in summer and winter.

Figure 11. Vertical Temperature Profiles in 2019

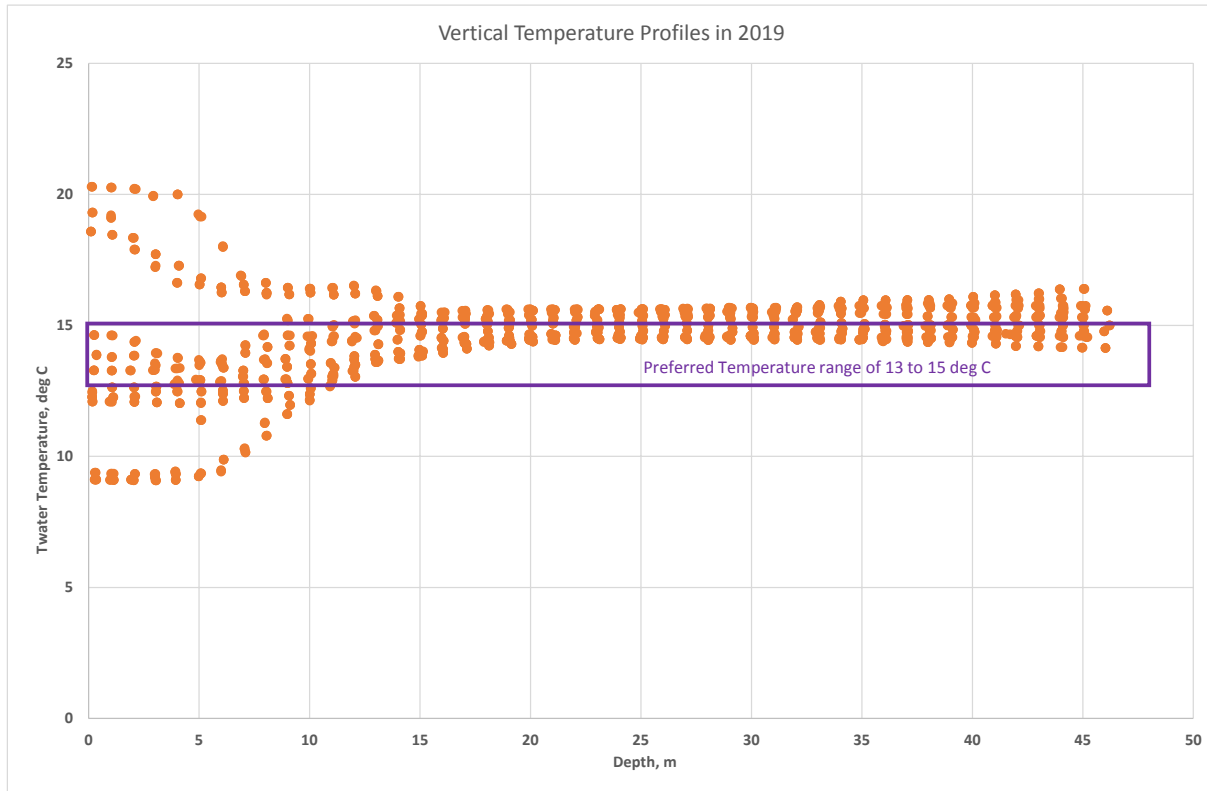
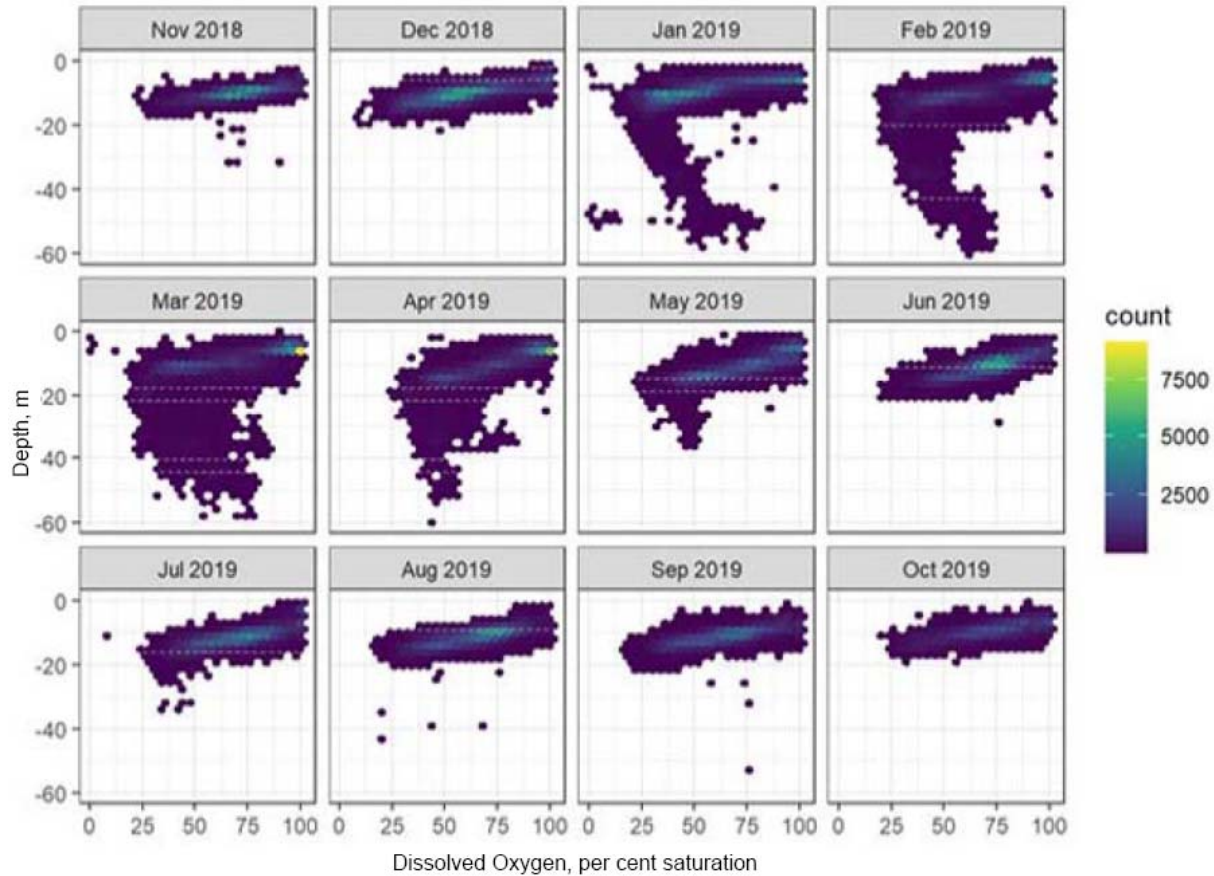


Figure 12 is a plot, month-by-month, of the depths (vertical scale) and DO (horizontal scale) for the monitor records for the seven skate that survived the 12 month monitoring period.

For eight months of the year, the depth range was limited to a maximum of 20 m depth, with most records showing the skate were between 8 m and 15 m depth.

During four months (January to April 2019) the skates were mostly higher in the water column (at 5 m to 10 m depth) but with excursions to 50 m depth (the bed of the harbour). The DO recorded by the monitors ranged from about 30 % at 20 m depth to around 50 % at 50 m depth. These recorded DO conditions are significantly different from the DO recorded by IMAS in the middle of the harbour (see Figure 6). The IMAS sensor string recorded that DO saturation ranged from about 25 % at 20 m depth to around 30 % at 50 m depth.

There is also a large difference between the DO recorded by the skate monitors at 10 m depth (30 % to 100 % saturation) compared to the values recorded by the IMAS sensors in mid-Harbour (mostly 60 % to 80 %, with a single month of 40 %). A possible explanation is that the skates take the opportunity to explore down the slope in the high DO water that occurs during an ocean inflow event.

Figure 12. Vertical Temperature Profiles in 2019

Source: Moreno and Semmens (IMAS, 2023)

This difference is recognized by Moreno and Semmens (IMAS, 2023) who noted that tags attached to skates that died in the study showed different DO levels than the water column sensors at the same depth; suggesting that DO conditions within the skate's preferred habitat appear to fluctuate dynamically by depth and horizontally across relatively small spaces.

Further investigations are necessary to determine why the DO conditions at Table Head differ from those in the rest of the harbour, and why Maugean Skates are concentrated in two relatively small zones (Table Head and Swan Basin) on the west side of the harbour.

The paper suggests *“that the deaths (of tagged skates) may have been related to stress caused (directly or indirectly) by the significant changes in the environmental conditions of the harbour. If this is the case, then recent changes in the environmental health of the harbour (especially dissolved oxygen levels), coupled with the consequences of climate change (including occurrence of extreme weather events), may already be challenging the skate's capacity to cope with the environmental conditions in Macquarie Harbour”*

There is no data in the paper that show that there are changes in the environmental health of the harbour. Thus, there is no basis for this inference. The uplift events that occurred in 2019 and which may, or may not, have contributed to increased mortality of skates are a natural occurrence that occurs regularly (as shown in Figures 4 and 15). Other than this extrapolation, and the conflicting DO results, the Moreno and Semmens (IMAS, 2023) paper is an excellent description of the location and behaviour of skates in Macquarie Harbour, and the wide range of environmental conditions that they experience.

Dissolved Oxygen in Macquarie Harbour

Wild-Allen et al (2020) have set out an oxygen balance for Macquarie Harbour for the years 2017-2018. The published oxygen inputs and losses for that period are set out in Table 1. An updated oxygen balance for the operation of the salmon farms is set out below.

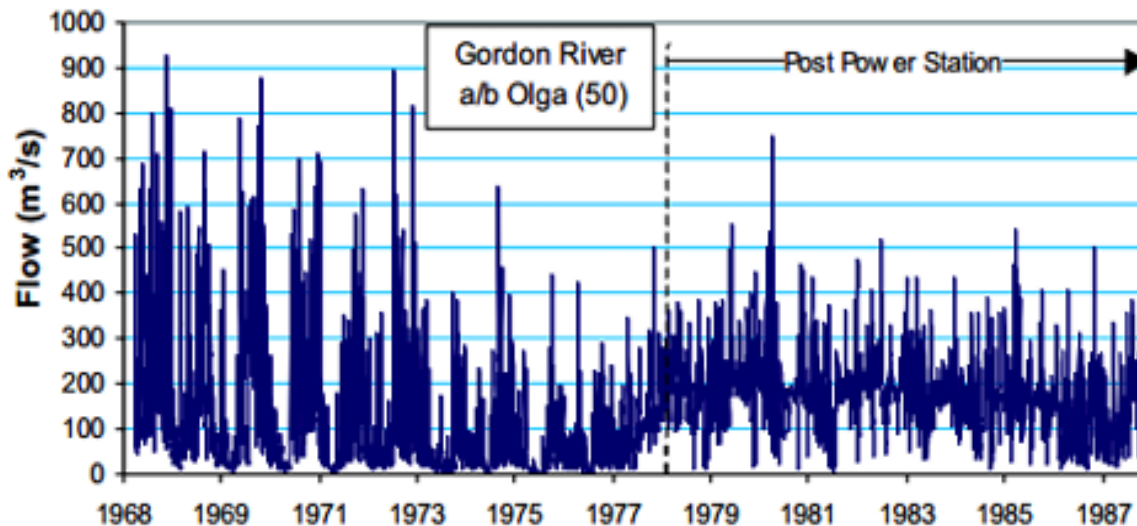
Table 1. Estimated 2017-18 Oxygen Inputs and Losses from Macquarie Harbour

Component	Oxygen, t/yr	Comment
Inputs of Oxygen to Macquarie Harbour		
Oxygen in river inflow	121,000	350 m ³ /s at 11 mg/L DO
Oxygen in ocean inflow	14,000	Seems low at 80 m ³ /s at 8 mg/L
Re-aeration on surface	11,000	
Phytoplankton and MPB	2,000	
Total inputs of oxygen	148,000	
Losses of Oxygen from Macquarie Harbour		
Oxygen in Harbour outflow	129,000	430 m ³ /s at 8 mg/L
Accumulation in sediments	12,000	Largely attributed to fish farm solids
Respiration of fish	5,000	50 mg/kg fish per hour for 11,400 t fish
Loss to the atmosphere	2,000	
Total losses of oxygen	148,000	

The oxygen balance is dominated by the oxygen that enters the surface layer in river inflow and then leaves as a brackish outflow. The oxygen in ocean water that enters in the channel and descends to the bottom of the harbour involves a smaller amount of oxygen.

The Gordon River power station is the largest power station in Tasmania. The pattern of flow in the river has been changed by the operation of the power station, as illustrated in Figure 13. Flow peaks are attenuated and the base flow rate is increased – this effect can be exacerbated by the requirement to maintain an environmental flow in the rivers. Higher river flow rates correspond to less intrusion of ocean water to the harbour – and less addition of oxygen to the lower layer of the harbour.

Figure 13. Flow Rate in Gordon River – 1968 - 1987



The potential impact of the oxygen demand by salmon farm respiration depends on: (1) the oxygen demand in the vertical profile; and (2) the location of the salmon farms in relation to the areas commonly used by skates.

Vertical Position of Demand

Salmon cages extend from the surface to 13 m depth. The fish move up and down in the cages in response to feeding opportunity, water temperature profile, light, oxygen levels and perceived threats. In winter, salmon can thrive at 2 m to 5 m depth, but in summer they swim at deeper levels (8 m to 11 m) seeking a compromise between lower temperature and lower DO.

I do not have access to data showing a plume of reduced DO near a Macquarie Harbour salmon farm. The measurements of Oldham et al (2018) indicate a reduction of 3 to 5 % in DO in salmon cages in the Huon estuary.

For Macquarie Harbour, a typical salmon farm may be 168 m in diameter with 100 t of fish in a 3 m deep layer. Oxygen demand at 50 mg/kg fish/hr (CSIRO, 2021) is 5 kg/hr.

The flow of water through the school of fish in the cage at a typical velocity of 0.04 m/s is 20 m³/s or 72,000 m³/hr. In the surface layer, the DO concentration is 9 mg/L, so the oxygen flux is 650 kg/hr. In the deeper layer, the DO concentration is 6 mg/L, so the oxygen flux is 430 kg/hr. The reduction in DO downstream of a fish cage due to fish respiration is around 1 % or 0.06 mg/L (small).

The depth preferences for skate, reported earlier, shows that the depth range was mostly between 8 m and 15 m depth, so that skate could potentially be affected by the plume from the cages in summer. In winter, the plume of reduced DO water from the salmon farms flows out to the ocean (at undetectably lower concentrations than without salmon farms).

Location of Salmon Farms Relative to Skate Locations

Most skates were found at Table Head, which is around 1.5 km west of the salmon farms. There are five other verified habitats for skates around the perimeter of Macquarie Harbour (DCCEEW, *Conservation Advice for Zearaja maugeana Maugean Skate*, 2023). All are more than 1 km from the nearest salmon pen and the DO in the surface waters at skate sites could not be impacted by respiration of salmon.

Outcome

It is very unlikely that the oxygen demand for salmon respiration can have a direct impact on skates because the reduction in DO is very small at the cages, and even smaller at distance and after the effect of surface re-aeration.

Potential Risk in Bottom Layer DO

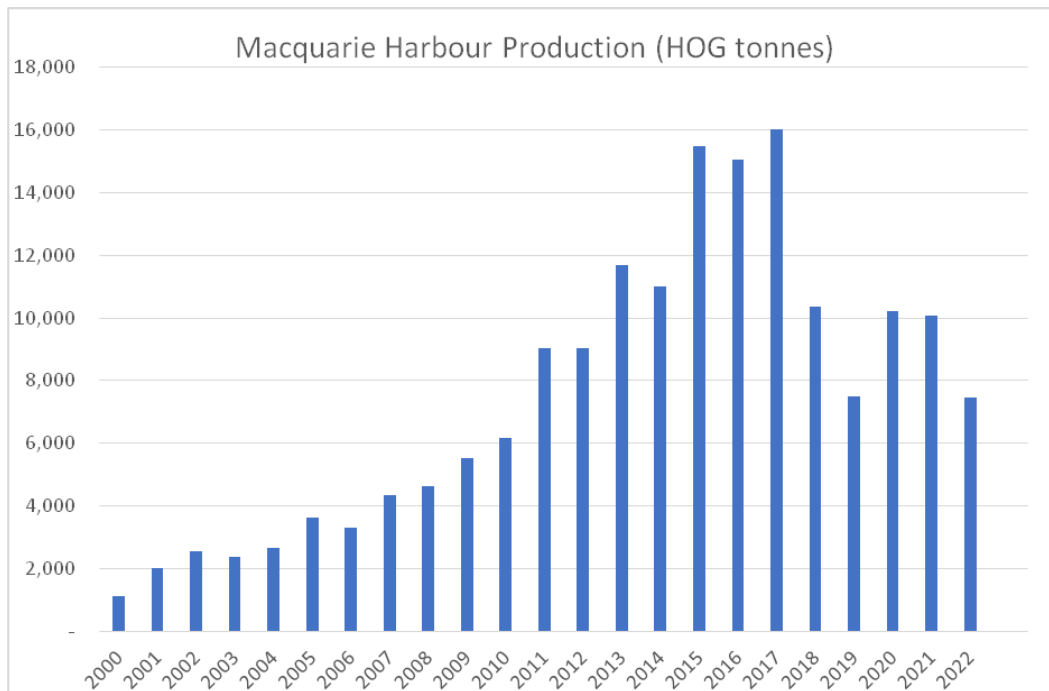
The second consideration is the potential for salmon food and faeces to reduce DO in the lower layer of the harbour from nitrogen and organic solids stimulating bacterial growth in the water column and the sediments with coincident use of oxygen.

The CSIRO model report (Wild-Allen, 2020) estimated that DO load in the sediments due to these processes was 12,000 t/yr, which is close to the estimated input of oxygen from the ocean (of 14,000 t/yr). This is the critical balance that determines the oxygen conditions that skate experience on their deep dives. The model predicted that if the 12,000 t/yr sediment load was removed, DO in the lower layer would increase by around 1 to 2 mg/L at 25 to 35 m depth (Fig 4-40 of CSIRO report). This assumption is checked in this Technical Memo.

Nitrogen and Organics Balance

According to Ross (IMAS, 2022) potential environmental impacts of salmon farms in the water column stem predominantly from the introduction of nitrogen (N) and phosphorus (P). However, carbon addition in fish feed is equally important as respiration of fish converts a proportion of the carbon supplied to carbon dioxide. Thus an updated nitrogen and carbon balance for salmon farms in Macquarie Harbour is provided in the following section for the year 2023. The mass balance is based on published information, particularly the mass balances published by Wang et al (2013) and Wang and Olsen (2023). The mass balance reflects the lower salmon production in 2018-2023 compared to 2013-2017, as shown in the production plot in Figure 14.

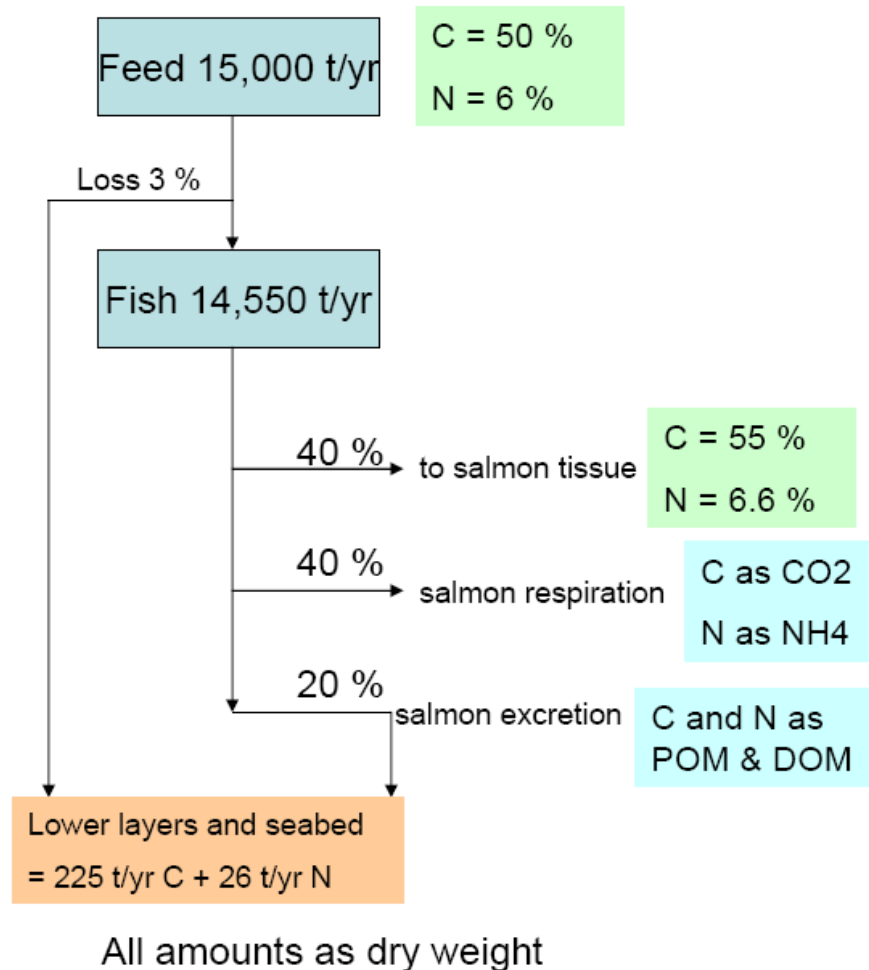
Figure 14. Salmon Farms Production in Macquarie Harbour (t/year)



Modern salmon farms are very efficient in their use of feed (97 % of feed is reported to be eaten by the fish and only 3 % escapes the fish cage). The feed is optimized for growth of salmon and 40 % of the feed is assimilated by the fish and converted to salmon mass.

Figure 15 shows the mass balance for fish feed supplied to all salmon farms in Macquarie Harbour. The same pathways apply to carbon and nitrogen, as explained below.

The feed input to salmon farms follows a seasonal pattern with peak input in Oct to Dec each year, and lower inputs in autumn to winter. Total inputs increased steadily from year 2000 to a maximum in 2017 (see Figure 14). Following Harbour wide declines in DO and associated declines in benthic faunal abundance (Ross et al., 2017), the permissible aquaculture biomass in Macquarie Harbour was reduced, and feed input since 2017 has been about half the earlier peak rate. Based on available data, the total input of fish feed in 2023 is estimated to be 15,000 dry tonnes.

Figure 15. Schematic Mass Balance for Fish Feed in Macquarie Harbour

The fish feed (of 15,000 t/yr as dry weight) is assumed to have a carbon content of 50 % and a nitrogen content of 6 % (based on Wang and Olsen, 2023). Other constituents of the fish feed are phosphorus, hydrogen, oxygen and trace elements.

The loss of fish feed through the base of the cages is 3 % or 450 t/yr, which corresponds to 225 t/yr of carbon and 26 t/yr of nitrogen. The fate and related oxygen demand of the lost fish feed is considered in conjunction with salmon excretion.

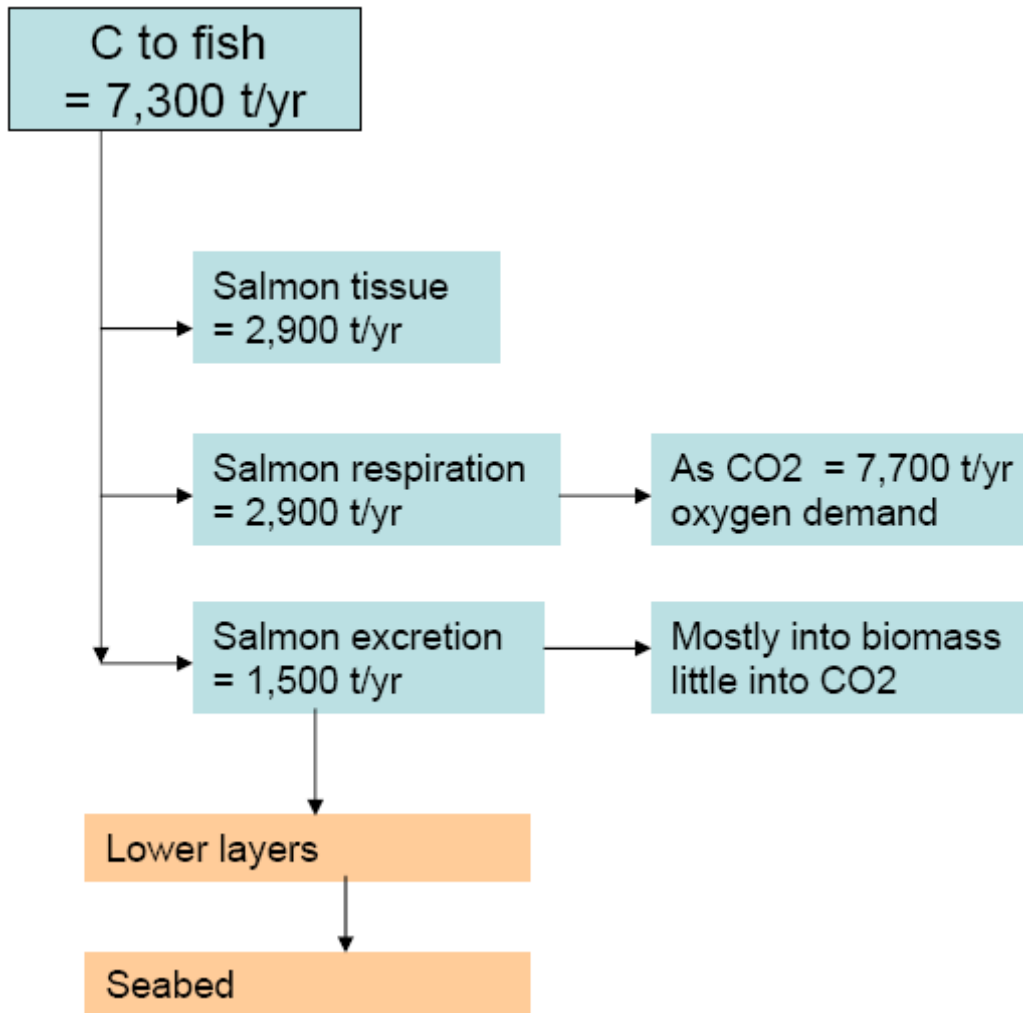
Growth or production of salmon is estimated to be 40 % of the fish feed, as an average over the year. It is recognized that the growth rate varies with the seasonal temperature and other conditions, but the feed rate is altered to adjust for this, and this balance is based on the average conditions over the year.

Salmon use an estimated 40 % of carbon for respiration and also release at the gills an estimated 40 % of nitrogen mostly as ammonia with a small proportion of urea (NH₂CONH₂).

To complete the balance, an estimated 20 % of the feed is assimilated by the fish and excreted as a combination of particulate organic matter (POM) and dissolved organic matter (DOM).

Figure 16 shows the extension of the mass balance for carbon.

Figure 16. Carbon Mass Balance for Fish Feed in Macquarie Harbour



The carbon balance shows the salmon assimilate 7,300 t/yr of carbon. Of this, 40 % goes into salmon growth (2,900 t/yr), 40 % goes into salmon respiration (2,900 t/yr) and 20 % goes into excretion.

Salmon Tissue

Salmon tissue is reported to have a carbon content of 55 %. Thus, the growth of salmon corresponds to 5,300 t/yr of salmon production ($2,900 / 0.55 = 5,300$). Allowing for 30 % water in adult salmon, the production rate is approximately 7,600 t/yr (which corresponds to the production rate in Figure 14).

Salmon Respiration

Salmon respiration converts 2,900 t/yr of carbon into 10,600 t/yr of carbon dioxide, which involves the fish withdrawing 7,700 t/yr of dissolved oxygen from the waters surrounding them.

Google Earth shows 77 farm cages in Macquarie Harbour, so this corresponds to 100 t oxygen demand/yr/cage. As noted earlier, the flow of water through the school of fish in the cage at a typical velocity of 0.04 m/s is 20 m³/s or 72,000 m³/hr. On average, the oxygen demand for respiration of 7,700 t/yr corresponds to 0.16 mg/L reduction in dissolved oxygen.

The peak rate in spring could be up to 0.3 mg/L DO. As surface DO is in the range of 7 to 8 mg/L, this estimate is close to the 3 % to 5 % measured by Oldham et al (2018).

Implications of Respiration on DO

Figures 5 to 7 show the DO at 10 m depth is typically at 60 % to 80 % saturation, reflecting a 2 to 3 mg/L reduction in DO. Most of this reduction can be attributed to the large oxygen demand from river inputs (see Table 1), respiration from the salmon farms also reduced oxygen concentration (albeit much smaller).

There is a strong gradient in DO from the surface to depth in the harbour. Thus, essentially all the oxygen demand in the surface layer by salmon is matched by an input of oxygen from surface re-aeration. Also, some of the oxygen demand is flushed to the ocean in the daily surface outflow.

The DO demand from respiration has no effect on dissolved oxygen levels in the deeper waters (at 15 to 30 m depth).

Salmon Excretion of Carbon

Salmon excreta is a combination of particulate organic matter and dissolved organic matter. Typically, the carbon and nitrogen content of fish excreta is lower than in the feed (Wang et al, 2023). Available data suggests that the carbon content decreases from 50 % in the feed to 35 % in the excreta while the nitrogen content decreases from 6 % in the feed to 4.5 % in the excreta. Nonetheless, the 1500 t/yr of carbon shown in Figure 16 is retained for this oxygen consumption analysis.

The excreta is processed by a range of small animals and bacteria in the water column and on the bed of the harbour (if the particles make it to the bed without being consumed). Ultimately the carbon ends up as living tissue in the water column (a small amount) or as sludge on the bed. A minor amount may be transported upward by free-swimming organisms and lost to the ocean in the harbour outflow.

For the calculation of oxygen demand, the following assumptions are made:

- One-third of the excreta is assimilated by organisms in the top layer;
- One-third of the excreta is assimilated by organisms in the lower layer;
- One-third of the excreta is assimilated by organisms in the harbour bed;
- The COD corresponds to complete conversion of C to CO₂;
- The BOD corresponds to a COD/BOD ratio of 2.0, as for similar faecal matter.

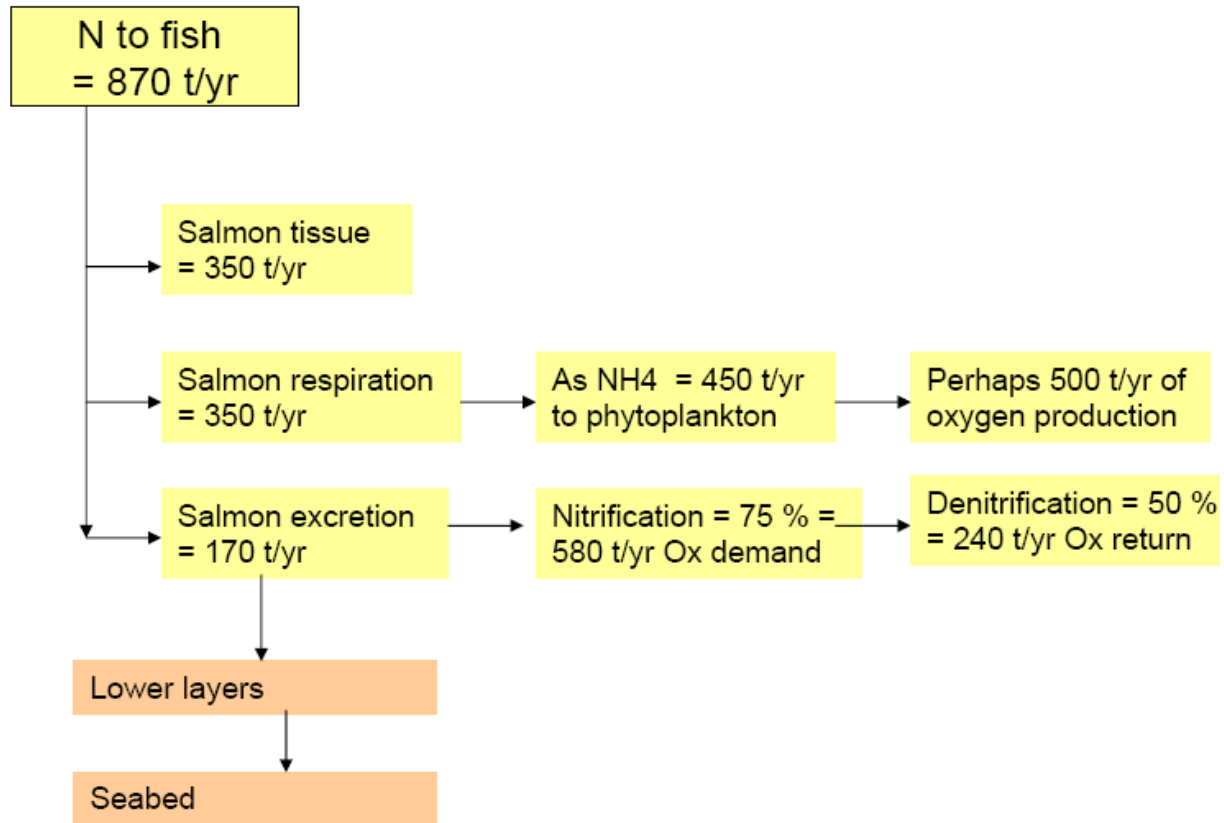
On this basis, the following calculations of oxygen demand in the lower layer/bed ensue:

- Total BOD due to carbon excretion is 4,000 t/yr;
- The BOD in the top layer is 1,330 t/yr;
- The BOD in the lower layer is 1,330 t/yr;
- The BOD on the seabed is 1,340 t/yr.

Experience in shallow treatment ponds (2 m to 4 m deep) is that most of the BOD is exerted by organisms on the bed. Macquarie Harbour is much deeper, and the food path and depth ranges for the use of the carbon (and nutrients) is not established as yet, so it is assumed that one third of carbon is assimilated in each of the top layer, lower layer and the bed.

Figure 17 shows the extension of the mass balance for nitrogen, starting with the 870 t N/yr assimilated by the fish.

Figure 17. Nitrogen Mass Balance for Fish Feed in Macquarie Harbour



The nitrogen balance shows that salmon growth uses 350 t/yr of nitrogen. Salmon release excess nitrogen at the gills in the form of ammonia and urea (assumed to be all ammonia). There is 170 t/yr of nitrogen in salmon excreta.

Salmon Tissue

Salmon tissue is reported to have a nitrogen content of 6.6 % (Wang and Olsen, 2023). Thus, the growth of salmon corresponds to 5,300 t/yr of salmon production ($350 / 0.066 = 5,300$). Allowing for 30 % water in adult salmon, the production rate is approximately 7,600 t/yr (which corresponds to the production rate in Figure 14).

Salmon Release of Excess Ammonia

Salmon release 350 t/yr of nitrogen as ammonia which rapidly dissolves in the seawater in the top layer. In other marine waters, the ammonia would be assimilated by phytoplankton or macrophytes in a few hours. There are no macrophytes near the fish cages, but field surveys have identified that the chlorophyll-a concentration over the top 15 m of the water layer is typically around 1 µg/L which shows there is sufficient phytoplankton habituated to the low light conditions of the harbour to take up the ammonia. The IMAS field surveys also demonstrate that there is no increase in ammonia in the surface waters which confirms that it has been assimilated.

The quantity of phytoplankton supported by a nitrogen discharge (as ammonia) of 350 t/yr is calculated using the Redfield ratio (Redfield, 1958), which states that the average composition of ocean plankton is 106C : 16N : 1 P.

Applying the ratio, the supply of 350 t/yr of ammonia would encourage the growth of around 3,000 t of phytoplankton (8 t/day) which through photosynthesis would supply around 3,600 t of oxygen to the surface layer.

It is not considered that the ammonia release has any effect on dissolved oxygen levels in the deeper waters (at 15 to 30 m depth) as the ammonia is dissolved and assimilated in the top layer.

Salmon Excretion of Nitrogen

As noted above, typically the carbon and nitrogen content of fish excreta is lower than in the feed (Elvines, et al, 2023). Available data suggests that the nitrogen content decreases from 6 % in the feed to 4.5 % in the excreta. Nonetheless, the 170 t/yr of carbon shown in Figure 17 is retained for this oxygen consumption analysis.

The excreta is processed by a range of small animals and bacteria in the water column and on the bed of the harbour (if the particles make it to the bed without being consumed). Ultimately the carbon ends up as living tissue in the water column (a small amount) or as sludge on the bed. A minor amount may be transported upward by free-swimming organisms and lost to the ocean in the harbour outflow.

Nitrification is the natural process that occurs in the environment by a group of specialised bacteria in which ammonia (NH_4^+) is converted to nitrites (NO_2^-) and then to nitrates (NO_3^-). The theoretical oxygen demand for this process is 4.57 g $\text{O}_2/\text{g NH}_4^+$. The pH in Macquarie Harbour is optimum for nitrification and denitrification.

Denitrification is a related natural process by another group of specialized anaerobic bacteria that convert nitrate to nitrogen gas and release water and oxygen. The theoretical oxygen recovered is 2.86 g $\text{O}_2/\text{g NO}_3^-$ reduced. The overall oxygen requirement for combined nitrification/denitrification is 1.7 g O_2 consumed per g of ammonia.

Neither nitrification nor denitrification is 100 % effective, and both processes are limited by low water temperature (and elevated DO in the case of denitrification). Based on analysis of nitrogen removal in wastewater treatment lagoons at Strahan (TasWater, 2023), nitrification in the region is about 75 % effective and denitrification is about 50 % effective.

For the calculation of oxygen demand, the following assumptions are made:

- Bacteria are assumed to nitrify and denitrify the released nitrogen;
- Oxygen requirement for nitrification is 4.6 g per g of nitrogen;
- The nitrification efficiency is assumed to be 75 %, based on the nitrification efficiency of the adjacent Strahan sewage treatment lagoons;
- Oxygen return from denitrification is 2.8 g per g of nitrogen;
- The denitrification efficiency is assumed to be 50 %, based on the denitrification efficiency of the adjacent Strahan sewage treatment lagoons.
- The remaining 25 % of excreted nitrogen is stored on the bed as dead tissue (sludge).
- One third of carbon is assimilated in each of top layer, lower layer and the bed.

On this basis, the following calculations of oxygen demand ensue:

- The oxygen demand for nitrification is 580 t/yr (factor is 4.6);
- The oxygen return from denitrification is 240 t/yr (factor is 2.8);
- The net oxygen demand in the water column is 340 t/yr.
- The net oxygen demand in the upper layer is 110 t/yr.
- The net oxygen demand in the lower layer column is 110 t/yr.

The remainder of the nitrogen in excreta is converted into tissue of bacteria/fungi and other micro-organisms and accumulated in the bed as sludge.

Lost Salmon Feed

As shown in Figure 15, 450 t/yr of salmon feed containing 225 t/yr of carbon and 26 t/yr of nitrogen falls through the salmon cages.

The most likely fate of the lost salmon feed is that native fish spend time under the cages and assimilate most of the excess feed coming down into their habitat. The remainder experience the fate of salmon excreta.

Alternatively, the lost feed can be consumed by bacteria. Using the same parameters as for the excreta load, the net effect on oxygen demand is as follows:

- Carbon in lost feed assimilated by organisms is 225 t/yr;
- The corresponding COD is 600 t/yr (complete conversion of C to CO₂);
- The corresponding BOD is 300 t/yr (biological conversion of C to tissue).
- One third of carbon is assimilated in each of top layer, lower layer and the bed;
- Oxygen demand from carbon in top layer is 100 t/yr;
- Oxygen demand from carbon in lower layer is 100 t/yr.

- Nitrogen in lost feed assimilated by organisms is 26 t/yr;
- The oxygen demand for nitrification is 72 t/yr (factor is 4.6);
- The oxygen return from denitrification is 36 t/yr (factor is 2.8);
- The net oxygen demand due to nitrogen in feed in the water column is 36 t/yr.
- One third of carbon is assimilated in each of top layer, lower layer and the bed;
- Oxygen demand from nitrogen in top layer is 12 t/yr;
- Oxygen demand from nitrogen in lower layer is 12 t/yr;
- The remainder of the nitrogen in lost feed is converted to sludge in the bed.

Oxygen Balance for Top Layer

The oxygen demand due to salmon farms in the top layer is estimated to comprise:

1. 7,700 t/yr due to salmon respiration;
2. 1,330 t/yr from bacterial demand to convert carbon in salmon excreta;
3. 110 t/yr from net nitrification of salmon excreta;
4. 100 t/yr due to carbon conversion of lost feed;
5. 12 t/yr due to net nitrification of lost feed;
6. -3,600 t/yr of oxygen returned from phytoplankton growth.

The total oxygen demand in the top layer is 5,650 t/yr. This is about 4 % of the estimated oxygen supply to the upper layer of the harbour of 134,000 t/yr (see Table 1). The volume of the top layer (surface to 10 m depth) is $1.8 \times 10^9 \text{ m}^3$. The average flushing time is 35 days, and the average DO concentration is about 7.4 mg/L ($=134,000 \text{ t/yr} / 1.8 \times 10^9 \text{ m}^3 / 35 \times 365$). Measured oxygen levels in the top layer range from 5 to 8 mg/L, which matches the calculated average value of 7.4 mg/L.

The salmon farms reduce the DO in the top layer by 4 % or 0.3 mg/L ($=5,650 \text{ t/yr} / 1.8 \times 10^9 \text{ m}^3 / 35 \times 365$). This minor decrease would have negligible effect on the survival of the skates in their normal habitat in the top layer near Table Head.

Oxygen Balance for Lower Layer

The oxygen demand due to salmon farms in the lower layer is estimated to comprise:

1. 1,330 t/yr from bacterial demand to convert carbon in salmon excreta;
2. 230 t/yr from net nitrification of salmon excreta;
3. 200 t/yr due to carbon conversion of lost feed;
4. 12 t/yr due to net nitrification of lost feed.

The total demand in the lower layer is 1,770 t/yr. This is about 16 % of the estimated oxygen supply from the ocean to the lower layer of the harbour of 11,000 t/yr (from Table 1). Alternatively, the estimated ocean water inflow averaging 80 m³/s over a year with a DO of 7 mg/L would contribute 17,000 t/yr, and the demand of the salmon farms in the lower layer of water would be around 10 % of the estimated oxygen supply.

Uncertainties

The main uncertainty is the depth at which the conversion of carbon to tissue (requiring oxygen) and nitrogen into nitrate and nitrogen gas (requiring oxygen) occur. This analysis has assumed that most of the conversions occur in the water column, mostly on the basis of the depth of the harbour and the measured oxygen sag at mid-water depth.

If fully saturated, the waters of the lower layer between 15 m and 35 m depth would contain about 10,000 t of dissolved oxygen. The vertical profiles of dissolved oxygen show that about 75 % of the oxygen in this layer is consumed. Assuming a typical residence time of 1 year, the total oxygen reduction in the lower layer is around 7,500 t/yr.

An estimate of the oxygen demand in the lower layer can be made from:

- 5 % of the river inflow oxygen demand (5 % of 121,000 t/yr = 6,000 t/yr);
- Estimated salmon farm demand of 1,770 t/yr;
- Extra 500 t/yr from settlement of native marine organisms in the harbour.

These are approximate estimates that total 8,270 t/yr; the total matches the calculated oxygen reduction of 7,500 t/yr. As a corollary, the calculated oxygen demand from the salmon farms is considered to be approximately correct.

The estimated average effect of the salmon farms is to reduce the dissolved oxygen in the lower layer by around 16 per cent or 1 mg/L. There will be seasonal and spatial variations which can only be explored using a calibrated 3-D model and following further research to gain a better understanding of the biochemical processing involving oxygen and biota in Harbour waters – particularly the lower layer.

This estimate is lower than the prediction by CSIRO that DO in the lower layer would increase by around 1 to 2 mg/L at 25 to 35 m depth if the 12,000 t/yr salmon load (CSIRO estimate) was removed. The load estimated here of 1,770 t/yr is lower because salmon production in 2017 (the year for the CSIRO prediction) was about twice current levels.

The majority of the oxygen demand on the lower layer comes from the river inflow, with organics settling from the top layer into the lower layer. On average, organics from river inflows and natural processes are estimated to reduce the DO in the lower layer to around 35 % saturation. The extra load from salmon farms reduces the DO to around 25 % saturation. These estimates match the measured values in the vertical DO profiles presented earlier.

Concerns about Low Dissolved Oxygen

As stated at the beginning of this Technical memo, the main concerns regarding low dissolved oxygen in Macquarie Harbour are:

1. The risk to the survival of the Maugean Skate, which is a threatened species that apparently survives in low numbers only in Macquarie Harbour;
2. The risk to other ecological processes and systems in Macquarie Harbour; and
3. Anoxic or near-anoxic conditions would encourage the movement of metals from the sediments into solution. The metals exist from past mining activities in the catchment and from natural erosion processes.

Implications for Skate Survival

Most records show the skates live mostly between 8 m and 15 m depth with the normal depth range being 2 m to 20 m for eight months of the year. In four months, the skates unexpectedly dived through waters to a depth of about 45 m when the deeper waters had higher DO than the waters at 15 to 20 m depth. Oxygen conditions at Table Head appear to be relatively stable, as shown in Figure 18.

Figure 18. DO at Various Depths at Table Head – 2016-2021



River inflow is the process that determines the extent of ocean water inflow to the harbour, and the oxygen content of the lower layer. High river flows cause less ocean inflow and less oxygen – low river flows result in more ocean inflow and more oxygen in the lower layer.

In the 4000 years since Macquarie Harbour changed from a freshwater lake to a stratified estuary, there must have been many variations in river inflow. It is unlikely that present DO conditions have not been experienced in the past.

The current evidence is that skates normally live in the top layer. Salmon farms reduce the DO in the top layer by 4 % or 0.3 mg/L. This minor decrease would have negligible effect on the survival of the skates in their normal habitat in the top layer near Table Head.

Salmon farms reduce the DO in the lower layer by 10 % to 16 % or 1 mg/L. Skates travel to greater depths at times when the DO at depth is higher than surface levels, so they appear to avoid events with very low DO. Uplift events can reduce DO at 7 to 12 m depth (see Figure 6) but skates appear to avoid this by moving to the ocean inflow region, where high DO ocean water is entering and causing the uplift event.

Implications for Harbour Ecology

Lower DO in the lower layer, combined with higher ammonia and nitrate concentrations inevitably causes a response in ecological conditions in Macquarie Harbour. There will be higher productivity due to the extra available nitrogen.

Ross (2020) notes that conditions in 1999-2003 compared to baseline surveys conducted in 2012 show a change in the broader benthic ecology, as demonstrated by a measurable increase in total abundance, species richness and species diversity. These observed changes include a decrease in burrowing taxa and an increase in more static suspension and deposit feeding tube builders.

DO and Sediments

The DO records show that there is always positive DO below about 30 m from 2018 and below 35 m in 2013-2014. Thus, it is unlikely that precipitated metals will come out into solution. No increase in DO is required at the level of the deep sediments.

Further investigations are required to ascertain the conditions of sediments on the sides of the harbour between 20 m and 35 m depth, and directly under the salmon cages.

Nitrification and TOC

Ammonia is a readily available nutrient and there is some phytoplankton in the upper layers and a range of other micro-organisms that would use the ammonia. It seems very likely that ammonia is being nitrified and converted to nitrate. According to Ross (2022) the conversion of ammonia to nitrate occurs throughout the entire water column, and the increase in nitrate concentration in deeper waters suggests that nitrification is significant in the sediments and the water column. This is consistent with the findings of Ross et al. (2016a) and Maxey et al. (2016) who found that the abundance of ammonia-oxidising archaea and rates of nitrification, respectively, increased markedly with depth in the harbour.

It is noted that the DO minimum in Macquarie Harbour occurs at around 20 to 25 m depth. It may be that most nitrification occurs in that depth range, causing a deficit of oxygen. However, nitrification is expected to occur mostly in the sediments, adding oxygen near the bed.

Total organic carbon (TOC) concentration is highly seasonal in the shallow waters (1, 2 and 5 m) with the highest concentrations occurring in winter and lowest occurring during summer/autumn. In deeper waters (10, 20 and 31 m), TOC is relatively stable. This indicates that most of the organic carbon entering Macquarie Harbour is from riverine sources because concentrations are highest above the halocline in fresh water and the seasonal peaks occur during the cooler months when riverine inputs are greatest. Aquaculture would account for a relatively small fraction of TOC in the harbour.

Conclusion

This analysis has confirmed the findings of previous reviews that river flows control the flushing time of the surface layer and the influx of ocean water into the lower layer. For the foreseeable future, DO conditions in the harbour are controlled by seasonal weather and long period rainfall cycles. Long term, climate change will also have an influence.

The aim of this Technical Memo is to estimate the amount of oxygen input required to balance the oxygen demand from the salmon farms in Macquarie Harbour and the best locations to add that oxygen.

It is concluded that to fully compensate for the salmon farms, the amount of oxygen that would need to be added to the lower layer is approximately **1,770 t/yr**. Further research is required to refine this estimate and to assess whether continual or just seasonal oxygen input would be satisfactory. It is possible that just event-driven input could be optimum.

For the pilot study of re-oxygenation, it would be appropriate to add the oxygen at 30 m depth. It should be noted that an increase in DO of around 1 mg/L is predicted, although that depends on mixing rates (lower mixing rates could allow an increase of up to 2 mg/L) and biological uptake (enhanced biological uptake of the oxygen could result in an increase of only 0.5 mg/L).

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1970-72 Lecturer in Hydraulics and Fluid Mechanics
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Dr Wallis has extensive experience in environmental assessments, water quality, oceanographic studies, and is recognized as one of Australia's experts in these fields. Dr Wallis was a lecturer in hydraulics and fluid mechanics at Swinburne University and at Monash University. He was awarded the Alexander Stewart Fellowship which allowed periods of work at the UK Water Pollution Research laboratory and at Resources for the Future in Washington DC.

At the Water Pollution Research Laboratory, he modelled fish populations in the North Sea and the envelope of response of fish to toxins.

He was part of the team that prepared the Air Quality Policy for Victoria, and developed the Plume Calculation Procedure for the Victorian EPA. He has extensive experience in the use of AERMOD, Ausplume and Auspuff, and in the design, collection and analysis of data from meteorological stations States.

Dr Wallis has served as a member of several expert panels including the Expert Panel on Dredging of Darwin Harbour and the SA Desalination Panel of Experts.