Australian Government
Department of Climate Change, Energy, the Environment and Water

Conservation Advice for *Zearaja maugeana* (Maugean skate)

In effect under the *Environment Protection and Biodiversity Conservation Act 1999* from 6 September 2023.

This document provides a foundation for conservation action and further planning.

Maugean skate *Zearaja maugeana. Copyright Jane Rucker/IMAS*

The Maugean skate was recently included in the 2023 Finalised Priority Assessment List for threatened species listing reassessment under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), with an assessment due date of 30 October 2024.

There is substantial concern for the survival of the species in the wild under ongoing cumulative anthropogenic impacts on the habitat conditions within Macquarie Harbour, Tasmania – the location of the species' last known viable population.

The Threatened Species Scientific Committee will undertake the listing assessment as a priority, however while this assessment is ongoing, the Committee also prioritised the updating of the current Conservation Advice for the species.

This Conservation Advice provides a summary of the current threats to the species and a foundation to guide urgent conservation planning, actions, and research for the Maugean skate while the Tasmanian Government's Conservation Action Plan and the Commonwealth's EPBC Act listing assessment are finalised.

Summary

The Maugean Skate (*Zearaja maugeana*) is currently listed as Endangered under both Tasmania's *Threatened Species Protection Act 1995* and the *Environment Protection and Biodiversity Conservation Act 1999*. The species is also a priority threatened species under the Australian Government's Threatened Species Action Plan (2022-2032). The species is endemic to Tasmania and is only known to have occurred in two estuaries in the south-west: Macquarie Harbour and Bathurst Harbour. There is considerable uncertainty surrounding the subpopulation in Bathurst Harbour, with recent evidence indicating that if the species does occur in that location, it is likely only in very small numbers.

Substantial recent evidence indicates a high risk of extinction for the species in the near future. The primary threat to the species is degraded water quality, in particular substantially reduced levels of dissolved oxygen throughout Macquarie Harbour. There is a significant correlation between the reduction in dissolved oxygen levels and increases in salmonid aquaculture due to the bacterial degradation of organic material introduced into the water column from fish-feed and fish-waste. Two significant mortality events were observed in 2019, coinciding with rapid changes in water quality (particularly dissolved oxygen) exacerbated by extreme weather events. Furthermore, the capture of juveniles in monitoring surveys has significantly decreased in recent years, indicative of possible recruitment failure in the remaining population.

Macquarie Harbour is a highly stratified estuary with substantial freshwater inflows from associated river systems. The primary natural source of reoxygenation of bottom water within the harbour is from ocean water ingress. Hydroelectric damming altering river flows from King and Gordon Rivers into Macquarie Harbour are thought to influence the inflow of ocean water. Altered river flows is not considered a primary cause of the low oxygen conditions within the harbour, however it is probable altered flow regimes have changed the natural oxygenation processes. There may also be a substantial benefit of modifying river flows to enable ocean water ingress into the harbour to remediate the current low dissolved oxygen levels. The most important ongoing secondary threat to the Maugean skate is thought to be interactions with recreational gillnetting. Ongoing heavy metal pollution and sediment contamination from historical mining operations upstream is also a possible threat to the species.

The Maugean skate is included in the 2023 Finalised Priority Assessment List (FPAL) with a due date for the listing assessment of 30 October 2024. This updated Conservation Advice will be in place while the listing assessment is completed. The Conservation Advice has identified several key urgent actions that should be implemented prior to summer 2023 to ensure the species does not go extinct including:

- Increasing the levels of dissolved oxygen in Macquarie Harbour, via a reduction in salmonid aquaculture organic loads and/or utilisation of mechanical/engineering environmental remediation technologies.
- Initiation of a captive breeding program, including all appropriate Commonwealth and state permits for collection of Maugean skate adults and eggs.
- Reinstate the CSIRO predictive monitoring modelling to inform modification of hydroelectric dam environmental flows.

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Conservation status

Zearaja maugeana (Maugean skate) is listed in the Endangered category of the threatened species list under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwth) (EPBC Act) effective from 4 March 2004.

At that time the Threatened Species Scientific Committee assessed the species to be eligible for listing as Endangered under criterion 2 and 3. The main factors that made the species eligible for listing in the Endangered category were: (1) the species having a restricted area of occupancy, (2) the occurrence of the species in a restricted number of locations, and (3) the extent and quality of habitat for the species are continuing to decline. The published Listing Advice for the species is available from the Species Profile and Threats Database.

Species can also be listed as threatened under state and territory legislation. For information on the current listing status of this species under relevant state or territory legislation, see the Species Profile and Threats Database.

Since the time of EPBC Act listing, substantial new information has become available on the current ongoing threats to the Maugean skate and the conservation status of the species. As outlined under 'Population and distribution' below, it is highly likely this species is found only in Macquarie Harbour in south-western Tasmania (Moreno et al. 2022), there has been apparent recruitment failure in recent years, and a likely 47% decline in relative abundance between 2014 and 2021 (Moreno & Semmens 2023). Current primary threats are ongoing.

A population viability analysis (PVA) for the Maugean skate was undertaken in July 2023 (Grant et al. 2023). Currently available demographic and life history information was used to construct models that predicted the risk of extinction within three generation lengths (27 years) covering the period 2014–2041. This 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 that 25% by 2041. When applied to IUCN Red List of Threatened Species (IUCN Red List) criteria, these population reduction estimates would result in a listing of Critically Endangered under IUCN Red List Criterion A4bd. Grant et al. (2023) state that "the risk of extinction in the wild for the Maugean skate appears to be a dire situation requiring urgent management intervention" (page i).

In August 2023 the Maugean skate was included in the 2023 Finalised Priority Assessment List for threatened species reassessment under the EPBC Act. This assessment has a due date of 30 October 2024.

Species information

Taxonomy

Conventionally accepted as *Zearaja maugeana* (Last & Gledhill 2007), Family: Rajidae. Previously known as *Raja* sp. L (Last & Stevens 1994). A recent study assigned the genus *Zearaja* as a junior synonym of *Dipturus* (Concha et al. 2019). However, *Zearaja* is still the formally accepted name by the Australian Faunal Directory and will be used herein until superseded by further supporting taxonomic data, with *Dipturus* considered a synonym.

Description

The Maugean skate is a medium-sized skate with a maximum total length of approximately 74 cm in males and 87 cm in females (Bell et al. 2016). It has an elongated narrowly-pointed snout, dark-edged ventral pores, and a quadrangular disc-shaped body. The dorsal surface of the species is smooth and is almost uniformly dark grey to brown with some small faint white spots. The tail of the species is moderately broad at the base, tapering towards large dorsal fins. Males of the species have three rows of thorns along the tail, while females have five. The species possesses strongly forked pelvic fins and claspers with extremely spatulate distal lobes (Last & Gledhill 2007).

The Maugean skate is distinguished from its sister *Zearaja* species by its smaller size at maturity, longer snout with a narrower disc and head, and smoother dorsal surface. The members of the *Zearaja* genus superficially resemble the genus *Dipturus*. The external morphology, including the neurocranium, pelvic girdle and scapulocoracoid, are of similar type between the two genera, but major differences exist in clasper morphology (Last & Gledhill 2007). The Maugean skate is externally morphologically similar to Tasmanian deepwater *Dipturus* species such as *D. gudgeri* (Whitley 1940) and *Dipturus* sp. J (Last & Stevens 1994). The Maugean skate has a long pointy snout similar to *Dipturus* species but is distinguished from them by its darker dorsal surface, broad thorny tail, and spatulate claspers (Last et al. 2008). The only other skate found within the same distribution of the Maugean skate is *Dentiraja lemprieri* (thornback skate) (Richardson 1845). However, the thornback skate is smaller in size, has a short and rounded snout, a brown to grey-black dorsal surface with fine spots and reticulations, and long narrow claspers (NRE Tas 2023a).

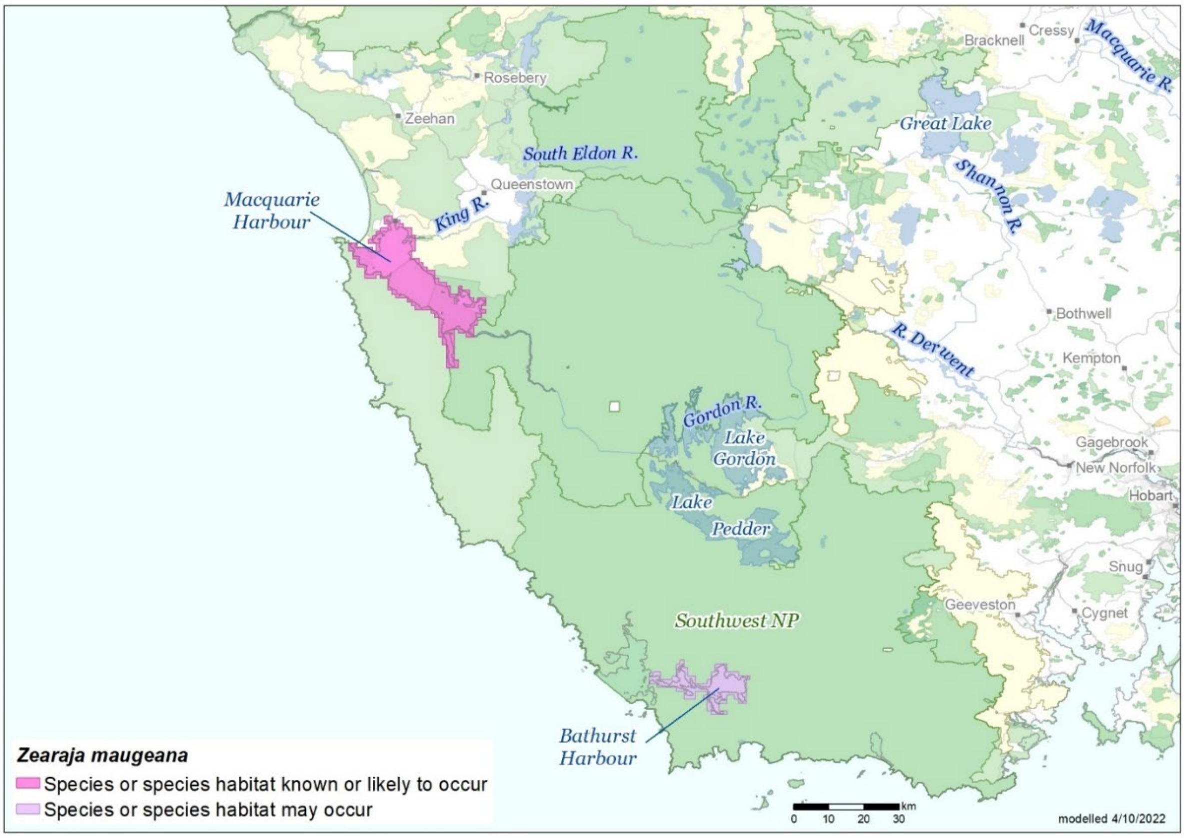
The egg cases of the Maugean skate are bright golden-green when freshly laid and become darker brown with age (Moreno et al. 2020). The egg cases are medium size (> 100 mm in total length). The shape of the egg case is rectangular, and the main body is relatively even in width at both the posterior and anterior ends. Very few fibroids are present on the dorsal and ventral body, and no attachment fibres or tendrils are present (Treloar et al. 2016; Moreno et al. 2020). The anterior horns are short, stout, and curved ventrally inwards (Treloar et al. 2016). The posterior horns are longer and straight (Moreno et al. 2020).

Distribution and population

The Maugean skate is endemic to Tasmania. The species has only been recorded in two isolated estuaries in south-western Tasmania, Macquarie Harbour and, to a lesser extent, Bathurst Harbour (Map 1; Table 1) (Last & Gledhill 2007; Bell et al. 2016). No specimens have been recorded from marine waters outside these two harbours, despite documented experimental trawl efforts across the region and detailed acoustic tracking of the Macquarie Harbour subpopulation (Last & Harris 1981; Bell et al. 2016; Moreno et al. 2020). Bell et al. (2016) also found no evidence that Maugean skate disperse outside Macquarie Harbour into the freshwater tributary of the Gordon River. Therefore, the Macquarie Harbour and Bathurst Harbour subpopulations are likely to be genetically distinct (Bell et al. 2016; Last et al. 2016; Weltz et al. 2018).

The species occurs within the Tasmanian Wilderness World Heritage Area across all of Bathurst Harbour and one-third of Macquarie Harbour (Table 1; DPIPWE 2017). Within Bathurst Harbour and Bathurst Channel, the species occurs within the Port Davey and Bathurst Harbour Marine Nature Reserve and the tenure of the Southwest National Park.

Map 1 Modelled distribution of Maugean skate from currently available information



Source: Base map Geoscience Australia; species distribution data Species of National Environmental Significance database.
Caveat: The information presented in this map has been provided by a range of groups and agencies. While every effort has been made to ensure accuracy and completeness, no guarantee is given, nor responsibility taken by the Commonwealth for errors or omissions, and the Commonwealth does not accept responsibility in respect of any information or advice given in relation to, or as a consequence of, anything contained herein.
Species distribution mapping: The species distribution mapping categories are indicative only and aim to capture (a) the habitat or geographic feature that represents to recent observed locations of the species (known to occur) or habitat occurring in close proximity to these locations (likely to occur); and (b) the broad environmental envelope or geographic region that encompasses all areas that could provide habitat for the species (may occur). These presence categories are created using an extensive database of species observations records, national and regional-scale environmental data, environmental modelling techniques and documented scientific research.

Table 1 Distribution and population summary[1]

Subpopulation		Tenure	NRM[2] Region	IMCRA Meso-scale Bioregion[3]	Area of Occupancy (AOO)	Number of individuals	Year first & last observed
1	Macquarie Harbour, TAS	Southwest National Park; Macquarie Harbour Historic Site; Farm Cove Game Reserve; Tasmanian World Heritage Wilderness Area (one-third of the harbour); unserved waters.	Cradle Coast	Franklin	~100 km²	~ 3200 (2016) Estimated subpopulation decline of 47% between 2014 and 2021	First: 1994 Last: 2023
2	Bathurst Harbour, TAS	Southwest National Park; Port Davey and Bathurst Harbour Marine Nature Reserve; Tasmanian World Heritage Wilderness Area	South	Davey	~16 km² However, eDNA study suggests species no longer occurs at this location (Moreno et al. 2022).	Four confirmed observations	First: 1989 Last: 1992

[1] Table adapted from Tasmania's Department of Natural Resources and Environment (NRE Tas) *Zearaja maugeana* Listing Statement (NRE Tas, 2023a)

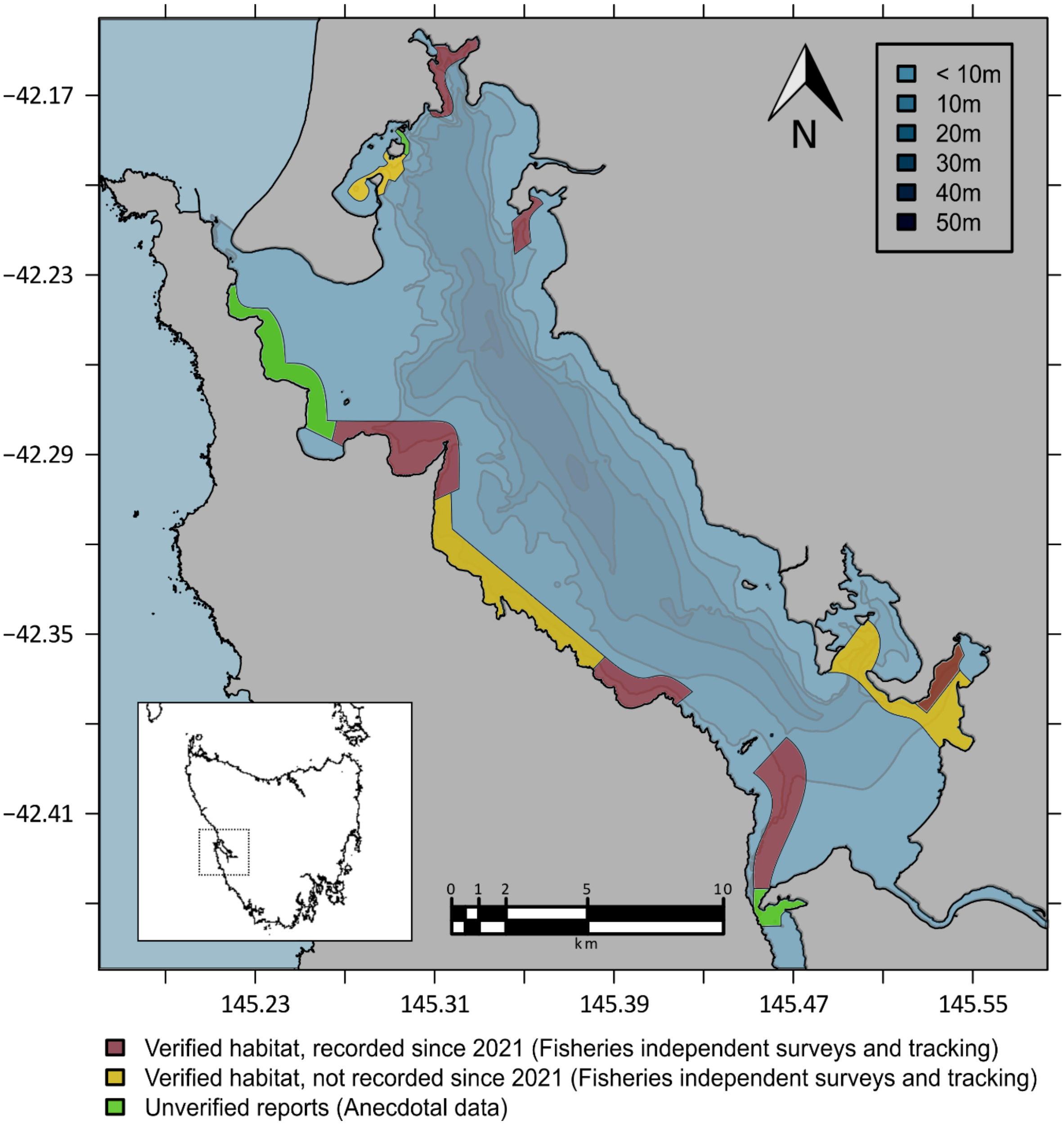
[2] NRM = Natural Resource Management

[3] IMCRA = Integrated Marine and Coastal Bioregionalisation of Australia Version 4.0 is the product of the combination of the Interim Marine and Coastal Regionalisation of Australia (IMCRA v3.3), which provided a marine regionalisation of inshore waters with the National Marine Bioregionalisation (NMB) for off-shelf waters.

Recent eDNA surveys of Bathurst Harbour could not confirm the presence of Maugean skate (Moreno et al. 2022), therefore Macquarie Harbour is considered to be the only current location where the species occurs. The species has been recorded across the extent of the Macquarie Harbour estuary, from the upper reaches to the entrance at Kelly Channel (Bell et al. 2016, Map 2), however in recent years it appears the species has a more restricted range within Macquarie Harbour, recorded primarily from the central, southwestern side of Macquarie Harbour near Liberty Point and Table Head (Moreno et al. 2020). The estimated area of occupancy for the Macquarie Harbour subpopulation is 100 km² (Table 1) though it is possible that the actual area of occupancy is less currently given the known verified and unverified preferred habitat (Map 2).

In 2016, the Macquarie Harbour subpopulation was estimated to be 3200 individuals (95% CL of 1827–6247) (Bell et al. 2016). However, recent research by Moreno & Semmens (2023) reports that an estimated decline in relative abundance of the species in Macquarie Harbour of up to 47% occurred between 2014 and 2021. This report also found a shift in population structure, with fewer juveniles and an increase in the median size of females captured in 2021 compared to 2012, with the scarcity of new recruits indicative of a decline in recruitment (Moreno and Semmens, 2023). A recent PVA was constructed for the Maugean skate (Grant et al. 2023) based on the best available information and incorporating known life history characteristics, population structure, mortality rates, and threats. Models were constructed over the period 2014-2041 (27 years, equating to three generation lengths). It was estimated that in the best-case scenario, the Maugean skate subpopulation in Macquarie Harbour would decline by 89% by

2041. Projections incorporating increased threats resulted in a best-case decline of 98% by 2041 and worst-case declines of > 99% including extinction probabilities of >25% in the Macquarie Harbour subpopulation.



Map 2: Known Preferred Habitat for Maugean skate. Provided by D. Moreno (25 August 2023), based on a) verified habitat where Maugean skate was known to occur but has not been caught since 2021 (based on research netting and tracking studies) (past areas); b) verified habitats where Maugean skate has been caught since 2021 (based on research netting and tracking studies) (current areas); and c) unverified reports (reported by locals but no records on tracking or catches when monitoring there).

There have only been four confirmed observations of Maugean skates in Bathurst Harbour. One individual was captured in 1988, two in 1989 and one in 1992 (Last & Gledhill 2007; NRE Tas 2023a). Based on these four confirmed sightings, if extant, the estimated Area of Occupancy (AOO) for the Bathurst Harbour subpopulation is 16 km^2 (Table 1). Within Bathurst Harbour, individuals have been recorded only at the lower reaches of the harbour, near the entrance at Bathurst Channel, and near Celery Top Islands (Moreno et al. 2022). No individuals of the species have been observed in Bathurst Harbour since 1992, despite multiple surveys conducted between 1992 and 2022 (Last & Gledhill 2007; Forbes et al. 2016; Treloar et al. 2016; Moreno et al. 2022). However, the species' distinctive snout markings were observed in the silty sediment in Bathurst Harbour in 2003 by Graham Edgar (Treloar et al. 2016), and Maugean skate DNA was detected at very low levels in a recent environmental DNA (eDNA) survey in 2022 (Moreno et al. 2022). Moreno et al. (2022) suggest that the findings from the eDNA surveys in Bathurst Harbour indicate that a subpopulation of the species in this location is either (1) absent and remnant DNA exists in the sediment (e.g. in egg cases), (2) only comprised of a very small number of individuals, or (3) consists of non-resident vagrants. Weltz et al. (2017) measured the rate of decay for Maugean skate eDNA in Macquarie Harbour and found that the eDNA can be detected for 4 to 16 hours after which the eDNA concentration drops below the detection threshold of the assay. It is not possible to determine the source of the low levels of eDNA detected in Bathurst Harbour and, as a result, the status of the Bathurst Harbour subpopulation remains uncertain, although it is unlikely this subpopulation is large.

Cultural and community significance

The cultural, customary, and spiritual significance of species and the ecological communities they form are diverse and varied for Indigenous Australians and their stewardship of Country. This section describes some examples of this significance but is not intended to be comprehensive or applicable to, or speak for, Tasmanian Aboriginal people. Such knowledge may be held by Tasmanian Aboriginal people who are the custodians of this knowledge and have the right to decide how this knowledge is shared and used.

The Maugean skate occupies the lands and waters of the Toogee People, composed of the Mimegin and Lowreenne bands in Macquarie Harbour and the Ninene band in Port Davey (State of Tasmania 2000; Maxwell-Stewart 2009; AIATSIS 2023). The area around Macquarie Harbour, including Sarah Island, was known by the local Tasmanian Aboriginal people as Langerrarerouna and comprises several documented Tasmanian Aboriginal sites (State of Tasmania 2000; Parks Tasmania 2023). Within Macquarie Harbour, there are three palawa kani (Tasmanian Aboriginal language) place names, including paralungatik (Macquarie Harbour), titikalangrruni (Grummet Island), and langarirruni (Sarah Island) (TAC 2023). Macquarie Harbour was crossed on craft during seasonal movements by Tasmanian Aboriginal people within the region (Maxwell-Stewart 2009). The Tasmanian Aboriginal sites identified within the region have contributed to the cultural significance of the Tasmanian Wilderness World Heritage Area that encompasses Bathurst Harbour and parts of the eastern section of Macquarie Harbour.

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 a priority conservation and recovery action. Further consultation with the Tasmanian Aboriginal peoples of these lands and waters will benefit the conservation of the species by providing awareness of, and being guided by, traditional knowledge and management practices on Country.

Relevant biology and ecology

Biology

The Maugean skate lives to approximately 10 years of age, with adults maturing at 4–6 years (Awruch et al. 2021). The species is sexually dimorphic in size, with females attaining a larger size than males (Treloar et al. 2016). Females attain maturity between 660–680 mm total length, and males at 632 mm total length (Bell et al. 2016).

Fertilisation is internal, with oviparous (egg laying) females having an asynchronous and discontinuous reproductive cycle in which only a proportion of females are reproductively active at any given time (Awruch et al. 2021). Females have seasonal variations in their reproductive activity throughout the year and are the least active during summer (Bell et al. 2016). Males are reproductively active throughout most seasons, but sperm production is generally at increased levels during spring and autumn, indicating a potential protracted mating season (Bell et al. 2016).

Available information on the biology of Maugean skate eggs and possible preferred locations or depths for egg laying is minimal. Current understanding is based on a pair of partially formed eggs found in the shell gland of a pregnant female (Treloar et al. 2006); a pair of eggs (one empty case and one live-egg) incidentally captured during a gillnet survey in Macquarie Harbour (Treloar et al. 2016); a substantial collection undertaken by Moreno et al. (2020) which resulted in the collection of 110 eggs, comprising 102 empty egg case, seven live eggs and one case containing a decomposing embryo; and four eggs laid by captive adult females (Moreno et al. 2020). The few live eggs that have been collected were from between 2.5 m water depth (Moreno et al. 2020) to 20 – 30 m water depth (Moreno et al. 2022; Treloar et al. 2007). Under captive conditions Moreno et al. (2020) report hatching to occur 31 weeks after oviposition, with the hatchling being 122 mm total length. Based on empty wild collected egg-cases, condition of hatching slit indicated a hatching success rate of just over 40% (Moreno et al. 2020).

Habitat

The Maugean skate occurs in brackish water habitat with high tannin loadings, poor light penetration, and silty substrate (Last & Gledhill 2007). The species strongly prefers benthic habitat in shallow channels between 5 m and 15 m in depth (Bell et al. 2016). It was originally hypothesised that Maugean skate may exclusively deposit eggs in deeper water as a strategy to reduce predation and provide more stable environmental conditions (especially temperature and salinity) (Treloar et al. 2016). However, as egg capsules have been detected across a wide range of depths (2.5–30 m), and acoustic electronic tracking has demonstrated habitat use by individuals in all depths (Bell et al. 2016; Moreno et al. 2020), this view has now changed. It remains unknown whether Maugean skate utilise specific preferred nursery grounds; current evidence suggests eggs are deposited freely on sediment throughout Macquarie Harbour (Treloar et al. 2016; Moreno et al. 2020). Waters in their preferred depth range generally have relatively stable temperatures (12–15 °C) and salinity (18–27 ppt), and naturally low-moderate dissolved oxygen concentrations (30–80% dissolved oxygen) (Bell et al. 2016; Morash et al. 2020), although oxygen levels in these areas have recently been measured at lower levels (refer to the Threats section). The Maugean skate displays diurnal patterns in depth utilisation and activity, and nocturnal foraging behaviour. The species is more active at night, utilising a broader range of depths, particularly shallower waters to forage. During the day, individuals return to deeper waters and become less active (Bell et al. 2016). Evidence suggests that there are no sex-specific patterns in habitat utilisation or distributional range (Bell et al. 2016). The Maugean skate shows high site fidelity, with a relatively small home range (< 3–10 km^2) (Moreno et al. 2020). Map 2 provides known preferred habitat for the species.

Macquarie and Bathurst harbours are fjord-like estuaries (also called deep coastal inlets; Keith et al. 2020). These estuaries are characterised by shallow ridges that create deep basins and shallow sills (a submerged sand bar partially blocking the mouth of the estuary) which restrict oceanic mixing, creating a highly stratified estuarine environment (Inall & Gillibrand 2010; Maxey et al. 2022). Naturally low dissolved oxygen concentrations are not uncommon in fjord-like estuaries, due to long residence time of basin waters. Several environmental drivers are known to influence dissolved oxygen distribution and concentrations in these systems, including freshwater river flows, tidal exchange, wind driven waves, deep water oceanic inflow, organic loadings, and microbial processing in the sediments and water column (Edwards & Edelsten 1977; Maxey et al. 2020; Maxey et al. 2022). Fjord-like estuaries have been classified as "aquatic critical zones" (Bianchi et al. 2018) due to high susceptibility to anthropogenic pressures (e.g., hydroelectric dams, sewage outfalls, land-use modification).

Macquarie Harbour

Macquarie Harbour is a fjord-like estuary that includes characteristics such as a shallow sill at the mouth, a strongly stratified water column, and deep basin waters to a maximum depth of 55 m (Cresswell et al. 1989; Ross & MacLeod 2017; Hartstein et al. 2019; Wild-Allen et al. 2020). The harbour is orientated in a North-West by South-East direction, is approximately 33 km long and 9 km wide, has an average depth of 15 m and a surface area of approximately 276 km^2. The elongated and constricted sill that connects the harbour to the ocean, Hells Gates inlet, is oriented to the northwest. The two main river tributaries (the Gordon and King rivers) are located on its northeast and southeast ends. The southern third of Macquarie Harbour is part of a World Heritage Area that extends southeast into the Gordon River catchment.

The water column is highly stratified on an almost permanent basis (Hartstein et al. 2019) and residence time of basin water is commonly over 100 days (Ross & MacLeod 2017; Wild-Allen et al. 2020). Phytoplankton growth throughout the Harbour is limited by low light due to the dark tannin-rich freshwater top layer (Last & Gledhill 2007). There are distinct layers within the water column: a tannin-stained mostly freshwater surface layer which exhibits seasonal thermal fluctuations, averaging 21 °C in summer and 8 °C in winter and is naturally high in dissolved oxygen and organic matter; an upper brackish layer (to approximately 10 m deep) which also exhibits thermal variation, ranging between 18 – 10 °C between summer and winter; a long residence time mid layer at around 15 – 30 m deep, with stable annual temperature, and naturally low dissolved oxygen; and deeper marine waters (>30 m) with a relatively stable temperature (at 2-4 °C), and naturally higher dissolved oxygen (from deep ocean water renewal, see below) (Cresswell et al. 1989; Morash et al. 2020; Ross et al 2022).

The main source of freshwater into Macquarie Harbour is from the Gordon River (catchment area of 5682 km^2), which provides approximately 80% of the freshwater input into the system (MHDOWG 2014; Hartstein et al. 2019; Maxey et al. 2020). The King River is the second largest contributor of freshwater into the harbour (catchment area of 802 km^2) and has poor water quality from ongoing pollution primarily from historical upstream copper and gold mining operations since the 1880's (Carpenter et al. 1991; Teasdale et al. 2003; Hartstein et al. 2019). Both the Gordon and King Rivers are regulated by hydroelectric damming operations that control approximately 25% and 60% of the river flow, respectively (Herzfled & Wild-Allen 2020) and have operated since the late 1970s. As outlined in the Threats section below, since

1978 the operation of the hydroelectric power station on the Gordon River has substantially modified river flow (MHDOWG 2024).

Substantial natural riverine organic carbon loads flow into Macquarie Harbour. It is estimated that the two major rivers (the Gordon and King rivers) contribute 90,000,000 – 180,000,000 kg of organic matter a year to the harbour (Maxey et al. 2020). However, only 30% of the organic carbon in river discharges into Macquarie Harbour is estimated to be labile (biologically available, and therefore a source of oxygen consumption) (Wild-Allen 2020), consistent with the estimation in other well forested catchments that the labile component of organic carbon in river discharge is small (Sun et al. 1997, Moran et al. 1999). Organic matter entering estuarine systems is oxidised by microbial communities, preferentially using dissolved oxygen, and microbial decomposition of organic matter is a key driver of deoxygenation and hypoxia (Maxey et al. 2020).

As is common with fjord-like estuaries, Macquarie Harbour is a naturally low dissolved oxygen environment due to the narrow shallow sill and long residence time of deep basin waters (Cresswell et al. 1989; MHDOWG 2014). The dissolved oxygen dynamics of Macquarie Harbour are complex, and due to the highly stratified nature of the harbour, vary significantly with depth: surface waters are well oxygenated from freshwater flows and wave action (generally >90% saturation), while deeper mid-waters are naturally oxygen-depleted (generally around 40-50% saturation) due to stratification and slow flushing of deep water (Wild-Allen et al. 2020; Ross et al. 2022). The deepest layer of marine water is naturally richer in oxygen than the mid-waters due to deep water oceanic renewal, however in recent years this has been less prominent (refer to the Threats section).

Given the highly stratified nature of the system the bulk of the freshwater river flow remain in the surface waters and is exported to the ocean (Wild-Allen et al. 2020). Ocean ingress and deep water ocean renewal is considered a major contributor of oxygen replenishment in fjord-like estuaries. In Macquarie Harbour, the presence of a long shallow channel leading to the mouth of the harbour (10 - 12 km long and less than 10 m deep in most places) and the shallow sill, restricts tidal mixing and reduces exchange with oceanic marine waters (Hartstein et al. 2019). Although oceanic deep water renewal only accounts for 7 - 13% of dissolved oxygen input into the harbour (Wild-Allen et al. 2020), it represents a much larger and important input of oxygen to the low-oxygen waters below the halocline (Pickard & Stanton 1980; MHDOWG 2014; Hartstein et al. 2019; Ross et al. 2020).

Deep water renewal events, driven by atmospheric conditions, low freshwater flows and strong north-westerly winds, bring oxygen-rich water over the sill into the basin, replenishing deep water oxygen levels (MHDOWG 2014; Hartstein et 2019; Ross et al. 2020). The magnitude of oceanic deep water renewal events are highly correlated with freshwater river flows (MHDOWG 2014; Maxey et al. 2022). Whilst smaller oceanic deep water renewal events are typical in summer months when river flows are lower, the larger oceanic deep water renewal events that transport volumes significant enough to relieve suboxic conditions in the upper reaches of the harbour are uncommon, currently estimated to occur only five to seven times per decade (Maxey et al. 2022). Their occurrence has been further reduced due to hydroelectric operations.

Bathurst Harbour

Bathurst Harbour itself is a large uniformly shallow (maximum depth of 10 m), fully mixed estuary (Last & Gledhill 2007). The Bathurst Channel that connects the harbour to Port Davey is permanently stratified, up to 50 m deep and more similar to Macquarie Harbour's hydrogeology (Last & Gledhill 2007). A shallow sill is present between Bathurst Channel and the deeper waters of Port Davey and the ocean (Edgar 1991; Last & Gledhill 2007). The harbour has a small tidal range of approximately 0.3 m. Two large rivers, the Old and the North Rivers, flow into Bathurst Harbour and the Spring River flows into the Bathurst Channel (Edgar 1991). Freshwater entering the estuary has been found to contain little particulate material or nutrients (Edgar et al. 1991). Dissolved oxygen levels in Bathurst Harbour are naturally higher than in Macquarie Harbour (Moreno et al. 2022). Overall, Bathurst Harbour is reported to be in relatively pristine condition (Treloar et al. 2016) and there are no tributaries subject to hydroelectric damming or upstream mining.

Diet

The Maugean skate has a specialised diet, mainly consisting of small epibenthic crustaceans, including crab and shrimp (Bell et al. 2016). Some small teleosts (ray-finned fish), annelids, cephalopods and tunicates have also been reported as minor dietary items (Bell et al. 2016; Weltz et al. 2019). The Maugean skate will take baited hooks and opportunistically consume discarded dead fish, although it does not appear to consume fish pellets from aquaculture farms within Macquarie Harbour (Bell et al. 2016; Weltz et al. 2019).

Physiology

The Maugean skate shows oxyconformity, where oxygen consumption occurs at rates proportional to environmental concentrations but cannot be regulated (Morash et al. 2020). Although research had previously suggested the species is well adapted to cope with naturally low dissolved oxygen levels, increasing evidence collected from within Macquarie Harbour indicates that decreased dissolved oxygen levels may impact the survival of all life stages (Bell et al. 2016; Moreno et al. 2020; NRE Tas 2023a) (refer to Threats section, below).

Genetics

Genetic analysis of the Macquarie Harbour subpopulation indicates low genetic diversity typical of a population that has undergone a genetic bottleneck or founder event (Weltz et al. 2018).

Habitat critical to the survival

This species occurs solely in state waters. The habitat critical to the survival of the Maugean skate is all of both Macquarie and Bathurst Harbours, which includes the area occupied by the known subpopulation in Macquarie Harbour and provides for potential range extension (through recovery or translocation). It is possible that the actual area of occupancy is less given the known verified and unverified preferred habitat (Map 2).

Habitat critical to the survival of the species should not be destroyed or modified. Actions that have indirect impacts on habitat critical to survival should be avoided, as should any actions that compromise the species' survival across all life stages.

No Critical Habitat as defined under section 207A of the EPBC Act has previously been included in the Register of Critical Habitat. Given Macquarie Harbour is the last remaining stronghold for the Maugean skate, the high risk of extinction of this species, and the ongoing substantial threats (outlined below), the Threatened Species Scientific Committee considers the 'verified habitat' outlined in Map 2 to be irreplaceable and necessary for the persistence and recovery of the species. This includes habitat verified both pre- and post-2021. The Committee recommends that the verified habitat of the Maugean skate be spatially defined and listed as Critical Habitat on the EPBC Act Register of Critical Habitat. The habitat for this species lies entirely in Tasmanian state waters and therefore consultation must be undertaken on this matter with the Tasmanian Government.

Important populations

In this section, the word 'population' is used to refer to a subpopulation, in keeping with the terminology used in the EPBC Act and state/territory environmental legislation.

Macquarie Harbour is the only population known to occur in any significant number and is, therefore, an important population for the conservation of the species. However, while the population in Bathurst Harbour may not currently be considered substantive, given the small population size of the species, restricted number of locations it has been documented to occur, and relatively small area of occupancy, it is still considered a potentially important population for the conservation of the species.

Threats

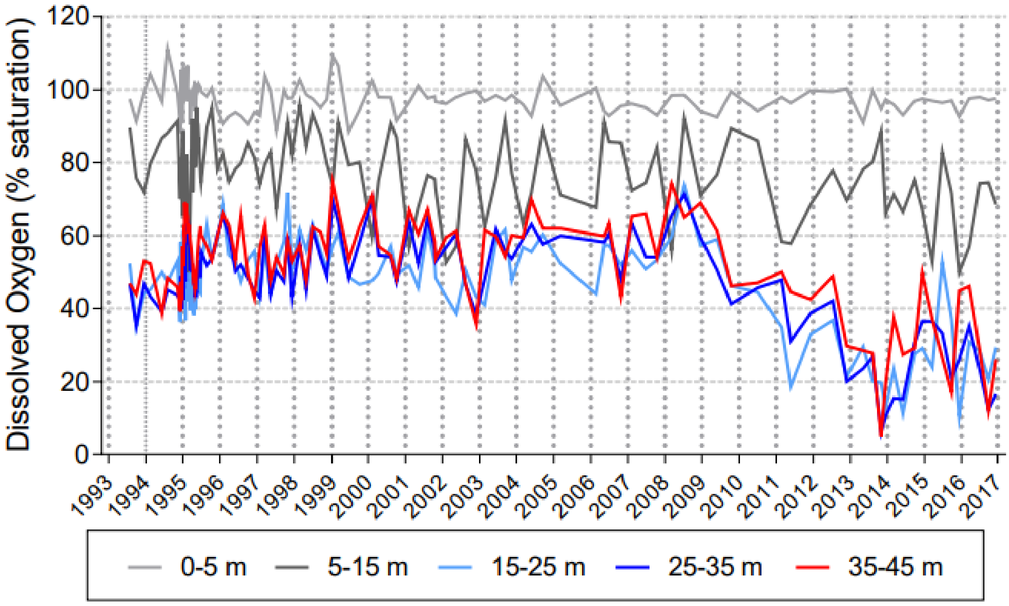
The primary threat to the Maugean skate is habitat degradation resulting from sustained reduction of dissolved oxygen. The most important cause of low dissolved oxygen is decomposition and remineralisation of organic carbon inputs to the Harbour (Maxey et al. 2020; Wild-Allen et al. 2020). Wild-Allen et al. (2020) estimated that rivers flowing into the Harbour contribute 45% of total nitrogen input, while salmonid aquaculture operations and sewerage combined contribute 25% (the contribution to this percentage from sewerage discharge is considered negligible, Ross et al. 2022). However, only 30% of riverine nitrogen load is labile, while salmonid waste is 100% labile (Wild-Allen et al. 2020) and so has larger impacts on dissolved oxygen levels (Maxey et al. 2020; Wild-Allen et al. 2020). Therefore, the most important anthropogenic contributor to the oxygen debt in Macquarie Harbour is ongoing salmonid aquaculture (Bell et al. 2016; Ross & MacLeod 2017; Kirkpatrick et al. 2019; Wild-Allen et al. 2020; Ross et al. 2022) (see Threat table), possibly compounded by hydroelectric power generation modifying river flows, and the impacts of climate change.

Interactions between major threats

River flow in the upper catchments of the Gordon and King rivers has been regulated by hydroelectric dams since 1978 and 1992, respectively. While the regulation of water flow through hydroelectric dams in Macquarie Harbour has altered water circulation patterns by moderating extremes in river flow (Maxey et al. 2022), dissolved oxygen concentrations across Macquarie Harbour were relatively consistent from 1993 until 2009, indicating that alteration in flow regimes had little impact on dissolved oxygen levels, nor on the subpopulation of Maugean skate. However, the progressive decline in dissolved oxygen levels from 2009 – 2015 coincided with a substantial increase in salmonid aquaculture (Figure 1; MHDOWG 2014; Ross & Macleod 2017; Ross et al 2022). In response, the Tasmania Environment Protection Authority (EPA) reduced the permissible captive salmonid biomass in 2017 and again in 2020. However, while salmonid biomass was reduced, the amount of fish-feed was increased in order to maintain production levels, and the EPA introduced Total Permissible Dissolved Nitrogen Output

(TPDNO) as a new measure in 2022. Despite these management measures, dissolved oxygen levels in the harbour have not improved substantially. Elasmobranchs are known to be susceptible to eutrophication and decreased oxygen, and changes in Maugean skate subpopulation in the harbour are evident.

Figure 1 Long term trend in dissolved oxygen within a number of depth ranges at EPA site 12



Source: Ross, Wild-Allen & McLeod 2017.

During extended periods of low dissolved oxygen concentrations, Maugean skates seek refuge in shallower waters where they can be exposed to higher temperatures and lower salinity, incurring a metabolic cost (Moreno et al. 2020). Further, Moreno and Semmens (2023) document probable recruitment failure in recent years and speculate this is due to eggs being exposed to very low dissolved oxygen concentrations during development. Two Maugean skate mortality events documented by Moreno et al. (2020) illustrate the complicated interrelationships between environmental parameters in Macquarie Harbour and oxygen depleted waters. The hot, dry summer weather of January/February 2019 created a period of high temperatures in surface waters. The warmer water temperatures increased the effects of oxygen depletion in the deeper waters of the harbour, causing adult Maugean skates to adapt by moving to the shallower waters that are typically more oxygenated, but at the time were also oxygen depleted (Ross et al. 2022). Mortalities occurred 2-4 weeks after this event, suspected due to prolonged exposure to reduced water quality. The second recorded mortality event occurred in April 2019, following a large westerly storm in March which created a large influx of oxygen-rich ocean water in the harbour. The dense ocean water replenished the bottom layers of the harbour but caused oxygen-poor water to rise throughout the water column. The Maugean skate was subject to prolonged exposure to oxygen depleted water throughout its range and mortalities appeared 2–4 weeks after the event, suspected again to be stress-related. It is expected that regulated river flows have the potential to both exacerbate and/or minimise such natural events.

The impacts of climate change are likely to further compound the impacts of low dissolved oxygen (see Threat table). Long-term data shows an increase of approximately 1.5 – 2 °C in mean temperature of deeper water layers within Macquarie Harbour from 1993 – 2020 (Ross et al. 2022). Climate change-induced increases to the volume and intensity of winter rainfall on the west coast of Tasmania will increase river flows and riverine organic matter loading (Maxey et al. 2020), further stimulating increased oxygen demand (Maxey et al. 2022). Increased rainfall is also expected to result in fewer deepwater renewal events by blocking marine intrusions over the sill resulting in more extended periods of basin water suboxia (Maxey et al. 2022). Reduced rainfall events in summer are expected to result in a higher frequency of more intense deep water renewal events (Maxey et al. 2022) potentially pushing deoxygenated bottoms waters up into the water column. While deep water renewal events are desirable when ocean waters trickle over the sill, sudden high-impact events can cause mortality events, as detailed above.

Other primary threats to the Maugean skate, as outlined in Table 2, include interaction with recreational and commercial gillnets and ongoing metal pollution and sediment contamination from upstream historical mining operations.

Minor threats

The following threats are poorly understood or of comparably lower consequence to the species and have therefore not been considered in Table 2. However, the potential for cumulative impacts from multiple threats, including those of lower consequence when considered in isolation, is of high concern. For instance, the cumulative impacts of habitat degradation, low genetic diversity, small population size and stochastic events place the Maugean skate at risk of extinction in the short-to-medium term (Table 2).

Predation: An additional potential threat to the species is natural predation by seals, crabs, and sea-lice. In recent decades, the presence of seals and sea-lice has increased in Macquarie Harbour with the expansion of salmonid aquaculture. The extent of the impact of natural predation of the skate is unknown and further research is required to explore rates of predation of different life-stages of the Maugean skate.

Marine debris: Marine debris is also likely causing habitat degradation within Macquarie Harbour and could potentially cause direct entanglement of the species (Parton et al. 2019). Maugean skates are likely particularly susceptible to entanglement in specific types of marine debris, such as nets and ropes, due to their long snout and spines (Bell et al. 2016). During 2017 and 2018 more than 11 tonnes of rubbish debris were removed at two annual clean-up events from Macquarie Harbour and surrounds by the Macquarie Harbour Shoreline Clean-up group (Cradle Coast Authority 2018). Marine debris collected included objects such as rope, polypile, nets, packing straps, and microplastics. In 2022, NRE Tas's 'quarter 3' marine debris monitoring program found that fish farming accounted for approximately 69% of the surveyed marine debris (NRE Tas 2023b). However, the extent of the interaction between Maugean skate and marine debris is currently unknown.

Low genetic diversity: The low genetic diversity and evidence of a historical bottleneck in the Macquarie Harbour subpopulation indicates that the species potentially has limited adaptive capacity to climate change and other substantial stressors. The likelihood of extinction following a stochastic event is high given the skate's small population size (Weltz et al. 2018; NRE Tas 2023a). The low genetic diversity of the remaining small subpopulation within Macquarie

Harbour means that there is a high risk of inbreeding depression (Weltz et al. 2018). The genetic diversity of Macquarie Harbour subpopulation has likely decreased further since the mortality events reported in 2019 and population declines documented between 2014-2021 (Moreno et al. 2020; Moreno and Semmens, 2023).

Sewerage/water discharge: One wastewater treatment plant discharges into Macquarie Harbour. Ross et al. (2020) notes that the organic load inputs from this treatment plant are relatively small compared to river and aquaculture inputs and are unlikely to have a major influence on harbour wide organic loads.

Introduced species: There is evidence of the green crab (*Carcinus maenas)*, an introduced species, in Macquarie Harbour (J Ross pers comm 20 August 2023). The current potential predation risk of the green crab on Maugean skate eggs is unknown. It is also unknown whether the green crab could compete with the native *Paragrapsus gaimardii* crab, which is currently a dominant food source of the Maugean skate; nor if the Maugean skate would prey upon green crabs.

Several introduced marine species are now known to occur within Bathurst Harbour, notably the New Zealand screw shell *Maoricolpus roseus* and the toxic dinoflagellate alga *Gymnodinium catenatum*. If the Maugean skate is extant in Bathurst Harbour, these introduced species may be a threat to the species through potential poisoning via bioaccumulation of toxins through the food chain; or through the loss of prey resulting from alteration of benthic communities; however preliminary reports suggest the likelihood of this threat is low (Hirst et al. 2007; Edgar et al. 2007).

Table 2 Threats

Threats in Table 2 are noted in approximate order of highest to lowest impact, based on available evidence.

Threat	Status [a]	Evidence
Pollution		
Reduced water quality due to salmonid aquaculture operations in Macquarie Harbour – organic matter input and associated reduction in dissolved oxygen concentrations.	• Timing: past/ current/ future • Confidence: observed and inferred • Likelihood: almost certain • Consequence: catastrophic • Trend: static • Extent: across entire known viable range – Macquarie Harbour (noting that Macquarie Harbour is the only stronghold of the species)	**Timing**: Salmonid aquaculture operations began in Macquarie Harbour in the late 1980s and includes both Atlantic Salmon (*Salmo salar)* and rainbow trout (*Onchorynchus mykiss*). These operations steadily increased from 2007 to a peak of 20,000 tonnes in 2014/15. In 2012, an expansion of the lease area for salmonid aquaculture from 564 ha to 926 ha was approved that would enable production to increase to ~29,000 tonnes. Due to a demonstrated reduction in water quality, including substantial mortality of captive salmonids, in early 2017 the maximum permissible captive salmonid biomass was lowered by the Tasmania Environment Protection Authority (EPA). In May 2020 biomass limits for salmonids in Macquarie Harbour was set at 9,500 tonnes. While the biomass limits were adhered to, feed was increased to maintain production. In September 2022 the EPA introduced a new measure of Total Permissible Dissolved Nitrogen Output (TPDNO) for Macquarie Harbour salmonid aquaculture. From 2008, nitrogen inputs increased steadily to a maximum of approximately 1000 tonnes in 2014 and 2015 (Ross et al. 2022). In 2016, Ross & MacLeod (2017) documented a major deterioration in sediment conditions and a decline in the total abundance and species richness of benthic fauna around salmon farming leases and in other sites across Macquarie Harbour. Increases in the presence of Dorvilleid worms (known indicators of benthic anoxia; Ross et al. 2016) and *Beggiatoa* sediment bacterial mats, were observed around aquaculture operations and as far afield as within the Tasmanian Wilderness Heritage Area (Ross and Macleod, 2017; Kirkpatrick et al. 2019; Ross et al. 2020). Relatively stable dissolved oxygen concentrations were recorded across Macquarie Harbour between 1993 and 2009 (MHDOWG 2014). Between years 2009 - 2014, dissolved oxygen concentrations decreased steadily across Macquarie Harbour, including within the Tasmanian Wilderness Heritage Area. In the deeper waters dissolved oxygen concentrations reduced from > 40% saturation to 10–20% saturation in depths >15 m (Ross et al. 2022). Since 2014, dissolved oxygen concentrations have varied seasonally but have not returned to pre-disturbance levels (EPA 2022; Ross et al. 2022). **Likelihood**: To explore the impact of anthropogenic organic carbon loads on dissolved oxygen conditions in Macquarie Harbour, Wild-Allen et al. (2020) simulated an oxygen process model scenario using conditions in 2017-2018 but omitting fish farm respiration and associated nutrient load (e.g. fish farm oxygen drawn-down) and observed a 50% reduction in hypoxic water in the harbour and a 40% reduction in hypoxic sediment. When this scenario was extended for another 2 years, hypoxia was further reduced, and healthy water (> 80% oxygen saturation) volume increased from 46% to 56%, and healthy

Threat	Status [a]	Evidence
		sediment increased from 32% to 36% of the total harbour area (Wild-Allen et al. 2020). Ross & McLeod (2017) also note that the organic wastes associated with salmonid farming increase biological oxygen demand and thereby decreased dissolved oxygen concentration. Due to the geographic size and limited oceanic influence of Macquarie Harbour, and the spatial distribution of aquaculture leases within Macquarie Harbour (NRE 2023b), aquaculture operations are almost certain to impact the Maugean skate throughout the entire harbour. The susceptibility of elasmobranchs in general to eutrophication and decreased dissolved oxygen concentration is well documented (e.g., Barausse et al. 2014; Sims 2019; Musa et al. 2020; reviewed in Schlaff et al. 2014), and changes in the Maugean skate subpopulation in Macquarie Harbour have been observed (see below). **Confidence and Consequence**: The Maugean skate in Macquarie Harbour is now considered to be at or possibly beyond the limits of its tolerance of environmental change (Moreno et al. 2023). Using catch per unit effort, Moreno et al. (2023) reported declines in the relative abundance of the Maugean skate in Macquarie Harbour of up to 47% during 2014 – 2021. Moreno et al. (2023) using data from 314 individuals report that these observed declines in relative abundance of the species are likely the result of high-impact environmental events, and longer-term demographic effects indicated by changes in the size structure of the subpopulation and apparent recruitment failure. Size composition data collected between 2012 and 2021 in the Maugean skate subpopulation in Macquarie Harbour indicates a shift in population structure, with fewer juveniles, and an increase in the median size of females captured in 2021 compared to 2012 (Moreno et al. 2023). Waters in the species' preferred depth range (5–15 m) when habitat conditions are considered suitable generally have stable temperatures (12–15 °C) and salinity (18–27 ppt) and low-to-moderate dissolved oxygen concentration (30–80%, although historic levels were likely higher) (Bell et al. 2016; Morash et al. 2020; Moreno et al. 2023). Exposure to changing environmental conditions, particularly low dissolved oxygen concentration, causes physiological stress and mortality in Maugean skates (Morash et al. 2020; Moreno et al. 2020). Morash et al. (2020) reported that oxygen uptake by adult Maugean skates was negligible following acute exposure (up to 20 hours) to dissolved oxygen concentration of 10–25%. Although individuals may have some capacity to acclimatise to low dissolved oxygen concentration (c. 20%) (see Moreno et al. 2020), sustained periods of low dissolved oxygen concentration or rapid fluctuations negatively impact biological processes (growth, energy update and reproduction) and survival (Moreno et al. 2020; Moreno et al. 2023). Using acoustic telemetry, Moreno et al. (2020) observed behavioural changes of individuals and a 44% mortality rate based on a sample size of 25 tagged Maugean skates. Of the 11 mortalities, 8 were attributed to two distinct episodes of environmental change. The first was categorised by low dissolved oxygen concentration (< 50%, and at times 0–20%) and temperatures exceeding 20 °C within the species preferred depth range (5-15 m). Tagged individuals moved to shallower sites, presumably to avoid areas with low dissolved oxygen concentration (Moreno et al. 2020). However, individuals in shallower sites may still incur metabolic costs associated with unfavourable

Threat	Status [a]	Evidence
		water temperatures and salinities in the areas to which they move (Moreno et al. 2020). Furthermore, the survival of eggs deposited within these refuge areas may be impacted by unfavourable temperatures and salinities in those locations (Bell et al. 2016; Moreno et al. 2020). The second episode was a severe weather mixing event that pushed dense oceanic water into Macquarie Harbour and displaced waters with low concentration of dissolved oxygen concentration from deep waters into the depths preferred by Maugean skates (Moreno et al. 2020). Low concentration of dissolved oxygen may further restrict the highly specialised diet of the Maugean skate by reducing the health of crustacean prey or impeding access to usual foraging areas if conditions there become unsuitable (Weltz et al. 2019; Moreno et al. 2020). **Trend**: In light of observed habitat degradation (e.g., documented in MHDOWG 2014; Ross et al. 2020; 2022), the permissible aquaculture biomass within Macquarie Harbour was reduced in 2017 and again in 2018. These changes have resulted in some reduction in organic matter inputs and some improvements to sediment health (EPA 2022; Ross et al. 2022). However, the present dissolved oxygen concentration, particularly at depths of 15-35 m (i.e., part of the depth range of the Maugean skate and where eggs can be found), remains lower than pre-2009 levels (Kyne et al. 2021; EPA 2022; Ross et al. 2022). There is no evidence to suggest that the small increase in dissolved oxygen concentration in Macquarie Harbour are a sustained long-term trend (EPA 2022) or have resulted in reduced impacts on Maugean skate. In September 2022, the EPA issued a Total Permissible Dissolved Nitrogen Output for Macquarie Harbour to improve dissolved oxygen levels within the harbour (EPA 2022). Given this new regulation focusses on only one component of the total organic carbon load from salmonid aquaculture operations, it is unknown whether this new regulation will address the known issues. The extent to which this new regulation has improved, or will improve, dissolved oxygen concentration in Macquarie Harbour is unknown. **Extent**: Due to the documented influence of salmonid aquaculture on dissolved oxygen concentration in Macquarie Harbour, the impacts of this activity on the Maugean skate is throughout the entirety of Macquarie Harbour and given that Macquarie Harbour is now considered the only known viable subpopulation for the species, these impacts extend across the species' entire range. Reduced dissolved oxygen concentration is thought to degrade critical habitat comprising core home range of Maugean skates, resulting in increased use of sub-optimal habitat by individuals, which is likely causing population-level problems (Bell et al. 2016; Moreno et al. 2020; Ross et al. 2022). Noting the Maugean skate has not been found within the Tasmanian Wilderness Heritage Area in recent years (Moreno et al. 2020; 2023) may indicate range restriction within Macquarie Harbour. The earliest life-history stages (i.e., eggs and neonates) may also be particularly susceptible to reduced dissolved oxygen concentration due to their narrower physiological tolerances and inability to move away from the most unsuitable conditions (Moreno et al. 2020).

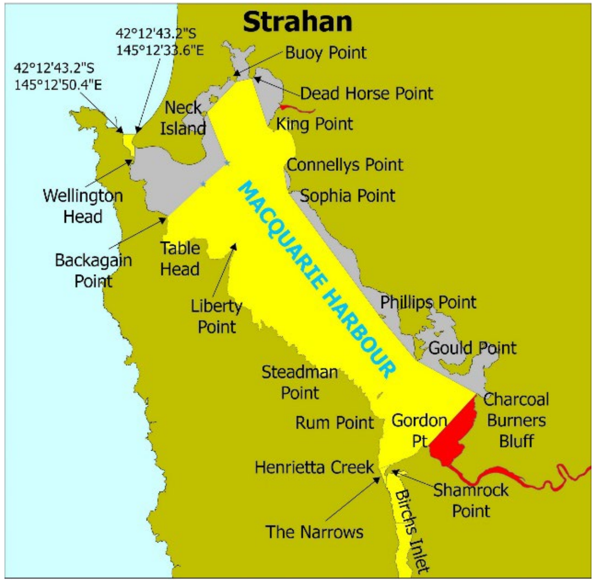
Threat	**Status** [a]	**Evidence**
Reduced water quality due to hydroelectric damming that alters the flow of the King and Gordon Rivers – linked to reduced water quality from salmonid aquaculture operations.	• Timing: past/ current/ future • Confidence: observed and inferred • Likelihood: almost certain • Consequence: catastrophic • Trend: variable, but likely increasing with climate change and increased demand on hydroelectricity for power generation • Extent: across entire known viable range – Macquarie Harbour (noting that Macquarie Harbour is the only stronghold of the species)	**Timing**: There are two major tributaries feeding into Macquarie Harbour – the Gordon River and the King River, both of which have had river flows regulated by hydroelectric dams since 1978 and 1992, respectively. The hydroelectric damming operations have altered natural river flows and resulted in steady river flows in naturally low-flow periods. This reduces the movement of ocean water into Macquarie Harbour over the sill at the harbour entrance and consequent replenishment of dissolved oxygen concentrations in deeper harbour waters (Ross & MacLeod 2017; Hartstein et al. 2019; Wild-Allen et al. 2020; Ross et al. 2022). Periodic dam releases add to the variability of freshwater discharge into the harbour and can double the average flow conditions for short periods of time (Hydro Tasmania 2016), resulting in impacts on the complex hydrological dynamics linked to dissolved oxygen concentrations replenishment in bottom waters in Macquarie Harbour (see habitat section for more details). Increased river flow due to water released from hydroelectric dams may reduce dissolved oxygen concentration by stimulating pelagic oxygen demand through increased input of riverine organic matter (Maxey et al. 2020; Maxey et al. 2022). Increased reliance on hydroelectric operations for energy production over the last two decades, coupled with the expansion of anthropogenic inputs into the system from salmonid aquaculture, has resulted in changes to environmental conditions in Macquarie Harbour (particularly reduced dissolved oxygen concentrations) (Moreno & Semmens 2023). **Likelihood:** To explore the sensitivity of water quality in Macquarie Harbour to varying freshwater inputs, Wild-Allen et al. (2020) simulated two oxygen process model scenarios for 2017-2018 with drier than normal conditions (10% and 20% less river flow in all rivers) and observed that much drier conditions resulted in an approximately 20% increase in marine oxygen influx and a small reduction in the volume of hypoxic water. These simulations showed that mean monthly simulated dissolved oxygen concentrations increased in deep water in Macquarie Harbour under drier conditions across all seasons, with the largest increase occurring in the 20% less river flow scenario. Wild-Allen et al. (2020) also simulated two oxygen process scenarios for 2017-2018 with wetter than normal conditions (10% and 20% more river flow in all rivers) and observed that much wetter conditions resulted in an approximately 20% suppression of marine oxygen influx and a small increase in hypoxic water volume. Findings of these scenarios showed that mean monthly simulated dissolved oxygen concentrations were reduced in deep water, with the largest decline simulated in the 20% higher river flow scenario in winter. Although these findings are not simulated to different hydrological damming operation scenarios, they provide evidence of the influence of changes to river flows on the dissolved oxygen concentrations in Macquarie Harbour. **Confidence and Consequence:** In isolation, the impact and consequence of altered hydrological flows associated with hydroelectric damming on the Maugean skate is unknown. Coupled with the substantially reduced dissolved oxygen concentrations associated with salmonid aquaculture, the management of hydrological flows has the potential of exacerbating and/or contributing to the improvement of, the current dissolved oxygen concentrations within Macquarie Harbour. **Trend:** There is seasonal variation in hydroelectric dam releases from the Gordon and King Rivers into Macquarie Harbour that are coupled with weather patterns, energy demand and capacity of other damming operations. Therefore, the impact of hydroelectric damming altering the natural flow of the King

Threat	Status [a]	Evidence
		and Gordon Rivers into Macquarie Harbour on water quality within Macquarie Harbour is variable. The variability of flows from hydroelectric dam releases will likely worsen under climate change scenarios. **Extent:** Due to the documented influence of hydroelectric damming operation on dissolved oxygen concentrations in Macquarie Harbour, the impacts of these operations on the Maugean skate is throughout the entirety of Macquarie Harbour and given that Macquarie Harbour is now the only known viable subpopulation for the species, these impacts extend across the species' entire range.
Climate change, extreme events and associated environmental changes		
Temperature and rainfall changes	• Timing: past/ current/ future • Confidence: observed and inferred • Likelihood: Almost certain • Consequence: Major • Trend: increasing • Extent: across the entire range	**Timing:** An assessment of the physico-chemical water quality within Macquarie Harbour conducted by Ross et al. (2022) showed a trend of increasing mean water temperature of approximately 1.5 – 2 °C within bottom waters from 1993 to 2020. Analysis of data between 2011 and 2021 showed significant correlations between rainfall and dissolved oxygen concentration along the entire harbour longitudinal axis (Maxey et al. 2022). 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). **Likelihood:** A clear positive relationship has been observed between external Sea Surface Temperature (SST) measured outside Macquarie Harbour, and water temperatures in Macquarie Harbour, particularly in spring and summer, when deep water oceanic renewal is more common under low natural river flows (Ross et al. 2022). The estuarine waters within Macquarie Harbour are therefore likely to be particularly susceptible to projected increases in SST in waters around Tasmania under climate change (State of Climate 2022). Climate change is also predicted to result in wetter winters and drier summers for the Tasmanian west coast, including the main rainwater catchments feeding into Macquarie Harbour. These predicted increases in rainfall within the Macquarie Harbour river catchment areas during in winter may result in increased river flows and increased organic matter loading into the harbour, resulting in increased riverine pelagic oxygen demand (Maxey et al. 2020; Maxey et al. 2022). There will likely also be fewer deepwater renewal events during winter as freshwater flows limit marine intrusions over the sill resulting in more extended periods of basin water suboxia (Maxey et al. 2022). Conversely, drier summers may lead to higher dissolved oxygen by allowing more marine water to enter due to lower river flows. **Confidence and Consequence:** Climate change and extreme weather events challenge the Maugean skate's capacity to cope with unstable environmental conditions (Moreno et al. 2020) and could have major impacts on the subpopulation when considered alone. The solubility of oxygen decreases as temperature increases. Moreno et al. (2020) documented assumed mortality events in tagged individuals in Macquarie Harbour and inferred that these were caused by environment events associated with temperature increases upward of 20 °C that were coupled with decreased dissolved oxygen concentrations. Findings from Moreno et al. (2023) support the occurrence of these mortality events, with their reporting of an observed decline of the species of 47% in Macquarie Harbour between 2014-2021. The restricted subpopulation size and number of locations occupied by the species means the Maugean skate is at high risk of extinction from extreme weather or stochastic events. The consequence of climate

Threat	Status [a]	Evidence
		change could be considered catastrophic if considered with cumulative impacts of other threats, particularly if declines in dissolved oxygen are not remediated. The species' ability to tolerate environmental changes, including thermal fluctuations, can be energetically costly (Moreno & Semmens 2023; NRE Tas 2023a). Water temperature changes could affect the Maugean skate's aerobic performance, energetic demands, fitness, and metabolic processes (Ross et al. 2022). Long-term metabolic stress could negatively affect growth, reproduction, and survival (NRE Tas 2023a). Within Macquarie Harbour, sustained water temperature increases could have synergistic effects with other documented stressors that have resulted in the low dissolved oxygen status within the harbour, such as salmonid aquaculture, and altered river flows from hydroelectric dams (Ross et al. 2022; NRE Tas 2023a). For instance, elevated water temperatures coupled with hypoxic conditions have been shown to increase egg mortality and decrease fitness in oviparous elasmobranchs (Musa et al. 2020). These cumulative effects increase the likelihood of catastrophic impacts of low dissolved oxygen concentrations on the health and survival of Maugean skate individuals across all life stages (Moreno et al. 2020; Moreno et al. 2023). **Trend:** The impacts from climate change, including changes to rainfall and water temperature, and changes to the frequency and intensity of deepwater renewal events, have been documented and are predicted to be increasing in western Tasmania, including Macquarie Harbour. **Extent:** Climate change and extreme weather events are likely to impact Maugean skate across the extent of their occurrence by altering the complex physico-chemical and hydrological conditions in the estuarine environments they occupy (Moreno et al. 2020; Ross et al. 2022).
Pollution		
Metal pollution and sediment contamination from upstream historical mining operations	• Timing: past/ current/ future • Confidence: inferred • Likelihood: likely • Consequence: unknown, possibly major • Trend: likely decreasing at a very slow rate • Extent: across entire known viable range – Macquarie Harbour (noting that Macquarie Harbour is the only stronghold of the species)	**Timing:** Macquarie Harbour is a heavily polluted estuary due to prolonged historical mining operations upstream in the King River catchment (Koehnken 1996; Last & Gledhill 2007). The King River has transported over 100 million cubic metres of mine tailings, smelter slag, and topsoil into Macquarie Harbour from the Mount Lyell copper mine, which was established in the 1890s (Stauber et al. 1996). Along with contributing to reduced water quality within Macquarie Harbour, the effluent run-off from this historic mining has also resulted in high levels of heavy metal contamination within the sediments (Koehnken 1996; Carpenter et al. 1991; NRE Tas 2023a). While the flow of heavy metal pollutants into Macquarie Harbour has decreased substantially, the input of heavy metals continues through acid mine drainage (EPA, 2017). During periods when the waters of Macquarie Harbour mix, mostly during strong westerly storm events, the heavy metals that mostly sit in the sediments are resuspended and may affect the organisms living in the harbour, including the Maugean skate. **Likelihood:** There has been no contaminant monitoring of the Maugean skate to date, so the impact on the species is unknown. It has however been documented that elasmobranchs are highly sensitive to heavy metal concentrations (reviewed in Tiktak et al. 2020). The effluent discharge of King River and release of heavy metals from the sediment within Macquarie Harbour, coupled with other anthropogenic activities such as salmonid aquaculture and hydroelectric damming, has likely contributed to reduced water quality in Macquarie Harbour, with potential impact on the fitness and survival of the Maugean

Threat	Status [a]	Evidence
		skate across all life stages and its preferred prey species (Last & Gledhill 2007; Last et al. 2016; Moreno et al. 2020). **Confidence and Consequence:** The contamination of heavy metals within the sediments of Macquarie Harbour may lead to the accumulation of pollutants in bottom-dwelling prey species that are consumed by the Maugean skate (NRE Tas 2023a). Consumption of prey species that have accumulated pollutants from heavy metals within the sediment may result in decreases in the overall health and fitness of the Maugean skate (NRE Tas 2023a). The health of crustacean prey species may also be negatively impacted by heavy metal contamination and reduced water quality and lead to decreased food availability for the Maugean skate that already has a highly specialised diet (Weltz et al. 2019). Talman et al. (1996) found that copper contamination and sediment organic matter content were a major determinant of the population structure of benthic invertebrates in Macquarie Harbour, with invertebrate abundance and diversity decreasing significantly as copper concentrations increased. **Trend:** The amount of heavy metals that are flowing down the King River and being deposited in the sediments of Macquarie Harbour is diminishing over time at a very slow rate (EPA 2017). **Extent:** The impacts of heavy metal pollution from historical mining on water quality and health of benthic sediments is likely experienced across Macquarie Harbour, with higher concentrations near the King River mouth. Given that Macquarie Harbour is now considered the only known viable subpopulation of Maugean skate, these impacts extend across the species' entire range.
Fishing		
Recreational and commercial gillnet fishing	• Timing: past/ current / future • Confidence: observed / suspected • Likelihood: almost certain • Consequence: major • Trend: may decline under new fishing regulations • Extent: across entire known viable range – Macquarie Harbour (noting that Macquarie Harbour is the only stronghold of the species)	**Timing**: Macquarie Harbour is a popular location for recreational gillnetting by local residents (mainly residing in Strahan and Queenstown) and visitors from the north-west coast. However, since the mid-1990s increasingly restrictive gillnetting regulations have been implemented for Macquarie Harbour (Lyle et al. 2014). There are currently two operational commercial gillnetting licences in Macquarie Harbour (NRE Tas 2023). **Likelihood**: The Maugean skate is susceptible to gillnetting capture due to its long snout and spines (Lyle et al. 2014; Bell et al. 2016). The species has commonly been caught as bycatch in gillnets set by recreational and commercial fishers in Macquarie Harbour in depths of 5-15m, especially in nets that were set with long soak times (i.e., overnight) (Steer and Lyle 2003; Lyle et al. 2014; Bell et al. 2016). Given the likelihood of interactions in this depth range, netting rules were changed in 2015, prohibiting netting in waters >5m deep, and in 2022 permitted net soak time was reduced to two hours and the setting of nets overnight was prohibited. The retention of all skate species was also prohibited to avoid misidentification (NRE Tas 2022). **Confidence and consequence**: Recreational fisher reports documented in Bell et al. (2016) describe occurrences where >10 Maugean skates have been caught in a single net. Mortalities of Maugean skate from entanglement in gillnets have been documented, but many individuals have been in 'fine' condition when released (Lyle et al. 2014; Bell et al. 2016). Post-release survivorship is unknown but is likely to be

Threat	Status [a]	Evidence
		lower in recent years due to an increase in parasitic lice and crabs that infest enmeshed animals. Lyle et al. (2014) estimated an overall initial mortality rate of 9% of Maugean skate in gillnets set overnight. Mortality of captured individuals generally occurs as a result of prolonged exposure to unfavourable conditions, post-release mortality, and depredation during net entanglement, for example, by *Squalus acanthias* (whitespotted dogfish), crabs, sea lice (Lyle et al. 2014; Bell et al. 2016), and possibly seals. Egg cases have also been observed entangled in gillnets (Treloar et al. 2016). The likelihood of capture and extent of consequence for the Maugean skate under the new regulations is unknown. Lyle et al. (2014) found that the condition of captured Maugean skate decreased with increased soak duration of gillnets and suggested that most animals that encounter nets in short daytime sets are likely to survive. However, Bell et al. (2016) documented evidence of sea lice damage to Maugean skate individuals captured in gillnets with short soak times of approximately two hours. Capture in gillnets, regardless of soak duration, can result in stress on the animal, which may impact reproduction and growth and result in mortality. Any fishing impacts will pose a level of risk to the species due to the restricted distributional range and small subpopulation size (Lyle et al. 2014). **Trend:** The historical and current level of capture and mortality from recreational gillnets is currently unknown and there is a commitment to ban recreational gill netting by 2030. Anecdotal reports from enduring local fishers (i.e., with > 50 years' experience) confirm that Maugean skate have been caught for many years in recreational and commercial gillnets. However, the historical and current level of capture and mortality from recreational gillnets is unknown. Despite this, there is a recognition that gillnetting poses a risk to Maugean skate and the importance of avoiding fishing interactions grows as numbers declines. From November 2022, new recreational fishing management regulations came into effect that extended areas closed to both recreational and commercial gillnetting, reduced soak times during the day from six hours to two hours, restrict activity to between sunrise and two hours after sunset, and prohibits taking any skate species (NRE 2022b). In addition, new commercial fishing management regulations have also come into effect for two commercial scale fishers in Macquarie Harbour that include (1) prohibition of fishing in the same areas as the recreational fishing, (2) a daytime maximum soak time of two hours, (3) no taking of any skates and rays, and (4) a summer closed season from 15 November 2022 to 14 April 2023. While these rule changes were implemented as temporary measures under a public notice, the Tasmania Government is seeking to incorporate them during their current Scalefish Rules (2015) review. There is a Tasmania Government commitment to phase out all recreational gill netting statewide by 2030. Under the phase out plan, from November 2025 all gillnets will need to be attended by fishers at all times, while from November 2027 nets will only be able to be used following a notifiable escape event from Atlantic salmon farms.

Threat	Status [a]	Evidence
		Extent: Currently, gillnetting in Macquarie Harbour is confined to the areas marked in grey on the map below (supplied by NRE Tas, 20 August 2023). As Macquarie Harbour is now considered the only known viable subpopulation for the species, any impact of gillnetting is significant. 
Recreational line fishing	• Timing: past / current / future • Confidence: observed / suspected • Likelihood: almost certain • Consequence: moderate • Trend: unknown • Extent: across entire known viable range – Macquarie Harbour (noting that Macquarie Harbour is the only habitat for the species)	**Timing**: While Macquarie Harbour offers relatively poor fishing due to its challenging marine environment, some hook and line recreational fishing occurs. While Tasmanian anglers do not require a licence, rules including bag and size limits apply to species caught. Since 2022, all skates regardless of species must be returned to the water immediately. **Likelihood**: The Maugean skate has been reported to be inadvertently captured on baited fishing lines, which has resulted in some mortalities (Bell et al. 2016; R Pearn 2021 pers comm. 14 Dec cited in NRE Tas 2023a). **Confidence and consequence**: The likely impacts from capture by hook and line fishing and improper handling techniques on Maugean skate individuals may impact reproduction, or growth, or result in mortality (Bell et al. 2016; NRE Tas 2023a).

Threat	Status [a]	Evidence
		Trend: The frequency of capture and level of mortality from hook and line fishing is currently unknown. While angling activity is limited in the harbour, more activity occurs over the warmer months, including holiday periods. **Extent**: Hook and line fishing is allowed throughout Macquarie Harbour and given that it is the only known viable subpopulation of the skate, potential impacts of hook and line fishing extend across the entire range of the species.

[a]Timing—identifies the temporal nature of the threat
Confidence—identifies the nature of the evidence about the impact of the threat on the species
Likelihood—identifies the likelihood of the threat impacting on the whole population or extent of the species
Consequence—identifies the severity of the threat
Trend—identifies the extent to which it will continue to operate on the species
Extent—identifies its spatial context in terms of the range of the species

Categories for likelihood are defined as follows:
Almost certain – expected to occur every year
Likely – expected to occur at least once every five years
Possible – might occur at some time
Unlikely – known to have occurred only a few times
Unknown – currently unknown how often the threat will occur
Categories for consequences are defined as follows:
Not significant – no long-term effect on individuals or populations
Minor – individuals are adversely affected but no effect at population level
Moderate – population recovery stable or declining
Major – population decline is ongoing
Catastrophic – population trajectory close to extinction

Each threat has been described in Table 1 in terms of the extent that it is operating on the species. The risk matrix (Table 3) provides a visual depiction of the level of risk being imposed by a threat and supports the prioritisation of subsequent management and conservation actions. In preparing a risk matrix, several factors have been taken into consideration, they are: the life stage they affect; the duration of the impact; the spatial extent, and the efficacy of current management regimes, assuming that management will continue to be applied appropriately. The risk matrix and ranking of threats has been developed in consultation with experts and using available literature.

Table 3 Risk Matrix

Likelihood	Consequences				
	Not significant	Minor	Moderate	Major	Catastrophic
Almost certain			Recreational line fishing	Temperature and rainfall increases due to climate change Recreational and commercial gillnet fishing Metal pollution and sediment contamination from upstream historical mining operations	Reduced water quality from salmonid aquaculture operations in Macquarie Harbour Hydroelectric damming that alters the flow of the King and Gordon Rivers
Likely					
Possible					
Unlikely					
Unknown					

Risk Matrix legend/Risk rating:

Low Risk	Moderate Risk	High Risk	Very High Risk

Priority actions have then been developed to manage the threats, particularly where the risk was deemed to be 'very high' (red shading) or 'high' (orange shading). For those threats with an unknown or low risk (blue and green shading respectively) research and monitoring actions have been developed to understand and evaluate the impact of the threats, where appropriate.

Conservation and recovery actions

Primary conservation objective

The primary objective is to prevent the extinction of the Maugean skate in the wild by rapidly addressing all significant threatening processes and implementing a captive breeding program. Key measures of success include:

- By 2024, the dissolved oxygen concentration within Macquarie Harbour waters is substantially improved and sustained (at least to pre-2009 levels).
- By 2024, an ex-situ captive breeding and insurance subpopulation has been established.
- By 2029, successful Maugean skate recruitment has been recorded within Macquarie Harbour.
- By 2041, the number of mature Maugean skate individuals in the Macquarie Harbour subpopulation has been maintained or increased compared to 2020.

Conservation and management priorities

The conservation and management actions are provided in approximate order of highest to lowest priority, based on available evidence.

Habitat loss/degradation

Urgent Priority – before summer 2023/24

- 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.
- Improve the dissolved oxygen concentrations within Macquarie Harbour through other activities. Given the complexities of this species and the urgency of the situation, ensure adequate consultation with appropriate experts and the community. Actions include:
    - mechanical remediation of the water quality within the harbour (i.e., the use of mechanical/engineering mechanisms to reoxygenate the waters of the harbour), including modelling of the efficacy and impacts of engineering solutions.
    - appropriate management and monitoring of hydroelectric regulated river flows in Gordon and King Rivers to allow ocean water influx whilst maintaining surface water oxygen levels; and to ensure key water quality indicators are met.
- A risk assessment to determine the most effective combination of the above options, with particular attention given to any action that may cause disturbance of the sediment (see below).

Medium priority – 1-4 years

- To secure the longer-term health of Macquarie Harbour, ensure the appropriateness of regulatory triggers given the uniqueness of the Macquarie Harbour environment. Assess whether biomass limits and Total Permissible Dissolved Nitrogen Output (TPDNO) should be supplemented and/or replaced with water quality indicators better aligned to specific water quality parameters for Macquarie Harbour and the protection of Maugean skate habitat.

- Implement new regulations to ensure water quality (specifically dissolved oxygen and organic matter content) in Macquarie Harbour is restored to pre-2009 levels.
- Assess the effectiveness of new regulations on improving overall water quality, and specifically on dissolved oxygen levels. Adapt regulation levels as required.
- Implement salmonoid aquaculture industry environmental trigger limits for dissolved oxygen in mid- and bottom-waters within Macquarie Harbour.

- Investigate strategies to remediate pollutants from historical mining run-off discharging from King River and the build-up of heavy metals within benthic sediments in Macquarie Harbour, particularly within known preferred habitat areas. Implement effective strategies once developed. Ensure thorough risk assessments are conducted on any strategies that have the potential for sediment disturbance and mobilisation of heavy metals.
- Given the high risk of extinction for this species and the fact that it appears to only be extant in Macquarie Harbour, all areas of known habitat for this must be considered as Critical Habitat.
    - Develop a habitat suitability habitat model (based on the 'verified habitat' outlined in Map 2 coupled with known environmental conditions for all life stages) and, following appropriate consultation, have the habitat for the Maugean skate listed as Critical Habitat on the EPBC Act Register of Critical Habitat.

Captive Breeding Program

Urgent Priority – before summer 2023/24

- Investigate techniques for *ex situ* management, captive breeding, including egg rearing, disease risk management for reintroductions and translocation for supporting the gene flow of the species, and to sustain viable population levels. Given the complexities of this species and the urgency of the situation, ensure adequate consultation with appropriate experts and the community. Key actions include:
    - Conduct a risk assessment using the NESP PACES ex-situ decision tool to support decisions on removal of breeding animals and eggs from wild.
    - Ensure husbandry protocols are developed using previous experiences with the Maugean skate and with closely related species.
- Develop and initiate a captive breeding program to establish a long-term insurance population.

Medium priority – 1-4 years

- If captive breeding program and environmental remediation actions are successful:
    - Identify possible suitable locations and timings for maximising the success of skate release, including viability of Bathurst Harbour as a release site.
    - Release and reintroduction of captive-bred skates into Macquarie Harbour, and potentially Bathurst Harbour.

Survey and monitoring priorities

Urgent Priority – before summer 2023/24

- Reinstate the oxygen process modelling for Macquarie Harbour developed by CSIRO, independent of industry, and broaden it for use in Maugean skate preferred habitat.
- Conduct further modelling to assess the impacts of hydroelectric flows on dissolved oxygen levels in Macquarie Harbour.
    - Run additional model scenarios to better characterise the impact of contrasting anthropogenic loads and seasonal dam releases on water quality.
- Improve the accuracy of the hydrodynamic and oxygen tracer 10-day forecast, by investing in ensemble model forecasting (using the available range of Bureau of Meteorology model forecasts), data assimilation of near real time data sets, a catchment model (including predicted dam releases) and an automated alert system to improve appropriate forecast delivery.
    - Better understand the fate of nutrient outflows from the harbour on the west coast shelf and local environmental values, by extending the analysis of model results and using remote sensing.

Medium priority – 1-4 years

- Continued population monitoring of the Maugean skate to support evaluating effectiveness of conservation actions and underpin all decision support analyses. This includes the development of a robust, non-harmful, and logistically feasible sampling method to effectively assess the Maugean skate population size, structure, status, and trend.
    - Initiate close-kin mark recapture analysis to estimate population size.
    - Develop improved population monitoring, including through techniques such as video sonar (ARIS).
- Continue to monitor water quality and benthic sediments to determine the health of the Maugean skate's habitat in Macquarie Harbour. Standardise existing dissolved oxygen monitoring programs in terms of their methodology, data collection, data storing and reporting.
- Continue benthic surveys in the Macquarie Harbour Environment Monitoring program to monitor macrofauna as an environmental condition indicator.
- Monitor the effectiveness of fisheries regulations implemented in November 2022 in Macquarie Harbour in reducing bycatch of Maugean skates.

Stakeholder engagement/community engagement

Urgent Priority – before summer 2023/24

- Engage with the salmonid aquaculture industry and Hydro Tasmania to foster collaboration and cooperation in priority actions.
- Engagement with the Strahan community, focused on a co-design approach to decision making on local issues related to management of Maugean skate. Focus on building social connections in working through understanding and managing fishing practices in the

harbour (including options for compliance, cooperation, education, signage); captive breeding options; understanding impacts to and needs of community as a result of changes to industry; and utilise/enable citizen science.

Medium priority – 1-4 years

- In collaboration with Tasmanian Aboriginal communities, develop and implement a program to integrate Aboriginal Traditional Ecological Knowledge with non-Indigenous scientific knowledge to facilitate two-way learning and improve conservation outcomes for the Maugean skate. For example, this integration could enhance the understanding of the species' presence and use in Macquarie Harbour, establishing long-term baselines for population assessments, understanding of the species' ecology, cultural significance, and any customary management systems in place.
- Engage and involve Tasmanian Aboriginal Traditional Owners in conservation actions, including implementing survey, monitoring, and management actions.
- Increase community understanding of the species' status and engage the community in recovery and conservation actions.
- Implement knowledge sharing between researchers and governing bodies to ensure new information about the Maugean skate and condition of Macquarie Harbour is made available to inform conservation and management activities for the species.

Information and research priorities

Urgent Priority – before summer 2023/24

- Fine tune the population viability analysis (PVA) to assess extinction risk and assist with prioritising management, conservation, and research actions.
- Investigate the levels of post-release mortality from incidental capture of Maugean skate in commercial and recreational fisheries, and test/introduce methods to reduce mortality associated with interactions.
- Quantify bycatch of Maugean skate in recreational and commercial gillnets to determine the impact on the species and assist decision-making for fishery managers.

Medium priority – 1-4 years

- Conduct habitat prediction modelling to determine key critical habitat (for all life stages) within Macquarie Harbour.
    - Determine the current extent of the distribution of the species, and current area of occupancy within Macquarie Harbour and Bathurst Harbour which supports habitat prediction modelling.
- Further investigate the population size and structure of the remaining individuals in Bathurst Harbour, and the suitability and feasibility of Bathurst Harbour as a future site for reintroduction.
- Investigate any correlation between decrease in dissolved oxygen and increase in specific metal incorporation into skate body tissue.
- Improve understanding of physiology and environmental ecology within Macquarie Harbour, including:

  - Determining the effect of different environmental characteristics, such as dissolved oxygen, temperature, and benthic sediment condition, across all life stages of the species.
  - Determining how reproductive success, egg survival and recruitment are being affected by environmental pressures.
  - Determining where and when egg deposition occurs within Macquarie Harbour, using Table Head/Liberty Point and Swan Basin as initial sampling locations.
  - Investigate anecdotal accounts of the species being identified in ocean waters outside Macquarie Harbour.

Fishing

Medium priority – 1-4 years

- Phase out all gillnetting (commercial and recreational) in Macquarie Harbour with actions including:
  - Engagement with the Strahan community, to explore community benefits options, with a focus on outcomes due to transition for gill netting restrictions.
  - Engagement with the Strahan community, to explore compliance options for supporting gill netting restrictions.
  - Accelerate the current plan to ban gillnetting by 2030 should bycatch continue, post-release survivorship is low, or modelling indicates that known preferred habitat continue to be exposed to incidental catch in commercial and recreational fisheries.
- Work with recreational fishers to establish reporting of Maugean skate interactions, for example through fisher surveys.
- Introduce best practice catch handling in commercial and recreational fisheries, and establish an educational program on threatened species awareness, handling and release techniques, to optimise post-release survival and fitness from incidental bycatch.
- Assess the effectiveness of the commercial scalefish fisheries management regulations implemented in November 2022 in reducing bycatch through an independent observer program.
- Develop information materials on the Maugean skate for tourism operators to educate tourists visiting the area on the species and increase the recognition of the importance of conservation actions for the species' recovery.

Climate change, extreme events, and environmental changes

Medium priority – 1-4 years

- Improve the predictability of extreme environmental events to enable possible management responses (such as altered river flows) to alleviate extreme detrimental conditions within the Macquarie Harbour, noting feasibility of such options needs to be explored.
- Foster resilience to future climate change by protecting preferred habitat for all life stages and restoration that can buffer against some climate change impacts.

- Continue to monitor temperature, both internal and external (SST), and marine heatwaves to better understand potential climate change or extreme weather event impacts and inform ongoing management of Macquarie Harbour.

Glossary

Term	Definition
Acoustic telemetry	using sound (acoustics) to relay information across open space (telemetry), usually by attaching acoustic transmitters (or "tags") to animals.
Aerobic	involving, needing, or relating to oxygen
Anthropogenic	of, relating to, or resulting from the influence of human beings on nature
Area of Occupancy (AOO)	the area within its 'extent of occurrence' which is occupied by a taxon, excluding cases of vagrancy
Benthic	of, relating to, or occurring at the bottom of a body of water
Bioaccumulation	the accumulation over time of a substance and especially a contaminant
Biomass	the total quantity or weight of organisms in a given area or volume
Brackish	somewhat salty or briny, as the water in an estuary or salt marsh
Cumulative	increasing or increased in quantity, degree, or force by successive additions
Deep water ocean renewal	the process by which dense ocean water from outside enters the harbour and sinks to the bottom, replacing the less dense resident water
Depredation	the act of preying upon
Environmental DNA (eDNA)	the genetic material present in environmental samples such as sediment, water, and air
Epibenthic	organisms that live on or just above the bottom sediments in a body of water
Eutrophication	excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life
Ex-situ	Outside, off site, or away from the natural location
Genetic bottleneck	occurs when a population is greatly reduced in size, limiting the genetic diversity of the species
Founder event	occurs when small numbers of ancestral individuals give rise to a large fraction of the population
Halocline	a relatively sharp discontinuity in ocean salinity at a particular depth
Hypoxia	a state in which oxygen is not available in sufficient amounts at the tissue level to maintain adequate homeostasis
Inbreeding depression	the reduced survival and fertility of offspring of related individuals.
Ingress	the action or fact of going in or entering
Labile	easily broken down or displaced
Marine intrusion	the movement of marine water into freshwater aquifers
Neurocranium	the upper and back part of the skull, which forms a protective case around the brain
Oviparous	egg laying
Oxyconformity	oxygen consumption occurs at rates proportional to environmental concentrations but cannot be regulated
Physico chemical water quality	the traditional 'water quality' indicators that include dissolved oxygen, pH, temperature, salinity and nutrients (nitrogen and phosphorus); and measures of toxicants such as insecticides, herbicides and metals
Population viability analysis (PVA)	a combination of ecology and statistics that brings together species characteristics and environmental variability to forecast population health and extinction risk
Remediation	the action of remedying something, in particular of reversing or stopping environmental damage
Scapulocoracoid	the unit of the pectoral girdle that contains the coracoid and scapula

Term	Definition
Stochastic	having a random probability distribution or pattern that may be analysed statistically but may not be predicted precisely
Stratified	formed or arranged into strata or layers
Suboxic	describing a zone of water, between the oxic and anoxic zones, in which the concentration of oxygen is very low
Subpopulation	an identifiable fraction or subdivision of a population
Translocation	the movement of something from one place to another

Links to relevant implementation Documents

This Conservation Advice is developed to be able to subsequently complement other planning instruments such as:

- Maugean skate listing advice (TSSC) 2004. Accessed on the Internet at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=83504

- Maugean skate listing Statement (NRE Tasmania). Accessed on the Internet at: https://nre.tas.gov.au/documents/Maugean%20skate%20-%20Listing%20Statement%20-%20Final.pdf

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