Ecology & Evolution | Nov 12, 2026 | 12 min read | By Bryan White

Salmon Farming, Dissolved Oxygen, and the Fight to Save Tasmania's Ancient Maugean Skate

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1. An Ancient Relic at the Edge of Extinction

In the remote, mist-shrouded waters of western Tasmania lies Macquarie Harbour, a sprawling, fjord-like body of water that looks almost prehistoric. Beneath its dark, tannin-stained waves lives a creature far older than the towering temperate rainforests lining its shores: the Maugean skate (Zearaja maugeana). With a flat, diamond -shaped body, pale grey-brown mottled skin, and an elongated snout, this gentle bottom-dwelling ray is a true living relic. Its evolutionary lineage traces back tens of millions of years to the ancient supercontinent of Gondwana. Yet today, this ancient animal is on the brink of extinction , surviving in only one place on the entire planet: the enclosed, isolated waters of Macquarie Harbour.

The survival crisis facing the Maugean skate is not caused by targeted hunting or direct fishing. Instead, it is the result of a silent, invisible ecological catastrophe unfolding in the water column itself: a catastrophic loss of dissolved oxygen . Over the past two decades, Macquarie Harbour became the heart of Australia's booming industrial salmon aquaculture industry. Hundreds of thousands of Atlantic salmon (Salmo salar), an introduced northern hemisphere fish , are raised in floating net pens across the harbor.

The collision between intensive fish farming and the fragile, unique physics of Macquarie Harbour has created a classic ecological squeeze. As fish waste and uneaten feed settle onto the seabed, they fuel vast blooms of oxygen-consuming bacteria . At the same time, the skate is trapped: it cannot move up into the fresh, sunlit surface waters because its marine body cannot tolerate low salt levels, nor can it retreat into the harbor's deep bottom basins, where oxygen levels have plunged to near zero. Understanding how this crisis emerged -- and whether cutting-edge engineering or strict regulatory cutbacks can save the skate -- reveals fundamental lessons about how fragile closed marine ecosystems truly are.

2. The Estuarine Physics of Macquarie Harbour: A Natural Oxygen Trap

To understand why salmon farming has caused such severe damage in Macquarie Harbour, one must first look at the unique physical geography of the estuary. Macquarie Harbour is roughly six times the size of Sydney Harbour, covering approximately 280 square kilometers, with depths plunging past 50 meters in its central channels. However, it connects to the open Southern Ocean through a remarkably narrow and shallow opening known ominously as Hells Gates . At this entrance, the water is only a few meters deep and barely 100 meters wide, severely restricting the natural tidal flow of clean, oxygen-rich seawater from the ocean.

Compounding this restricted entrance is a massive influx of freshwater from two major river systems: the Gordon River and the King River. These rivers drain the

wet, peat-rich wilderness of western Tasmania, pouring huge volumes of cold, tea-colored, tannin-rich freshwater into the harbor's surface layer. Because freshwater is less dense than salty ocean water, it floats neatly on top, creating a persistent, two-layered water column separated by a sharp boundary known as a halocline (a salinity gradient).

This layering acts like a physical lid. The top 3 to 5 meters of the harbor is almost entirely fresh, stained dark with tannins that block sunlight from penetrating into the deeper water. The deeper water, from roughly 10 meters down to the sea floor, consists of trapped, salty marine water that entered through Hells Gates during past storm surges or high tidal pushes. In a normal open bay, wind and wave action continually stir the water from top to bottom, replenishing oxygen. But in Macquarie Harbour, the dark freshwater lid prevents wind energy from mixing air down into the salty deep layer.

As a consequence, the deep waters of Macquarie Harbour rely entirely on rare, powerful oceanic "recharge events" -- periods when strong southerly winds and heavy tides force dense, oxygenated seawater over the shallow entrance sill at Hells Gates, where it sinks into the central basins. Even before modern industry arrived, Macquarie Harbour's deep basins were naturally low in oxygen. But the ecosystem had achieved a delicate dynamic balance over thousands of years -- a balance that was completely shattered when industrial fish farming expanded into the harbor.

3. The Organic Influx: How Salmon Pens Drive Harbor-Wide Hypoxia

Atlantic salmon farming began in Tasmania in the 1980s, but during the 2000s and 2010s, operations in Macquarie Harbour underwent an explosive expansion. Production surged from modest trial leases to an industrial scale supporting more than 20,000 metric tons of salmon biomass at peak stocking levels. Atlantic salmon are active, fast-growing carnivores that require high-protein feed pellets. Raising millions of these fish inside open-mesh sea cages floating in the harbor introduced an unprecedented load of organic carbon , nitrogen , and phosphorus into the system.

The environmental consequences stem from two separate biological processes: direct fish respiration and benthic decomposition. First, the salmon themselves consume massive amounts of oxygen directly through their gills as they swim, feed, and grow. Second, and far more damaging, is the constant downward rain of organic material. Feces from millions of fish, along with uneaten feed pellets that drift through the pen nets, sink steadily through the water column and settle onto the harbor bed.

When this immense organic carpet reaches the sea floor, it provides an unlimited banquet for benthic bacteria and microbes. As these microorganisms decompose the fish feces and pellets, they breathe in dissolved oxygen from the surrounding water, a process known as benthic microbial respiration . Because the deep salt water is cut off from atmospheric air by the freshwater lid, the microbes consume dissolved oxygen far faster than rare ocean recharge pulses can replenish it.

By 2014 and 2015, scientific monitoring by the Institute for Marine and Antarctic Studies (IMAS) and CSIRO began sounding alarms. Dissolved oxygen levels below 15 meters were plunging below 20% to 30% saturation, creating widespread dead zones, or hypoxic zones . In the deepest channels, oxygen vanished completely, turning the

sediments into anoxic, black mud where sulfur -reducing bacteria began producing toxic hydrogen sulfide. The harbor was suffering from severe organic over-enrichment, transforming a naturally low-oxygen basin into a suffocating aquatic trap.

4. The Physiological Trap: Anatomy and Struggles of the Maugean Skate

The creature caught directly in the crosshairs of this oxygen crisis is the Maugean skate. Skates are closely related to sharks and rays; they are cartilaginous fish that spend their lives gliding across the sediment or burying themselves under sand and silt to ambush prey like small crabs, shrimp, and worms. The Maugean skate is unique because it is one of the very few elasmobranchs (sharks and rays) adapted to life in a brackish, enclosed estuarine system.

However, its adaptation has strict biological limits. Research led by Dr. Amy Morash, Dr. Jeremy Lyle, and Associate Professor Jayson Semmens has revealed the precise physiological boundaries of the skate. Like most marine rays, the skate requires salty water to maintain its internal fluid balance (osmoregulation). If it swims into the fresh, tannin-rich surface water (0 to 3 meters depth), its cells take on excess water, leading to severe osmotic stress. This means the skate cannot escape upward to breathe the oxygen-rich surface waters.

At the same time, the skate cannot retreat into the deep water below 15 to 20 meters, because the seabed there is chronically hypoxic or completely anoxic. This leaves the entire wild population compressed into a razor-thin vertical layer between roughly 5 and 15 meters depth -- a phenomenon scientists call a habitat squeeze . Within this narrow comfort zone, the skate must find food, evade predators, mate, and lay its delicate leathery egg cases (often called "mermaid's purses").

When oxygen levels dip even within this 5-to-15-meter layer, the skate is forced into metabolic crisis. Controlled physiological studies demonstrated that the Maugean skate acts as an oxyconformer : as the oxygen level around it drops, its metabolic rate drops with it. To survive acute drops in oxygen, the skate switches to anaerobic metabolism (burning stored energy without oxygen). Within hours, levels of glucose and lactate surge in its bloodstream, indicating severe metabolic strain. While an adult skate can survive in 20% oxygen saturation for 24 to 48 hours, prolonged exposure leads to exhaustion, immune system suppression, reproductive failure, and death. For developing embryo skates inside egg cases stuck to the seabed, lack of oxygen is swiftly fatal, suffocating the next generation before they can even hatch.

5. The 2019 Storm Overturn: A Catastrophic Near-Extinction Event

The theoretical danger of this habitat squeeze turned into a horrifying reality in the summer of 2019. A period of unusual weather, marked by severe windstorms and sudden barometric shifts, triggered an environmental phenomenon known as a harbor "overturn." The physical layers of the harbor were violently disturbed, causing the deep, completely oxygen-starved water from the bottom basins to surge upward into the mid-water depths where the skates lived.

The result was an immediate, catastrophic die-off. Adult skates, trapped between toxic, anoxic bottom water and fresh surface water, were suffocated in massive numbers. IMAS population monitoring led by researchers David Moreno and Jayson Semmens tracked the disaster using underwater acoustic receivers and standardized netting surveys. Their findings were devastating: between 2014 and 2021, the Maugean skate population in Macquarie Harbour crashed by an estimated 47% . Nearly half of the entire wild species vanished in a matter of a few short years.

By 2023, independent scientific estimates suggested that fewer than 1,000 mature breeding adult skates remained alive in the wild. The Australian Government's Threatened Species Scientific Committee (TSSC) reviewed the latest empirical data and updated its formal conservation advice. The verdict was stark: the Maugean skate met the criteria for being reclassified as Critically Endangered -- just one step away from total extinction in the wild. The TSSC identified the degradation of water quality and severe dissolved oxygen depletion caused by salmon farming as the single greatest threat driving the species toward oblivion.

6. Engineering a Lifeline: The Macquarie Harbour Oxygenation Project

Faced with the imminent threat of extinction and mounting public outrage, the aquaculture industry and government authorities turned to an extraordinary technological intervention: attempting to mechanically re-oxygenate an entire natural harbor. Rather than immediately shutting down or drastically reducing the multi-million-dollar salmon farming operations, the federal and state governments collaborated with industry bodies (Salmon Tasmania, Tassal, Huon Aquaculture, and Petuna) and research institutions to launch the Macquarie Harbour Oxygenation Project (MHOP) , which later expanded into the Oxygenation Offset Program in Macquarie Harbour (OOPMH) .

The core technology relies on large, specialized barges anchored in the harbor that extract water from below the halocline, super-saturate it with pure liquid oxygen using industrial micro-bubble and nanobubble diffusers, and pump the enriched water back into the deep water layer. Nanobubbles are microscopic gas pockets that remain suspended in water for extended periods without immediately floating to the surface and escaping, allowing the dissolved oxygen to dissolve directly into the water column.

By mid-2026, Tasmania's Environment Protection Authority (EPA) formalized this technological requirement, mandating that salmon farming companies increase their mechanical oxygenation capacity to offset an average oxygen demand calculated at 10.3 metric tons of oxygen per day . The goal of this machine-driven aeration is to create artificial oxygen refuges and prevent another catastrophic overturn event like that of 2019.

Simultaneously, conservation biologists launched an emergency captive breeding program. Scientists from IMAS carefully collected wild Maugean skate eggs and a small founding cohort of adult skates, transporting them to high-tech biosecure aquaculture facilities at IMAS Taroona in Hobart. In early 2024, the team celebrated a historic milestone: the first-ever captive hatching of Maugean skate pups. While these captive breeding triumphs offer a crucial genetic insurance policy, scientists emphasize that captive animals cannot save a species if their only natural wild home

remains an uninhabitable, oxygen-starved dead zone.

7. Scientific Realities vs. Techno-Fixes: The Regulatory Crossroads

While the mechanical oxygenation program represents an impressive engineering effort, independent marine scientists and conservation organizations remain deeply skeptical of relying on machines to sustain an entire estuary. Pumping 10 metric tons of oxygen per day into a 280-square-kilometer harbor is often compared to trying to air-condition an open stadium during a heatwave. It treats the symptom -- low dissolved oxygen -- while allowing the underlying disease -- thousands of tons of fish feces and uneaten feed raining onto the sea floor -- to continue unabated.

Leading marine ecologists, environmental organizations such as the Australian Marine Conservation Society (AMCS) and Environment Tasmania, and the federal Threatened Species Scientific Committee have consistently argued that the only scientifically guaranteed method to restore oxygen levels to pre-2009 baselines is a substantial, immediate reduction in fish biomass. Under Australia's primary national nature law -- the Environment Protection and Biodiversity Conservation (EPBC) Act -- conservation groups formally petitioned the Federal Environment Minister to reconsider the 2012 decision that originally permitted the massive expansion of salmon farming in Macquarie Harbour.

This legal challenge created an intense political and economic debate. The salmon industry is a major economic engine for Tasmania's remote West Coast, supporting hundreds of direct and indirect jobs in towns like Strahan. Industry leaders and local representatives argue that abruptly terminating farming leases would devastate the local economy and community livelihoods. Conversely, marine scientists point out that under federal and international biodiversity commitments, allowing an ancient endemic vertebrate to go extinct to protect an industrial agricultural lease sets an alarming legal precedent.

Furthermore, climate change is compounding the crisis. Ocean waters entering the harbor have warmed by roughly 1.5 deg C over recent decades. Warmer water holds less dissolved oxygen naturally and speeds up the metabolic rate of both salmon and bacteria, accelerating oxygen drawdown. When heavy rainfall seasons occur, as seen in late 2025 and 2026, increased river discharge deepens the freshwater lid, further blocking natural oceanic recharge. In a warming world, Macquarie Harbour simply lacks the ecological resilience to absorb the waste load of intensive industrial farming.

8. Comparative Systems Telemetry: Environmental Shifts Across Four Decades

The trajectory of Macquarie Harbour illustrates how rapidly intensive human resource extraction can alter the fundamental biogeochemistry of an enclosed marine ecosystem. The table below synthesizes four distinct operational regimes across the harbor's modern environmental history:

| Parameter / Metric | | Pre-Aquaculture Baseline (Pre-2000) | | Peak Farming Expansion (2014-2016) | | Storm Overturn Crisis (2019) | | Mitigated State (2024-2026) |

| Salmon Biomass in Harbor | | 0 to <2,000 tonnes | | >20,000 tonnes (Peak) | | ~13,000-15,000 tonnes | | ~10,000 tonnes (Capped) |

| Bottom Water DO (>15m Depth) | | 50% to 65% Saturation | | <15% to 25% (Severe Hypoxia) | | 0% to 10% (Near Total Anoxia) | | 25% to 40% (Fluctuating) |

| Maugean Skate Population Status | | Stable / Unmeasured Baseline | | Declining / Habitat Compressing | | 47% Population Crash | | <1,000 Mature Adults (Critically Endangered) |

| Artificial Oxygen Injection | | None (Natural Cycles Only) | | None | | Emergency Trials Proposed | | 10.3 tonnes O_2 /day Mandated |

| Skate Vertical Habitat Envelope | | Broad (~5m to 35m Depth) | | Compressed (~5m to 18m Depth) | | Severely Squeezed (~5m to 10m Depth) | | Restricted Buffer (~5m to 15m Depth) |

| Captive Insurance Colony | | None | | None | | None | | Active (IMAS Taroona Facility) |

This telemetry synthesis highlights that while artificial oxygen injection provides a temporary buffer against catastrophic total-anoxia events, the deep waters of Macquarie Harbour remain in a precarious state, well below the historical baseline required for the skate's natural recovery.

9. Conclusion: Navigating the Safe Operating Limits of Coastal Waters

The saga of Macquarie Harbour is a powerful case study in modern environmental science, illustrating what happens when human industrial activities ignore the physical and thermodynamic boundaries of an ecosystem. An estuary with a shallow entrance sill, heavy freshwater stratification, and slow water turnover has a finite, strictly limited capacity to process organic waste. When that carrying capacity is exceeded, the consequences cascade through every level of the ecosystem, culminating in the near-loss of a unique lineage that survived tens of millions of years of natural climate shifts.

Technological solutions like the Oxygenation Offset Program demonstrate the ingenuity and determination of engineers and marine scientists to prevent immediate extinction. Mechanical aeration has undoubtedly provided an emergency buffer during recent periods of high rainfall and stagnant water exchange. However, technological life support cannot replace a healthy, functioning ecosystem. As long as millions of finfish continue to release thousands of tons of organic waste into an enclosed, stratified basin, the Maugean skate will remain trapped on life support.

The path forward requires bold, long-term environmental stewardship. Globally, modern aquaculture is increasingly exploring closed-containment systems, offshore deep-water sites with high oceanic flushing, and land-based recirculating aquaculture systems (RAS) that capture and treat organic waste before it ever reaches natural waterways. Transitioning salmon farming out of sensitive, semi-enclosed estuaries like Macquarie Harbour would allow the seabed to slowly detoxify, dissolved oxygen to naturally recover, and the Maugean skate to reclaim its ancient home. Preserving the skate is more than saving a single species; it is a

test of whether modern society can recognize ecological limits and choose coexistence over extinction.

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