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Dear Director

I write to provide the Tasmanian Government's response to the draft Conservation Advice and Listing Assessment for the Maugean Skate.

I note that both the Conservation Advice and the Listing Assessment are critical documents to ensure that conservation actions are focused and appropriate to support the recovery of the species. With this outcome in mind, the Department of Natural Resources and Environment Tasmania (NRE Tas) has considered the document and provides important new information and clarifications that should be considered in finalising the Conservation Advice and Listing Assessment.

Since the Tasmanian Government's publication of the Conservation Action Plan for Maugean Skate in January 2024, there has been significant, coordinated and collective action from Government, scientific experts and key stakeholders which has resulted in the acquisition of substantial new data and information relating to both the skate and water quality within Macquarie Harbour. Furthermore, the adaptive management framework to manage salmonid farming in Macquarie Harbour has also continued with the monitoring undertaken under this framework producing critical data and information relevant to the current risk profile and impacts of salmonid aquaculture on dissolved oxygen within Macquarie Harbour.

The Tasmanian Government considers that action to support the recovery of the Maugean skate must be informed by the best available science. NRE Tas analysis, is that uplisting of the Maugean skate to Critically Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), has not been met. The associated narrative in the draft Conservation Advice, relies heavily on information, data or assumptions that are highly uncertain, out-dated or otherwise contested.

This includes:

- That the initial population viability analyses (PVA) commissioned by the Department of Climate Change Energy Environment and Water (DCCEEW) to estimate extinction risk, explore the potential threat scenarios and inform priority conservation actions associated with captive breeding is now out of date and cannot be relied upon to provide meaningful population estimates. It is acknowledged that the modelling was undertaken with a sense of urgency and without access to much of the information and data that we now have available.

- The catch-per-unit-effort (CPUE) results from Maugean skate surveys in Macquarie Harbour in 2023 and 2024 have recently been reported (Attachment 1) and these results do not support several key assumptions upon which the draft Conservation Advice and Listing Assessment heavily relies. This includes a strong indication that the estimated mature population size of 40-120 in 2023 is a miscalculation and underestimates the true current population size. Further, the survey data does not support the assumption that the species is experiencing total recruitment failure nor is it consistent with the precipitous and sustained rate of population decline used in the PVA.
- The data presented by the EPA in the Macquarie Harbour Oxygen Status Report September 2024 (Attachment 2) shows the continual improvement in dissolved oxygen levels in Macquarie Harbour. In particular, the results demonstrate that two thirds of Macquarie Harbour have middle and deeper waters exhibiting DO levels within the Default Guideline Values (DGVs) and their historical range. The remaining one third of Macquarie Harbour has DO levels close to the DGVs and historical range with an improving trend and reasonable prospects to further improve on the current trend.

Importantly, the observed data indicates that water quality can improve significantly, concurrent with salmon farming. As such, the consequence of salmon farming causing water quality impacts to the skate can no longer be considered to be ‘catastrophic’ and the Tasmanian Government considers that when the existing management and regulatory controls of the adaptive management framework are recognised, the residual risk rating should be amended to a lower consequence category.

The new information provided by NRE Tas indicates that much of the current scientific content within the draft Conservation Advice and Listing Assessment is out of date and inaccurate and needs to be reviewed and amended in accordance with the current information and data.

NRE Tas understands that the draft Conservation Advice and Listing Assessment were written at a point in time. However, the document does not adequately reflect progress made towards implementing actions under the Conservation Action Plan; or the Adaptive Management Framework such as the ban on recreational gill netting, the introduction of oxygen mitigation plans for the salmonid farming industry, and the introduction of the Marine Finfish Environmental Standard and associated Environmental Licence conditions. As this information informs threats to the species, NRE Tas would like to see the draft Conservation Advice and Listing Assessment revised to ensure that it accurately reflects the current management and regulatory environment.

NRE Tas are convening an expert technical panel to critically review and update the PVA. The aim is to increase scientific consensus, facilitate greater confidence in the updated estimates and explicitly identify key areas of uncertainty. Leslie Gidding-Reeve, Deputy Chair of the National Recovery Team for the Maugean Skate and Director, Marine Species

Conservation Section within DCCEEW has been invited to participate in this review along with NRE Tas and suitably credentialed scientists.

While noting the purpose of the public consultation in regard to the Maugean skate is to elicit additional data, information and perspectives to inform the final listing assessment and the associated conservation advice, it is recommended that DCCEEW ensures that the outputs of the planned PVA review process are able to be adequately incorporated.

I therefore do not support the updating of the Conservation Advice or the Uplisting of the species at this time.

Additional specific feedback is provided in the tables below and broadly relates to the following key themes:

- new data and information that are available or otherwise imminent and should be taken into account;
- assessment of threats, including confidence, trend and assignment of risk; and
- general comments to improve accuracy and clarity.

Should you wish to discuss the content of this submission further please contact General Manager Environment Jo Crisp (Chair National Recovery Team for the Maugean Skate): jo.crisp@nre.tas.gov.au.

Yours sincerely

Jason Jacobi
SECRETARY

26 September 2024

Attachments:

1. Moreno *et al* (2024) Interim Report Number 2 - Macquarie Harbour Maugean skate population status and monitoring
2. EPA (2024) Macquarie Harbour Status update for dissolved oxygen
3. Brook (2024) Conservation Status Overview of the Maugean Skate (*Zearaja maugeana*)

Table 1: NRE Tas response to selected consultation questions

Question / NRE Tas response
1 - Is the information used to assess the nationally threatened status of the species robust? Have all the underlying assumptions been made explicit? Please provide justification for your response.
The Committee's assessment of the species threat status relies heavily on the PVA of Grant *et al* (2023) and its supplement Grant and Simpfendorfer (2023). Several issues regarding the assumptions and parameters used in the PVA have been identified, including in the recent critique undertaken by Professor Barry Brook and forwarded to DCCEEW. Concerns include: 1. Data selection and discard of data that may be useful for examining outliers. For example, including skate numbers from pre-2014 surveys (when soak times were longer) where a measure of error for Catch Per Unit Effort (CPUE) may be more informative. Additional years data (2012-2021) appear to have been used for smaller skate (<60cm) than for larger skate (>60cm; 2014-2021). 2. Lack of reported error rates and extrapolation of data with the assumption that trends are consistent across over time, sexes, size classes and the whole harbour. For example, standard errors are not applied to the linear regression of catch proportions used to estimate population decline (Figure 4; Grant *et al*., 2023), available data indicates that sexes do not have the same mortality rates (Bell et al., 2016), and, the data used to estimate population size may only apply to the size range of tagged animals rather than the entire population. 3. Skew in data resulting from selective methods used to monitor the skate population, i.e. under-representing juveniles. 4. Addition of catastrophic events on top of the modelling which reduces numbers down further and is essentially "double dipping". 5. New relevant demographic and environmental data (see *Consultation Question 2* for detailed list). 6. Improved harbour conditions and reductions in salmonid biomass and oxygen draw down (resulting from the introduction of biomass caps and subsequent TPNDO limits by the Environment Protection Authority Tasmania (EPA)) which are inconsistent with the PVA model assumption that conditions in the harbour conditions are deteriorating and are not reversible, and introduction of Environmental Standards for Marine Finfish Farming | EPA Tasmania and associated Environmental Licence Conditions. Note that the Chair of the National Recovery Team for the Maugean Skate (NRE Tas General Manager, Environment) will convene a small team of independent scientific experts to review and update the PVA based on contemporary information, expertise and science. As stated above, the Deputy Chair of the National Recovery Team for the Maugean Skate and Director, Marine Species Conservation Section within DCCEEW has been invited to participate in this review.
2 - Can you provide additional data or information relevant to this assessment?
A large volume of contemporary data relating to Macquarie Harbour and the Maugean skate is available that has not been incorporated into the PVA/Listing Assessment or the draft Conservation Advice.

New information includes:

1. EPA monitoring report (Sep 2024) showing that dissolved oxygen (DO) levels have returned to, or are trending towards EPA Site Specific Guideline Values (SSGVs) and interim Default Guideline Values (DGVs) water quality ranges for Macquarie Harbour at all measured depths (noting that EPA monitoring measures to 1 metre above the harbour floor, but does not cover the harbour floor and the effect of available DO on egg development has been identified as a key knowledge gap).

   This challenges the assumption underlying the Population Trend Analysis (Grant *et al.* 2023) that there is no mitigation of threats in the future (pg. 72 current draft Conservation Advice / Listing Assessment) and that "the primary cause of the population size reduction, i.e., reduced quality and extent of habitat resulting from the sustained reduction of dissolved oxygen, has not ceased and may not be reversible" (pg. 79 current draft).

2. Additional updated population, demographic and environmental parameters relevant to the PVA, including:
   a. That the species appears to have a higher potential lifetime reproductive rate than was input into the model (based on female fecundity observed in optimal captive conditions) (Semmens pers comm, 19/9/24).

   b. Generation length has been estimated as 6 years (Moreno *et al*., *In review*), rather than 9 years as applied to the PVA.

   c. Addressing uncertainty about wild hatching success. Moreno *et al*. 2020 have previously reported an estimated natural hatching success of 41% based on analysis of 51 empty egg cases collected from Macquarie Harbour. An alternative success rate of 11% has been estimated based on the egg collection undertaken in December 2023 to establish the captive initiative (Semmens pers comm, 19/9/24). Additionally, data on hatching success of eggs laid by the captive female Maugean skate indicate that optimal conditions of captivity may increase egg viability. Evidently, there is a large amount of variation and uncertainty in our understanding of egg viability and hatching success in Macquarie Harbour and associated anthropogenic or environmental drivers.

   d. Evidence of at least one recent successful recruitment event occurring since 2021 (based on monitoring surveys in Macquarie Harbour) (Moreno *et al*. 2024) which does not support hypotheses of sustained recruitment failure.

   e. Field surveys suggest stable abundance over recent years (CPUE from monitoring surveys in Macquarie Harbour show that the population has not declined beyond 2021 levels, with an approximately level trend between 2021 and September 2024; Moreno *et al*. 2024) and do not support the continued ongoing population decline that was input into the model. In addition, data from Lyle *et al*., (2014) suggests that CPUE across the harbour was similar in 2012 as it was in 2021.

   f. Field surveys effectively discount the lower estimate of 40 mature animals: 40 mature individuals were caught in 2023 and 31 mature individuals caught so far in 2024, noting only partial sampling has been undertaken in 2024 (Moreno *et al*. 2024).

3. Promising results from the Macquarie Harbour Oxygenation Project trial suggest that mechanical oxygenation of the harbour has utility as a tool to offset low oxygen, whether from salmonid aquaculture, or other processes (further challenging the assumption underlying the PVA of no mitigation of threats in future).

4. Following increasing restrictive regulations, a total prohibition on recreational gillnetting in Macquarie Harbour will be implemented from 1 November 2024.

5. Two commercial fishers in Macquarie Harbour are strictly regulated. NRE Tas is seeking advice from IMAS to further understand any residual level of risk to the skate and any further measures associated with commercial gillnetting.

6. Recent genetic work (Moreno *et al*., *In review*) shows that the Maugean skate in Macquarie Harbour constitutes a single, homogenous population. Despite their low genetic diversity, no signs of recent bottlenecks or inbreeding depression were found, as was reported in a previous study (Weltz et al, 2018) and referenced on pages 17 and 22 of the current draft Conservation Advice. The species appears to have remained viable at small population sizes for over 7000 years (i.e. naturally stable at low population sizes). Despite this evident resilience against inbreeding depression, the low genetic diversity of the population still means that they may have restricted adaptive potential and are vulnerable to disease outbreaks and rapid environmental change.

   The section 'Genetics' and references to a "genetic bottleneck or founder event (Weltz et. al 2018)" on page 17 and, the discussion on 'Low genetic diversity' on page 22 should be updated accordingly. Note that the Weltz et al (2018) study, currently referenced throughout, used microsatellite-based markers which are not a feasible way to measure inbreeding accurately in species with low allelic diversity like the Maugean skate (Moreno *et al*., *In review)*.

   There remains considerable uncertainty around the Maugean skate population and demographic status and trends, due to the current reliance on gill netting surveys to monitor the population in Macquarie Harbour, a method with widely acknowledged limitations. In particular, gill net surveys have resulted in limited recaptures (Bell et al. 2016), are biased towards larger individuals which restricts the ability to estimate juvenile size classes (Moreno and Semmens 2023) and, are constrained by limited fishing effort due to ethical considerations (Lyle et al, 2011). Accordingly, there is a focus on progressing complementary species monitoring approaches, with two approaches in particular being well-advanced.

7. Further genetic analyses (close-kin mark recapture) are in train that will inform population numbers (delivery date June 2025).

8. A recent trial conducted by IMAS has demonstrated the utility of Adaptive Resolution Imaging Sonar (ARIS) for surveying Maugean skate in Macquarie Harbour concluding it to be a promising tool for investigating trends in relative abundance and distribution as well and demographic dynamics (Semmens and Moreno pers comm). The trial thoroughly tested and compared different deployment methods and recommends survey design considerations to optimise data collection and the resulting population estimates. Further ARIS surveys are an identified high priority for implementation and planning is currently underway.

Other planned priority initiatives that will inform scenario modelling:

9. Extension to previous CSIRO oxygen process modelling (due Dec 2024) will inform exploration of potential management strategies to further improve harbour conditions. Importantly, re-runs of the model with contemporary salmonid aquaculture oxygen draw down values, to estimate the contemporary contribution of salmonid aquaculture activities to the harbour's oxygen balance, are also planned.

10. Updated PVA analyses (from NRE Tas convened expert workshop and review and update of the PVA modelling using updated data and information) will be available soon, per response to Consultation Question 1.

3 - Have you been involved in previous state, territory or national assessments of this species? If so, in what capacity?

Subsequent to listing as *Endangered* under the *Tasmanian Threatened Species Protection Act 1995* (TSP Act) in 2002 (noting that *Endangered* is the highest threat category under the TSP Act), NRE Tas was involved in the drafting and review of a new Listing Statement published in 2022.

Listing Statements are reviewed and approved by the Tasmanian Scientific Advisory Committee, considered and noted by the Community Review Committee, and approved by the NRE Tas Secretary prior to publication. NRE Tas was also involved in range state consultation and early consultation via membership on the National Recovery Team for Maugean Skate, for the current draft Conservation Advice and Listing Assessment under the EPBC Act.
4 - Do you have any additional information on the ecology or biology of the species not in the current advice?
See Consultation Question 2 above for detailed list.
5 - Has the survey effort for this taxon been adequate to determine its national adult population size? If not, please provide justification for your response.
No. See responses to Consultation Questions 1 and 2 above for detailed consideration of issues regarding the PVA used to estimate current population size of mature adults and rate and trajectory of decline.
6 - Do you accept the estimate of the total population size of the species? If not, please provide justification for your response.
Obtaining robust estimates of the status and trend of the Maugean skate population numbers are essential to inform conservation and management efforts and there has been substantial effort invested in improving species knowledge. Several issues regarding the assumptions and parameters used in the PVA have been identified (listed above in response to Consultation Question 1) and therefore the estimate of total population size of the species, as provided in the Conservation Advice must be viewed with a high level of caution. The projected extinction probability and the minimum estimated population size of 40 mature animals derived in the Grant *et al.* (2023) PVA are not supported by current data (Moreno *et al.,* 2024).
7 - If not, can you provide a further estimate of the current population size of mature adults of the species (national extent)? Please provide supporting justification or other information. If, because of uncertainty, you are unable to provide a single number, you may wish to provide an estimated range (if so, see targeted questions on the front end of the public consultation draft document for ranges and confidence levels)
As outlined above, a robust review and update of the PVA to incorporate the most contemporary information and science has been identified as a priority action and is being initiated by NRE Tas. This will result in updated estimates of the skate population size and trajectory.
8 - Does the current and predicted rate of decline used in the assessment seem reasonable? Do you consider that the way this estimate has been derived is appropriate? If not, please provide justification of your response.
The way the estimate of decline was derived is not considered appropriate. Several issues regarding the validity of assumptions and parameters used in the PVA have been identified (listed above in response to Consultation Questions 1 and 2) and therefore the current and predicted rate of decline should be viewed with caution. Furthermore, the most recent monitoring results show that catch per unit of effort (CPUE) is variable, from 0.17 skate (N/m/hr) in 2014, to a low of 0.09 N/m/hr and 0.04 N/m/hr in 2021 and 2022 respectively and increasing to 0.11 N/m/hr and 0.13 N/m/hr in 2023 and 2024 respectively, noting sampling is incomplete for 2024. The previously reported decline of 47% between 2014 and 2021 (Moreno et al. 2023) can be adjusted to 35% and 23% when the baseline year (2014) is compared to 2023 and 2024 respectively (Moreno *et al.,* 2024).

11 - *Please provide (if known) any additional evidence which shows the population is stable, increasing or declining.*
The CPUE results from recent population monitoring surveys suggest that there may not be ongoing population decline as was input into the PVA model; the population decline observed to 2021 appears to have now stabilised, with a more stable, leveling trend between 2021 and September 2024 (Moreno *et al*., 2024) (refer to Consultation Questions 2 and 8). The updated relative abundance data reported in Moreno *et al* 2024 shows the population does not appear to have declined further and there are positive signs of at least one year-class of recruits coming into the population since 2021. The authors note that it is too soon to determine what this leveling of the population trend and recruitment event mean for the future population trajectory. They also note that while the skate population in Macquarie Harbour has not significantly increased since 2021, recovery of the adult biomass is not expected in the time frame of the most recent monitoring, as it takes six years for hatchlings to become mature adults.
13 - *Do you have any information on the existence and/or size of the subpopulation in Bathurst Harbour?*
Preliminary results from recent genetic analyses of DNA from Maugean skate specimens collected from Bathurst Harbour show the presence of potential variant sequences that are absent in Macquarie Harbour specimens (Moreno *et al*., *In review*). This may indicate that the two populations have been genetically isolated and for unknown reasons, the Maugean skate appears not to have persisted in Bathurst Harbour. We suggest amending the text on page 11 to reflect this.
18 - *Do you consider that all major threats have been identified and described adequately?*
1. Arguably, the principal threat to Maugean skate is “habitat degradation – primarily sustained reduction of dissolved oxygen” as named up in the Conservation Advice. This threat is broadly understood to comprise the interaction of multiple processes, including salmonid aquaculture, climate change and other environmental factors. Noting that the most compelling evidence direct linking between a threatening process and a species impact comes from Moreno *et al* 2020 which explicitly relates inferred mortality events to the combined impact of salmonid aquaculture and environmental extremes. However, Table 2 (pg 24 – 28) considers the processes as separate threats, which may not be the most appropriate treatment. Notwithstanding the above comments, the PVA and the draft Conservation Advice focus heavily on past, rather than current environmental conditions in Macquarie Harbour. Recent environmental monitoring data shows that the “reduction in water quality due to salmonid aquaculture” is diminishing over time and is reasonably expected to continue to do so. Further, the most recent skate survey data indicate that the declines in population abundance have not been sustained and do not meet the threshold for “catastrophic” consequence. Given the threshold is not currently met, it seems unrealistic to assign “Catastrophic” as a future consequence because the environmental impact of salmonid aquaculture appears to have peaked and is diminishing due to adaptive management. “The trend and timing (under status) should be reviewed as the current information indicates assigning this as a “future” and “static” process is not justified. In contrast to impacts attributed to salmonid aquaculture, the impact of climate change is predicted to worsen (declining trend) over time. The designation of risk for this process should be reviewed (see below). 2. Extreme environmental events, such as overturning events, have been temporally correlated with elevated mortality rates of Maugean skates (Moreno *et al.* 2020) but are not adequately considered in the discussion of threats. We consider these events to be one of the most concerning threats to the species and recommend that they receive more thorough consideration, including a detailed description and appropriately high listing in *Table 2 – ‘Threats in approximate order of highest to lowest impact, based on available evidence’*. Noting that the PVA model assumes a catastrophic event every 5 years.

Hydrodynamic modelling work undertaken by CSIRO (a validated salinity model and in-development oxygen process model due in December 2024) will progress understanding of the environmental dynamics of the harbour and may feed into development of medium-term conservation actions outlined in the 'Climate change, extreme events and environmental changes' section on pg. 44 of the current draft. 3. Macquarie Harbour appears to be experiencing rapid warming as a result of climate change. Given that climate change is listed second in the draft's *Table 2 – 'Threats in approximate order of highest to lowest impact, based on available evidence'* – we query why is it referred to as a "secondary threat" on pg. 2 and suggest that its threat rating should be elevated in this summary section. 4. As noted in Question 2, a total prohibition on recreational gillnetting in Macquarie Harbour will be implemented on 1 November 2024, leaving only two commercial gillnet licences operating in the Harbour. The commercial operations are able to be regulated far more tightly than recreational fishers and therefore the threats table (pg 28 and 29) should be updated to reflect the extent to which this potential impact has been mitigated, including reviewing the assigned likelihood (suggest 'unlikely' rather than 'likely') and consequence (suggest 'minor' rather than 'major') – which would see this categorised as a 'low risk'.
19 - To what degree are the identified threats likely to impact on the species in the future?
A number of threats treated as ongoing have already been reduced and mitigated to various extents. See responses to Consultation Questions 1, 2, and 18 regarding temporal nature of threats and ongoing environmental improvements. Acknowledging that the threats relating to dissolved oxygen depletion in Macquarie Harbour are still a primary concern requiring adequate attention and resourcing, we suggest that they are reframed and discussed in-light-of the recent information indicating that the threat of salmonid biomass and oxygen drawdown has been significantly reduced, can be further reduced and, is less likely to impact the species in the future at the current trajectory. This is especially pertinent given the EPA has placed caps on total permissible dissolved nitrogen output (TPDNO) in the harbour, effectively limiting production in the harbour and reducing one factor that influences dissolved oxygen concentrations in the harbour.
20 - Can you provide additional or alternative information on past, current or potential threats that may adversely affect the species at any stage of its life cycle?
Research into low egg viability observed in Macquarie Harbour and impacts of heavy metal pollution, potential changes to prey availability and/or predation dynamics have been identified as key knowledge gaps for this species.
21 - Can you provide supporting data/justification or other information for your responses to these questions about threats?
See responses to Consultation Questions 1, 2, and 18.
22 - Can you recommend any additional or alternative specific threat abatement or conservation actions that would aid the protection and recovery of the species?
In addition to progressing priority conservation actions identified in the NRE Tas Conservation Action Plan for the Maugean Skate (CAP), and filling knowledge gaps identified above, research and development into potential options to increase the viability of eggs *in situ* is a potential under-explored conservation action(s).

24 - Would you recommend translocation (outside of the species' historic range) as a viable option for a conservation action for this species?
Translocation of captive-bred skate into Macquarie Harbour is a recommended conservation action in the CAP, the Roadmap of Agreed Actions and DCCEEW's published 2023 Conservation Advice. All three conservation documents propose translocation of skate to other areas if the habitat is found to be suitable (with Bathurst Harbour, New River Lagoon and Pieman River raised as possible alternative sites); significant work is required to assess suitability of these (and potentially other) alternative sites for translocation of Maugean skate. More information on the ecology of Maugean skate is required prior to translocation, particularly outside of the species' historic range. Detailed analysis of potential impacts from the release of Maugean skate to alternative release sites also needs to be undertaken.
31 - Do you have comments on any other matters relevant to the assessment of this species?
NRE Tas recommends further development of this draft Conservation Advice / Listing Assessment, to account for new information and issues outlined in this table, including consideration of Listing Assessment criteria relying on the current PVA.

Table 2. General comments on the Conservation Advice

Noting TSSC's consideration of previous comments (provided by DCCEEW on 15 Aug 2024), the below table highlights (1) **new information** available to support further drafting of the Conservation Advice and (2) **several specific changes to text** requested by NRE Tas.

Current draft text	Comment or recommended changes
Pg. 17 – The EPA (2024) outlined that there appears to be a total of 6,975 ha of potential habitat for the species within its preferred habitat of shallow channels (Bell et al. 2016). Within this area, there is a total of 3,455 ha currently verified as habitat for the species.	Incorrect reference. This text was added based on NRE Tas range state consultation comments citing information in the NRE Tas submission to the reconsideration decision (Marine Farming Expansion, Macquarie Harbour, Tasmania – EPBC 2012/6406) – in turn citing Australian Government's current Conservation Advice for the Maugean Skate.
Pg. 37 -38 Risk Assessment	The current risk assessment within the document does not conform to current contemporary standards for a risk assessment. It confuses threats with activities and does not apply a residual impact in the consequence rating. As outlined within current water quality data for Macquarie Harbour water quality has significantly improved to historical levels across the two thirds of the harbour concurrent with salmon farming. As such, the consequence of salmon farming causing water quality impacts to the Skate can no longer be considered to be 'catastrophic' and the Tasmanian Government considers that when the existing management and regulatory controls of the adaptive management framework are recognised the residual risk rating should be considered as unlikely. NRE Tas recommends that the outcomes of the reviewed PVA process should inform a revised risk assessment process for the species.

Current draft text	Comment or recommended changes
Pg. 39 – "*Eliminate or significantly reduce the impacts of salmonid aquaculture on dissolved oxygen concentrations. The fastest and simplest way to achieve this is by significantly reducing fish biomass and feeding rates*."	This statement is no longer appropriate given current water quality data for the harbour and population data for the Maugean skate indicate that the existing actions being taken to manage salmon in the harbour have led to a recovery of dissolved oxygen levels across the harbour and are back within historical ranges
Pgs – 39 – 44 Conservation and Recovery Actions	NRE Tas recommends that this entire section is reviewed in light of new scientific evidence presented with this submission.
Pg. 20 – "*However, while salmonid biomass was reduced, the amount of fish feed was increased in 2019, 2020 and 2021. In 2022, the EPA introduced 'Total Permissible Dissolved Nitrogen Output' (TPDNO) as a new measure with the aim of capping biomass by limiting fish feed inputs, measured as the amount of nitrogen which can be released to the environment via feed (EPA 2022a).*"	Note EPA Introduced Biomass and TPDNO caps and production in the harbour is about 50% lower than it was during the period when DO levels were at their lowest. Amend as follows: *However, while salmonid biomass was reduced, the amount of fish feed was increased in 2019, 2020 and 2021. In 2022, the EPA introduced 'Total Permissible Dissolved Nitrogen Output' (TPDNO) as a new measure with the aim of limiting fish feed inputs, measured as the amount of nitrogen which can be released to the environment via feed (EPA 2022a).*
Pg. 24 – "*While the biomass limits were adhered to, feed input was increased during this time, possibly impacting the remediation benefit of reduced biomass (EPA 2022a)*."	Amend as follows: *While the biomass limits were adhered to, feed input was increased marginally during this time, possibly impacting the remediation benefit of reduced biomass (EPA 2022a).*
Pg. 32 – "*In isolation, the impact and consequence of altered hydrological flows associated with hydroelectric damming on the Maugean skate is moderate…*"	The oxygen process modelling in train will specifically inform the impact and consequence of altered hydrological flows.

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Interim Report Number 2 - Macquarie Harbour Maugean skate population status and monitoring

David Moreno, Sean Tracey & Jayson M. Semmens

20/09/2024

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Executive summary

The Maugean skate (*Zearaja maugeana*) is an endangered species, now restricted to Macquarie Harbour on the west coast of Tasmania, Australia. Recent research has detected a potential decline in the skate population, raising concerns for the conservation status of the species. In response, a gillnet survey program to monitor the population status of the species was developed. The first interim report from this program was released in May 2023 and reported data up until the end of 2021. Results presented here cover all sampling events conducted to date, including the first full three-years (2021-2023) of the dedicated monitoring program, along with initial results from the program in 2024. A reanalysis of research gillnet data collected between 2012 and 2019 is also presented.

Size composition data collected across a range of projects on Maugean skate between 2012 and 2021 indicated that the median size of females had significantly increased, and the proportion of juveniles and sub-adults captured had significantly decreased with an absence of recruitment detected for a period of approximately eight years through the 2010s and into 2020. Using catch per unit effort (CPUE) as a measure of relative abundance, a significant decline of 47% in CPUE was identified between 2014 and 2021.

The updated relative abundance data reported here shows the population does not appear to have declined further and there are positive signs of at least one year-class of recruits coming into the population since 2021, although it is too early to determine what this leveling of the population trend and recruitment event mean for the future population trajectory. It is important to note that the Maugean skate population in Macquarie Harbour has not significantly increased since 2021. However, significant recovery of the adult biomass is not expected in the time frame of the most recent monitoring, as it takes six years for hatchlings to become mature adults.

This interim report highlights the crucial importance of further monitoring to understand population trends. Considering new data, it is also critical to update population models that are being considered regarding conservation action plans for the species.

Introduction

The endangered micro-endemic Maugean skate (*Zearaja maugeana*) is only known from two isolated estuarine systems located on the west coast of Tasmania, Australia, Bathurst and Macquarie Harbours, representing one of most restricted distributions of any elasmobranch (Last and Gledhill, 2007). A recent environmental DNA study (Moreno et al., 2022) has demonstrated that the vast majority, if not all, of the remaining Maugean skate live only in Macquarie Harbour. Monitoring the population of Maugean Skate in Macquarie Harbour is critical to ensure the most contemporary information is available to determine population viability and apply appropriate conservation action as required.

Netting surveys in Macquarie Harbour to accommodate a range of project objectives first commenced in 2012, additional surveys were funded by the Sustainable Marine Research Collaboration Agreement (SMRCA) from 2021 to 2023 and the Department of Natural Resources and Environment Tasmania from 2024 to September 2025. The first interim report in this series reported on data from the 2021 survey and a reanalysis of the survey data set from 2012 to 2019 (Moreno and Semmens, 2023). Findings identified that the median size of females had significantly increased between 2014 and 2021, while there was no significant change in the median size of males. The proportion of juvenile and sub-adults relative to adults caught declined significantly from ~17-21% in the 2012 and 2013-2014 surveys to the lowest proportions recorded in 2021 at 2.2%.

In 2014, catch per unit of effort (CPUE) was 0.17 skate caught per metre of net per hour (N/m/hr) for all sites combined. In 2021, CPUE was 0.09 N/m/hr. This represented a 47% decline in estimated relative abundance across the harbour.

Here we report an update on the current data set, including the reanalysis of the data set from 2012 to 2019, the 2021-2023 net surveys, and the data collected to date from the 2024 surveys (Aug and Sept 2024).

Objectives

The objectives addressed in this report are:

Assess the size composition of Maugean skate catches as an indicator of population change, in particular recruitment variability.

Compare catch per unit effort (CPUE) changes through time to describe changes in relative abundance.

Methods

Sampling methodology and historical data

Gillnet surveys were conducted at roughly three-month intervals between February 2021 and December 2023 to coincide with the austral seasons, noting that previous analysis demonstrated that CPUE was not related to season (Bell et al., 2016). In 2024, sampling was conducted in August (five days) and September (four days). Sampling was not conducted earlier in 2024 due to a prioritisation for the research team to secure an ex-situ population of Maugean Skate at the IMAS Taroona facility in the first half of the year, and then adverse weather through winter was unsuitable for sampling. We have included 2024 data collected so far as a point comparison, but it is subject to change as two further trips are still planed. Therefore 2024 data should be seed as preliminary and we urge caution when interpreting trends.

Since 2021, surveys have been conducted in three areas within the Harbour based on previous knowledge of skate movement and distribution as determined by acoustic telemetry, and areas of higher skate abundance identified through earlier systematic random sampling across the Harbour (Bell & Lyle, 2016; Bell et al., 2016; Moreno et al., 2020, Treloar et al., 2016). Importantly, these three areas were comparable with the survey design in 2014 in terms of geographic location and fishing intensity, allowing 2014 to be considered a baseline for the post-2020 dedicated population monitoring program. These sites were (A) the Table Head / Liberty Point area, (B) the World Heritage Area, and (C) the Swan Basin area, which includes Pine Cove and Long Bay and Swan Basin (Figure 1).

Maugean skate were captured using standard monofilament graball nets (50 m long by 33 mesh drops with a 114 mm stretched mesh size). From 2021 nets were set during daytime and soak times were restricted to under 2 hrs. All Maugean skate captured from 2021 onwards were measured (total length (TL)), sexed, tagged, tissue samples collected, sexual maturity determined for females using ultrasonography, body condition assessed using a biometric impedance analysis (BIA) unit, 0.5 -1.0 ml of blood extracted via a caudal venipuncture, and a photograph taken before being released. Skate were submerged in a recirculating processing tub throughout the procedure (except for length measurement), with the dissolved oxygen levels kept at 100% through supplementary oxygen. The processing of each individual was completed in less than 10 minutes.

All animal handling and processing procedures were conducted under University of Tasmania Animal Ethics approvals (A23857 & A30685). The research was conducted under NRET Permits to Take Threatened Fauna for Scientific Purposes: TFA20167; TFA22271; TFA23014; TFA24130 and TFA23035 and NRET Living Marine Resources Management Act Scientific Research Permits: 20075; 21080; 22018; 22091; 24056 and 23087.

The sampling gear (gillnets) and broad methodology used throughout the current and previous studies has not changed. The Table Head / Liberty point area is the only site that has been consistently sampled throughout. However, the distribution, intensity and timing of sampling varied due to different project objectives (i.e., replicating netting behaviour of recreational gillnetting, acoustic tagging and collection of animals for experimental physiology), with these projects occurring in 2011, 2013, 2015, 2016, 2017 and 2019. Catches from these years are shown in Table 1, but are excluded from subsequent analyses due to potential sampling bias.

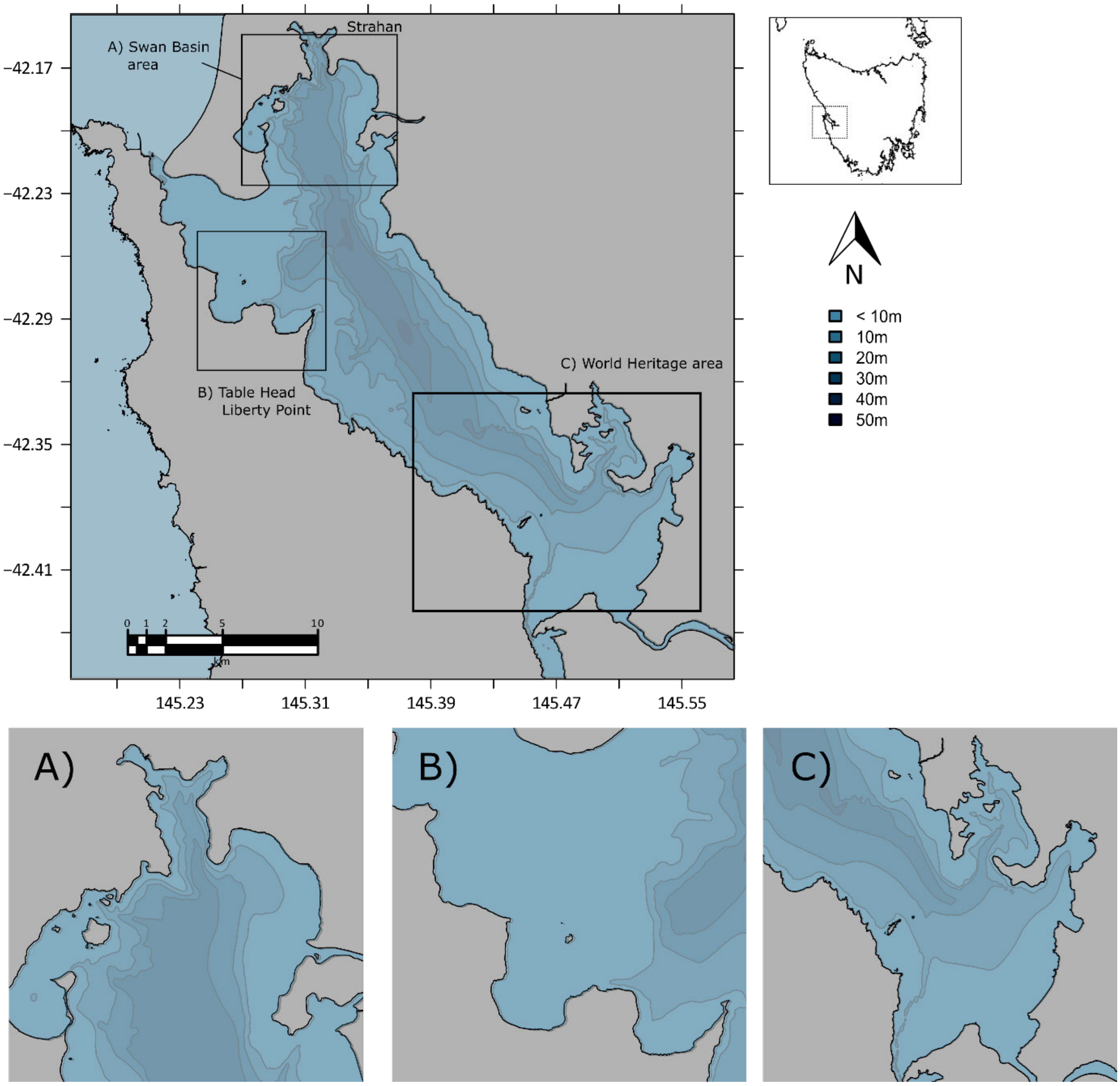

Figure 1. The primary sampling areas for Maugean skate population monitoring with inserts showing the complex bathymetry of (A) Swan Basin, (B) Table Head, and (C) and the World heritage Area.

Data analysis

Maugean skate in Macquarie Harbour constitute a single population (Weltz et al., 2018; Moreno et al., *In review*). There are no site-specific differences in sex or size frequency distribution (Bell et al., 2016). In contrast, there are clear differences in site specific abundance patterns, with the Table Head / Liberty point area containing a significantly higher proportion of skate than any other site in Macquarie Harbour (Bell et al., 2016). Therefore, to account for potential site-specific biases introduced by changes in the fishing effort across the different studies, analysis of size frequency data was conducted for both total catch across the three reference sites (2014, 2021-2024 data only), and the Table Head/ Liberty Point area only (all years, noting exceptions outlined in previous section). Sex specific size dimorphism is a feature of Maugean Skate (Bell et al., 2016), as such, size frequency composition (total length; TL) was reported by sex.

A Kruskal Wallace (KW) test was used to test for Rank (~median) differences in size by year. A post hoc planned comparison of rank differences (~median) using a Dunn test with a Bonferroni correction was used to test for significant differences for each sampling year from 2021 against the baseline year

(2014). A post hoc planned comparison of mean size differences using a Wilcox test with a Bonferroni correction was used to test for significant differences for each sampling year from 2021 against the baseline year (2014). Significant differences in size frequency distribution for each sampling year from 2021 against the baseline year (2014) were tested using a bootstrapped Kolmogorov-Smirnov test with a Bonferroni correction.

Relative abundance

For the surveys conducted from 2017 onwards a maximum set duration of two hours was applied, with fishing limited to daytime sets only. By contrast, some longer daytime set durations, along with overnight sets were conducted in the earlier studies (Bell et al., 2016, Lyle et al., 2014). Several skate mortalities were linked to these longer set durations necessitating a more conservative approach to gear usage to reduce the likelihood of negative impacts on the skate (and other bycatch).

To explore changes in relative abundance through time, only data from 2014 and 2021-2024 were analysed. Sampling in these years was restricted to daytime only and had a similar spatial and temporal design (4 seasonal surveys targeting the same sites). An exception was 2024, where seasonal sampling did not occur, due to reasons outlined previously. It is important to note that sampling in 2024 is incomplete and results from this year may be subject to change, therefore, 2024 values are presented as a point estimate and should be considered preliminary. There were 10 longer duration deployments in 2014, where soak times were greater than 5 hrs. These deployments were excluded from CPUE calculations to account for potential effects of increases in catch from extended soak times.

CPUE was estimated as the number of Maugean skate caught per net metre per hour (N/m/hr). Yearly CPUE metrics were calculated for the entire Harbour and each of the three reference areas separately. Juvenile /sub-adult and adult specific CPUEs are also presented.

Results and Discussion

Catch, effort and size composition

There was a total of 1,851 individual gillnet deployments in Macquarie Harbour from 2012 to September 2024 (Table 1), with 886 in the Table Head / Liberty Point (THLP) area. A total of 489 individual skate were captured (female = 224, male = 250, not recorded=15), of those, 333 were captured in the THLP area (females = 148, males = 176, not recorded = 9). The smallest individual captured was 150 mm TL and the largest was 870 mm TL (Figure 2).

A total of 140 skate have been tagged with dart tags since 2021 and this is now and ongoing feature of the monitoring program. A total of two tagged skate have been recaptured over this period. Three recaptures of two animals occurred soon after release on the latest trip (September 2024) at the THLP site (at liberty <1 day).

Table 1. The amount of net sampling effort and catch of Maugean skate from 2011 to 2024. There was no sampling in 2020 due to the COVID-19 pandemic. The data from 2011, 2013, 2015, 2016, 2017 and 2019 were excluded from subsequent analysis due to the potential for the introduction of sampling bias as described in main body of text.

Year	Days fished	Net deployments	Mean soak time (hours)	Total number caught	Total caught >600mm	Total caught <600mm
2012	10	201	2.6	113	80	28
2013	7	116	2.7	46	38	8
2014	23	354	2.7	169	133	33
2015	2	71	2.5	9	6	3
2017	1	18	1.8	9	7	2
2018	5	102	2.2	46	42	3
2019	9	95	1.3	16	16	0
2021	17	263	1.9	46	44	1
2022	18	455	1.6	25	18	6
2023	14	302	1.8	58	40	10
2024	9[1]	195[1]	1.5	38	31	6

[1]Additional trips planned for 2024.

Harbour wide size composition

In the Harbour wide data (all reference sites; Figure 2), the size of females differed significantly by year ($\chi^2 = 9.26$, $p = 0.054$). Compared to the 2014 baseline, median female size was significantly different in 2021 (D = 32.8, $p = 0.012$) but not in subsequent years. Mean female size was significantly different to the baseline in 2021 ($p < 0.01$) and 2022 ($p = 0.03$) but not subsequent years. Size frequency distribution of females differed significantly from the baseline in 2021 (D = 3.4, $p < 0.01$), 2022 (D = 0.33, $p = 0.037$), but not in 2023 ($p = 0.066$) or the portion of data so far collected in 2024 ($p = 0.16$). The size of males differed significantly by year ($\chi^2 = 9.16$, $p = 0.056$). Compared to the 2014 baseline, median male size was significantly different in 2022 (D = -33.3, $p = 0.04$) but not in other years. Mean male size was significantly different to the baseline in 2022 ($p < 0.01$) but not in other years. Size frequency distribution of males differed significantly from the baseline in 2021 (D = 22, $p = 0.058$), 2022 (D = 0.26, $p = 0.02$) and 2023 (D = 0.26, $p = 0.045$), but not so for the portion of data collected to date in 2024 ($p = 0.2$).

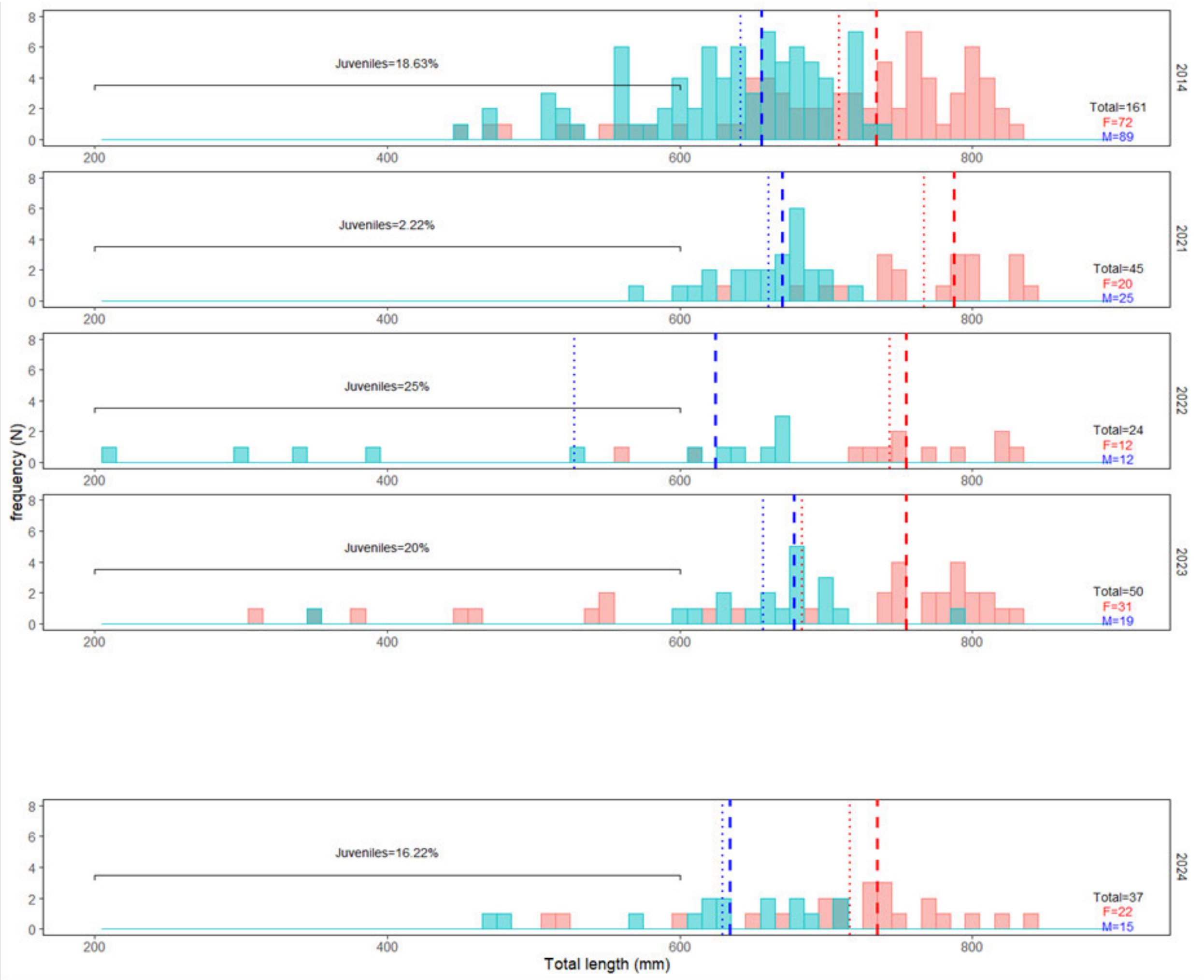

Figure 2. Size distribution of male (blue) and female (red) Maugean skate sampled from all sites during 2014 (top panel; FRDC 2013-008), 2021-2023 (second to fourth panels; SMRCA study), and 2024 (bottom panel; current NRE study). Note that this panel is separated from the other panels to highlight that 2024 sampling is currently incomplete. Vertical dashed and dotted lines indicate median and mean lengths of males (blue) and females (red), respectively. Sample sizes are indicated (Total = sexes combined, M = males, F = females). Values above the horizontal bracket indicates the proportion of individuals < 600 mm (juveniles and sub-adults) present in each sample. Note some individuals were released without length measurements.

The gillnets that have been used across all surveys are subject to a selectivity bias whereby smaller animals tend to be under-represented in the sample. Maugean skate tend to be lightly entangled in the meshes by the rostrum (and rostral spines), such that some individuals have been observed to drop out of the meshes while the net is under tension during hauling. Small individuals (< 500 mm TL) with a less pronounced snout (and very small rostral spines) are less likely to be caught or retained in the meshes. However, the same nets have been consistently used for all sampling, therefore, any size selectivity bias is expected to have been constant through time, justifying an examination of temporal trends in size composition.

The decline in recruitment, possibly due to lower hatching success or juvenile survival, coupled with the growth of existing adults (i.e., an ageing population) reported between 2014 and 2021 raised significant concern for the species due to the changes in population structure. The data indicated that there was an absence of successful recruitment for a period of approximately eight years up until 2021 based on back calculation of unvalidated size at age data founded on growth curves developed for the species (Bell et al., 2016). In 2021, the percentage of juveniles/sub-adults reported across the harbour was the lowest of all sampling years accounting for 2.2% of the total skate caught.

Sampling in 2022 identified the first evidence of juveniles since sampling in 2014. Although the total number of skate caught in this year was low, the percentage of recruits relative to adults sampled was 25%, equivalent to the percentage reported in 2012. Juvenile and sub-adults continued to appear in sampling in 2023 and 2024 at 20% and 16.2% respectively, the sample size in these years was comparable to those in 2018 and 2021, noting that there is an intention to conduct two additional sampling events in 2024.

Table Head / Liberty Point size composition

At THLP (Figure 3), the size of females did not show an overall difference by year ($\chi^2 = 6.2$, $p = 0.181$). However, compared to the 2014 baseline median female size was significantly different in 2021 (D = 21.04, $p = 0.035$) but not in subsequent years. Mean female size was significantly different to the baseline in 2021 ($p < 0.01$) but not in subsequent years. Size frequency distribution of females differed significantly from the baseline in 2021 (D = 3.5, $p = 0.026$), and 2024 (D = 0.37, $p = 0.024$), but not so for 2022 ($p = 0.238$) or 2023 ($p = 0.072$). The size of males did not show an overall difference by year ($\chi^2 = 0.743$, $p = 0.86$). Compared to the 2014 baseline median male size was not significantly different in 2021, 2023 or 2024. No males were captured at THLP in 2022. Mean male size was not significantly different to the baseline in any of the years with captures. Size frequency distribution of males did not differ significantly from the baseline in 2021 (D = 0.23, $p = 0.1$), 2023 (D = 0.29, $p = 0.1$), or for the portion of 2024 sampled to date (D = 0.3, $p = 0.12$).

Size composition data indicated that the median size of females caught at this site increased from 2012 to 2021. Since 2021 the median size has decreased to approximately the same as estimated in 2018. This shift is related to the detection of juveniles and sub-adults (≤ 600 mm), with the former absent and the latter in low numbers in the 2018 and 2021 sampling events. The median size of males at the THLP site has remained relatively stable since 2012, shifting to a lower size in 2022 and 2024 due to the relative number of juvenile and sub-adult skate sampled in these years.

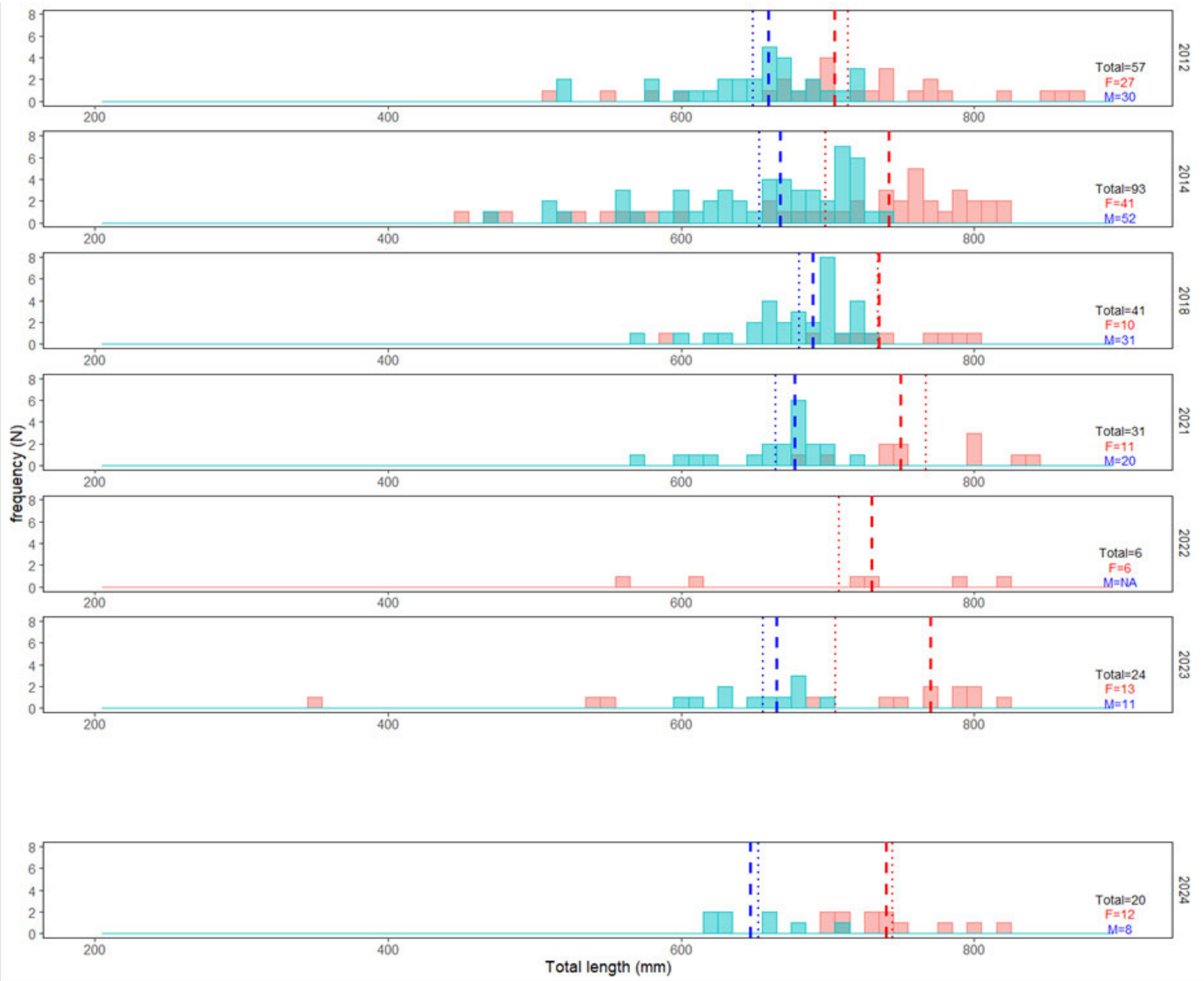

Figure 3. Size distribution of male (blue) and female (red) Maugean skate sampled from Table Head/Liberty Point during 2012 (top panel; FRDC 2010-016), 2013-14 (second panel; FRDC 2013-008), 2017-18 (third panel; FRDC 2016-068), 2021-2023 (fourth to sixth panels; SMRCA study), and 2024 (bottom panel; current NRE study). Note that this panel is separated from the other panels to highlight that 2024 sampling is currently incomplete. Vertical dashed and dotted lines indicate median and mean lengths of males (blue) and females (red), respectively. Sample sizes are indicated (Total = sexes combined, M = males, F = females).

Catch Per Unit of Effort (CPUE)

In 2014, CPUE was 0.17 N/m/hr for the three reference sites combined (Figure 4). While not directly comparable due to methodological inconsistencies, catch rates from 2017 and 2018 were relatively consistent with 2014 values (Moreno et al., 2020). In 2021, CPUE declined to 0.09 N/m/hr (Figure 4). This observed decline in relative abundance was likely the result of two high impact environmental events that occurred in 2019 that resulted in high mortality (~44%) of individuals being electronically tracked at the time (Moreno et al., 2020) combined with longer-term demographic effects resulting from changes in the size structure of the population driven by an ageing population and an absence of recruitment for a protracted period. This decline in relative abundance triggered substantial concerns for the population as it indicated a 47% decline across the Harbour.

In 2022, CPUE decreased further to 0.04 N/m/hr, however, given the lack of recruitment in previous years and the increase in CPUE in subsequent years, this may be related to a lack of skate in the three sampling regions in this year at the time of sampling. In 2023 and 2024 (noting partial sampling in the latter), CPUE increased to 0.11 N/m/hr and 0.13 N/m/hr respectively. This translates to an adjustment of the point-to-point decline against the baseline year of 2014 to 2021 of 47% presented in the previous interim report, to 35% and 23% when the baseline year is compared to 2023 and 2024 respectively.

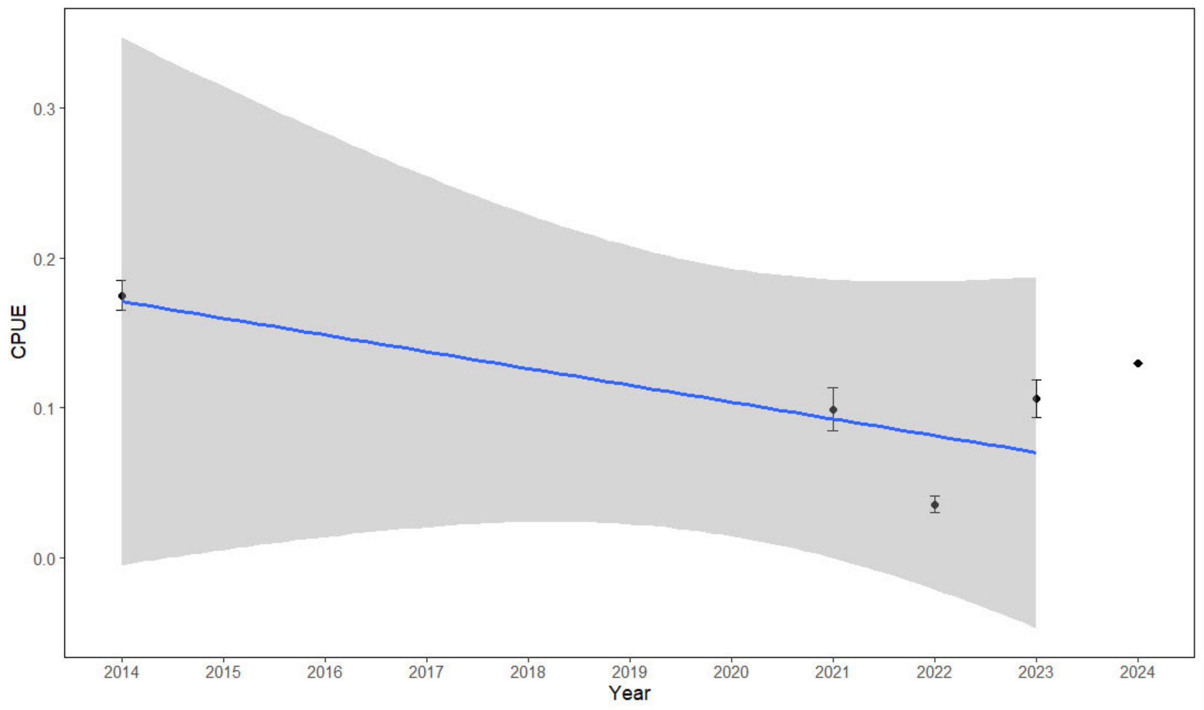

Figure 4. Catch Per Unit of Effort (CPUE) of Maugean skate caught from the three reference sites in Macquarie Harbour. The error bars represent an approximate standard error calculated based on variability in skate per net hour caught between individual deployments. The blue line is a fitted linear regression, and the grey shading indicates the variance around the regression line.

While the decline in relative abundance of adults between 2014 and 2021 was significant (Figure 5), representing a 47% reduction, the decline in relative abundance of juveniles and sub-adults was greater (87%) and the lack of recruitment was a substantial contributor to the overall decline in relative abundance presented in Figure 4.

The influence of recruitment also contributed disproportionately to the increase in relative abundance since 2021 with CPUE for skate less than 600 mm TL now being at comparable levels to the baseline year of 2014 (Figure 6). The linear regression indicates a negative slope, driven by data collected in 2021 and 2022 which were still influenced by the protracted absence of recruitment through the mid-2010s, confounded by the selectivity of the sampling method masking the presence of this cohort due to their small size leading to net avoidance in those two years.

The adult biomass declined between 2014 and 2021 (Figure 5), however, not at the same rate as juveniles and sub-adults (Figure 6). This suggests that natural age-based mortality was reducing the population at a lower rate than the absence of recruits. Except for 2022, CPUE of adults has stabilised since 2021 (Figure 5).

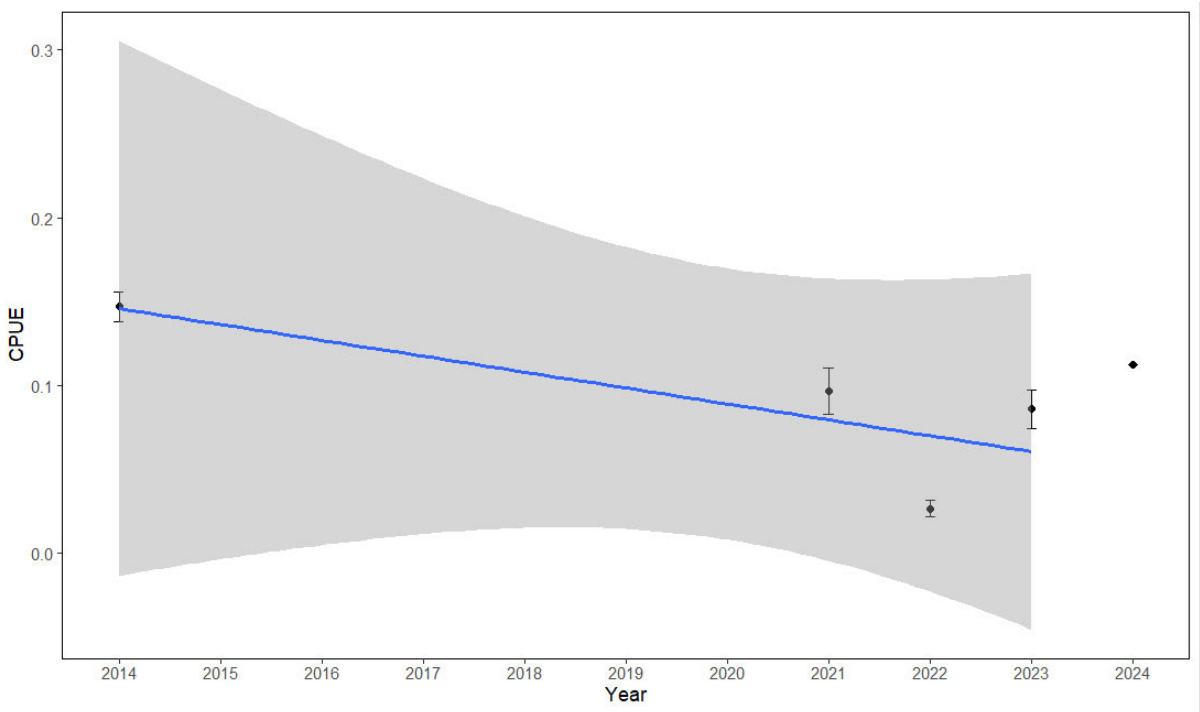

Figure 5. Catch Per Unit of Effort (CPUE) of adult (greater than 600 mm in total length) Maugean skate caught from the three reference sites in Macquarie Harbour. The error bars represent an approximate standard error calculated based on variability in skate per net hour caught between individual deployments. The blue line is a fitted linear regression, and the grey shading indicates the variance around the regression line.

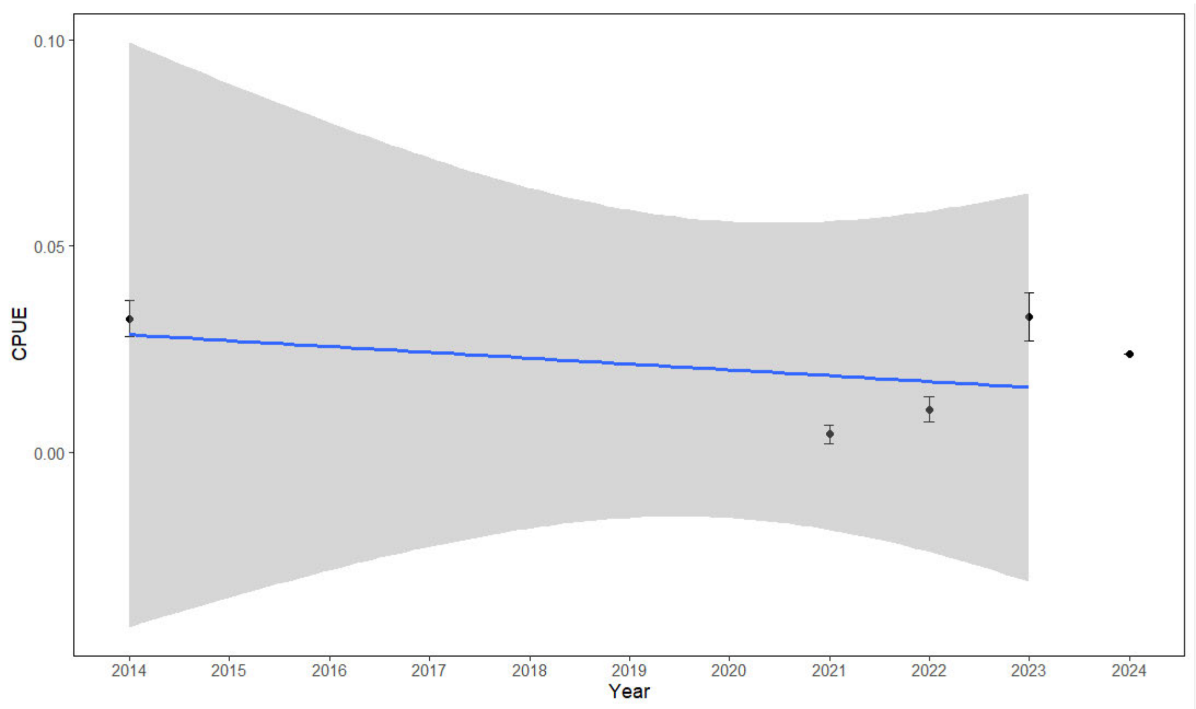

Figure 6. Catch Per Unit of Effort (CPUE) of juvenile and sub-adult (less than 600 mm in total length) Maugean skate caught from the three reference sites in Macquarie Harbour. The error bars represent an approximate standard error calculated based on variability in skate per net hour caught between individual deployments. The blue line is a fitted linear regression, and the grey shading indicates the variance around the regression line.

Site specific CPUE

Previous investigations into the distribution, movement, and habitat use of the Maugean skate show that Table Head and Liberty Point are a critical habitat for the species within the harbour. As such it is a focal sampling site with over 47% of all skate sampled from the area. The CPUE trend through time between Table Head and the whole system (based on the three reference sites) remained consistent, with the site being an important driver in the relative abundance from the Harbour due to the substantial contribution of skate catch from the area.

In 2014, CPUE was reported at 0.25 N/m/hr for the THLP area. In 2021, CPUE decreased to 0.14 N/m/hr representing a decline in relative abundance of 44% at the site. In 2022, CPUE decreased further to 0.02 N/m/hr before increasing to 0.11 N/m/hr in 2023, and to date in 2024, 0.14 N/m/hr (Figure 7B).

The decline in relative abundance was also evident in CPUE at the Swan Basin site (2014 = 0.12, 2021-2023 = 0.04, 2024[1] = 0), although the slope of the linear regression (-0.009; Figure 7A) was less than that fitted to the THLP data (-0.02; Figure 7B). In contrast to the decline reported in the previous two sites, the linear regression fitted to the data collected from the site within the World Heritage Area reported a positive slope (0.002) indicating an increase in relative abundance in this area compared to 2014, particularly in 2023 and the partial survey data from 2024 (Figure 7C).

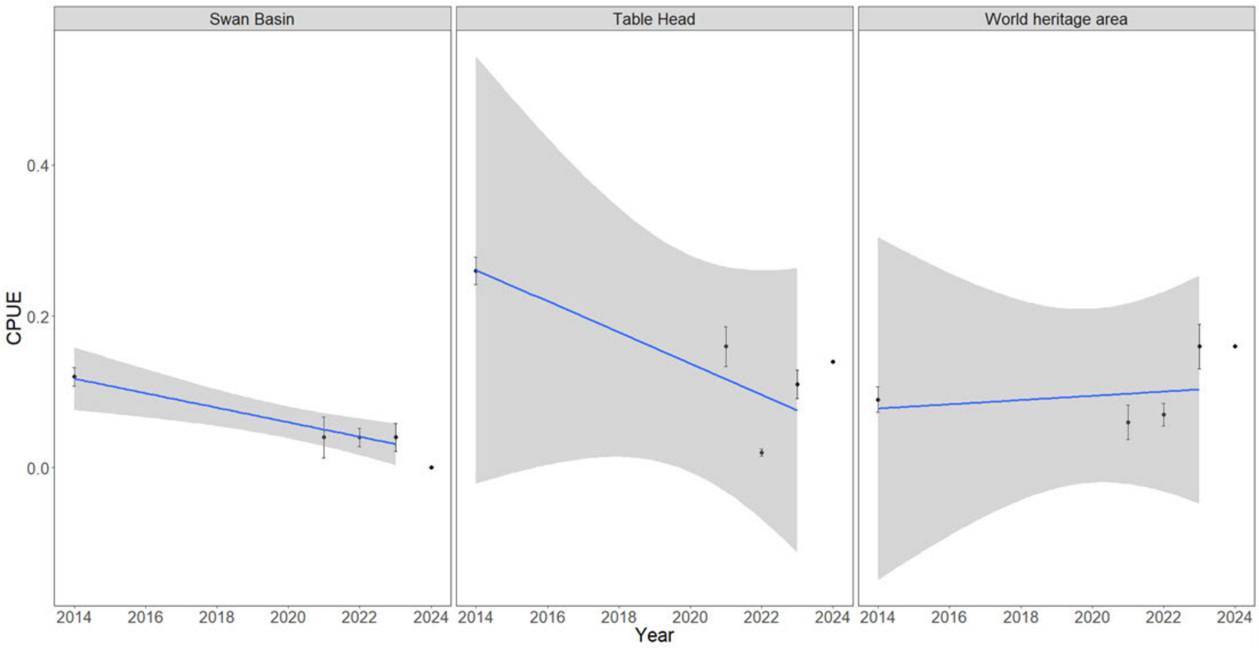

Figure 7. Catch Per Unit of Effort (CPUE) of Maugean skate caught from the three reference sites in Macquarie Harbour. The error bars represent an approximate standard error calculated based on variability in skate per net hour caught between individual deployments. The blue line is a fitted linear regression, and the grey shading indicates the variance around the regression line.

Conclusion

This updated interim report identifies the importance of continued monitoring of the Maugean Skate population. While there was evidence of significant decline in the population of the Maugean Skate between 2014 and 2021 based on CPUE and a lack of recruitment observed, recent surveys indicate a capacity for recovery and at least one recruitment event in the last 3 years. The decline in population

[1]Survey incomplete for 2024.

observed to 2021 appears to have stabilised. Although, skate are still at very low levels and potentially subject to major environmental events leading to mortality as observed in 2019.

Monitoring of the Maugean Skate population should be considered a cornerstone of any conservation actions going forward to ensure contemporary in-situ data is available to assess trends in the population, particularly as substantial work is being conducted to determine the causative links to factors that may affect the population and conservation actions are being considered. This advice is consistent with the first listed priority, '*Continued population monitoring of the Maugean skate to support evaluating effectiveness of conservation actions and to underpin conservation planning decisions',* under the 'Urgent action' category of the 'Survey and monitoring priorities' in the *Zearaja maugeana* (Maugean Skate) Conservations Advice (DCCEEW, 2024).

Gear selectivity is limiting early detection of recruitment events and alternate monitoring methods should be considered to complement netting surveys. A recently tested method using sonar-based systems to detect skate has shown great promise (Moreno et al. *In review*). The sonar-based method can identify skate to species and identify juveniles. This method could be used in a random stratified transect experimental design methodology to provide an alternate population size estimate to complement other model-based assessments. This advice is consistent with the first listed priority, '*Continued population monitoring to include the development of a robust, non-harmful, and logistically feasible sampling method to effectively assess the Maugean skate population size, structure, status and trend…including through techniques such as video sonar (ARIS)',* under the 'Medium-term actions' category of the 'Survey and monitoring priorities' in the *Zearaja maugeana* (Maugean Skate) Conservations Advice (DCCEEW, 2024).

It is recommended that any population models, including Population Viability Assessment (PVA) models are updated routinely as new data comes to light. This recommendation is consistent with the first listed priority, '*Fine tune the PVA to assess extinction risk and assist with prioritising management, conservation and research actions'* under the 'Urgent action' category of the 'Information and research priorities' in the *Zearaja maugeana* (Maugean Skate) Conservations Advice (DCCEEW, 2024).

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Macquarie Harbour

Status update for dissolved oxygen

September 2024

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Introduction

This report provides a status update of environmental monitoring results for dissolved oxygen measured across various sites within Macquarie Harbour. The results provided in this report have been collected as part of the independent EPA water quality monitoring program for Macquarie Harbour (described below), and the Broadscale Environmental Monitoring conducted by industry as part of the requirements within the Environmental Licences to farm finfish in Macquarie Harbour (described below).

Dissolved oxygen measurements collected under these separate environmental monitoring programs can be compared against water quality guideline values for aquatic ecosystems established by the EPA. These values represent aspirational targets. Water Quality Guideline Values can be set at varying scales of specificity, dependent on data availability. For further information on the EPA's process for establishing Water Quality Guideline Values refer to the EPA document, Technical Guidance for Water Quality Objectives (WQOs) Setting for Tasmania.

Water Quality Guideline Values for Aquatic Ecosystems

For Macquarie Harbour, two different sets of Water Quality Guideline Values have been established, these include Site Specific Guideline Values (SSGVs) and interim Default Guideline Values (DGVs).

Site Specific Guideline Values for Aquatic Ecosystems

Site Specific Guideline Values (SSGVs) for aquatic ecosystems provide the highest level of specificity as the information is based on historical data available for an individual monitoring site. For the purpose of this review, SSGVs for dissolved oxygen (mg/L) have been derived for the three EPA long-term monitoring sites (Denoted MH12, MH27 and MH34, see Map 1) using data collected between June 1993 and October 2009. SSGVs have been derived for 3 depths (10, 25 and 35 metres) for MH12 and MH27 and 2 depths (10 and 21 metres) for MH34. The SSGVs for each site are presented in Table 1 and are utilised within this report to compare changes in dissolved oxygen at the three EPA long-term monitoring sites.

Table 1 – Annual SSGVs for dissolved oxygen (mg/L)

Site and depth	20th Percentile	80th Percentile
MH12 – 10m	6.0	7.9
MH12 – 25m	3.7	4.9
MH12 – 35m	3.9	5.3
MH27 – 10m	5.1	8.1
MH27 – 25m	3.3	4.3
MH27 – 35m	3.5	4.8
MH34 – 10m	4.9	7.9
MH34 – 21m	3.1	4.3

Interim Default Guideline Values for aquatic ecosystems

Interim Default Guideline Values (DGVs) for aquatic ecosystems have been derived for Macquarie Harbour. The interim DGVs have been established for three segments of Macquarie Harbour (denoted NW Macquarie Harbour – Segment 121, Central Macquarie Harbour – Segment 120 and SE Macquarie Harbour – Segment 119) and have been derived from data collected between May 1993 and October 2009 across 40 sites within Macquarie Harbour. Interim DGVs for dissolved oxygen have been established for each of the three segments, with the 20th percentile representing the lower interim DGV and the 80th percentile representing the upper interim DGV. The interim DGVs for each segment are presented in Table 2 and represent annual interim DGV for depth ranges between 6-25 metres. Within this report, the interim DGVs are used to compare long term changes in dissolved oxygen measured across industry monitoring sites within the three segments of Macquarie Harbour.

Note, the interim DGVs for the less than 6 metre and greater than 25 metre depth ranges have been calculated from the same historical EPA dataset (May 1993 – October 2009) from which the Interim DGVs for the 6-25 metre depth range were calculated. Interim DGVs presented for the less than 6 metres and greater than 25 metre depths have not yet been published on the EPA website. These have been included on figures 9, 10 and 11 below to assist with interpreting the dissolved oxygen measurements.

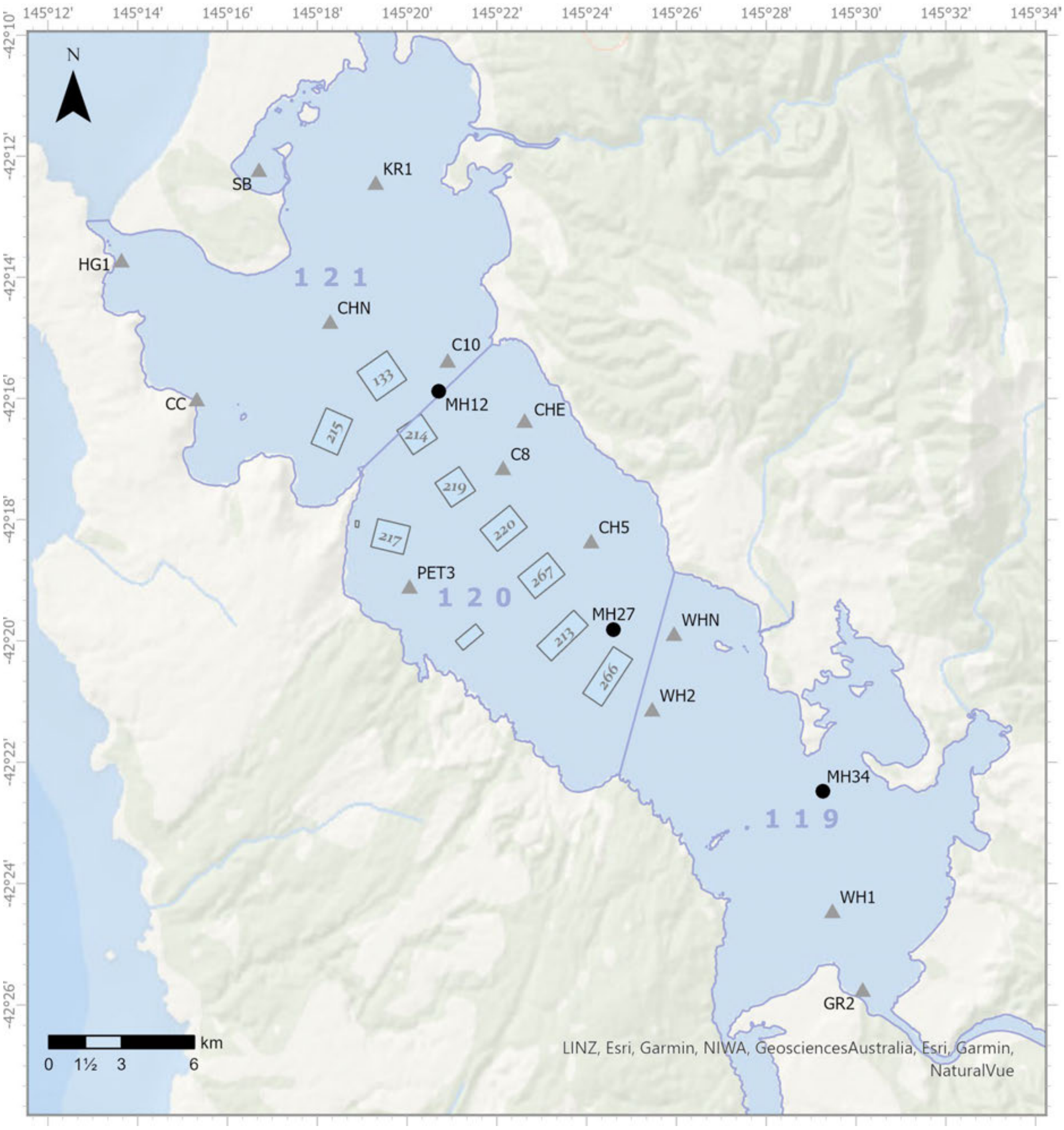
Table 2 – Annual interim DGVs for dissolved oxygen (mg/L) in Macquarie Harbour. Note Interim DGVs have not been published for less than 6 m and greater than 25m

	NW Macquarie Harbour (Segment 121)		Central Macquarie Harbour (Segment 120)		SE Macquarie Harbour (Segment 119)	
Depth (metres)	20th Percentile	80th Percentile	20th Percentile	80th Percentile	20th Percentile	80th Percentile
6 – 11	6.9	8.9	6.9	9.2	6.5	9.2
11 – 15	5.2	7.0	4.6	6.9	4.1	6.8
16 – 20	4.3	5.7	3.6	4.9	3.2	4.6
21 – 25	4.0	5.2	3.2	4.2	2.9	4.1

Independent EPA water quality monitoring program

The EPA has conducted water quality monitoring in Macquarie Harbour since 1993. Monitoring was formalised under the Mount Lyell Remediation Research and Demonstration Project (MLRRDP) established in 1995, and later expanded to include the World Heritage Monitoring Project. Monitoring under these projects was undertaken on a seasonal basis until February 2023. In September 2023, a single monitoring program was instigated for the entire Harbour.

The EPA undertakes quarterly monitoring of physico-chemical, nutrient and metal data at 15 sites throughout Macquarie Harbour. The EPA data allows for the characterisation of waters entering Macquarie Harbour from the Gordon and King Rivers and entering/exiting the Harbour to the oceanic environment. The EPA monitoring sites are in addition to the 17 sites monitored monthly by the salmon industry under the Broadscale Environmental Monitoring (BEM) requirements of the environmental licences.



Map 1 – Monitoring sites within Macquarie Harbour. Black circles represent EPA monitoring sites and grey triangles represent the 14 industry monitoring sites used in this report.

Results

MH12

Site MH12 is located within the northwestern part of the Harbour and is situated approximately 2.2 km southwest of Sophia Point (Map 1). The site is between 45 to 50 m deep.

The rolling median for dissolved oxygen at MH12 has periodically dipped below the lower SSGV of 6.0 mg/L for the 10 metre depth range. Prior to 2010 these events tended to be of short duration lasting one to three months (Figure 1). Since 2010 there has been a gradual reduction in the rolling median, with an increase in frequency and duration of periods below the SSGV range. The lowest recorded values of dissolved oxygen at 10 metres depth at MH12 (3.8 mg/L) occurred during 1995.

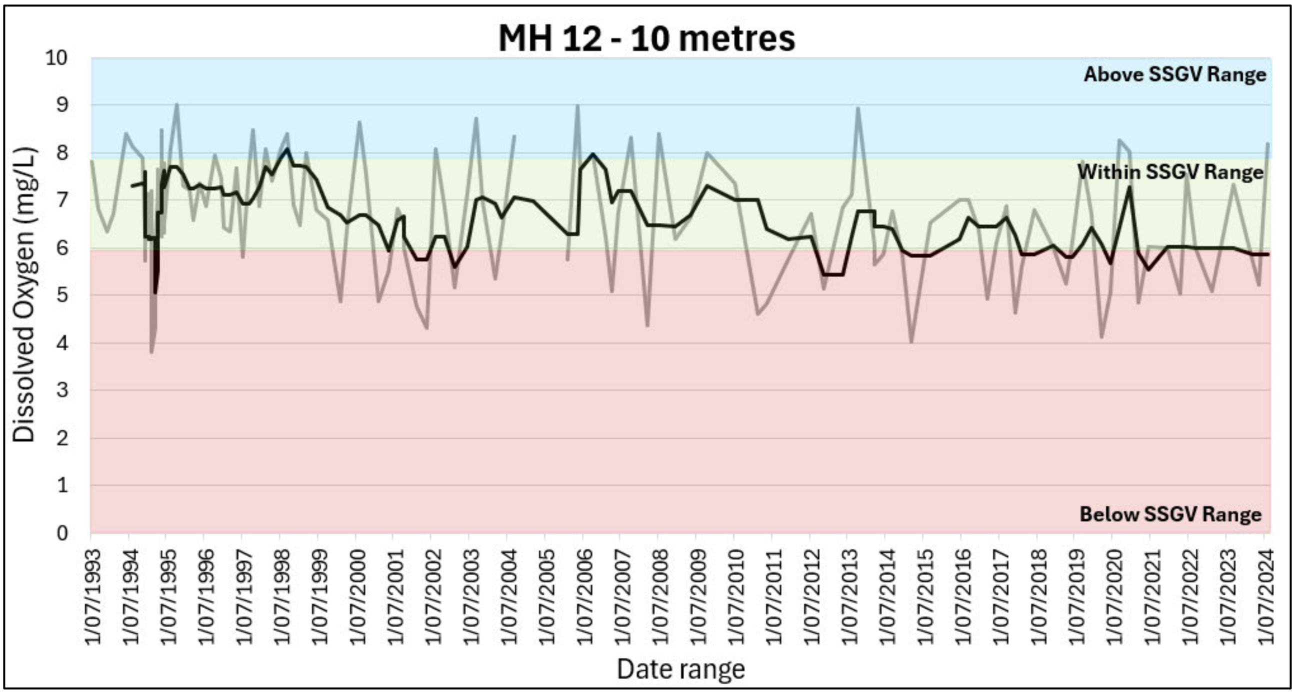


Figure 1 – Dissolved oxygen (mg/L) measurements at 10 metre water depth at EPA monitoring site MH12. The grey solid line represents the raw quarterly dissolved oxygen measurements, while the black solid line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

The rolling median for dissolved oxygen at MH12 for the 25 metre depth declined sharply in late 2010, falling to as low as 1.2 mg/L in 2014 (Figure 2). Since 2014 the rolling median has gradually increased to the current value of 3.8 mg/L. From July 2010 to April 2019 all dissolved oxygen readings were below the SSGV of 3.7 mg/L with the lowest reading being below 1.0 mg/L in December 2013. Since April 2019 dissolved oxygen readings have ranged from 1.4 to 5.2 mg/L, with readings since December 2021 being above 2.0 mg/L.

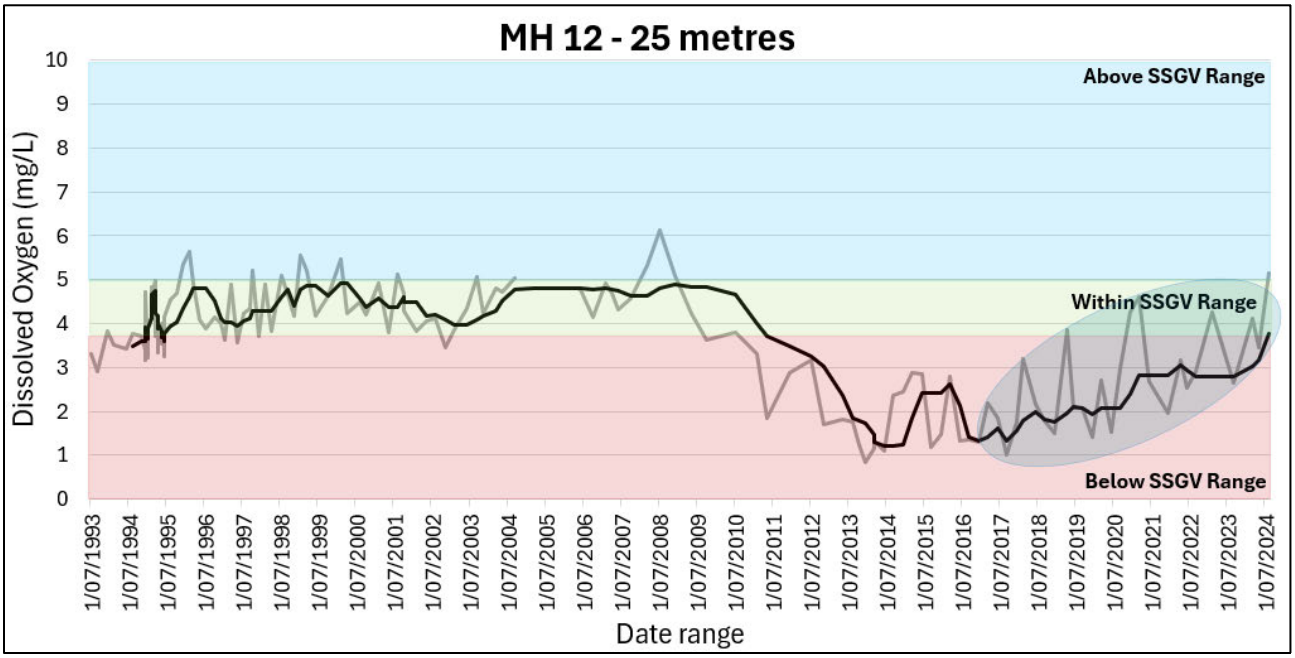


Figure 2 – Dissolved oxygen (mg/L) measurements at 25 metre water depth at EPA monitoring site MH12. The grey solid line represents the raw dissolved oxygen measurements, while the black solid line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

The rolling median for dissolved oxygen at MH12 for the 35 metre depth declined sharply in late 2010, falling to as low as 1.8 mg/L in June 2014 (Figure 3). Since June 2014 the rolling median for dissolved oxygen has gradually increased to the current value of 4.2 mg/L, which is within the SSGV range for MH12.

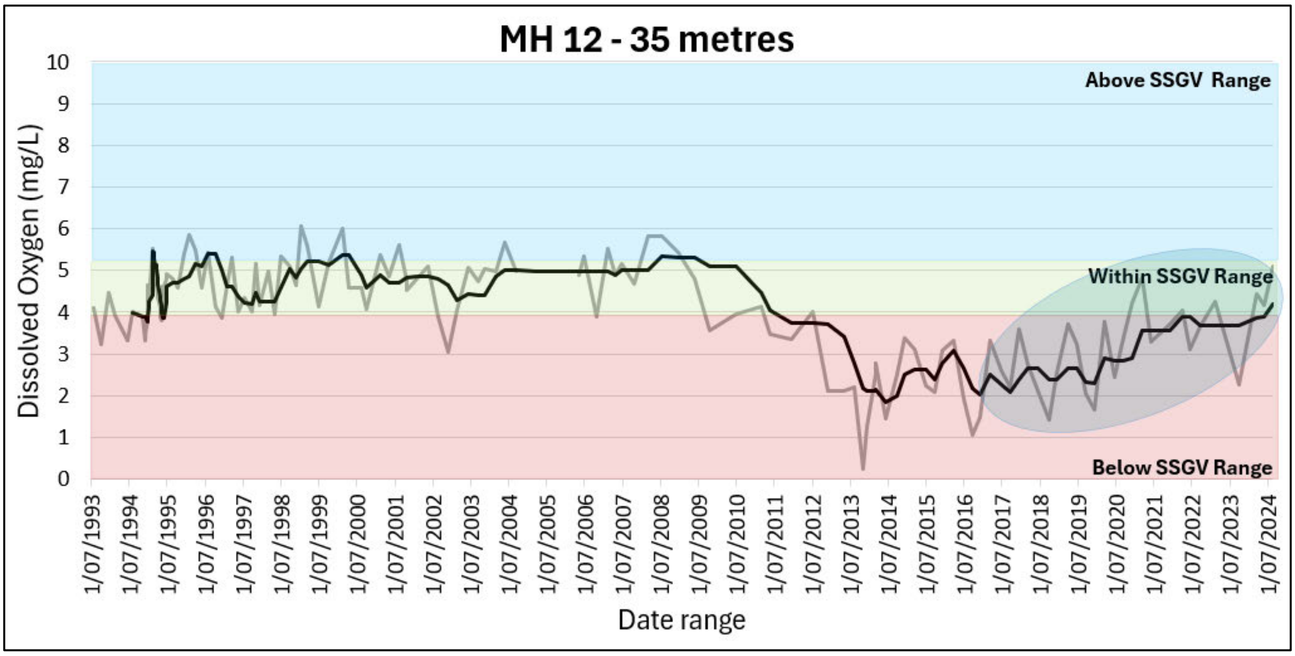


Figure 3 – Dissolved oxygen (mg/L) measurements at 35 metre water depth at EPA monitoring site MH12. The grey solid line represents the raw dissolved oxygen measurements, while the black solid line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

MH27

Site MH27 is located within the central part of the Harbour, situated approximately 2.5 km southwest of Coal Point (Map 1). The site is between 35 to 40 m deep.

The rolling median for dissolved oxygen at MH27 has periodically dipped below the lower SSGV limit of 5.1 mg/L for the 10 metre depth. Prior to 2010 these events tended to be of short duration lasting one to three months (Figure 4). Since 2010 there has been a gradual reduction in the rolling median, with an increase in frequency and duration of periods below the SSGV range. On two occasions dissolved oxygen levels have been recorded below 3.0 mg/L. The rolling median for dissolved oxygen calculated for 10 metres (5.5 mg/L) currently sits within the SSGV limits for MH27.

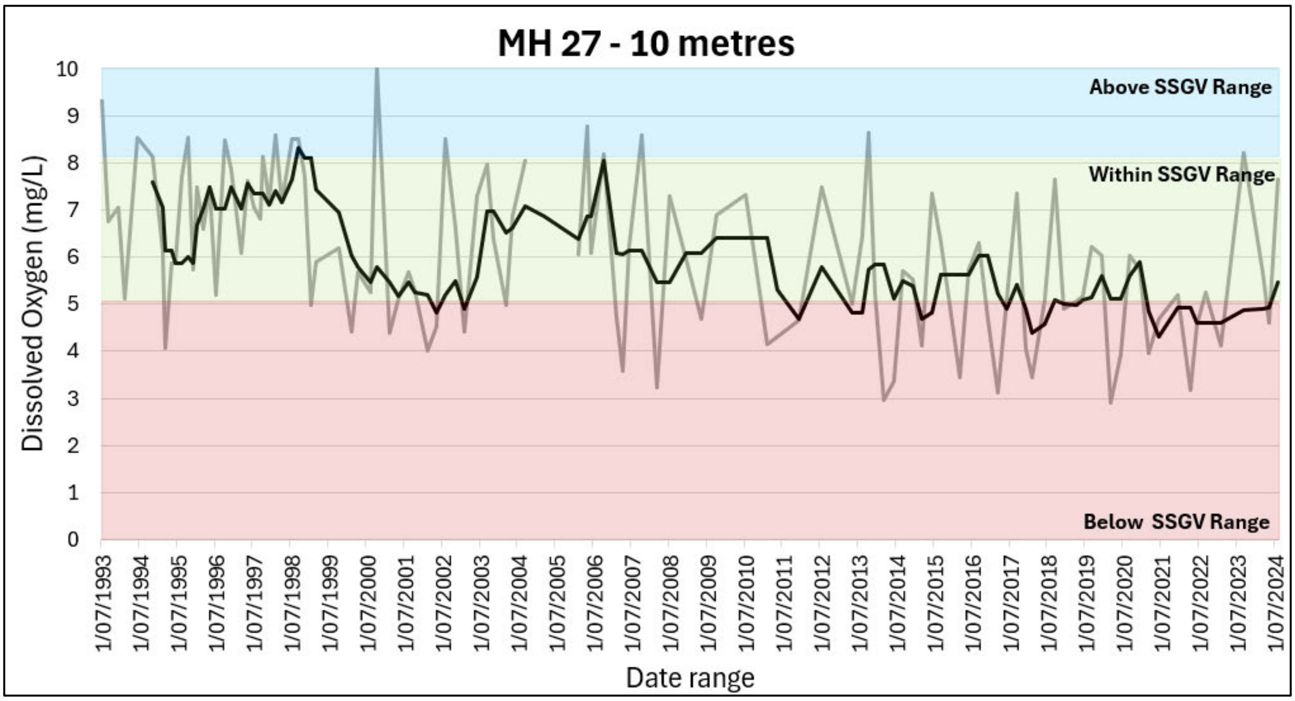


Figure 4 – Dissolved oxygen (mg/L) measurements at 10 metre water depth at EPA monitoring site MH27. The grey solid line represents the raw dissolved oxygen measurements, while the black solid line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

The rolling median for dissolved oxygen at MH27 for the 25 metre depth declined sharply from 2010, falling to as low as 0.8 mg/L in 2014 (Figure 5). From December 2014 to September 2020 all dissolved oxygen levels measured at 25 metres from MH27 ranged between 0.1 to 1.7 mg/L and the rolling median varied between 0.7 to 1.4 mg/L. Since September 2020 dissolved oxygen levels have increased from 1.1 to 4.5 mg/L resulting in the rolling median also increased from 1.1 to 2.3 mg/L.

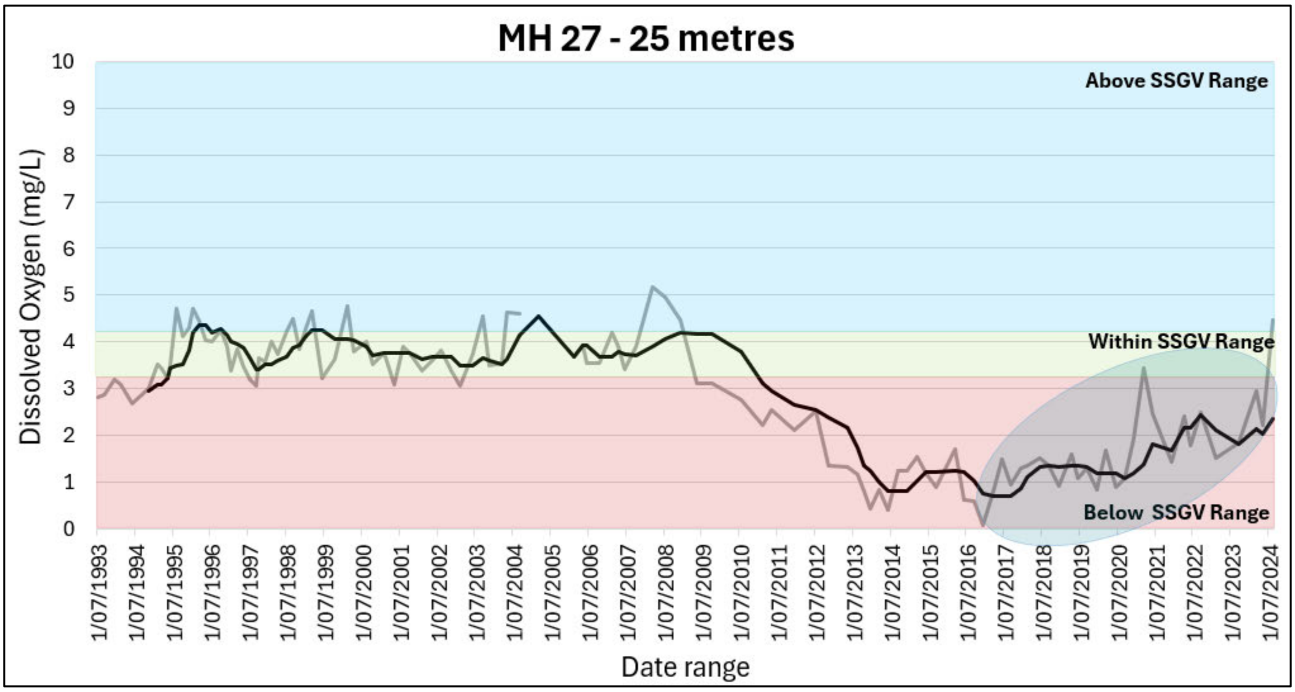


Figure 5 – Dissolved oxygen (mg/L) measurements at 25 metre water depth at EPA monitoring site MH27. The grey solid line represents the raw dissolved oxygen measurements, while the black solid line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

The rolling median for dissolved oxygen at MH27 for the 35 metre depth declined sharply in mid 2012, falling to as low as 1.0 mg/L in September 2014 (Figure 6). Since 2014 the rolling median has gradually increased to the current value of 3.1 mg/L. On numerous occasions between July 2013 and July 2018 dissolved oxygen levels were observed below 1.0 mg/L with the lowest value being 0.0 mg/L in September 2016. Since September 2018 all readings have been above 1.0 mg/L.

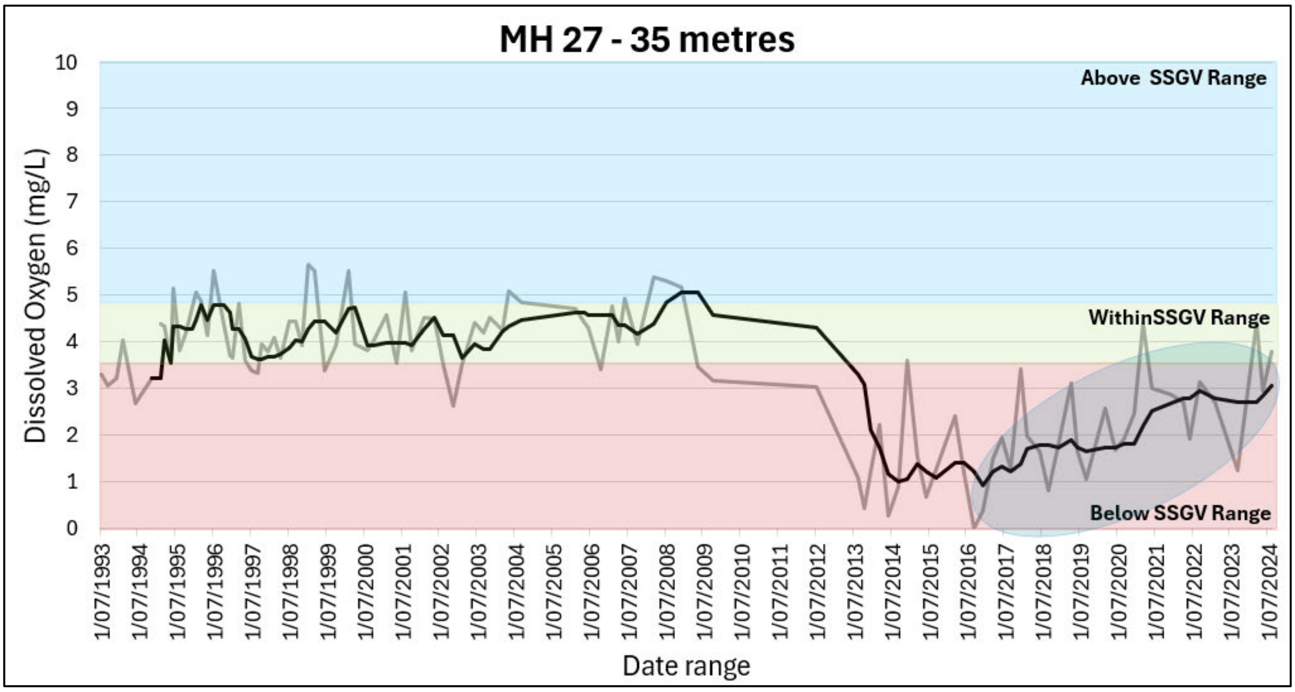


Figure 6 – Dissolved oxygen (mg/L) measurements at 35 metre water depth at EPA monitoring site MH27. The grey solid line represents the raw dissolved oxygen measurements, while the black solid line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

MH34

Site MH34 is located within the southeastern part of the Harbour and is situated approximately 1.2 km south of Gould Point within the World Heritage Area (WHA) (Map 1). The site is between 20 to 25 m deep.

The rolling median for dissolved oxygen at MH34 has periodically dipped below the lower SSGV of 4.9 mg/L for the 10 metre depth. Prior to 2010 these events tended to be infrequent (Figure 7). Since 2015 the rolling median has frequently been calculated to be below the lower SSGV.

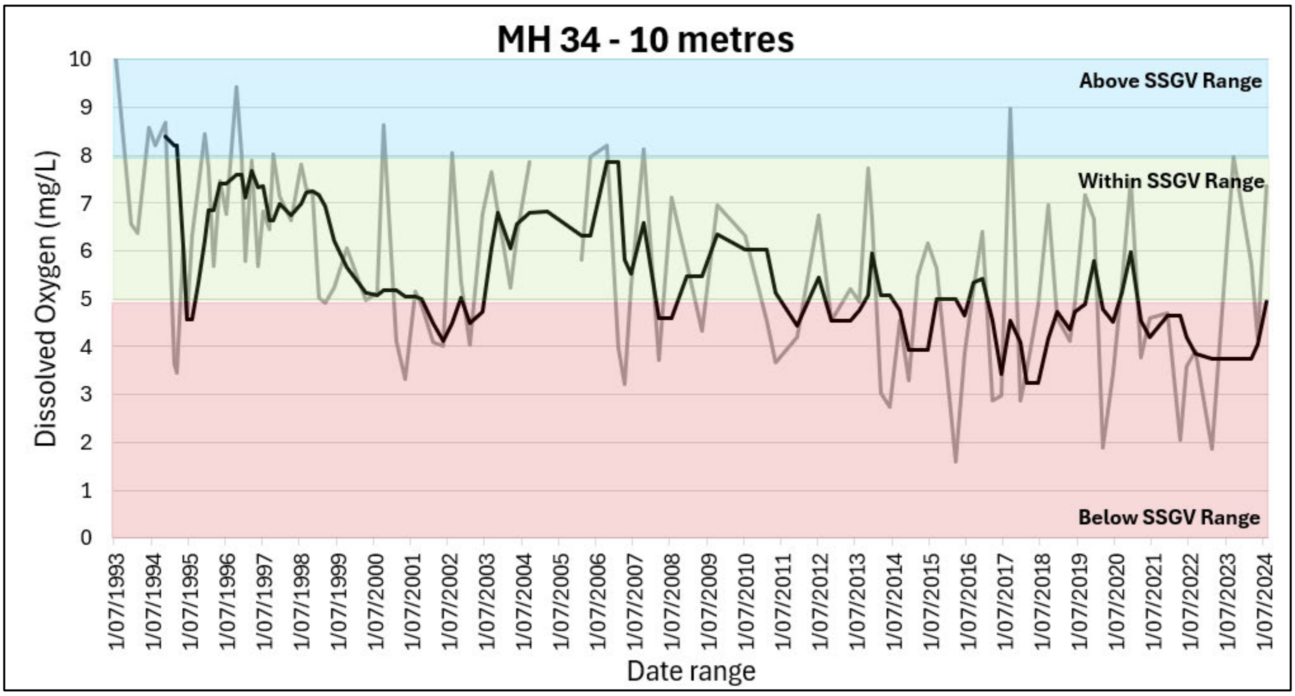


Figure 7– Dissolved oxygen (mg/L) measurements at 10 metre water depth at EPA monitoring site MH34. The grey solid line represents the raw dissolved oxygen measurements, while the black line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

The rolling median for dissolved oxygen at MH34 for the 21 metre depth started to decline sharply in July 2010, falling to as low as 1.0 mg/L in December 2014 (Figure 8) and continued to decline to 0.7 mg/L in 2017. The rolling median has shown a gradual increase since September 2017 with the current value being 1.8 mg/L. This is considerably lower than the lower SSGV range of 3.1 mg/L. Since June 2020 dissolved oxygen levels have not been observed below 1.0 mg/L, with a sharp increase of 4.6 mg/L measured in August 2024.

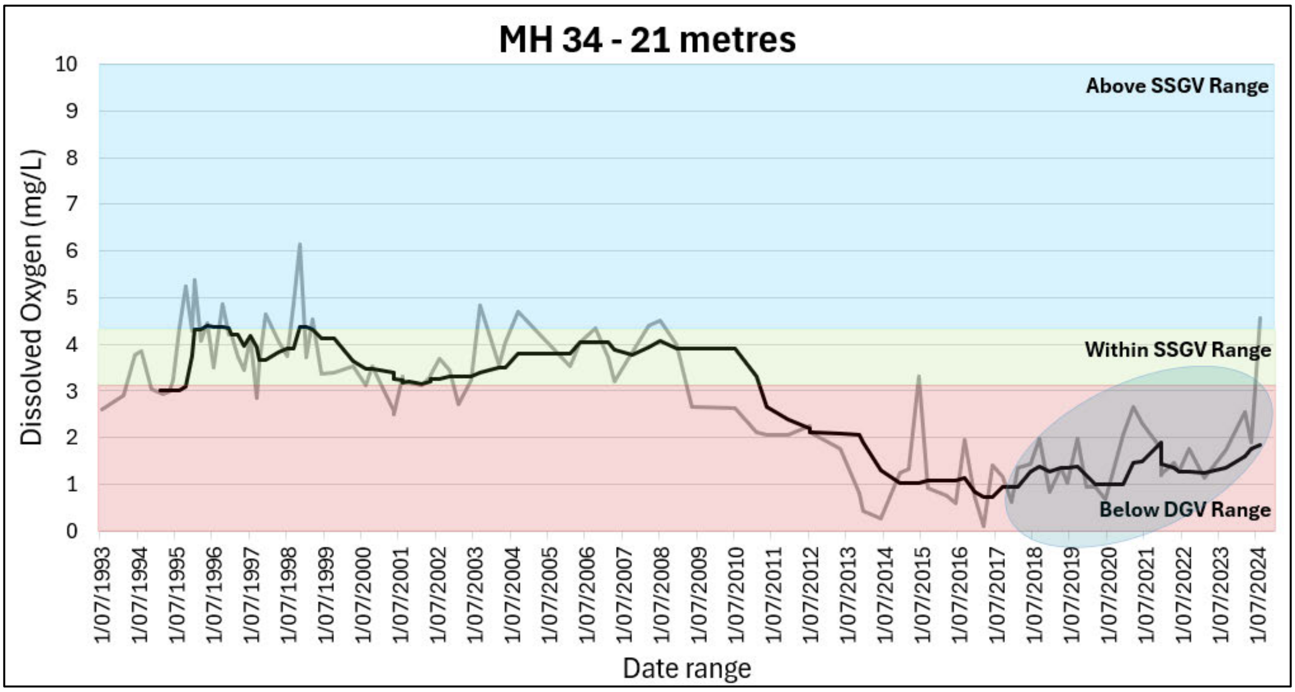


Figure 8– Dissolved oxygen (mg/L) measurements at 21 metre water depth at EPA monitoring site MH34. The grey solid line represents the raw dissolved oxygen measurements, while the black line represents the dissolved oxygen rolling median. SSGVs are represented on the figure, with the blue window being above the SSGV range, the green window being within the SSGV range and the red window being below the SSGV range.

Conclusions

The EPA monitoring data presented in this report for the three monitoring sites within Macquarie Harbour provides a long time series of quarterly observations of dissolved oxygen concentrations across multiple depths. The data demonstrates that at 10 metres water depth across the three monitoring sites that there has been a reduction in the median dissolved oxygen concentrations in Macquarie Harbour, which began to reduce in about 2010. For depths greater than 20 metres, a sharp decline in the median dissolved oxygen concentrations was observed across the three monitoring sites and this commenced in approximately 2010, with median concentrations at these depths varying across the three monitoring sites. Since 2017, there has been a general increase in the median dissolved oxygen concentrations below 20 metres across the three monitoring sites, with the largest improvements in median dissolved oxygen concentrations being observed since 2020. The two monitoring sites in the NW section (MH 12) and the Central section (MH 27) of Macquarie Harbour have shown the greatest improvement in median dissolved oxygen concentrations below 20 meters compared to the MH 34 monitoring site which is the closest of the three stations to the Gordon River.

Industry Broadscale Environmental Monitoring

The salmon farming companies have been required to conduct Broadscale Environmental Monitoring (BEM) within Macquarie Harbour since October 2011. This monitoring program has required up to 17 sites to be monitored to characterise water quality within the Harbour, including waters entering the Harbour from the Gordon and King Rivers and waters entering/exiting the Harbour to the oceanic environment. This report has collated dissolved oxygen data from 14 industry monitoring sites within the Harbour (Map 1), excluding data sampled within the rivers and outside of Macquarie Heads, to describe the water quality condition of the Harbour in three segments. For Segments 121 (NW Macquarie Harbour) we have combined data from 5 sites (KR1, CHN, CC, SB and HG1), for Segment 120 (Central Macquarie Harbour) we have combined data from 5 sites (C10, CHE, C8, CH5 and PET3), and for segment 119 (SE Macquarie Harbour) we have combined data from 4 sites (WH1, WH2, WHN and GR2). Note, C10 was included into Segment 120 as the site is close to the boundary of 2 segments (121 and 120) and its location is adjacent to where finfish farming occurs hence the water quality would be more reflective of conditions around these farms.

The industry broadscale environmental monitoring data presented in this report provides a snap-shot across two 12-month periods (2016/2017 and 2023/2024). The 2016/2017 period was chosen to illustrate the dissolved oxygen status of the Harbour when the EPA Director became responsible for environmental regulation of salmon farming in Macquarie Harbour. This was the period when the EPA Director first issued determinations to reduce the biomass of salmon in the Harbour. The 2023/2024 period was chosen to provide an update on the current dissolved oxygen status within the Harbour.

In contrast to the EPA independent monitoring data presented in the previous section of this report, the industry BEM data presented below has been averaged across the sites within each segment of Macquarie Harbour to provide representative median dissolved oxygen profiles calculated using 12 months of data. Median dissolved oxygen profiles are compared to the published interim DGVs for aquatic ecosystems.

Results

NW Macquarie Harbour – Segment 121

The dissolved oxygen conditions across the depth profile of NW Macquarie Harbour (Segment 121, map 1) have improved since 2016/2017 (Figure 9). The latest 12-month period (Sept 2023 – Aug 2024) demonstrates that across the entire depth range surveyed, median dissolved oxygen concentrations measured are within the interim DGV range.

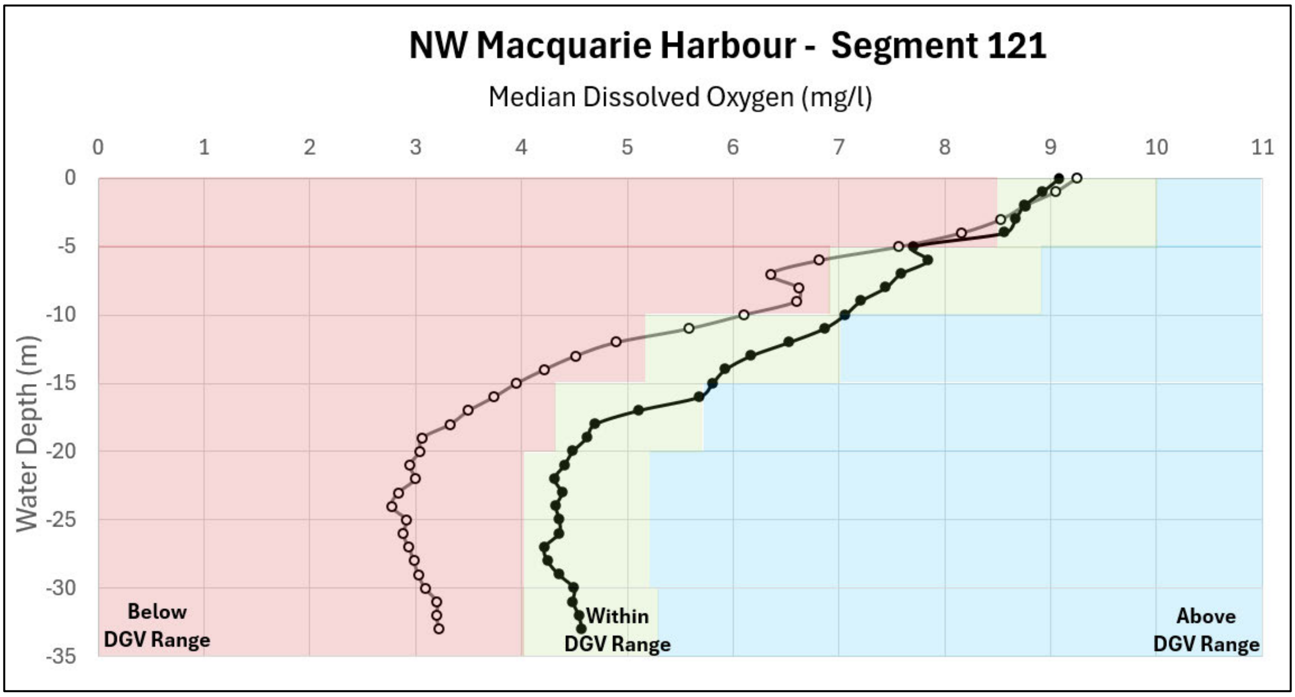


Figure 9 – Median dissolved oxygen (mg/L) profile averaged across five monitoring sites (KR1, CHN, CC, SB and HG1) within NW Macquarie Harbour. The data represented by the open circles on the figure are the median dissolved oxygen data calculated from 12 months of data from Sept 2016 – Aug 2017, and the data represented by the black circles are the median dissolved oxygen data calculated from 12 months of data from Sept 2023 – Aug 2024. Interim DGVs are represented on the figure, with the blue window being above the interim DGV range, the green window being within the interim DGV range and the red window being below the interim DGV range.

Central Macquarie Harbour

The dissolved oxygen conditions across the depth profile of Central Macquarie Harbour (Segment 120, map 1) have improved since 2016/2017. The data demonstrates that for the last 12-month period dissolved oxygen levels across the entire depth range surveyed, are within the interim DGV ranges published by the EPA for the Central Macquarie Harbour (Figure 10).

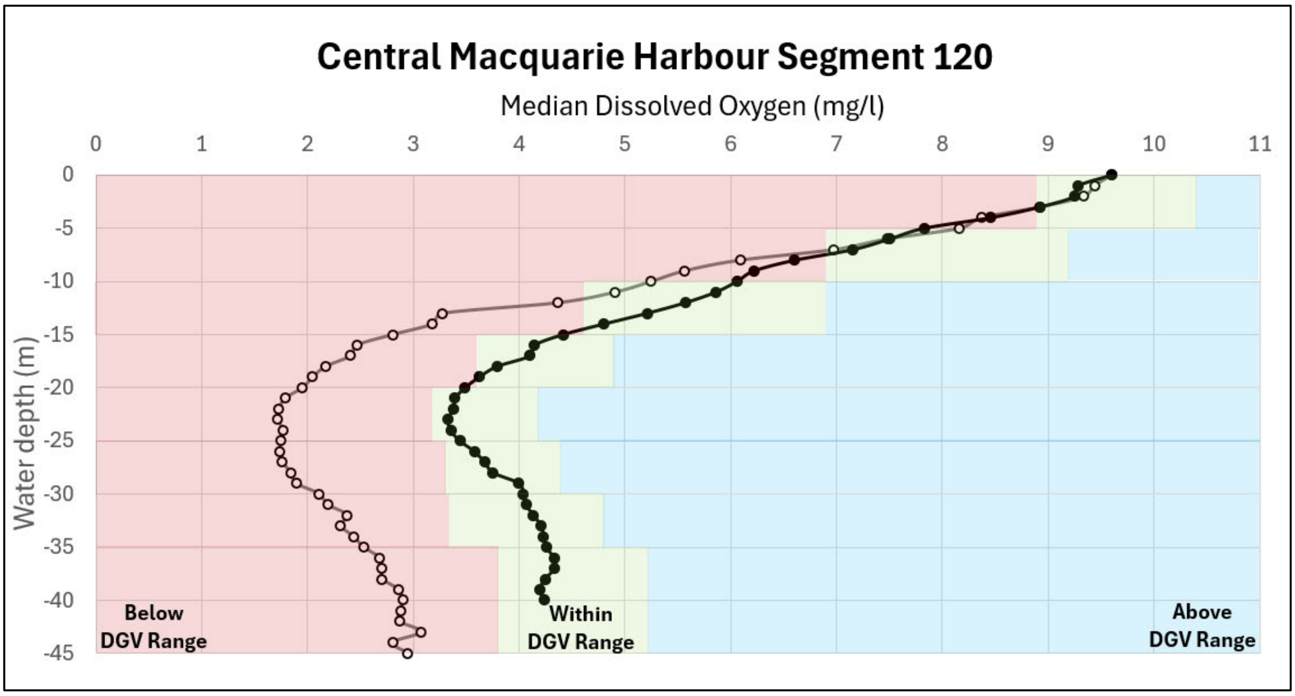


Figure 10 – Median dissolved oxygen (mg/L) profile averaged across five monitoring sites (C10, CHE, C8, CH5 and PET3) within Central Macquarie Harbour. The data represented by the open circles on the figure are the median dissolved oxygen data calculated from 12 months of data from Sept 2016 – Aug 2017, and the data represented by the black circles are the median dissolved oxygen data calculated from 12 months of data from Sept 2023 – Aug 2024. Interim DGVs are represented on the figure, with the blue window being above the interim DGV range, the green window being within the interim DGV range and the red window being below the interim DGV range.

SE Macquarie Harbour – Segment 119

The dissolved oxygen conditions across the depth profile of SE Macquarie Harbour (Segment 119, map 1) have generally improved since 2016/2017 (Figure 11). The latest 12-month period (Sept 2023 – Aug 2024) demonstrates that above 10 metres, dissolved oxygen concentrations have remained stable to measurements undertaken during the 2016/2017 period. Between 10 – 16 metres median dissolved oxygen concentrations have improved with values within the DGV Range and below 16 meters there has been continual improvement in median dissolved oxygen concentrations. However, below 16 metres, further improvement of dissolved oxygen concentrations are needed within SE Macquarie Harbour to reach the interim DGV range.

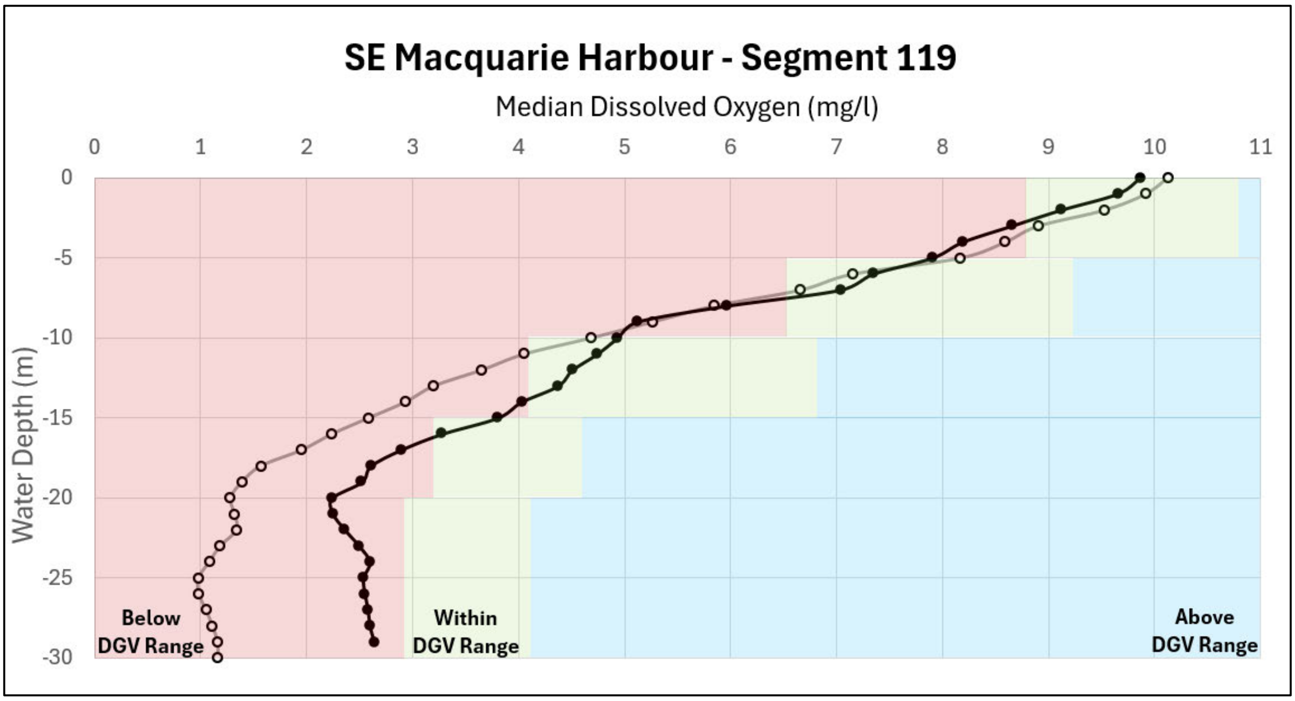


Figure 11 – Median dissolved oxygen (mg/L) profile averaged across four monitoring sites (WH1, WH2, WHN and GR2) within SE Macquarie Harbour. The data represented by the open circles on the figure the median dissolved oxygen data calculated from 12 months of data from Sept 2016 – Aug 2017, and the data represented by the black circles are the median dissolved oxygen data calculated from 12 months of data from Sept 2023 – Aug 2024. Interim DGVs are represented on the figure, with the blue window being above the interim DGV range, the green window being within the interim DGV range and the red window being below the interim DGV range.

Conclusions

The industry broadscale environmental monitoring data presented in this report demonstrates an improvement of dissolved oxygen conditions across the Harbour. The upper 16 metres of the water column across all segments of the Harbour are generally within the interim DGV range. Below 16 metres the median dissolved oxygen concentrations measured have increased across the NW and Central segments of Macquarie Harbour and are now within the interim DGV ranges published by the EPA. However, further improvements of dissolved oxygen concentrations of bottom waters of the SE segment of Macquarie Harbour are needed to allow the median dissolved oxygen concentrations to reach the interim established DGV ranges.

TASMANIA

ENVIRONMENT PROTECTION AUTHORITY

Briefing Report:

Conservation Status Overview of the Maugean Skate (*Zearaja maugeana*)

Barry W. Brook, School of Natural Sciences, University of Tasmania, 2 September 2024

Executive Summary

1. The Maugean skate (*Zearaja maugeana*), a fish species endemic to Tasmania's west coast, faces significant threat, with its population now restricted to Macquarie Harbour.

2. A major cause of the species' population decline appears to be habitat degradation, driven by a combination of low dissolved oxygen levels and deep-water turnover events, nutrient outflows from salmon farming, and altered river flows due to hydroelectric operations.

3. Climate change likely exacerbates these issues by reducing overall oxygen solubility in the Harbour waters, along with increasing temperatures and altered precipitation patterns, which can combine to intensify hypoxic conditions detrimental to the skate and other fish.

4. Conservation efforts, including the Macquarie Harbour Oxygenation Project and regulatory measures targeting salmon farming, have had some success, but are hampered by the complex interplay of multiple threats and the high natural variability of the system.

5. A recent population viability analysis (PVA) projects a high probability of extinction for the species within two decades if these threats are not effectively mitigated. However, the robustness of the PVA is constrained by its reliance on sparse and uncertain data, a lack of mechanistic details, and its underlying precautionary assumptions.

6. Specifically, the method of initialisation of the PVA limits its ability to assess the impact of threats and could lead to overly pessimistic results. A more robust, multidisciplinary modelling approach, linking environmental factors directly to the skate's vital rates, is urgently needed.

7. Multiple working hypotheses are proposed herein to explain the skate's decline, ranging from synergistic effects of human activities and natural environmental variability to genetic bottlenecks and disease outbreaks. Each proposition demands specific testing and tailored interventions and should be evaluated using causal models and adaptive management.

8. A Population and Habitat Viability Assessment (PHVA) workshop is recommended to reassess the current PVA, refine the approach to data analysis and model parameterisation, and develop a more robust, science-based action plan. This would involve integrating ecological, genetic, and environmental data with a broader stakeholder engagement process.

9. The aquaculture industry disputes the exclusive blame on salmon farming, highlighting the need for a more nuanced approach to risk assessment and consequent conservation strategies.

10. Immediate actions should prioritise improving water quality and natural flows in Macquarie Harbour, reducing nutrient outflow, enhancing environmental monitoring, and expanding the captive-breeding program with possible future releases. Collaboration among industry, government, and conservation groups is crucial for the long-term survival of the Maugean skate.

Section 1: Overview of Situation

The below section is my encapsulation of the large body of literature on the skate's conservation status in a concise format. It is not my intention to take any position herein.

The Maugean skate (*Zearaja maugeana*), a fish species endemic to Tasmania's west coast, is under threat. Once found in both Macquarie and Bathurst Harbours, it now apparently persists only in the former[1]. This habitat is unique but fragile, influenced by limited ocean exchange and freshwater inflows. The species is currently listed as Endangered under both Tasmania's *Threatened Species Protection Act 1995* and the *Environment Protection and Biodiversity Conservation Act 1999*, with nearly a 50% population decline from 2014 to 2021[2]. Recent modelling suggesting a high probability of extinction within two decades if ongoing threats are not sufficient abated. Stressors in Macquarie Harbour include low dissolved oxygen levels, nutrient loading and organic waste from salmon farming. These factors can create hypoxic conditions with the potential to cause significant mortality. Hydroelectric operations have also altered river flows, leading to a reduced oxygenated water influx and exacerbated low oxygen levels. Climate change compounds these threats, with rising water temperatures and changing precipitation patterns intensifying hypoxic conditions. Historical mining has also left a legacy of heavy metal pollution, further degrading the habitat.

Conservation efforts include the Macquarie Harbour Oxygenation Project and regulatory measures to reduce salmon stocking densities and enhance environmental monitoring. Despite these, the multifaceted threats constrain their effectiveness. Continuous monitoring since 2012 has provided valuable data, but gaps in understanding the skate's reproductive biology and juvenile survival complicate targeted conservation strategies[3]. There is an urgent need for coordinated conservation actions. Immediate threat mitigation and long-term sustainable habitat management will be essential to prevent the extinction of this unique species.

Primary Threats and Environmental Challenges

Habitat Degradation: Based on the synthesis of current literature on the species, the most significant threat seems to be habitat degradation, driven by low dissolved oxygen levels in Macquarie Harbour. Dissolved oxygen is crucial for survival, and its depletion creates hypoxic conditions harmful to the skate. Nutrient loading and organic waste exacerbate these low oxygen levels, leading to increased biological oxygen demand and oxygen depletion.

Salmon Farming and Nutrient Pollution: Aquaculture operations in Macquarie Harbour exert significant stress on the environment, though the extent of their impact remains debated. Waste from salmon farms increases nutrient levels, but unlike many waterways, Macquarie Harbour's dark, tannin-rich waters inhibit algal blooms due to limited light penetration and the potential

[1] https://nre.tas.gov.au/conservation/threatened-species-and-communities/lists-of-threatened-species/threatened-species-vertebrates/maugean-skate

[2] https://www.threatenedspecieslink.tas.gov.au/Pages/Maugean-Skate.aspx

[3] https://nre.tas.gov.au/Documents/Fact%20Sheet%20-%20Maugean%20Skate%20Conservation%20under%20the%20EPBC%20Act%201999%20-%20DCCEEW.pdf

presence of dissolved metals from historical mining runoff. Consequently, oxygen depletion in the Harbour is not driven by algal decomposition but by other factors. The Maugean skate, which predominantly resides in the 0–15 metre depth range, faces heightened mortality risks during "turnover" events. These occur when oceanic waters spill into the Harbour, displacing low-oxygen deep waters and causing rapid shifts in dissolved oxygen levels. This phenomenon has previously led to fish kills, underscoring the complex oxygen dynamics in the Harbour.

Hydroelectric Operations: Hydropower developments in inland areas of western Tasmania has altered the natural river flow into Macquarie Harbour. Damming reduces the influx of oxygenated water, disrupting natural water turnover essential for healthy oxygen levels, exacerbating low oxygen conditions, and stressing the skate's habitat.

Climate Change: Rising temperatures reduce oxygen solubility in water, worsening hypoxic conditions. Altered precipitation patterns affect freshwater inflows, salinity, and nutrient dynamics within the harbour. Climate-induced changes, such as more frequent and intense storms, can also lead to more frequent anoxic events, impacting skate survival.

Historical Mining Pollution: Legacy pollution from historical mining adds complications to the primary environmental challenges described above. Heavy metals and other contaminants from past mining operations settle in harbour sediments, contributing to ongoing water quality issues and having toxic effects on marine life, including the Maugean skate.

Anoxic Events: Acute events that result in temporarily critically low oxygen levels pose a direct threat to the Maugean skate. These phenomena, often triggered by storms mixing the water column, result in mass mortality of benthic organisms, including skates.

Addressing these challenges adequately requires understanding their synergistic interactions and their cumulative impact on the ecosystem (see Section 3). Effective conservation strategies must improve water quality management, enforce stricter aquaculture regulations, and implement adaptive measures against climate change. Coordinated efforts are essential to halt the decline of this unique and critically endangered species.

Conservation Efforts and Mitigation Measures

Conservation efforts have involved a mix of regulatory measures, technological interventions, and collaborative initiatives targeting the skate's habitat in Macquarie Harbour[4]. These strategies focus on improving water quality, enhancing monitoring, and fostering stakeholder engagement.

Macquarie Harbour Oxygenation Project: This project, led by the salmon-farming industry and supported by regulatory bodies, aims to increase dissolved oxygen levels in the harbour using mechanical oxygenation systems. Early results show some success in improving water quality, but challenges remain due to the complexity and high resource demands.

[4] https://environment.gov.au/biodiversity/threatened/species/pubs/83504-conservation-advice-06092023.pdf

Regulatory Measures: Efforts include reducing salmon farm stocking densities, enforcing stricter feed management and waste disposal practices, and periodically reviewing these regulations to protect the skate's habitat.

Enhanced Environmental Monitoring: Since 2012, monitoring programs have tracked key environmental parameters such as dissolved oxygen levels, water temperature, salinity, and nutrient concentrations. New technologies like real-time sensors and remote sensing have provided high-resolution data that would be useful for adaptive-management strategies.

Research and Data Collection: Ongoing research has sought to address knowledge gaps about the skate's reproductive biology and juvenile survival rates. Studies have focused on life history, habitat preferences, and population dynamics, but require an expanded effort.

Ex-Situ Conservation: Off-site conservation interventions, notable the IMAS-supervised captive breeding program, have been implemented to safeguard against extinction and maintain a genetic repository for possible reintroduction into the wild.

A draft Listing Assessment was released by the Australian Department of Climate Change, Energy, the Environment and Water for consultation; it recommends upgrading the conservation status of the species to critically endangered, based on threats, decline and projected risk[5].

Industry Concerns and Critiques

The aquaculture industry, including Salmon Tasmania and Petuna Aquaculture, have emphasised the economic significance of salmon farming in Tasmania, which supports over 5,000 jobs and many local socioeconomic benefits. They argue that current regulatory and management practices are sufficient to mitigate impacts on the Maugean skate's habitat. Industry representatives have highlighted compliance with stringent environmental regulations, including reduced stocking densities and improved feed management practices, and pointed to substantial investments in environmental monitoring and mitigation projects, such as the Macquarie Harbour Oxygenation Project, as evidence of their commitment to sustainable practices. The industry has disputed the sole attribution of habitat degradation to their operations, arguing that multiple factors, including climate change and historical mining activities, also contribute to declining water quality in Macquarie Harbour. They have critiqued the Population Viability Analysis (see Section 2) as unreliable and argued for wider use of advanced methodologies like environmental DNA (eDNA) analysis as a non-invasive tool for detecting the presence (and potentially viability) of the Maugean skate. In short, they have argued against disproportionately targeting the aquaculture sector.

Despite disputes, the industry has recognised the need for collaborative efforts. The establishment of a stakeholder advisory group, with representatives from aquaculture, government, conservation organisations, and local communities, has been advocated. This would promote transparent decision-making and develop scientifically sound and socially equitable conservation strategies, while supporting the west coast region's economic vitality.

[5] https://www.dcceew.gov.au/sites/default/files/documents/consultation-document-maugean-skate-2024.pdf

There is currently (September 2024) a call for comments on the Listing Assessment[6].

In the next three sections, I consider the above arguments in more detail, including a critical assessment of the recent population viability analysis (PVA), an evaluation of the plausible factors (or combination thereof) that might have caused the skate's decline, and a high-level set of recommendations of what actions to focus on to move the conservation program forward.

Section 2: Critical Evaluation of the Population Viability Analysis

A PVA for the Maugean skate was recent published as a governmental report:

Grant MI, Moreno D, Semmens J & Simpfendorfer C (2023) Population viability analysis of the Maugean skate *Zearaja maugeana*. Report prepared for the Australian Government Department of Climate Change, Energy, the Environment and Water, pp 40.[7]

Using current demographic and life history data, models predicted the risk of extinction over three generation lengths (27 years), spanning 2014–2041. The PVA projected a best-case scenario of an 89% population decline by 2041 if current trends continue, and a worst-case scenario of over 99% decline, with extinction probabilities of >25% by 2041. Key factors driving this modelled decline included low recruitment rates, habitat degradation, and environmental pressures. According to IUCN Red List criteria, these population reduction estimates would qualify the Maugean skate for a Critically Endangered listing under Criterion A4bd.

Inadequate recruitment was identified as a primary driver of the projected decline, with low juvenile survival rates due to deteriorating environmental conditions in Macquarie Harbour. Habitat degradation, particularly low dissolved oxygen levels, was argued to be a major stressor, exacerbated by nutrient pollution from salmon farming. Organic waste from these operations, leading to hypoxic conditions, was simulated as a substantial mortality stress to the skate population. Hydroelectric operations could compound the problem by altering river flows and reducing the influx of oxygenated water into the harbour, reducing habitat quality. Extreme weather events and temperature anomalies might also lead to sudden population declines.

The salmon industry has critiqued the PVA on multiple fronts. The current PVA, based on limited and uncertain information, estimates the mature female population at 40-120 individuals, which qualifies for a critically endangered (CR) species. However, the industry argues that this estimate, excluding unknown Bathurst Harbour populations, relies on uncertain baseline data. Population assessments since 2012, derived from three different studies, offer a limited and variable data set. Notably, the 2014 population estimates—which ranged between 1,827 and 6,247—were marked by a high degree of uncertainty due to low recapture numbers, including on trend data. The IUCN population-decline criterion for CR requires a >50% extinction probability within three generations, but the PVA relies on future scenarios that are, inevitably,

[6] https://www.dcceew.gov.au/environment/biodiversity/threatened/nominations/comment/zearaja-maugeana

[7] https://www.dcceew.gov.au/sites/default/files/documents/75748.pdf

largely speculative in nature. Ongoing conservation efforts, including re-oxygenation projects and a government action plan, suggest the need for expert reassessment of the PVA's precautionary application. Further, using methods like eDNA, which provide high sensitivity (albeit with low resolution), non-invasiveness, broader spatial and temporal coverage, and cost-effectiveness, can offer more accurate and comprehensive data compared to traditional catch-per-unit effort metrics, leading to better-informed conservation and management strategies.

Clearly, the reliability of the PVA is constrained by the quality of the underlying data[8]. In brief, comprehensive data are needed across several domains: accurate estimates of population size, density, age structure, and sex ratio; detailed reproductive data including breeding patterns and survival rates; mortality rates from natural and anthropogenic causes to distinguish population fluctuations; identification and monitoring of critical habitats for various life stages; levels of genetic diversity and gene flow to assess resilience; climate and oceanographic conditions to understand environmental impacts; quantification of threats like overfishing and pollution to prioritize conservation actions; behavioural data on movement and habitat use for effective protected area design; and a range of survey methods (observational and indirect) to detect presence and density across habitats, providing comprehensive data without direct capture.

The industry's full list of criticisms on the PVA is extensively documented and referenced, and naturally tackles the conclusions from a vested interest (a shutdown of operations in Macquarie Harbour would be economically damaging). Nonetheless, I judge their assessment to be well argued and largely justified. Further, I suspect that the scientists who developed the PVA would agree with their central premise: that underlying uncertainties undermine our current ability to draw firm conclusions about the future fate of the skate. This can be attributed, in large part, to the broad set of probable underlying cause(s) of threat (see section 3).

As someone who has worked as a specialist on population viability analysis for nearly 30 years (first scientific paper on the topic was in 1997[9]), the 2023 report on the skate's viability strikes me as a mostly reasonable effort but constrained (as is often the case in PVAs) by severe information gaps. A bigger problem is that the outcome is essentially 'forced', as I explain below.

The approach uses a matrix-based project model with environmental stochasticity. A range of sensitivities are explored for juvenile mortality, fecundity, longevity and maximum rates of population increase, although a very low value (R_{MAX} = 3% pa) was focused on for subsequent scenario analysis to be 'conservative' (i.e., not overly optimistic, a common precautionary approach). The population trend analysis is based on five catch-proportion estimates (without associated uncertainty) and two alternative exponential decline models fitted to three data points. A Beverton-Holt contest competition model was used to simulate density-dependent feedback (including rebound potential). However, this seems strikingly at odds with the low R_{MAX} value: typically, a function simulating population regulation in fish would be based on a far higher *potential* intrinsic rate of increase, which makes the estimates extremely precautionary.

In addition, a secular trend was also imposed upon the matrix projections, which resulted axiomatically in a projected population decline. That is, the decline was an *enforced*

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[8] https://conbio.onlinelibrary.wiley.com/doi/pdf/10.1111/cobi.13414
[9] https://www.sciencedirect.com/science/article/pii/S0006320797000268

deterministic result of the modelling rather than an *emergent* result of the simulated impacts of different external threats, as is common practice to simulate in PVA. I consider this a problem, because the cause of the decline would, in reality, be driven via either its effect on: a) habitat quality (impacting carrying capacity and the shape/parametrisation of the density-dependent function), and/or b) vital rates (survival and/or fecundity), and should be propagated through the model in this way. The harvest function in RAMAS Metapop[10] (the software used to implement the PVA) can be used when simulating direct removals, but it is not intended as a 'brute force' way to tune the baseline scenario. As it stands, the model is not predictive or exploratory because the outcome is essentially "baked in" by the choices made during parameterisation.

The three main threats to the Maugean skate population that were simulated in the scenario analysis a reduction in habitat quality and extent (environmental O_2 depletion), 'catastrophic' events that exacerbate effects of environmental O_2 depletion, and recreational fishing, including seal depredation, simulated via additional mortality above the (already declining) baseline. These are all reasonable threats to explore, but there is a problem of circularity ('double-dipping') if these factors are responsible for the decline in the first place[11]. Removals for ex-situ captive-breeding were also explored. As seen by their Figures 13 – 16, the baseline scenario results in nearly identical predictions to any of the challenge scenarios because, as identified above, the decline imposed absolutely dominates the forecast, resulting in only small deviations for the other scenarios and extremely tight confidence intervals. In short, as a consequence of the baseline modelling choices, the impact of any further stochastic threats is essentially impossible to assess, because of the overriding influence of the underlying deterministically driven negative trend imposed upon all model runs[12]. This makes the forecasts of the best- and worst-case declines, of 89% and > 99% in Macquarie Harbour, as effectively a preordained outcome, given the underlying issues with the PVA's baseline parameterisation.

My conclusion is that a population viability analysis approach holds promise as a tool for guiding the conservation management of the Maugean skate. But to achieve this aim, the whole exercise would need to be redone from the ground up, with a clear focus on linking the modelled processes directly to impacts on vital rates and density-dependent feedback, and on various aspects of habitat quality, rather than indirectly via top-down changes to population growth. A meta-modelling approach would be ideal for this purpose, but would require a substantial body of new work, done in collaboration with specialist modellers, marine ecologists and industry partners. This could be linked to a pattern-oriented approach to model validation[13], done prior to running the scenario analysis, to ensure that the baseline model is not compromised by double dipping or deterministic bias prior to assessing the impacts of threatening factors.

My suggestion would be to support a set to two population and habitat viability assessment (PHVA) workshops. The first workshop should set the goal of scoping the work required (with expert and stakeholder consultation), delegating the required modelling tasks as modular projects (assigned to appropriate specialists). Interim work would then undertake data analysis, model development and parameterisation, and pattern-oriented baseline validation. The

[10] https://www.ramas.com/metapop-6-0
[11] https://www.jstor.org/stable/2641621
[12] https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/eap.1589
[13] https://besjournals.onlinelibrary.wiley.com/doi/10.1111/2041-210X.13720

second workshop would then set out to design the appropriate scenarios and adaptive management interventions to be realistically simulated, and undertake the analysis collectively. This is further elaborated upon at the end of section 4 of this briefing document.

Section 3: Hypotheses on Causes of Threat and Possible Interventions

Based on synthesising the available literature, in this section I explore the potential causes of the threat now faced by the Maugean skate, using approach of multiple working hypotheses[14], causal-inference[15] frameworks, and ecosystem-based management[16] principles. Each hypothesis I propose considers different environmental and anthropogenic factors, supported by evidence and proposed testing methods and are also summarised in tabular form. Interventions are recommended to mitigate the identified threats and promote recovery.

The numbering represents a proposed plausibility rank order, based on the current evidence.

1. Synergistic Effects of Environmental and Human Factors: The decline of the Maugean skate may be due to the combined effects of natural environmental variability and human activities. This hypothesis requires integrated studies to understand how these factors interact. Interventions would require creating a multi-faceted management plan that address both direct and indirect effects, such as enhancing buffer zones around sensitive areas and fostering collaboration among various sectors. *Plausibility:* The interaction between natural environmental variability and human activities can create compounded effects that are more severe than any single factor alone. The absence of local human impacts in Bathurst Harbour yet the decline in the skate population suggests broader interactions are at play. *Counter-Argument:* Synergistic effects are complex and difficult to isolate, making it challenging to determine the specific contributions of each factor, potentially diluting targeted interventions.

2. Climate Change and Global Environmental Factors: Anthropogenic climate change impacts, including elevated water temperatures and altered precipitation patterns, are hypothesised to lead to changes in water quality that are detrimental to the skate's habitat or the physiology of the species directly. Analysis of long-term monitoring of climate variables and their impacts on the harbour's ecosystem will help test this hypothesis. Developing climate adaptation strategies, such as habitat restoration and creating refugia, would enhance the skate's resilience against these changes. *Plausibility:* climate change is a significant global factor influencing local environmental conditions, including water temperature and chemistry. The skate's decline in both harbours, including Bathurst Harbour where local human impacts are minimal, suggests that broader climatic changes are crucial. *Counter-Argument:* The broad

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[14] https://doi.org/10.1641/B570708

[15] https://ftp.cs.ucla.edu/pub/stat_ser/r350.pdf

[16] https://link.springer.com/chapter/10.1007/978-3-030-45843-0_3

and long-term nature of climate change effects makes it difficult to link directly to the immediate decline of the skate, potentially overshadowing more immediate local factors.

3. Combined Effects of Multiple Stressors: The interaction of multiple stressors, including human-induced changes and natural variability, could be overwhelming the skate's capacity to adapt. Integrated monitoring and analysis of multifactorial environmental data are necessary. Conservation strategies that address all significant stressors would, in this case, be crucial for long-term persistence. *Plausibility:* The decline is likely due to multiple stressors acting in combination, including human-induced changes and natural variability. *Counter-Argument:* This hypothesis is probably too broad and non-specific, making it difficult to pinpoint specific interventions, and the complexity of interactions may obscure primary drivers.

4. Environmental Degradation Solely from Direct Human Activities: The decline in the Maugean skate population is hypothesised to be primarily due to environmental degradation caused by human activities, such as salmon farming and hydroelectric operations in Macquarie Harbour. These activities contribute to reduced dissolved oxygen levels through nutrient loading and organic waste, creating hypoxic conditions detrimental to the skate's survival. To test this hypothesis, regular measurement of water quality parameters (oxygen levels, salinity, temperature) and pollutant levels is necessary. The interventions include regulating farming practices, modifying water-flow regimes, and enhancing environmental monitoring to mitigate the impacts. *Plausibility:* Despite the apparent lack of local human activities in Bathurst Harbour, Macquarie Harbour's significant human impact suggests that local human activities still play a crucial role in habitat degradation. *Counter-Argument:* The absence of significant human activities in Bathurst Harbour leading to skate decline suggests that human activities alone might not be the sole or even primary driver, potentially pointing to broader factors.

5. Natural Habitat Suitability and Ecological Factors: Natural variability in habitat suitability, such as differences in salinity, temperature, and sediment types, might be causing the decline. Habitat assessments and additional ecological modelling would help test this hypothesis. Interventions should focus on habitat restoration and environmental regulation to maintain suitable conditions for the skate. *Plausibility:* Natural variability in habitat suitability, such as differences in salinity, temperature, and sediment types, might be causing the decline. The skate's loss in, or apparently permanent movement out of, Bathurst Harbour, points to natural habitat factors potentially reaching unsuitable thresholds. *Counter-Argument:* Focusing on natural habitat changes may underestimate the significant and immediate impacts of anthropogenic factors, potentially leading to insufficient conservation actions in Macquarie.

6. Additive Effects of Environmental Stressors and Genetic Bottleneck: Environmental stressors combined with a genetic bottleneck could be leading to decreased resilience and increased mortality in the skate population. Genetic studies to assess diversity and resilience are needed to test this hypothesis. Conservation strategies should focus on reducing environmental stressors and implementing genetic management programs, such as habitat corridors or captive breeding. *Plausibility:* Environmental stressors combined with a genetic bottleneck can significantly reduce a population's resilience and increase mortality. The historical isolation of the skate populations suggests genetic factors might play a role. *Counter-*

Argument: The genetic bottleneck might be a consequence rather than a cause of the population decline, diverting attention from more immediate environmental stressors.

7. Disease Outbreak: A disease outbreak, possibly exacerbated by environmental stressors, could be contributing to the decline. Screening skate populations for pathogens, especially during and after periods of environmental stress, will help confirm this hypothesis. Health monitoring and the implementation of biosecurity measures are critical interventions to prevent and manage disease outbreaks. *Plausibility:* Disease outbreaks, especially those exacerbated by environmental stressors, are a plausible cause of population decline. Historical correlations and pathogen presence support this hypothesis. *Counter-Argument:* Disease might not be the primary driver of decline but rather a symptom of broader environmental degradation, leading to conservation efforts that do not address root causes effectively.

8. Predation or Competition: Increased predation or competition from other species (including invasives), whose population dynamics might have changed because of local human activities or global environmental change, could be contributing to the decline of the Maugean skate. Ecological studies on predator-prey relationships and competition dynamics are necessary. Managing predator populations and enhancing skate habitat could mitigate these impacts. *Plausibility:* There is global precedence: increased predation or competition from other species have caused declines in other threatened species. *Counter-Argument:* Predation or competition might not be as significant as direct environmental changes caused by human activities.

9. Genetic Bottleneck and Limited Genetic Diversity: A genetic bottleneck unrelated to environmental conditions may be causing increased vulnerability. As with hypothesis #6, genetic diversity assessments will help confirm this hypothesis. Interventions include captive breeding programs and efforts to enhance genetic diversity through habitat connectivity and other measures. *Plausibility:* Reduced genetic diversity can increase vulnerability to environmental changes and reduce reproductive fitness, making this a plausible cause of decline. Genetic studies support the presence of a bottleneck effect. *Counter-Argument:* Genetic issues might be a secondary consequence of other stressors rather than a primary cause, potentially overlooking the need for immediate habitat management.

10. Interaction Between Climate Change and Local Pollution: Climate change could be amplifying the effects of local pollution. Detailed modelling of the combined impacts of climate change and pollution on water quality and skate habitat would be essential. *Plausibility:* Climate change amplifying the effects of local pollution is a plausible hypothesis, as changes in temperature and precipitation can exacerbate the impacts of pollutants. This combined effect is supported by environmental data. *Counter-Argument:* Distinguishing the specific contributions of climate change versus local pollution can be difficult and potentially dilute the focus of conservation efforts on more controllable local factors.

Summary Table of Hypotheses and Interventions

Hypothesis: A proposed explanation for the decline of the Maugean skate, based on observed data and logical reasoning.

Description: A brief summary of the hypothesis, explaining the potential cause of the decline and its impact on the skate's population.

Evidence/Support: The type and strength of data supporting the hypothesis. This may include correlations, observed trends, historical data, or scientific studies indicating the validity of the hypothesis.

Testing Approach: Methods to test the hypothesis, involving specific actions, measurements, and analyses. These may include environmental monitoring, genetic studies, pathogen screening, ecological assessments, or modelling.

Interventions: Recommended actions to mitigate the hypothesised cause of decline. These interventions are designed to address the specific issues identified by the hypothesis and may involve regulatory measures, habitat restoration, adaptive management, stakeholder engagement, or technological innovations.

Hypothesis	**Description**	**Evidence/Support**	**Testing Approach**	**Interventions**
1. Synergistic Effects of Environmental and Human Factors	Combined natural and anthropogenic factors creating severe habitat degradation	Complex interactions observed	Integrated ecological and environmental studies	Multi-faceted management plans, stakeholder collaboration
2. Climate Change and Global Environmental Factors	Broad climatic changes affecting water temperature and chemistry	Global climate trends	Long-term climate and water quality monitoring	Develop adaptation strategies, habitat restoration
3. Combined Effects of Multiple Stressors	Interaction of human-induced changes and natural variability	Multifactorial environmental data	Integrated monitoring and analysis	Comprehensive conservation strategies
4. Environmental Degradation Solely from Direct Human Activities	Decline due to pollution and habitat alteration from aquaculture and hydroelectric operations	Strong correlation with oxygen levels decline	Environmental monitoring, pollutant analysis	Regulate activities, modify practices, enhance monitoring
5. Natural Habitat Suitability and	Natural variability in habitat suitability causing the decline	Ecological and environmental data	Habitat assessments, ecological modeling	Habitat restoration, environmental regulation

Hypothesis	Description	Evidence/Support	Testing Approach	Interventions
Ecological Factors				
6. Additive Effects of Environmental Stressors and Genetic Bottleneck	Stressors combined with low genetic diversity reducing resilience	Genetic data, environmental stressors	Genetic diversity studies, resilience assessments	Genetic management, reduce environmental stressors
7. Disease Outbreak	Potential disease outbreak impacting vulnerable populations	Historical correlations, pathogen presence	Pathogen screening, health assessments	Health monitoring, biosecurity measures
8. Predation or Competition	Increased predation or competition from other species	Ecological observations	Predator-prey studies, competition dynamics	Manage predator populations, enhance skate habitat
9. Genetic Bottleneck and Limited Genetic Diversity	Reduced genetic diversity leading to vulnerability	Genetic analysis	Genetic diversity assessments	Captive breeding, genetic diversity enhancement
10. Interaction Between Climate Change and Local Pollution	Climate change amplifying effects of local pollution	Combined environmental data	Model impacts of climate and pollution	Reduce pollution, adapt to climate impacts

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Section 4: Recommended Actions

Addressing the conservation challenges of the Maugean skate requires a multifaceted, adaptive approach that integrates scientific research, technological innovation, regulatory measures, and stakeholder collaboration. Some of this work has already commenced and has yielded success, including major investments into mechanical re-oxygenation, and a significant potential shown for the expansion of the captive-breeding-and-release intervention.

Habitat Restoration and Regulation

Improving the water quality in Macquarie Harbour will clearly be essential for the survival of the Maugean skate. Key actions include: (i) *Mechanical Oxygenation.* Expanding the Macquarie Harbour Oxygenation Project to enhance dissolved oxygen levels in critical habitats. This involves deploying additional mechanical oxygenation systems and optimizing their operation based on real-time data. (ii) *Reducing Nutrient Pollution.* Implementing appropriate controls on salmon-farming practices to minimise nutrient loading. This includes reducing or reallocating fish stocking densities, improving feed-management practices, and enhancing waste-treatment processes to minimise organic waste entering the harbour. (iii) *Restoring Natural Water Flows.* Working with hydroelectric operators to modify dam operations in a way that increases the renewal of oxygenated water into the harbour. This could involve adjusting water release schedules to mimic natural flow patterns, thereby improving water circulation and oxygenation.

Adaptive Management and Stakeholder Engagement

Developing adaptive management frameworks allows for responsiveness to new data and changing environmental conditions. This approach involves: (i) *Improved Monitoring and Research*. To enhance understanding of the Maugean skate's ecology and population dynamics, it is crucial to implement continuous and detailed environmental monitoring. Direct underwater surveys, undertaken regularly and combined with proxy methods such as eDNA analysis, would provide more accurate and timely assessments of population status and habitat conditions. Long-term monitoring of dissolved oxygen levels, water temperature, salinity, and nutrient concentrations will help track environmental changes and the effectiveness of mitigation measures. (ii) *Flexible Conservation Strategies.* Regularly updating conservation plans based on monitoring results and scientific research is essential, allowing for the continuous refinement of strategies to ensure their effectiveness in mitigating threats. (iii) *Stakeholder Advisory Group.* Establishing a line of consultation that includes representatives from the aquaculture industry, government agencies, conservation organisations, and local communities, to guide actions and ensure transparent and inclusive decision making. (iv) *Public Awareness.* Launching education and outreach programs to raise awareness about the Maugean skate's conservation status and the importance of preserving its habitat. Engaging the public and local communities in conservation efforts to foster a sense of stewardship and support for conservation initiatives.

Research and Data Collection

Filling key knowledge gaps about the Maugean skate's biology, particularly its reproductive biology and juvenile survival rates, remains a critical priority. Recommendations include: (i) *Comprehensive Ecological Studies.* Undertaking detailed studies on the skate's life history, habitat preferences, and population dynamics. This will inform targeted conservation strategies and enhance our understanding of the species' ecological requirements. (ii) *Genetic Diversity Assessments.* Analysing the genetic diversity of the Maugean skate population to identify genetic problems and inform captive-breeding programs. Mitigating the loss of genetic diversity during a population-size bottleneck event is essential for maintaining the species' reproductive fitness, population viability, and resilience to future environmental changes and threats.

Ex-Situ Conservation

While in-situ conservation must remain a primary focus, expanding on preliminary ex-situ measures, such as the IMAS captive breeding, would provide an additional safety net against extinction. These programs should aim to: (i) *Establish Viable Captive Populations.* Expand upon the captive breeding program to maintain a genetic repository of the species. Captive populations can serve as a source for reintroduction efforts if wild populations continue to decline but are prone to genetic problems (low-founder-size effects) and behavioural changes that compromise their fitness in natural conditions. Funding of $2.1M was announced in August 2024 to support this effort[17]. (ii) *Reintroduction Strategies.* Prepare for reintroduction of captive-bred individuals into the wild when habitat conditions improve. Reintroduction efforts should be carefully planned and monitored to ensure their success and sustainability. This might include a carefully planned re-establishment of the Bathurst Harbour population as an adaptive management experimental release and monitoring effort.

KEY RECOMMENDATON

Population and Habitat Viability Assessment (PHVA) Workshop

I recommend convening and adequately funding a Population and Habitat Viability Assessment (PHVA) via two workshops[18] to enhance the model-based forecasts and conservation actions. This is an imperative action for successful adaptive management[19]. This would bring together experts in population modelling, marine ecology, habitat restoration, and stakeholders from relevant industries and government agencies. The primary goal of the PHVA would be to develop a comprehensive, science-based action plan that addresses the identified gaps in current conservation strategies and ensures the long-term viability of the Maugean skate population.

The first workshop should undertake a detailed scoping session to outline the key areas of focus, such as refining demographic data, understanding habitat requirements, and assessing the impacts of environmental stressors. Participants should include one or more experts in population viability analysis, working in collaboration with marine ecologists, conservation geneticists, members of the National Recovery Team[20], and representatives from the salmon farming industry, hydroelectric companies, and local communities. This collaborative approach would facilitate the integration of diverse perspectives and expertise, ensuring that the conservation strategies developed are both scientifically robust and practically implementable.

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[17] https://minister.dcceew.gov.au/plibersek/media-releases/consultation-uplisting-maugean-skate
[18] https://www.cpsg.org/our-approach/workshop-processes/phva-workshop-process
[19] https://link.springer.com/article/10.1007/s10531-023-02568-0
[20] https://www.cradlecoast.com/natural-resource-management/our-work/current-projects/national-recovery-team/

This workshop should prioritise the development of more refined and accurate models that directly link environmental factors to changes in the Maugean skate's vital rates. This would involve revisiting the current matrix model and exploring alternative approaches that better capture the complexity of density dependence and environmental stochasticity and avoid the problems of double dipping and proscribed forecasts (see section 2). Additionally, the workshop could explore meta-modelling approaches that integrate various data sources, such as eDNA, remote sensing, and traditional survey methods, to provide a more comprehensive understanding of the population dynamics and habitat conditions. It is likely that further work on the data analysis, model parameterisation and model validation, would then be undertaken by one or more groups (assigned as modular tasks) prior to reconvening for workshop two.

In the second workshop, participants would engage in scenario-planning exercises to evaluate the potential outcomes of different conservation actions under various future conditions. This would include sensitivity analyses to identify the most critical parameters influencing the population's viability and to assess the robustness of different management strategies. Scenarios should be designed to account for the synergistic effects of multiple threats (see section 3), including habitat degradation, climate change, and anthropogenic pressures, ensuring that the conservation actions are both comprehensive and adaptable.

A key focus of the second workshop should be the development of a coordinated habitat restoration plan that integrates mechanical oxygenation, nutrient pollution reduction, and the restoration of natural water flows. Given the critical role of ex-situ conservation as a safety net, the workshop should outline clear guidelines for the expansion of captive breeding programs and the strategic reintroduction of individuals into the wild. This would involve setting specific targets for genetic diversity, establishing protocols for the selection of founder individuals, and developing monitoring frameworks to assess the success of reintroduction efforts. The potential for re-establishing the Bathurst Harbour population, and the demographic requirements for the releases, should also be explored as part of a broader adaptive management strategy.

To ensure the long-term success of the conservation plan, the workshop could help facilitate the formation of a Stakeholder Advisory Group that includes representatives from all relevant sectors. This group would play a crucial role in guiding the implementation of the action plan, ensuring that decisions are transparent, inclusive, and supported by the broader community. Additionally, public outreach efforts should be designed to raise awareness about the Maugean skate's conservation needs and to foster a sense of stewardship among local communities.

In sum, the conservation of the Maugean skate, in Macquarie Harbour and beyond, necessitates timely and coordinated actions that address both ecological and socio-economic factors, within a collaborative framework involving all stakeholders. It is not a time to take any irreversible actions, given the dearth of current data relevant to the situation. Instead, improved monitoring and research, restoring and regulating habitats, and adopting adaptive management practices, there is scope to develop effective and sustainable strategies to protect this unique species. Ongoing commitment and comprehensive efforts are essential to ensure the long-term survival of the Maugean skate and the preservation of its critical habitat in Macquarie Harbour.