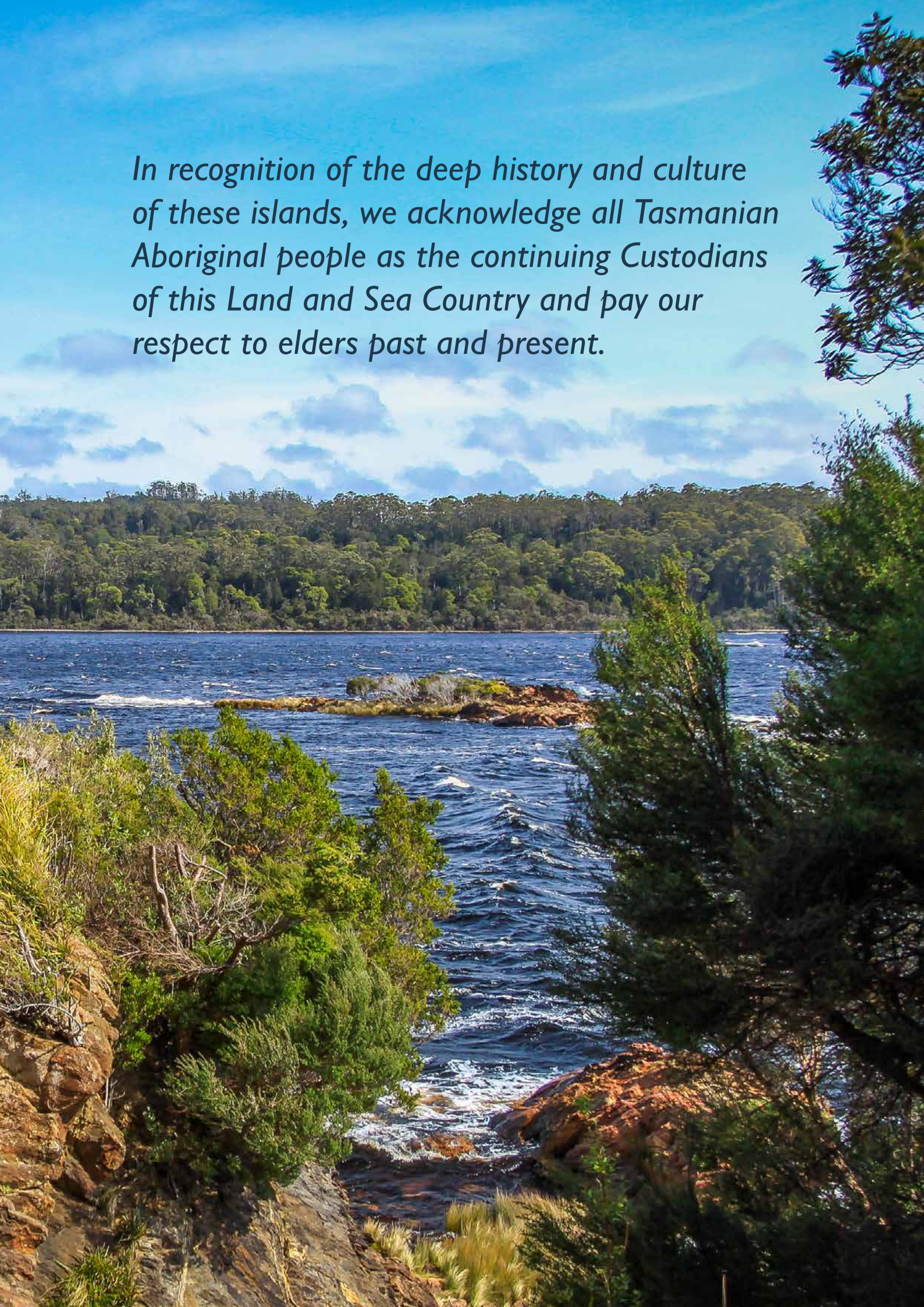
Conservation Action Plan for the Maugean skate

Department of
Natural Resources and Environment Tasmania

Tasmanian Government


In recognition of the deep history and culture of these islands, we acknowledge all Tasmanian Aboriginal people as the continuing Custodians of this Land and Sea Country and pay our respect to elders past and present.

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NRE Tas (2024) Conservation Action Plan for the Maugean Skate.
Department of Natural Resources and Environment Tasmania, Hobart, Australia.

Department of Natural Resources and Environment Tasmania
Published January 2024

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ISBN: 978-1-74380-187-1 PDF

Photo credits: Front cover - Two week old Maugean skate hatched in captivity. Red lights are used to mimic low light conditions in Macquarie Harbour, David Moreno, IMAS, 2024, Inside cover - Macquarie Harbour, NRE Tas.

Acknowledgement

The Department of Natural Resources and Environment Tasmania acknowledges the significant contribution of scientists and information custodians, industry representatives, conservation groups, Tasmanian Aboriginal people, local community members and representatives of all levels of government in working to recover the Maugean skate. The Department would especially like to acknowledge and thank members of the National Recovery Team for their advice and assistance in developing this Conservation Action Plan. Recovery Team membership is detailed in Appendix 1.

Acronyms

ABS	Australian Bureau of Statistics
ARIS	Adaptive Resolution Imaging Sonar
CAP	Conservation Action Plan
CCA NRM	Cradle Coast Authority Natural Resource Management
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DO	Dissolved Oxygen
EPA	Environment Protection Authority Tasmania
FRDC	Fisheries Research and Development Corporation
IMAS	Institute for Marine and Antarctic Studies
LiDAR	Light Detection and Ranging
NRE Tas	Department of Natural Resources and Environment Tasmania
PVA	Population Viability Analysis
RMPS	Resource Management and Planning System of Tasmania
TPDNO	Total Permissible Dissolved Nitrogen Output
TSPA	*Threatened Species Protection Act 1995*
TWWHA	Tasmanian Wilderness World Heritage Area
ZAA	Zoo and Aquarium Association (Australasia)

Introduction

The Maugean skate (*Zearaja maugeana*) is a cartilaginous fish in the skate (Rajidae) family. Its genus, *Zearaja*, comprises a small group of skates recognised for having a long snout with a quadrangular disc, dark-edged ventral pores, and claspers with extremely spatulate distal lobes (Last and Gledhill, 2007). The genus consists of only three species: the New Zealand rough skate (*Zearaja nasuta*) found in New Zealand, the yellownose skate (*Zearaja chilensis*) found in Chile, and the Maugean skate (*Zearaja maugeana*) found in Australia. It is the only species of skate in the world known to mostly inhabit brackish waters (Treloar *et al*. 2017).

Endemic to Tasmania, the Maugean skate is listed as endangered under both Tasmania's *Threatened Species Protection Act 1995* (TSPA) and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The species has also been included as a priority threatened species under the National Threatened Species Action Plan (2022-2032).

The Maugean skate has been recorded in two estuaries in southwestern Tasmania, Macquarie Harbour and Bathurst Harbour. Surveys indicate that the species is now found in extremely low numbers or no longer present in Bathurst Harbour (Moreno *et al.* 2022) and Macquarie Harbour is considered to hold the sole remaining viable population (Moreno *et al.* 2020).

Species information, including description, population trends and distribution, can be found in the Tasmanian Government's Maugean skate Listing Statement released in 2022 (NRE Tas 2022). As such ecological and species information will not be duplicated in detail in this document.

Conservation Action Plan purpose

This Conservation Action Plan (CAP) builds on the work of the Tasmanian and Australian Governments' threatened species experts and scientific advisors. In 2022 the Tasmanian Government's Maugean skate Listing Statement was released. In September 2023, the Australian Government's Department of Climate Change, Energy, the Environment and Water (DCCEEW) published updated Conservation Advice from its Threatened Species Scientific Committee. Both documents set a foundation for urgent and longer-term conservation actions and research ahead of the release of this CAP.

The CAP sets out the objectives and actions designed to support recovery of the Maugean skate and complements existing conservation planning documents for the species mentioned above. The CAP is intended to fulfil the general intent of a Recovery Plan, while retaining the capacity to be flexible, adaptive and responsive as new information becomes available.

The CAP provides a coordinated approach to identifying resources to implement priority activities, critical research and management actions.

The CAP has been prepared by the Department of Natural Resources and Environment Tasmania (NRE Tas), with input from the National Recovery Team for the Maugean Skate (the Recovery Team), published scientific data and associated local, national and international experts to support NRE Tas' Secretary in performing functions under section 7 of the TSPA. Implementation of the CAP will take place with reference to relevant legislation, including the objectives of the Resource Management and Planning System of Tasmania (RMPS).

The overarching purpose of the CAP is to outline interventions to minimise the extinction risk of the Maugean skate and to maximise the probability of recovery for the species in the wild. This purpose will be achieved through the five objectives listed below.

Conservation Action Plan objectives

The five objectives are designed to give effect to the CAP's purpose, and establish the framework for conservation action and for tracking of the impacts and effectiveness of the Plan.

Objective 1: Ensure that viable habitat in Macquarie Harbour is available to meet the needs of the Maugean skate

Continue to monitor, maintain and, where needed, improve environmental conditions in Macquarie Harbour, to provide viable habitat for a self-sustaining population of Maugean skate.

Objective 2: Establish an ex-situ Maugean skate population for future reintroduction

Act immediately to minimise the extinction risk for the Maugean skate by establishing and maintaining a captive breeding population *ex-situ*, and investigate opportunities to reintroduce skate to Macquarie Harbour or establish new populations in areas of suitable wild Tasmanian habitat.

Objective 3: Implement strategies to reduce threats to the Maugean skate population

Mitigate and manage the potential impacts caused by threats such as climate change/marine heatwaves, aquaculture, historical mining activities, hydro-electrical generation, fishing and gillnetting, and depredation of Maugean skate individuals by other species.

Objective 4: Actively engage key stakeholders, including the community, in Maugean skate conservation recovery actions

Work closely with stakeholders to identify opportunities for direct involvement in conservation actions with a particular focus on sharing learnings and promoting community participation in, benefits from, and understanding of Maugean skate conservation actions.

Objective 5: Maintain and strengthen the knowledge base for Maugean skate recovery

Coordinate the data gathering and knowledge sharing efforts of research organisations, government agencies, the aquaculture industry, environmental groups and the community to ensure that data related to Maugean skate recovery are properly curated, widely accessible and used in decision-making. This will require broadening the evidence base for conservation decision-making, including understanding of the benefits and impacts of management actions on the skate population, habitat quality, local industries and harbour users, traditional owners and the broader community. It will also require an improved understanding of long-term climate change impacts on the skate population.

Conservation Action Plan development

The need for considered management action to recover the Maugean skate has brought together a diverse range of stakeholders. Research, management and recovery actions for the Maugean skate have been determined after analysing existing research, data and knowledge provided by organisations and individuals. Between August 2022 and July 2023, a series of workshops coordinated by NRE Tas and DCCEEW analysed current science and knowledge of the environment within Macquarie Harbour and the biology, population and resource needs of the Maugean skate to consider threats and potential conservation actions for the species.

These workshops included individuals with a significant interest, or relevant technical expertise, in Maugean skate ecology, conservation planning and the environment, and social and economic values of Macquarie Harbour and included local community representatives.

Conservation management actions identified during the workshops were evaluated through an externally-led Structured Decision-Making Workshop which assessed the benefits, impacts and levels of certainty associated with actions, in relation to key objectives. The results of the Workshop were then used to inform the actions identified in the 'Conservation Actions' section below.

Technical working groups convened under the Recovery Team have consolidated and refined priority actions. The working groups have drawn on learnings from local, national and international remediation, conservation and recovery projects and expertise. They have sought to identify relevant and practical approaches to apply science; with the safety of the skate and the health of Macquarie Harbour front and centre in decision making.

The CAP also draws on existing conservation planning documents and published research including, as mentioned above, the NRE Tas Maugean skate Listing Statement (published in July 2022) and the DCCEEW Conservation Advice (published September 2023). However, there is no intention to duplicate in full the content of these documents.

Finally, the CAP is informed by the knowledge of the people of Strahan and the West Coast who have generously shared local knowledge and perspectives.

Plan review and timeframe

This CAP seeks to establish a coordinated approach to skate recovery for the next three years (2024-2026). NRE Tas will oversee the implementation of the CAP and its actions will be reviewed by the Recovery Team annually or when new information becomes available. Estimated timelines associated with conservation actions are presented in the 'Conservation Actions' section below.

Criteria for success

The CAP will be deemed successful if, within three years, the following have been achieved:

- Threats to the health of Macquarie Harbour, and specifically to the Maugean skate population, are better understood, managed and, where feasible, reduced.
- An *ex-situ* captive breeding population has been established, and:
  - a plan for reintroduction of these individuals back to Macquarie Harbour has been developed; and
  - research and planning to inform the feasibility of release of the species in other locations has been completed.
- There is increased understanding of the species' ecology and response to anthropogenic impacts.
- The Maugean skate population is being adequately monitored using sufficiently accurate methods, and the population has increased as a result of recovery actions.
- There is increased understanding of the Maugean skate and shared commitment by key stakeholders, Tasmanian Aboriginal people and other members of the community to recovery efforts and monitoring.

Distribution and habitat

The Maugean skate is found in brackish waters with individuals showing a preference for shallow channels between 5 and 15 metres in depth although they have been detected at 0.6 to more than 55 metres in depth (Bell *et al.* 2016). Waters preferred by the species generally have relatively stable temperatures (12–15 °C) and salinity (18–27 ppt), and naturally low-moderate dissolved oxygen concentrations (40–80% dissolved oxygen) (Bell *et al.* 2016; Morash *et al.* 2020). The species is more active at night using a broader range of waters to forage. Egg capsules have been detected across a wide range of depths (2.5–30 m).

The species has been recorded in only two estuaries in west and south-western Tasmania. These are Bathurst Harbour in the South-West National Park and Tasmanian Wilderness World Heritage Area (TWWHA), and Macquarie Harbour on the West Coast, adjacent to the township of Strahan, part of which is also located inside the TWWHA. Only four records of the species have been confirmed from Bathurst Harbour, with the last record from this location occurring in 1992. This is despite multiple surveys conducted between 1992 and 2016 (Last and Gledhill, 2007; Treloar *et al.* 2016). While there are anecdotal reports of Maugean skate individuals from elsewhere in Tasmania, no confirmed specimens have been recorded from waters outside these two harbours.

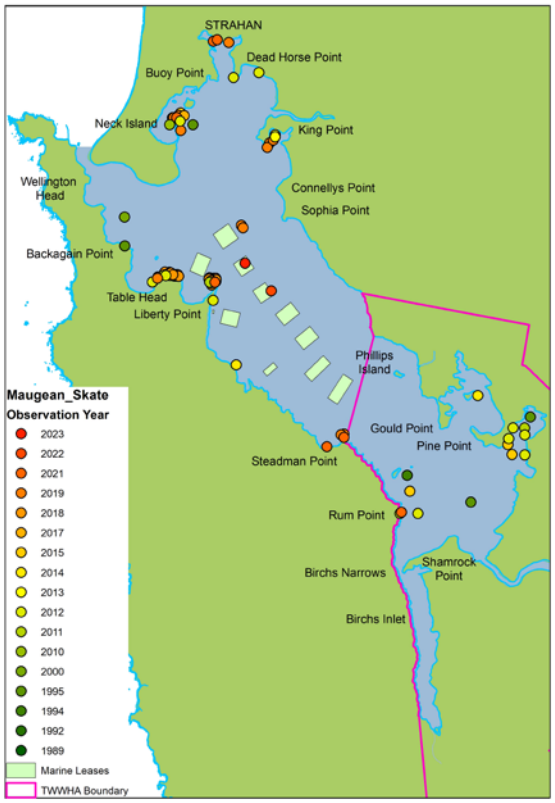

Figure 1: Map of Macquarie Harbour with locations of Maugean skate observations as recorded in the Natural Values Atlas (source NRE Tas).

Figure 2: Map of Bathurst Harbour with locations of Maugean skate observations as recorded in the Natural Values Atlas (source NRE Tas).

Macquarie Harbour

Macquarie Harbour is a large estuarine system of approximately 281 km^2, with complex hydrodynamics and variable environmental conditions. The harbour has a deep central basin with a shallow, narrow entrance. Freshwater in-flows are highly variable and enter the harbour from two major catchments, the Gordon River and the King River.

The Macquarie Harbour aquatic ecosystem is highly stratified, with a freshwater, tannin-rich top layer, brackish mid-layer and deep waters which are close to marine salinity (EPA 2017). In combination, these features mean that there is limited exchange of the deeper harbour waters with the ocean, which leads to naturally low levels of oxygen in harbour depths and mid-layers (Wild-Allen *et al.* 2020). While natural oxygen levels in the harbour have historically been highly variable, monitoring data indicates that anthropogenic uses of the harbour and catchments, including aquaculture and upstream hydro-electric power generation, also influence dissolved oxygen (DO) concentrations. Monitoring data indicates that around 2009, DO concentrations commenced a period of significant decline. While some signs of improvement have been observed in recent years, DO concentrations remain well below 2009 levels (Ross *et al.* 2022).

Figure 3 shows average DO levels at various depths recorded in Macquarie Harbour from 1993 through to 2023. Of note is that while the surface oxygen levels (0 - 5 meters) remain relatively constant due to wind and wave churning and riverine flows, the lower levels of the water column show declining oxygen levels from 2009 reaching very low levels in 2013. The graph may indicate some slight improvement in the DO levels within the lower harbour levels from 2017.

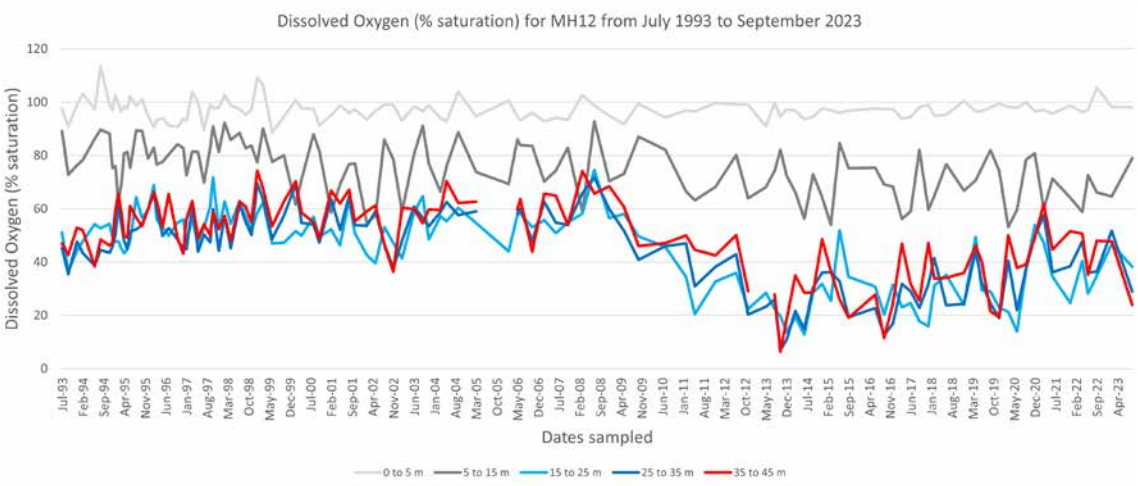

Figure 3: Dissolved oxygen levels at various depths in the water column from 1993 to 2023 (source EPA).

In fjord-like estuaries, such as Macquarie Harbour, DO levels and distribution are complex, variable and driven by the combined effects of river flow, tidal exchange, oceanic deep-water renewal, wind, organic loading, and microbial processing in the sediments and water column (Edwards and Edelsten 1977; Maxey *et al.* 2020; Maxey *et al.* 2022).

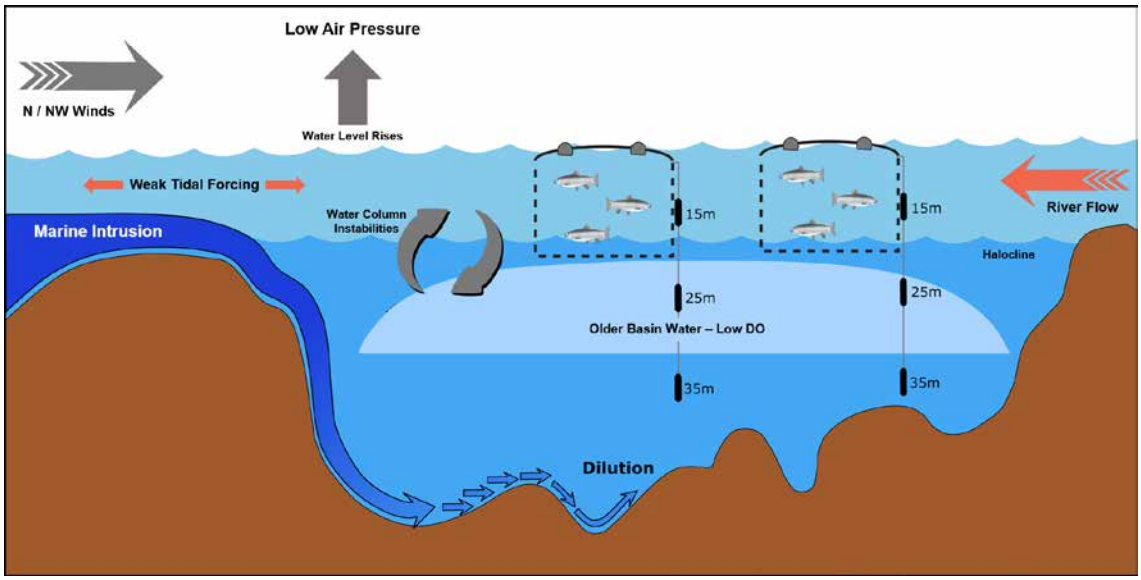

Figure 4: Conceptual model highlighting the drivers of deep-water renewal in Macquarie Harbour (Hartstein *et al.* 2019).

Climate change is likely to be causing higher water temperatures. High water temperatures are a threat to skate recruitment and survivorship, and may compound reduced DO levels since warmer waters hold less oxygen. The mean temperature of Macquarie Harbour's bottom waters increased by approximately 1.5 – 2°C from 1993 to 2020 (Ross *et al.* 2022).

Bathurst Harbour

Bathurst Harbour is a large, shallow (maximum depth of 10 m), fully mixed estuary. The Bathurst Channel that connects the harbour to Port Davey is permanently stratified and up to 50 m deep (Last and Gledhill 2007). DO levels in Bathurst Harbour are naturally higher than in Macquarie Harbour (Moreno *et al.* 2022). No hydro-electric power generation or upstream mining currently occurs in tributaries entering Bathurst Harbour, and no aquaculture operations occur in the area. In addition, the area has been subjected to very limited historical and modern recreational and commercial fishing pressure.

The Maugean skate has been recorded from Bathurst Harbour but relatively little is known about the species' past presence or abundance in this location. Only four individuals are confirmed to have come from Bathurst Harbour, with the species not having been recorded since 1992. It is now thought to be extinct, or to occur in very low numbers, at this location despite very low levels of anthropogenic impact. Conversely, Macquarie Harbour has been subject to a variety of anthropogenic impacts over the past century.

Gillnet and other surveys have been used in Bathurst Harbour to sample skate populations. A recent environmental-DNA (e-DNA) survey of the harbour undertaken in 2022 by the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS) detected a presence of skate e-DNA at very low levels (Moreno *et al*. 2022). Explanations for the low traces of Maugean skate DNA are: very few individuals exist in Bathurst Harbour; latent DNA is left over in the sediments from biological material, such as egg cases; or the Maugean skate is rare and transient within the system (not considered likely) (Moreno *et al*. 2022).

It is possible that with further investigation Bathurst Harbour and other similar estuaries in the TWWHA may prove to be suitable locations for the reintroduction of captive-bred individuals.

Population

IMAS currently monitors Maugean skate in Macquarie Harbour in quarterly surveys using monofilament gillnets. Survey efforts using this technique have been ongoing since 2012. The sampling protocol for collecting skates has been modified over this time to reduce the risk of skate mortality (noting that this monitoring work requires a permit under the TSPA and the *Living Marine Resources Management Act 1995*).

e-DNA, remote operated vehicles, tow cameras, dive transects, and baited remote underwater video have also been used to survey the population in both Macquarie Harbour and Bathurst Harbour. However, there are considerable logistic and resourcing considerations that currently limit the feasibility of applying these techniques in routine monitoring (Moreno and Semmens 2023).

Survey methods using Light Detection and Ranging (LiDAR) and Adaptive Resolution Imaging Sonar (ARIS) technologies have been investigated. ARIS in particular has potential advantages over gillnet surveys (e.g. lower risk of impacts to skate, increased efficiency and accuracy).

In 2014, the Macquarie Harbour sub-population was estimated, with a high degree of uncertainty, to be 3,200 individuals (Bell *et al*. 2016). Noting the uncertainty associated with the 2014 data, recent research estimates that a decline in relative abundance of the species in Macquarie Harbour of up to 47% occurred between 2014 and 2021 (Moreno and Semmens 2023).

A Population Viability Analysis (PVA) has recently been undertaken for the species (Grant *et al*. 2023). The PVA estimated a best-case scenario of a population decline of 89% by 2041 and worst-case scenario of > 99% decline, including extinction probabilities of greater than 25% by 2041 for some scenarios of environmental decline.

Uses and Impacts on Macquarie Harbour

The conditions in Macquarie Harbour have changed markedly since the 1800s, influenced by activities in and around the estuary including mining, hydroelectricity generation, marine farming operations, fishing, and the effects of climate change (Moreno and Semmens 2023). Figure 5 provides a summary of key historical and contemporary harbour uses and activities, together with notable climatic and other events that may have impacted the skate population within Macquarie Harbour.

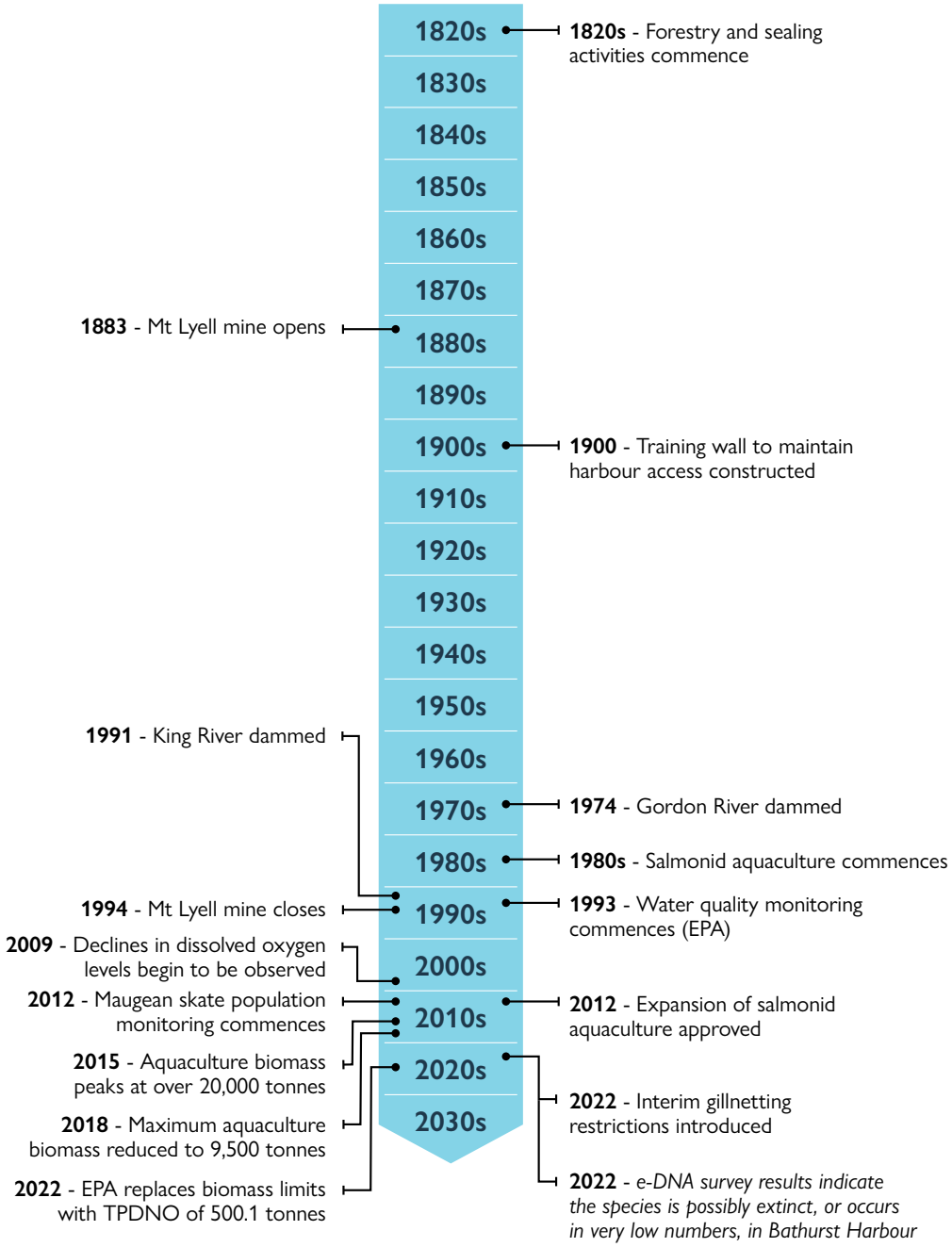

Figure 5: Timeline of events in Macquarie Harbour

Aquaculture

Aquaculture activities in Macquarie Harbour are an important contributor to the region's community and economy. The industry is a key employment provider in the West Coast Council area. Aquaculture began in Macquarie Harbour in the late 1980s. From 2005, the industry expanded, reaching a maximum standing biomass peak of over 20,000 tonnes in 2014-15. Environmental monitoring has shown a corresponding decrease in harbour water quality commencing around 2009, including reductions in DO concentrations (Ross and Macleod 2017). As a result of a significant decline in seabed ecosystem health in 2016, the standing biomass limit for the harbour was progressively lowered by the EPA from early 2017, culminating in a standing biomass cap of 9,500 tonnes in 2018 (EPA 2022).

In 2022, the EPA began regulating salmonid production in Macquarie Harbour through a cap on dissolved nitrogen outputs in place of standing biomass caps. A nitrogen cap provides better control over feed inputs, which are more closely related to overall environmental impact. The resulting Total Permissible Dissolved Nitrogen Output (TPDNO) of 500.1 tonnes represents a reduction of dissolved nitrogen output of approximately 60% compared to 2014-15 peak levels (EPA 2022). The Statement of Reasons for the 2022 TPDNO determination is available on the EPA website at Statement of Reasons - TPDNO Determination - 1 September 2022 to 31 August 2027.pdf (epa.tas.gov.au).

Feed provided to farmed fish increases nutrients available in the water column. Nutrients are then taken up through the primary production cycle, which consumes oxygen. DO can be recharged though atmospheric and hydrodynamic processes. However, the time taken for these processes to take effect and the extent and nature of impact is dependent on a number of variables. Any change to aquaculture operations or stocking rates needs to consider animal welfare, length of the salmon production cycle, biosecurity issues and operational and logistical constraints.

The EPA has developed dissolved oxygen targets, which are published as Interim Default Guideline Values for Macquarie Harbour to guide remediation work. These targets use data from 1993-2009 to define preferred oxygen conditions in surface, mid, and bottom waters, across three different regions of the harbour.

Hydroelectricity generation

The major freshwater inputs into Macquarie Harbour, the Gordon and King Rivers, are both used for hydro-electric power generation. Hydro Tasmania's catchment area represents 70% of the overall catchment area of the King River catchment and 35% of the overall catchment area of the Gordon River catchment. John Butters Power Station lies 20 km upstream of the harbour and discharges into the King River, which receives unregulated inputs from the Queen River before entering the harbour. The Gordon Power Station lies more than 75 km upstream of the harbour, and significant inflows are received from major tributaries downstream (Franklin, Denison, Maxwell, others) of the power station.

River inflows influence the degree to which high DO oceanic waters enter the system. Low river flows are thought to facilitate entry of oceanic water into the harbour at certain times of the year, however, the relationship between river in-flows and entry of oceanic water, and the resulting effects on DO, are complex and timescale dependent, and are also influenced by other factors, including weather events and tides (Wild-Allen *et al.* 2020; Ross *et al.* 2022).

Operation of the Gordon and John Butters Power Stations is dependent on multiple factors, many of which are difficult to predict, including inflows to other catchments across the State used for generation of hydroelectricity, wind and solar generation, electricity demand and the National Electricity Market. The operation of the Gordon Power Station in itself does not cause low DO water to enter the harbour, as water released from the turbines is reoxygenated shortly after discharge, due to high flow velocities and turbulence in the middle Gordon River (Locher 2001).

Mining

The Mount Lyell Copper Mine was established in the 1890s in the King River catchment (Stauber *et al.* 1996) and has been important to the West Coast economy and community. Run-off from historical mining activities has led to reduced water quality and high levels of heavy metal contamination within the sediments of the harbour (Koehnken 1996). Since 1995 mine operation includes containment of mill tailings in a tailings dam, and some management of acid mine drainage from the site. The mine is currently under care and maintenance, pending potential reopening. While the flow of heavy metal pollutants into the Queen and King Rivers which discharge into Macquarie Harbour has decreased substantially over time, input of heavy metals into the harbour continues at a reduced rate in association with weather events and water run-off. The EPA monitors heavy metal concentrations in the harbour, results of which indicate a gradual decrease in historic levels of some heavy metals, including copper, over time. There is no direct evidence on the threat presented by heavy metals to the Maugean skate. Heavy metal pollution has been linked to decreased reproductive success in other elasmobranchs (Tiktak *et al.* 2020).

Fishing

Both recreational and commercial gillnetting occur in Macquarie Harbour, and recreational line-fishing also occurs. Gillnetting is historically important in this region due to the lack of accessible sea fisheries and the limited opportunities for line-fishing due to the nature of the harbour.

Changes to rules and fisher education programs have occurred over recent years after considerable consultation. In November 2022, NRE Tas implemented interim measures to reduce the likelihood of incidental bycatch of Maugean skate from fishing activities. These interim measures were formalised through statutory rules with effect from 1 November 2023. NRE Tas has prohibited take of any species of skate in Macquarie Harbour, including those caught by line-fishers.

For recreational gillnetters, measures included additional spatial closures in important areas of skate habitat, a two-hour maximum soak time for gillnets, and a prohibition on overnight netting to reduce risks to skate of depredation by sea lice, crabs and other species.

Commercial gillnetting in the harbour is limited to two licence holders. Commercial gillnetters are subject to the same area closures as those for recreational gillnetters. Commercial gillnetters are permitted to set nets overnight, but under the measures introduced, are subject to a seasonal closure at times of the year (late Spring to mid-Autumn), when the Maugean skate is considered most at risk from fishing activities.

The NRE Tas Recreational Sea Fishing Strategy 2021-2030 outlines a transition away from recreational gillnetting by 2030 across the State.

A range of educational materials about the Maugean skate has been produced, including information signage at the Strahan boat ramp, information included in the annual State Government *Recreational Sea Fishing Guide*, and through education and awareness activities delivered through NRE Tas community engagement programs and by the local Cradle Coast Authority Natural Resource Management organisation (CCA NRM).

Cultural significance and community engagement

Approximately one third of the area of Macquarie Harbour is located within the boundary of the TWWHA. The TWWHA is recognised through the World Heritage Convention as having both cultural and natural heritage of Outstanding Universal Value, the protection of which is of global importance for present and future generations. Tasmanian Aboriginal sites identified within the region highlight the cultural significance of the TWWHA.

There is no known published information on how Tasmanian Aboriginal people relate to Maugean skate and what this may mean for the cultural significance of the species. Ascertaining the cultural significance of the species is an important conservation and recovery action and will require further consultation and engagement with the Tasmanian Aboriginal people to ensure traditional knowledge and management practices are incorporated into conservation efforts.

The 2021 Census indicates the total population of the West Coast Local Government Area is 4,263. Key employers in the area include mining accounting for more than one third of all jobs, tourism related industries and aquaculture (ABS 2021).

The people of the West Coast have shown a long-term interest and willingness to share local knowledge and participate in citizen science and recovery actions for the Maugean skate. A series of meetings were held in Strahan and Queenstown during 2023 to better understand the varying views, interests and impacts across the West Coast community. Broader discussions were had, which are important and will inform actions of government but are outside the scope of this CAP. Overall, the sentiment of the community was "nothing about us without us" – the notion that actions should be carried out with the participation of members of the community who are directly impacted. The CCA NRM project to showcase the uniqueness of the Maugean skate and the threats it faces has been raising the profile of the species in partnership with the local community.

Direct Threats to Maugean skate

Table 1: Priority known and potential threats for the Maugean skate, based on available evidence. Interactions occur between the major threats and may lead to cumulative impacts to the skate.

Threat	Description	Evidence	Impact
Reduced water quality in Macquarie Harbour - in particular substantially reduced DO levels.	Macquarie Harbour is naturally low in DO and has also been impacted by historical and ongoing anthropogenic activities, including expansion of aquaculture and changes in river flows due to generation of hydroelectricity and leachate from mining operations (Koehnken 1996; Ross *et al.* 2022). The substantially reduced DO levels in Macquarie Harbour in recent years have also been attributed to the decomposition of high levels of organic matter in the water column (Ross and Macleod 2017). Water temperature and salinity also affect skate habitat use and physiology, including through the reduced solubility of oxygen in water as temperature increases (Moreno *et al.* 2020; see Climate Change below). Environmental monitoring shows that DO levels in middle and bottom waters underwent a significant decline beginning around 2009. Trends then showed signs of a gradual improvement from about 2017, and remain low compared to pre-2009 levels (see Figure 3).	Moreno *et al.* (2020) observed mortality of skate individuals attributed to low DO concentrations and warm water temperatures. Deep water recharge events bring oxygen-rich water over the sill into the basin, replenishing deep water oxygen levels (MHDOWG 2014; Hartstein *et al.* 2019; Ross *et al.* 2020). Oceanic deep water renewal events are influenced by wind speed and direction, atmospheric pressure, tidal events and freshwater river flows (Maxey *et al.* 2022).	Known. Reduced DO in Macquarie Harbour is a significant threat to the Maugean skate. While the species has high tolerance to changes in DO concentrations, salinity and temperature, changing environmental conditions (particularly over relatively short timeframes) can cause behavioural responses, physiological stress, and can result in mortality of adult skate. Changes to water quality also have the potential to reduce survival rates for skate eggs and juveniles (Moreno *et al.* 2020).

Table continues

Threat	Description	Evidence	Impact
Climate change, warming waters and the occurrence of extreme weather events	Climate change and the occurrence of extreme weather events directly influence water quality in Macquarie Harbour, including through higher water temperatures causing reduced DO levels, changes to freshwater flows into the harbour, and extreme weather events leading to inversion of the harbour water column and changes to DO levels at the skate's preferred depth (Moreno *et al.* 2020) of between 5 and 15 metres.	Moreno *et al.* (2020) observed mortality of skate individuals attributed to low DO concentrations and warm water temperatures. The mean temperature of Macquarie Harbour's bottom waters has increased by approximately 1.5 – 2 °C from 1993 to 2020 (Ross *et al.* 2022). Another significant heatwave event is predicted for the 2023-24 summer (CSIRO 2023). Climate change predictions for the west coast of Tasmania suggest that there will be greater and more intense rainfall in the winter and lower rainfall in summer after 2050 (Grose *et al.* 2010).	Known. Higher water temperatures reduce oxygen solubility, and climate change is likely to contribute to other changes to water quality in Macquarie Harbour given the influence climate and weather events have on environmental conditions in the Harbour (eg, through influence on river in-flows). Increased temperatures may also impact skate directly through behavioural changes and physiological stress.
Incidental bycatch from fishing activities in Macquarie Harbour	Both recreational and commercial gillnetting occur in Macquarie Harbour. Maugean skate ecology and feeding behaviour may exacerbate the risk of incidental capture by gillnets in some circumstances, because the Maugean skate is more likely to use shallow areas where gillnetting occurs in response to physiological stress, and also appear to be more active at night when many gillnets are set (Moreno *et al.* 2020).	The Maugean skate is particularly susceptible to capture in gillnets, with mortality associated with long soak times and related depredation by whitespotted dogfish, crabs (including introduced species) and sea lice (Lyle *et al.* 2014; see 'predation and depredation' below).	Known. While mortality of Maugean skate caught in gillnets has been observed (Lyle *et al.* 2014), current catch rates and post-release survival rates for Maugean skate in Macquarie Harbour are not known.

Table continues

Threat	Description	Evidence	Impact
Incidental bycatch from fishing activities in Macquarie Harbour *continued*	Recreational line-fishing also occurs in Macquarie Harbour and presents a potential threat to Maugean skate due to the potential for post-release mortality. However, this fishing method is considered to present a lower relative risk to the species, because it is a less effective method of capture than gillnets, and considered less likely to expose skate to depredation.		Gillnetting measures (see 'Fishing' section) are expected to reduce the likelihood of skate mortality from fisher interactions. However, the potential for gillnetting activities to impact the skate population remains.
Predation and depredation	'Predation' is used here to refer to events relating to free-ranging Maugean skate or their eggs, while 'depredation' refers to predator-prey interactions which occur as a result of a Maugean skate being immobilised or injured (e.g. when caught in a gillnet).	Depredation by sea lice, crabs and whitespotted dogfish is a known cause of mortality for Maugean skate caught in gillnets (Lyle *et al.* 2014). There is no evidence to suggest that sea lice have an impact on free-ranging skate individuals or their eggs. Seals are present in Macquarie Harbour and predation and/or depredation of Maugean skate is possible, however, no confirmed instances have been observed. There is also potential for crabs and other benthic fauna to predate on Maugean skate eggs (Moreno *et al.* 2020), particularly given there is anecdotal evidence for an increase in the abundance of the introduced crab *Carcinus maenas*, in the harbour.	Uncertain. There is currently no evidence to suggest that predation is having a significant impact on the Maugean skate population. The impact of depredation is also uncertain, given that current catch rates and post-release survival rates for Maugean skate caught by fishers in Macquarie Harbour are not known.

Table continues

Threat	Description	Evidence	Impact
Heavy metals pollution	Historical mining activities in the King River catchment have led to elevated levels of heavy metals in Macquarie Harbour (Koehnken 1996). There is potential for heavy metals to decrease reproductive success and contribute to degradation of skate habitat in the harbour (NRE Tas 2022).	While there is no direct evidence on the threat presented by heavy metals to Maugean skate, heavy metal pollution has been implicated in decreased reproductive success of other elasmobranchs (Tiktak *et al*. 2020).	Uncertain. This is the subject of further research.
Genetic diversity and stochastic (random) risk	Species with limited genetic diversity have reduced capacity to adapt to changing ecological conditions. Species with small populations and limited geographic distributions and/or number of subpopulations are at increased risk of extinction due to stochastic events.	The Maugean skate is identified as at increased risk of extinction due to low genetic diversity, a small population size and as now only known to occur in one location (Weltz *et al*. 2018).	Uncertain. Any impact is likely to be amplified if the population continues to decline.

Priority Conservation Actions

This section outlines priority conservation actions identified during the conservation planning process.

The presented list of actions is derived from the full suite of potential actions identified during the series of workshops described earlier. The conservation planning process was not always able to achieve consensus amongst participants on the priority conservation actions. Consequently, consistent with the overarching purpose of this CAP to minimise the extinction risk of the Maugean skate and to maximise the probability of recovery for the species in the wild, NRE Tas has included priority conservation actions based on:

- immediate conservation interventions – including research, monitoring and community engagement activities – that are needed to prevent the extinction of the species and establish the foundation for longer term recovery.
- population size and trends for the species which indicate that every skate individual is important in increasing the probability of recovery.
- accepting that some economic and social impacts may be unavoidable if extinction of the species is to be prevented. However, consistent with the objectives of the RMPS, the priority conservation actions aim to minimise such impacts where possible.

Descriptions of indicative costs and priority ratings are included in Tables 2 and 3 respectively. Priority Conservation Actions are detailed in Table 4.

Table 2. Indicative costs for conservation actions

Costs are estimated over a three to five-year period, recognising that some costs will be incurred on an ongoing, per annum basis, while others will be one-off costs (e.g. capital costs).

Indicative costs	
Low	< $200,000
Medium	$200,000 – $2,000,000
High	> $2,000,000

Table 3. Action priority/timeframe ratings

The priority and timeframe for conservation actions is summarised as current, (in recognition of the significant work program underway), as well as short, and medium to long-term.

Priority / timeframe ratings	
Current	Action is currently in progress or imminent
Short-term	Action begins within 1 year of CAP publication
Medium to long-term	Action begins between 1 and 5 years from CAP publication

Table 4. Priority Conservation Actions

Action	Timeframe	Involved groups	Cost	Status
Objective 1: Ensure that viable habitat in Macquarie Harbour is available to meet the needs of the Maugean skate				
Amend the Marine Farming Development Plan to refer to Environmental Standards for Marine Finfish farming, and vary Environmental Licence conditions to incorporate these Standards to adaptively consider: • oxygen demand monitoring. • reduction of oxygen demand over time. • shorter licence timeframes to enable adaptive review and adjustment of conditions.	Current	State Government (EPA, NRE Tas)	Low (implementation) Potentially High (socio-economic depending on conditions).	In progress
Investigate and trial engineering solutions in Macquarie Harbour to effectively increase supply of DO. Steps include: • international scan of technology options. • planning and approval of pilot study to trial technology. • implementation of pilot study, including monitoring and assessment of effectiveness in increasing DO concentrations and any adverse impacts.	Current	Salmon industry, IMAS, State Government including EPA (permitting, DO optimal levels), Australian Government, Local Government, Fisheries Research and Development Corporation (FRDC)	Low (investigate options) High (implementation)	In progress
Further investigate options to reduce or offset oxygen demands, or to supplement oxygen levels, in Macquarie Harbour, which may include injection and mixture of buoyant water into Macquarie Harbour depths, injection of oxygen using or adapting method trialled in pilot study, and engineering options to increase the capacity of marine water to enter the harbour. Selection of options will take into account:	Short-term	State Government, Australian Government, Local Government, EPA, Salmon industry, IMAS, FRDC	High	Further investigation planned by Recovery Team, implementation dependent on results of investigation and pilot study described above.

Table continues

Action	Timeframe	Involved groups	Cost	Status
Objective 1: Ensure that viable habitat in Macquarie Harbour is available to meet the needs of the Maugean skate (continued)				
• results of oxygen injection pilot study. DO levels within Macquarie Harbour and variance from DO targets. • identification and mitigation of potential environmental impacts (including exploring transition to renewable energy sources). • approvals. • cost benefit analysis of options. • analysis of expected benefits to Maugean skate recovery.				
Assess and model the role of hydropower-generated flows in the DO dynamics of Macquarie Harbour and investigate options for adjusting hydro-electric water flows in the Gordon and King Rivers to facilitate entry of high DO marine water into the harbour (i.e. oceanic recharge), including assessment of any opportunistic changes to river flows in late 2023 and early 2024.	Current (investigation of options)	Hydro Tasmania, State Government, CSIRO	Low (investigation of options)	In progress (investigation of options)
Develop, implement and operationalise options for adjusting hydro-electric water flows in the Gordon and King Rivers to facilitate entry of high DO marine water into Macquarie Harbour (i.e. oceanic recharge) informed by real-time hydrodynamic modelling of the harbour. Requires an assessment of risks to other threatened species at other operational sites and integration with other harbour uses.	Medium to long-term (implementation of options)	Hydro Tasmania, State Government, CSIRO	High. Cost of implementing options not yet known. Further assessment required in relation to impacts on power generation.	To be assessed
Develop an integrated spatial model of habitat dynamics in Macquarie Harbour to better understand the available habitat for skate, their physiology and their prey availability under various seasonal conditions and particularly in periods of environmental stress (e.g. marine heatwaves).	Medium	State Government, CSIRO, IMAS	Medium	To be assessed

Action	Timeframe	Involved groups	Cost	Status
Objective 2: Establish an ex-situ Maugean skate population for future re-introduction				
Initiate captive breeding trial utilising existing IMAS facilities, including: • securing relevant permits and approvals. • collection of eggs from Macquarie Harbour with the intent to rear in captivity. • removal of a small number of adult skate individuals from Macquarie Harbour to establish an insurance population. • temporary holding of females to support collection of eggs. • development of accompanying husbandry, welfare and biosecurity protocols and procedures.	Current	IMAS, ZAA, Tasmanian Aboriginal people, CCA NRM, State Government, Australian Government, Local Government	Medium	In progress
Explore managed reproduction technologies for the species, including genetic monitoring and assisted reproduction, informing decisions to enhance conservation strategies.	Short-term	IMAS, CSIRO	High	Planned
Establish additional, self-sustaining captive breeding sub-populations in Tasmania. Incorporate investigation of the feasibility of breeding and holding facilities in Strahan or other non-Tasmanian locations.	Short-term	IMAS, ZAA, Tasmanian Aboriginal people, CCA NRM, State Government, Australian Government, Local Government, CSIRO	High	Planned
Reintroduce captive-bred Maugean skate individuals into Macquarie Harbour, dependent on status and trends of existing sub-population and presence of suitable habitat and environmental conditions.	Medium to long-term	IMAS, ZAA, Tasmanian Aboriginal people, CCA NRM, State Government, Australian Government, Local Government	To be assessed	To be assessed

Table continues

Action	Timeframe	Involved groups	Cost	Status
Objective 2: Establish an ex-situ Maugean skate population for future re-introduction (continued)				
Investigate opportunities to establish new Maugean skate sub-populations in the wild, by translocating captive bred individuals to other areas if the habitat is found to be suitable (e.g. Bathurst Harbour, New River Lagoon), including in areas with the potential to act as refuges from the impacts of climate change and extreme weather events. May include habitat suitability assessments and investigation into Bathurst Harbour sub-population.	Medium to long-term	IMAS, ZAA, Tasmanian Aboriginal people, CCA NRM, State Government, Australian Government, Local Government, CSIRO	To be assessed	To be assessed

Action	Timeframe	Involved groups	Cost	Status
Objective 3: Implement strategies to reduce threats to the Maugean skate population				
Introduce new fishing restrictions through the *Living Marine Resources Management Act 1995*.	Current	State Government	Low	In progress
Increase awareness of best practice catch handling and release for recreational line-fishers to optimise post-release survival from incidental bycatch.	Short-term	State Government, Local Government, West Coast community groups	Low	Planned
In consultation with the community, develop a timeline and process for bringing forward the planned ban of recreational gillnetting in Macquarie Harbour to ensure the urgent cessation of the activity and reduce the potential for skate mortality due to depredation and post-release stress.	Short-term	State Government, Local Government, West Coast community groups	Low	To be assessed

Table continues

Action	Timeframe	Involved groups	Cost	Status
Objective 3: Implement strategies to reduce threats to the Maugean skate population continued				
In consultation with commercial licence holders, develop a timeline and process for the urgent cessation of commercial gillnetting in Macquarie Harbour to reduce potential for skate mortality due to depredation and post-release stress.	Short-term	State Government, Local Government, West Coast community groups	Low	To be assessed
Support increased Tasmania Police and NRE Tas Fishery Officer presence on the harbour to monitor compliance.	Current	State Government	Low	In progress
Implement Marine Finfish Environmental and Technical Standards to protect and maintain environmental values and the ecological character of Macquarie Harbour including water quality investigative trigger values and monitoring of sensitive habitats as part of the broadscale monitoring program. Environmental Standards for Tasmanian Marine Finfish Farming 2023	Current	EPA	Medium	In progress
Continue to manage the potential impacts of heavy metals already occurring in the harbour as a legacy of historical mining activities, by avoiding disturbance of the benthic sediments – including potential impacts related to the oxygenation pilot project.	Current	State Government (including EPA), Local Government	Low	In progress
Continue to monitor, as part of routine testing, ongoing releases of heavy metal pollutants occurring as a legacy of historical mining activities, to minimise the amount of heavy metals entering the harbour and the potential for remobilisation of currently stable tailings waste.	Medium to long-term	State Government (Mineral Resources Tasmania, EPA), Local Government	Medium to High	To be assessed

Action	Timeframe	Involved groups	Cost	Status
Objective 4: Actively engage key stakeholders, including the community, in Maugean skate conservation recovery actions				
Establish a dedicated Maugean skate recovery action webpage that serves as the principal online focus for sharing and reporting progress on recovery activities and as a gateway to related pages maintained by other partner organisations e.g. NRE Tas, IMAS, FRDC.	Short-term	CCA NRM, Recovery Team	Low	In progress
Investigate impacts and benefits to the West Coast community from conservation actions, including engagement of social science expertise in conservation planning.	Short-term	CCA NRM, IMAS, West Coast community groups, State Government, Local Government	Medium	In progress
Collaborate with and engage Tasmanian Aboriginal people in recovery actions, including but not limited to: • removal of Maugean skate individuals or eggs from Macquarie Harbour for captive breeding program. • potential translocation of captive bred individuals to areas of suitable habitat. • Public education about the cultural values of skate and the Macquarie Harbour ecosystem. • opportunities for on-country conservation planning.	Current	Tasmanian Aboriginal people, CCA NRM, State Government, Local Government, Australian Government, research institutions	Low	In progress
Recognise Tasmanian Aboriginal cultural knowledge and the potential significance of Maugean skate and related species and collaborate on activities to maintain and share such knowledge, where appropriate.	Short-term	Tasmanian Aboriginal people, CCA NRM, State Government, Local Government, Australian Government, research institutions	Low	Planned

Table continues

Action	Timeframe	Involved groups	Cost	Status
Objective 4: Actively engage key stakeholders, including the community, in Maugean skate conservation recovery actions (continued)				
Maintain and expand community involvement in the species recovery program including citizen science (e.g. skate monitoring app below), co-design and knowledge sharing, information sessions and education resources.	Current	CCA NRM, IMAS, West Coast community groups, State Government, Local Government, Australian Government	Medium	In progress
Encourage the use of existing apps that will enable harbour users to report both skate presence and related environmental information that will assist to better understand skate behaviour and distribution.	Short-term	Tasmanian Aboriginal people, community members, fishers, State Government, Local Government, CCA NRM, research institutions	Low	Planned

Action	Timeframe	Involved groups	Cost	Status
Objective 5: Maintain and strengthen the knowledge base for Maugean skate recovery				
Continue to monitor the current population status of the skate (abundance, trends, and age structure) using quarterly gillnet surveys, and/or other monitoring techniques, to provide the evidence base to make conservation planning decisions and assess the effectiveness of implemented conservation actions.	Current	IMAS	Medium	In progress
Continue to investigate and implement, where appropriate, additional population monitoring methods such as ARIS and close-kin mark recapture population analysis.	Current	IMAS, CSIRO	Medium	In progress
Continue environmental monitoring in Macquarie Harbour and investigate opportunities to consolidate and optimise monitoring effort, including: • identification of duplication. • location, quality and diversity of sensors. • ensuring data is fit for purpose and relevant to future decision-making related to Maugean skate recovery. • continued monitoring and regulation of processes not currently considered to significantly contribute to reduced water quality (e.g. TasWater sewerage inputs, minor marine heatwaves or seasonal weather variations).	Short-term	State Government (including EPA), IMAS, CSIRO, Hydro Tasmania, Salmon industry	Low	Planned

Table continues

Action	Timeframe	Involved groups	Cost	Status
Objective 5: Maintain and strengthen the knowledge base for Maugean skate recovery (continued)				
Undertake quarterly monitoring of physio-chemical, nutrient and heavy metal data at 15 additional sites throughout Macquarie Harbour, including: • comparing data to long-term datasets for sites monitored since 2013 (oxygen logger) and 1993 (quarterly water sampling). • providing monitoring coverage for a longitudinal section along the deepest part of Macquarie Harbour. • deploying additional logger instrumentation within the TWWHA. • investigation of areas on the western side of the harbour for deployment of three additional sets of data logging equipment.	Current	EPA, CSIRO	Medium	In progress
Re-initiate Oxygen Process Modelling for Macquarie Harbour, and incorporate additional modelling to predict: • habitat suitability and impacts to suitability with changes in DO. • DO dynamics under contrasting hydro-electric flow management and various marine heatwave scenarios. • catchment in-flows, including timing preferences for predicted dam releases. • impacts of climate change and prolonged marine heatwaves. • impacts of nutrient loading on DO including impact of offsetting oxygen demand through mechanical oxygenation processes.	Current	CSIRO, State Government, Hydro Tasmania, Bureau of Meteorology, Salmon Tasmania	Medium	In progress

Table continues

Action	Timeframe	Involved groups	Cost	Status
Objective 5: Maintain and strengthen the knowledge base for Maugean skate recovery (continued)				
Improve the understanding of Maugean skate physiology and environmental thresholds and preferences within Macquarie Harbour, including determining: • the effect of different environmental characteristics, such as DO, temperature, salinity across all life stages of the species. • how reproductive success, egg survival and recruitment are being affected by environmental pressures.	Short-term	IMAS, CSIRO	Medium	In progress
Improve the understanding of ecological preferences and threats, including: • distribution and abundance of preferred prey species in Macquarie Harbour and prey dynamics under various environmental conditions. • impacts of changing environmental conditions and reduced water quality on prey.	Current	IMAS	Low	In progress
Collate, independently review, and update scientific data as new information or technologies become available, including the option of incorporating artificial intelligence (to optimise data gathering, model recovery scenarios, etc).	Medium-term	State Government, IMAS, CSIRO	Low	Planned
Conduct an annual Maugean skate Science Seminar in Strahan (with video access) to provide updates on the results of scientific studies undertaken on Maugean skate.	Short-term	IMAS, CSIRO, CCA NRM	Low	Planned
Establish and maintain a Maugean skate science webpage that enables public access to relevant data and publications in one location.	Short-term	IMAS, FRDC, CSIRO, CCA NRM	Low	In design

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Appendix 1: National Recovery Team for the Maugean skate

As an advisory body, the National Recovery Team for the Maugean skate provides advice on recovery actions to a range of stakeholders, including the Australian and Tasmanian governments. One of the roles of the Recovery Team is to recommend and coordinate activities which facilitate implementation of the CAP and the Australian Government's Conservation Advice for the species. It provides a representative, collaborative and transparent framework for coordinated conservation management of the species.

Participant	Organisation	Purpose
Colin Simpfendorfer	Australian Government Threatened Species Scientific Committee	Representative of Australian Government Threatened Species Scientific Committee
Leonardo Guida	Australian Marine Conservation Society	Representative of environmental-NGO sector
Clint Mayes	Copper Mines Tasmania	Representative of mining industry
Iona Flett	CCA NRM	Representative of local NRM organisation
Karen Wild-Allen	CSIRO	Technical specialist on Macquarie Harbour environmental dynamics
Toby Patterson	CSIRO	Technical specialist on elasmobranchs
Lesley Gidding-Reeve (Vice-chair)	DCCEEW (Marine Species Conservation Section)	Representative of the Australian Government agency accountable for species
Alyssa Giffin	DCCEEW (Marine Species Conservation Section)	Representative of the Australian Government agency accountable for species
Darryl Cook	EPA (Salmon Environmental Regulation Division)	Representative of independent environmental regulator
Bec Sheldon	Hydro Tasmania	Representative of hydro-electric energy producer
Jayson Semmens	IMAS	Technical specialist on the species
David Moreno	IMAS	Technical specialist on the species
Jeff Ross	IMAS	Technical specialist on Macquarie Harbour
Maree Fudge	IMAS	Engagement and social science specialist
Jo Crisp (Chair)	NRE Tas (Environment)	Representative of State Government agency accountable for threatened species
Tom Duncan (Coordinator)	NRE Tas (Environment)	Representative of State Government Agency accountable for threatened species
Davina Gregory-Dunsmuir	NRE Tas (Environment)	Representative of State Government Agency accountable for threatened species

Table continues

Participant	Organisation	Purpose
Jarrod Edwards	NRE Tas (Marine Resources)	Aboriginal Cultural Fisheries
Sven Frijlink	NRE Tas (Marine Resources)	Representative of State Government Agency accountable for aquaculture and fisheries
Matt Barrenger	Salmon Tas	Representative of aquaculture industry, with operations in Macquarie Harbour
Harriet Brinkhoff	Strahan Community Aquaculture Forum	Representative of West Coast community
David Midson	West Coast Council	Representative of Local Government
Laura Simmons	ZAA, SEA LIFE ANZ	Technical specialist on ex-situ conservation techniques

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