

Restorative Aquaculture:

An Evidence-Based Assessment of NSW Oyster Aquaculture

2026



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Executive Summary

Restorative aquaculture is the farming of aquatic species in a manner that delivers measurable ecological benefits while producing food and supporting regional economies. Unlike conventional sustainability approaches that seek to minimise environmental harm, restorative aquaculture aims to generate a net positive environmental outcome through improvements to water quality, habitat condition, biodiversity and ecosystem resilience (TNC 2021).

Recognising the need for robust and defensible evidence, The Nature Conservancy (TNC) has developed two complementary frameworks. The first, the Global Principles of Restorative Aquaculture (TNC 2021), provides a high-level assessment of whether an aquaculture system is likely to deliver restorative outcomes through three environmental benefit roadmaps: water quality, habitat and biodiversity, and carbon sequestration. The second, the Monitoring, Evaluation and Learning (MEL) Framework (TNC 2024), provides a structured set of indicators that allow environmental benefits to be measured, evaluated and tracked over time.

This project applied both frameworks to the NSW oyster aquaculture industry. Part 1 assessed NSW oyster farming against TNC's restorative aquaculture principles and decision-making roadmaps. Part 2 mapped the available scientific evidence against the MEL framework's 16 indicators to determine where benefits are well-supported, where uncertainty remains, and where future research should be prioritised.

Key Findings

This assessment found strong evidence that NSW oyster aquaculture aligns with the intent and principles of restorative aquaculture.

NSW oyster farming is uniquely positioned within estuarine environments that have experienced significant historical declines in natural shellfish reefs and continue to face pressures from nutrient enrichment, sedimentation and habitat loss. Oysters are extractive, filter-feeding organisms requiring no feed, fertiliser or freshwater inputs. Through filtration, nutrient uptake and habitat provision, they are capable of delivering a range of ecosystem services while supporting a highly productive regional industry.

Application of TNC's restorative aquaculture environmental benefit roadmaps found that NSW oyster aquaculture is:

TNC Roadmap	Outcome
Water Quality	Most Likely Restorative
Habitat & Biodiversity	Most Likely Restorative
Carbon Sequestration	Not Likely Restorative

Water Quality

Nutrients incorporated into oyster tissue and shell are permanently removed when oysters are harvested. Removal rates are species-specific, so annual removal varies with the size and species mix of harvest. Every 1,000 tonnes of Sydney rock oysters harvested removes 5.58 tonnes of nitrogen and 0.69 tonnes of phosphorus, and every 1,000 tonnes of Pacific oysters removes 4.46 tonnes of nitrogen and 0.55 tonnes of phosphorus. Across the 22/23, 23/24 and

24/25 production years, NSW oyster harvest removed an average of 15.8 tonnes of nitrogen and 2.0 tonnes of phosphorus.

Water filtration by oysters underpins many of the industry's environmental benefits. Current production (based on 2024/25 figures) is estimated to filter roughly 2 trillion litres of water, removing phytoplankton and suspended particles while improving water clarity and supporting broader ecosystem function (NSW Farmers 2025; Bayne *et al.* 1999).

Importantly, the magnitude of these benefits is highly context dependent. Oyster aquaculture is unlikely to offset catchment-scale nutrient loads in large river-dominated estuaries. However, evidence suggests that in smaller, lower-nutrient systems, nutrient removal can be ecologically meaningful and contribute towards maintaining favourable water-quality conditions.

The evidence for denitrification is more complicated. While international research consistently demonstrates enhanced nitrogen processing around oyster habitats, the only NSW study found nitrogen cycling was dominated by Dissimilatory Nitrate Reduction to Ammonium (DNRA), indicating retention rather than removal of nitrogen in that system (Erler *et al.* 2017). Consequently, denitrification remains an important research priority and should be considered only partially supported in the context of NSW.

Habitat & Biodiversity

Australia has lost most of its shellfish reefs, with less than 1% of Native oyster reefs and ~8% of Sydney rock oyster reefs remaining (Gillies *et al.* 2018). Against this backdrop, oyster farming infrastructure introduces hard substrate and structural complexity into otherwise soft-sediment estuaries, creating habitat that supports a diverse range of marine life.

Research in Port Stephens recorded 90 fish species from 51 families using leases, with fish abundance and diversity comparable to adjacent natural habitats such as seagrass, mangroves and remnant oyster reefs, and far higher than bare sediment (Martínez-Baena *et al.* 2022). International syntheses have also consistently shown elevated levels of biodiversity and abundance around shellfish farms (Theuerkauf *et al.* 2022), with one analysis estimating an extra 348–1,110 kg of fish per hectare per year relative to reference habitats (Barrett *et al.* 2022).

The assessment found that NSW oyster aquaculture avoids habitat removal, presents negligible entanglement risk to marine mammals, predominantly farms native species, and actively incorporates management measures to minimise impacts on sensitive habitats such as seagrass. Collectively, these characteristics support a strong conclusion that oyster farming contributes positively to estuarine habitat values and biodiversity, with the main open question being whether higher numbers at the farm represent genuine added production or the attraction of animals from surrounding habitat.

Climate Change

While oysters are often promoted as climate-friendly food production systems, the evidence does not currently support characterising oyster farming as a carbon sequestration activity under the TNC framework.

Current scientific understanding indicates that shell formation does not constitute a marine carbon dioxide removal pathway, as calcium carbonate formation releases carbon dioxide during the calcification process (Pernet *et al.* 2025). While emerging research has proposed that oyster farming may support carbon storage through enhancement of the biological pump (Chen *et al.* 2025), the findings are contested and require further validation (Pernet *et al.* 2026).

Nevertheless, oysters remain one of the lowest-emission animal proteins available. NSW oyster production has an estimated greenhouse gas footprint of ~0.93 kg CO₂e per kg of product, substantially lower than most animal protein sources (NSW Farmers 2025).

Evidence Base & Future Priorities

Assessment against the TNC MEL Framework shows the evidence for restorative benefits is strong, even if some measures are not yet fully quantified for NSW. Across the 16 indicators:

- 6 are *Well Supported* by direct NSW data; and
- 10 are *Partially Supported* – the benefit and mechanisms are established (often through strong overseas or interstate evidence), but NSW-specific measurement is needed.
- None were unsupported.

The strongest evidence exists for nutrient bioextraction, water filtration, greenhouse-gas performance, habitat provision, the mobile fauna that farms support, and the overall enhancement of biodiversity relative to bare sediment.

Knowledge gaps are concentrated around denitrification, farm-versus-non-farm water-quality responses (chlorophyll a, dissolved oxygen and plankton communities), sediment biogeochemistry and wave attenuation. Recruitment of the farmed oyster itself is well quantified, but the spawning and recruitment of the wider associated community, and the contribution of farm larvae to wild oyster populations, require further work.

Development of a nutrient removal calculator offers the clearest short to medium term return. This requires a targeted sampling program to establish how oyster size relates to meat and shell weight across estuaries and seasons, followed by creation of a simple tool where growers enter shell length and harvest numbers. This would let farms quantify their contribution to estuary health and give government and markets a defensible basis for recognising that service.

Conclusion

This assessment demonstrates that NSW oyster aquaculture satisfies the core principles of restorative aquaculture and provides strong evidence of measurable environmental benefits, particularly in relation to water quality and biodiversity. While some uncertainties remain, the weight of evidence indicates that NSW oyster farming is broadly restorative, delivering ecosystem services alongside food production.

The industry is therefore well-positioned to be recognised as a leading example of restorative aquaculture globally. With continued investment in targeted monitoring and evidence generation, NSW oyster aquaculture can further strengthen its environmental credentials, support emerging ecosystem-service markets and contribute meaningfully to both estuary health and regional economic development.

Environmental benefits of NSW oyster aquaculture

WATER QUALITY

1 Filters & clears the water
Oysters remove algae & fine sediment. A Sydney rock oyster filters 3 L/hr; a Pacific oyster 5-8 L/hr

2 Curbs algal blooms
Grazing phytoplankton keeps algal biomass and eutrophication in check

3 Removes nutrients at harvest
Sydney rock: 5.58 kg N + 0.69 kg P per tonne;
Pacific: 4.46 kg N + 0.55 kg P per tonne

4 May boost denitrification
Seabed deposits help bacteria turn nitrogen into inert N₂ gas – likely, but not yet confirmed in NSW

HABITAT & BIODIVERSITY

5 Adds 3-D habitat
Racks, posts & longlines add hard structure to bare estuaries; colonised by barnacles, mussels, sponges & algae, and used by 90 fish species on NSW leases

6 More fish & invertebrates
1.95x the abundance and 11.4x the richness of open sediment – fish and mobile invertebrates.[^]

7 Seabed life often enhanced
Moderate biodeposits feed worms & crustaceans; heavy stocking in poorly-flushed sites can reduce diversity

8 Seagrass shading is managed
Only light-permeable longlines, designed to move with tides and currents, are permitted over seagrass

9 May lower disease
Oyster filtration cut blue crab infection by 32.7% in a US study[^]

EMISSIONS & CLIMATE CHANGE

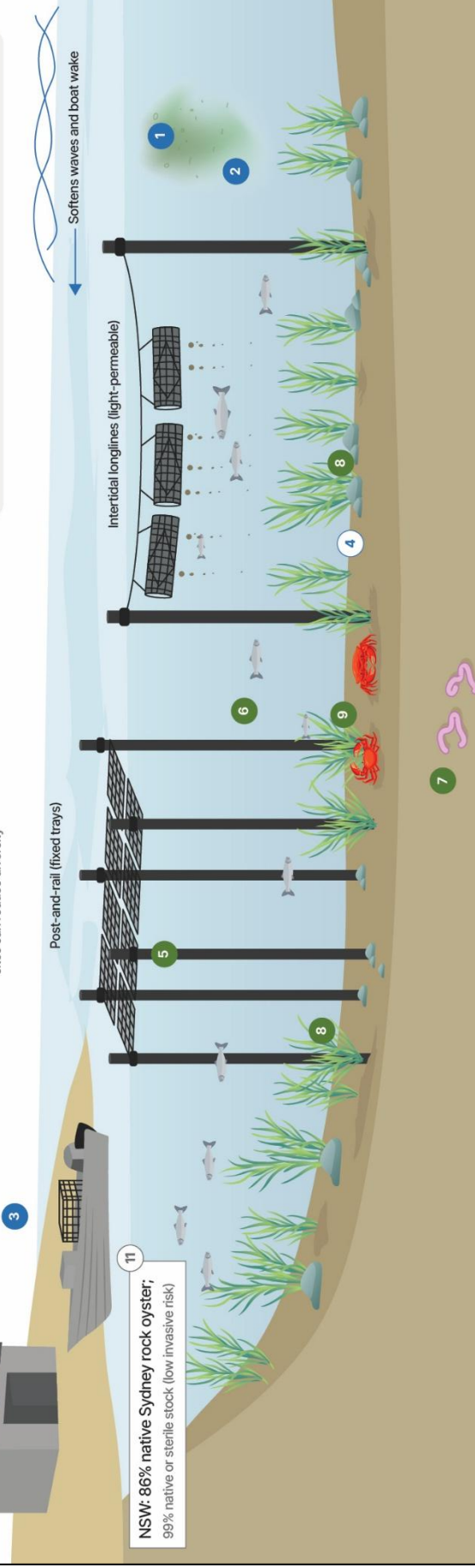
10 Very low emissions
3.75 kg CO₂e per 100 g of protein – among the lowest carbon footprints of any farmed protein. No feed, freshwater, fertilisers or chemicals used

11 Breeding for a changing climate
Sydney rock oysters are bred for tolerance to warming & acidification; fertile stock may spread traits to the wild

A carbon store, not CO₂ removal
Oyster shell is a sink for carbon, but does not result in atmospheric CO₂ reduction

Ecosystem carbon-capture unproven
One study claiming oysters store carbon by driving the biological pump has been formally challenged

Bottom line: a very low-emission food — but growing oysters does not remove CO₂ from the atmosphere.



AT A GLANCE — across the whole NSW industry, each year

- Filters ~2 million litres of estuary water. Like emptying & cleaning Sydney Harbour four times over.
- Removes ~15.8 tonnes of nitrogen & ~2.0 tonnes of phosphorus. A nutrient removal service valued at \$1.8m-\$9.5m.
- Produces ~66 million oysters (2,900 tonnes). Well under the 7,500 tonne estimated sustainable level.
- Total emissions 2,640 t CO₂e. The cost to offset would be 1.5 cents per dozen.

For more information see NSW Farmers (2026), Restorative Aquaculture: An Evidence-Based Assessment of the NSW Oyster Industry, FRDC Project 2024-057.

[^] Global / Proxy data.

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Abbreviations

APVMA	Australian Pesticides and Veterinary Medicines Authority
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DNRA	Dissimilatory Nitrate Reduction to Ammonium
FSANZ	Food Standards Australia New Zealand
GVP	Gross Value of Production
MCDR	Marine Carbon Dioxide Removal
MEL	Monitoring, Evaluation & Learning
MUP	Minor Use Permit
NATA	National Association of Testing Authorities
NOAA	National Oceanographic & Atmospheric Administration
OISAS	Oyster Industry Sustainable Aquaculture Strategy
PAC	Pacific Oyster
PES	Payments for Ecosystem Services
POAA	Priority Oyster Aquaculture Area
SMURF	Standard Monitoring Unit for Recruitment of Fishes
SRO	Sydney Rock Oyster
TNC	The Nature Conservancy
UNSW WRL	University of New South Wales Water Research Laboratory

Introduction

The NSW Oyster Industry

Oyster farming is the oldest and most valuable aquaculture industry in New South Wales (NSW), with a history spanning more than 150 years. Today, the NSW oyster industry is a cornerstone of regional coastal economies, combining deep cultural heritage with modern, environmentally responsible farming practices.

In 2024-25, the industry was valued at \$76.4 million at the farm gate, accounting for approximately 71% of total NSW aquaculture production by value (NSW DPIRD 2026). NSW is Australia's largest producer of edible oysters, with ~230 farming businesses operating across ~2,400 aquaculture leases. Collectively, the industry harvests ~66 million oysters (~5.5 million dozen) each year for the market (NSW DPIRD 2026), with a further 200+ million juvenile oysters of varying sizes under cultivation for future harvests.

Oyster leases occupy ~3,000 hectares of water across 36 coastal estuaries, extending from Wonboyn Lake on the south coast, to the Tweed River on the Queensland border (Figure. 1).

Three species of edible oysters are commercially cultivated, each with distinct growth rates and production characteristics:

- **Sydney rock oysters (*Saccostrea glomerata*):**
An iconic native species and the backbone of the industry accounting for ~86% of total production. Sydney rock oysters typically take 2.5–4 years to reach market size.
- **Pacific oysters (*Magallana gigas*):**
Pacific oysters grow more rapidly than Sydney rock oysters in NSW waters, typically reaching market size in 1-2 years. They currently make up ~14% of NSW production.
- **Native oyster¹ (*Ostrea angasi*):**
A boutique species representing less than 1% of production, with a 2–3 year growth cycle.

Economic & Social Importance:

Beyond farm-gate value, the oyster industry delivers substantial flow-on benefits. A BDO (2023) assessment found that for every \$1 of farm-gate value, the industry generates \$4.17 in total economic contribution, reflecting strong linkages to processing, transport, wholesale, retail, hospitality, and tourism. Based on a GVP of \$76.4 million, the total economic contribution of the NSW oyster industry is therefore estimated to exceed \$315 million.

The same study calculated that the lease-based aquaculture industry (i.e. oysters and mussels), supports close to 800 full-time equivalent (FTE) positions. Such employment is especially important in regional and coastal communities, with aquaculture providing entry level and long-term opportunities for early school leavers, indigenous people and those facing barriers to employment (Barclay *et al.* 2016).

¹ "Native oyster" is the standard common name for *Ostrea angasi* under the Australian Fish Names Standard; it does not imply that other cultivated species are non-native.



Figure 1. Commercial oyster producing estuaries in NSW.

A History of Oyster Use and Cultivation:

The harvesting of oysters along the east coast of Australia pre-dates European settlement by thousands of years. Oyster shells are commonly found in Aboriginal middens, some of which have been carbon-dated to around 6,000 Before Present (BP), demonstrating the long-standing cultural and nutritional importance of oysters to Aboriginal communities (Stockton 1977). This date aligns with the period after post-glacial sea-level stabilisation, when estuaries suitable to oysters formed along the NSW coast.

Following European colonisation, oysters were harvested extensively for food and burned in large quantities to produce lime for building mortar. This practice rapidly depleted wild stocks, leading to legislative intervention. Under the Oyster Beds Act (1868) the burning of live oysters for lime was prohibited, and growing demand for edible oysters encouraged the development of commercial cultivation.

The formalisation of the industry followed with the proclamation of the Oyster Fisheries Act in 1884, which introduced the leasing of oyster beds and regulated the harvesting of product. From this period onward, oyster farming became closely linked to the settlement and growth of coastal NSW, shaping the identity and economy of many coastal communities.

Production Trends & Industry Change:

Oyster production in NSW grew steadily through the late 19th and early 20th centuries, reaching a peak in 1976-77 at approximately 9,375 tonnes (Figure 2), equivalent to ~168 million oysters (~14 million dozen). At current average unit prices taken from NSW DPIRD (2026), this peak would represent a farm-gate value of approximately \$180 million (i.e. ~2.5 times the value of current production).

Since reaching peak production in the mid-1970s, the industry has experienced a sustained decline in overall production. This decline has been attributed to a combination of deteriorating estuarine water quality, increasing coastal development pressures, disease outbreaks, changing industry economics, and competition from other oyster species. Over the same period, consumer preferences have evolved, with growing demand for premium oysters characterised by quality, consistency, provenance and distinctive flavour profiles, prompting a shift in industry focus from maximising production volume to producing higher-value products (Schrobbach *et al.* 2014). Looking ahead, climate change is expected to exacerbate existing challenges, with pressures such as marine heatwaves, disease outbreaks, and harmful algal blooms projected to become more frequent and severe (Leith & Haward 2010; Western & Keating 2017).

A transition towards more environmentally sustainable farming practices has also played a role. The adoption of lower-density stocking, and infrastructure designed to minimise environmental impact has, in some cases, reduced overall production capacity but delivered higher-quality product. This shift has been further reinforced by evolving community expectations and regulatory frameworks that emphasise the role of growers as responsible stewards of estuarine ecosystems.

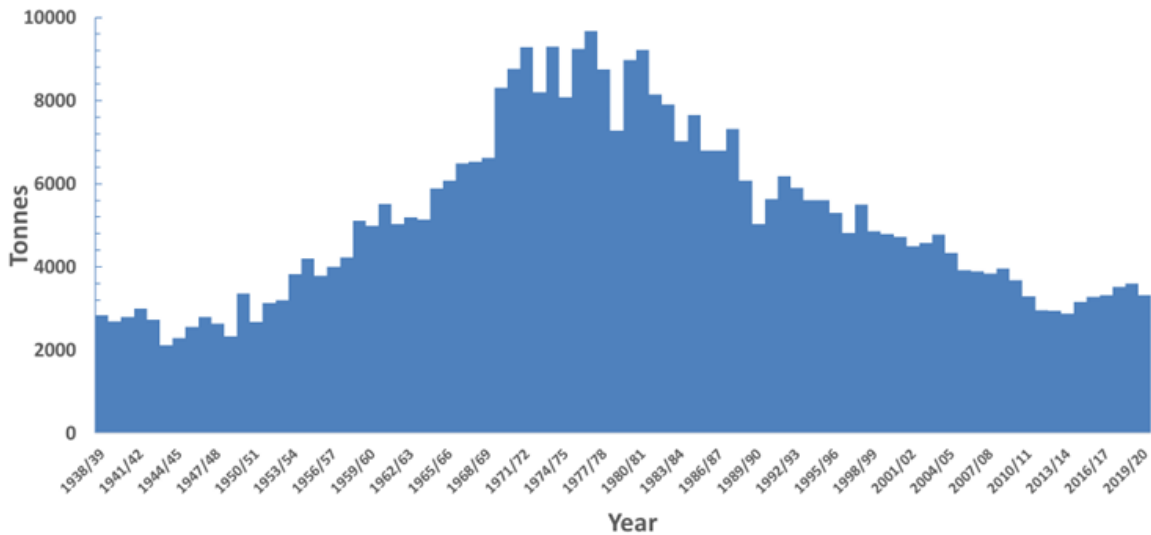


Figure 2. Annual NSW oyster production from 1938/39 to 2020/21 (NSW DPIRD 2021).

Over the last 15 years, production has shown signs of rebound, underpinned by innovation, favourable growing conditions, selective breeding, and strong market demand for premium oysters. This evolution reflects a move toward a quality-focused, environmentally responsible industry positioned for long-term resilience rather than maximum short-term output.

Seed Supply & Production:

The supply of juvenile oysters (spat) remains a key feature of NSW production. Around 85–90% of Sydney rock oyster spat comes from natural wild settlement (NSW DPIRD 2024b). Farmers place reusable plastic slats on racks in the lower reaches of estuaries coinciding with peak spawning and settlement periods from February onwards. These slat ‘bundles’ provide a hard, complex structure that encourages oyster larvae to settle from the water column (Figs. 3 & 4).

After 6-9 months, the plastic slats are retrieved and flexed to release the catch. These ‘single-seed’ oysters are then handled and grown individually for the rest of the production cycle.

Although wild catch remains the main source of Sydney rock oyster spat, hatchery production is increasing. Conversely, Pacific oysters and Native oysters are produced almost entirely from hatchery-derived seed, with the exception of a small Pacific wild-spat harvest in Port Stephens.



Figures 3 & 4. Catching slats on a rack system.

Farming Infrastructure & Production Methods:

NSW oyster farming uses a diverse range of grow out systems. The choice of gear is influenced by environmental conditions, including estuary morphology, hydrology, biology and climate, as well as operational factors such as technology, finance and labour availability.

Since the late 1990s, the industry has undergone a significant transition towards more environmentally sustainable infrastructure. Treated timber and hydrocarbon-based preservatives have been progressively phased out in favour of UV-stable, recyclable high-density polyethylene (HDPE) materials (OceanWatch Australia 2024).

Contemporary farming infrastructure typically includes HDPE-encapsulated timber posts, along with HDPE mesh baskets, trays, and bags. In parallel, there has been a marked shift away from intertidal post and rail systems (Figure 5) toward intertidal post-supported longlines (Figure 6), and floating cultivation (Figures 7 & 8). As identified by OceanWatch Australia (2024), this evolution has been driven by increased mechanisation, labour efficiency gains, improved resilience and adaptability to extreme weather events, and changing community expectations around environmental performance.



Figure 5. Intertidal trays on post & rail infrastructure.

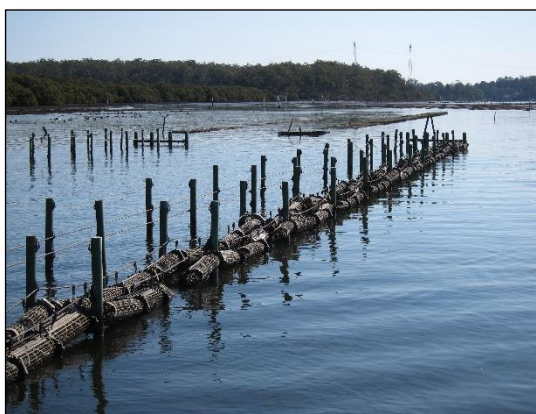


Figure 6. Intertidal, post-supported, longline cultivation.



Figures 7 & 8. Floating cultivation.

The widespread adoption of systems such as BST, SEAPA, Hexcyl, FlipFarm and Zapco underscores Australasia's leadership in oyster farming innovation. These globally recognised technologies were developed in Australia or New Zealand, largely by oyster farmers responding directly to the challenges of high-energy estuarine environments. Australasian growers pioneered the adjustable long-line system and refined robust, purpose-built HDPE baskets, clips and floating systems that are now regarded internationally as best practice.

Future Outlook:

In 2024, the NSW Government launched the NSW Aquaculture Vision Statement, setting an ambitious target to double the farm gate value of the NSW aquaculture sector to \$300 million by 2030 (NSW DPIRD 2025b). The oyster industry is at the heart of this ambition. The roadmap that underpins the NSW Aquaculture Vision Statement highlights twelve strategic goals.

1. NSW Aquaculture Steering Committee
2. Marine aquaculture investment
3. Closing the gap targets
4. Oyster industry risk management
5. Environmental benefits
6. Institutional investment
7. Streamline administration
8. Water quality
9. Business security
10. Industry expansion
11. Social licence
12. Innovative research

Some of the key initiatives highlighted through the roadmap include: investing in research infrastructure, extending lease tenure from 15 to 30 years to attract investment, supporting the Sydney rock oyster breeding program and increasing Aboriginal participation in aquaculture businesses. More details about the NSW Aquaculture Vision Statement can be found at: https://www.dpiird.nsw.gov.au/_data/assets/pdf_file/0010/1649854/NSW-Aquaculture-Vision-Statement-Roadmap-glossy.pdf

Achieving this growth ambition will depend on the industry's ability to remain resilient in the face of a changing climate. Recognising this, the Vision Statement identifies risk management and innovation as key strategic priorities, reflecting the sector's exposure to climate-related threats including warming temperatures, marine heatwaves, ocean acidification, altered rainfall and salinity regimes, harmful algal blooms, and disease. This vulnerability has been mapped for the Australian edible-oyster industry, together with practical adaptation pathways for growers and agencies (Leith & Haward 2010; Western & Keating 2017), and is already being addressed through selective breeding for QX resistance and acidification tolerance (Parker *et al.* 2024). As the water-quality, habitat, and low-emissions benefits described in this report depend on a viable and productive oyster industry, strengthening climate resilience is essential to maintaining these restorative outcomes over the long term.

Restorative Aquaculture

Restorative aquaculture is the farming of aquatic species that deliver direct ecological benefits and have the potential to achieve a net positive environmental outcome.

This definition shifts aquaculture beyond the traditional focus on product supply and places emphasis on the environmental effects of farming activities. The extent and type of benefits will vary depending on the species cultivated, the infrastructure used, the practices employed, and characteristics of the surrounding environment.

Restorative aquaculture parallels regenerative agriculture on land. Rather than aiming for a neutral footprint, restorative approaches actively improve ecosystem condition, enhancing biodiversity, supporting habitat recovery, and improving water quality, while still producing food and other products (Figure 9). This positions restorative aquaculture as a practical approach for repairing degraded environments and supporting resilient coastal communities.

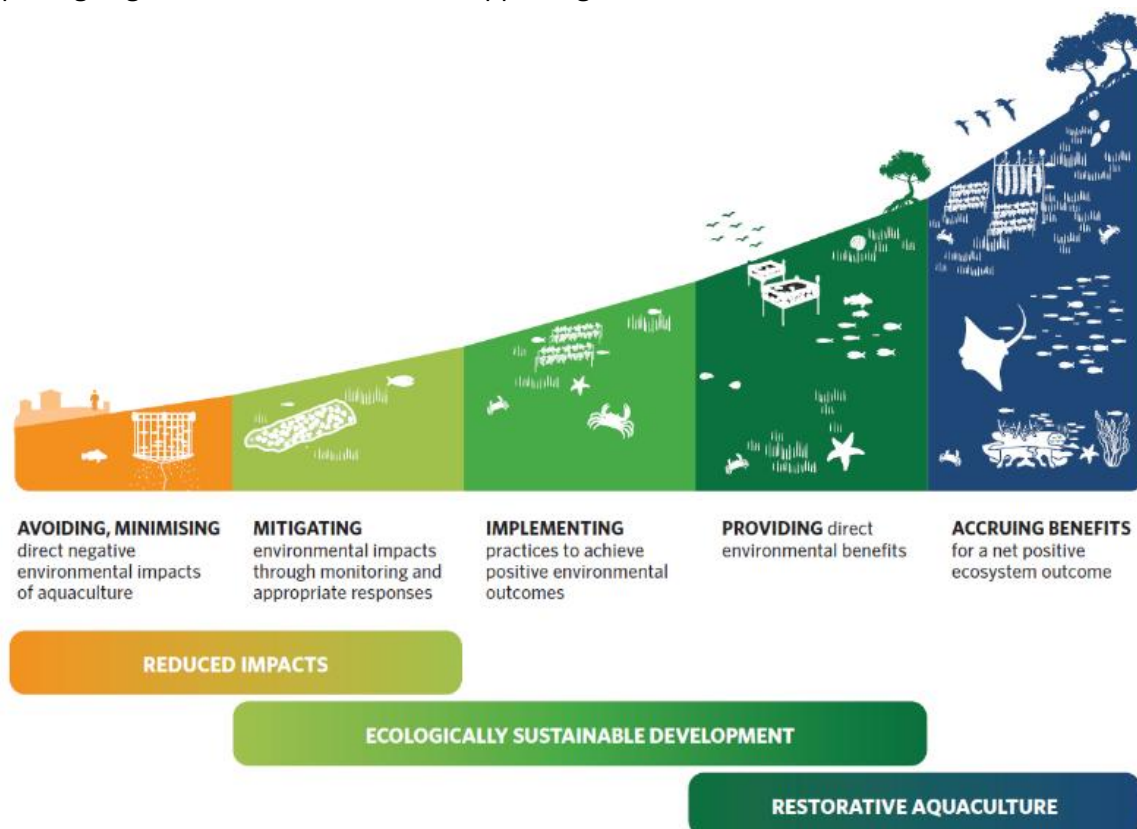


Figure 9. The Restorative Aquaculture Pathway (The Nature Conservancy 2021).

The Need for Restorative Aquaculture:

The growing interest in restorative aquaculture reflects mounting pressures on aquatic ecosystems and the limitations of conventional management and restoration approaches. Coastal systems globally have experienced extensive degradation due to nutrient pollution, habitat loss, overexploitation, climate change, and cumulative impacts from expanding coastal populations (UNEP 2006; Halpern *et al.* 2008). Many historically productive ecosystems, such as oyster reefs, seagrass meadows, kelp forests, wetlands, mangroves and saltmarsh, have

suffered severe declines, resulting in the loss of critical ecosystem functions including water filtration, habitat provision, shoreline protection, and carbon cycling (Jackson *et al.* 2001; Barbier *et al.* 2011).

As global demand for aquatic foods continues to grow, aquaculture is expected to play an increasingly important role in food security, particularly as wild-capture fisheries have largely plateaued (Figure 10). At the same time, aquaculture development is occurring amid widespread concerns about declining ecosystem health, reinforcing the perception that food production and environmental outcomes are at odds. Restorative aquaculture offers an alternative paradigm, positioning aquaculture as both a sustainable source of food and a potential driver of ecosystem repair and long-term resilience.

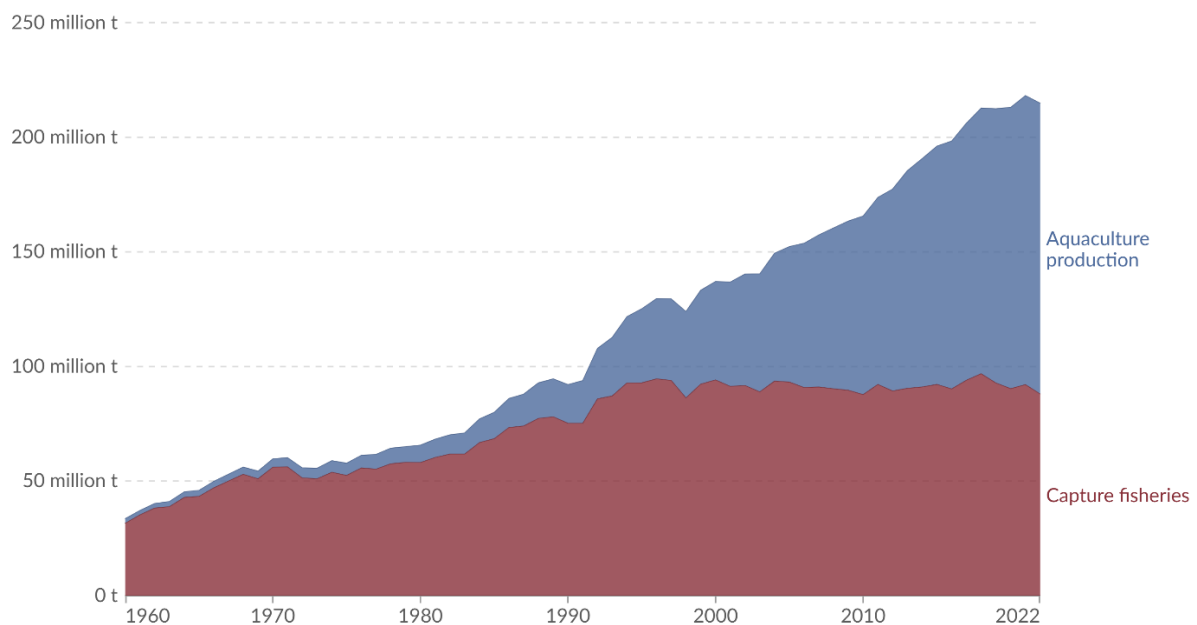


Figure 10. Global seafood production (World Bank (2026))

This paradigm is increasingly backed by evidence. In a systematic review of 129 studies, Gentry *et al.* (2020) confirmed that marine aquaculture, and bivalve farming in particular, can deliver a range of ecosystem services beyond the production of food, although the strength of evidence varies markedly by service, being well established for functions such as nutrient absorption but still limited for others such as cultural services (i.e. livelihoods, tourism).

More recently, Overton *et al.* (2024) identified twelve distinct ecologically beneficial outcomes achievable through aquaculture, spanning species recovery, habitat restoration and rehabilitation, bioremediation, climate-change mitigation and coastal defence, among others. Critically, they caution that positive intentions do not guarantee positive ecological outcomes, and that clear, measurable indicators are essential both to demonstrate genuine benefit and to guard against greenwashing. This principle directly motivates the indicator-based assessment applied in Part 2 of this report.

Restorative Bivalve Aquaculture:

Bivalve molluscs are naturally aligned with restorative aquaculture. Their biology, and the farming systems used to grow them, deliver a suite of environmental advantages. They require no feed, fertilisers, pesticides, chemical additives, or freshwater; they thrive in extensive, open water systems with a very small carbon footprint; and they actively enhance water quality by removing excess nutrients and reducing turbidity.

When implemented in the right locations and managed appropriately, bivalve aquaculture can therefore simultaneously improve ecosystem health, support regional local communities and contribute to food security.

Timescale and Net Positive Outcomes:

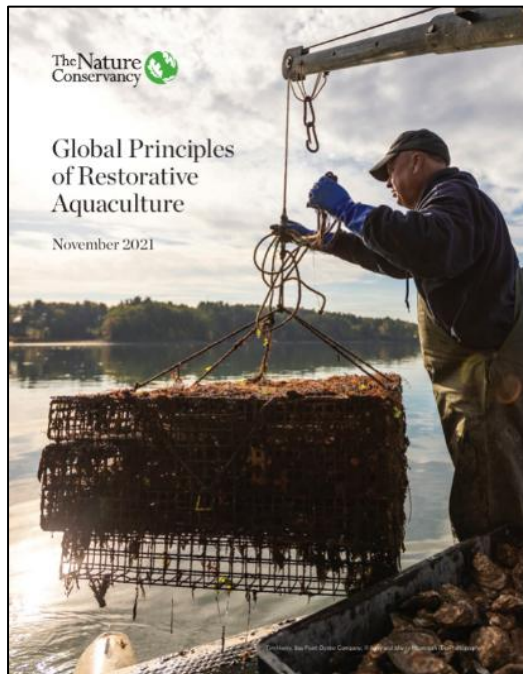
Some environmental benefits of bivalve aquaculture can occur immediately, such as water filtration and creation of habitat, while others, like recruitment and stock recovery, take time to develop. For this reason, restorative aquaculture is defined by its *potential* to deliver a net positive environmental outcome, recognising that benefits may be incremental and cumulative rather than instantaneous.

While environmental benefits are context-specific and can be difficult to generalise, the current body of science highlights several consistent positive outcomes, including:

- Water quality improvements
- Habitat creation and biodiversity enhancement
- Potential contributions to climate change mitigation.

TNC Restorative Aquaculture Principles & Frameworks

To advance global understanding, and to encourage adoption of restorative aquaculture, The Nature Conservancy (TNC) has developed two complementary resources:



Global Principles of Restorative Aquaculture (2021)

This document sets out the core principles of restorative aquaculture, and operationalises these through a series of dichotomous flow charts that provide an initial assessment of whether an operation is:

- i) Most likely restorative,
- ii) Potentially restorative, or
- iii) Not likely restorative.

Dichotomous flow charts are provided for the three key benefit areas:

- i) Water quality improvement,
- ii) Habitat and biodiversity, and
- iii) Carbon sequestration.



A Global Monitoring, Evaluation & Learning (MEL) Framework for Regenerative & Restorative Aquaculture (2024)

Designed primarily for individual businesses, this framework provides practical tools so operators can measure and track progress toward restorative outcomes. For molluscs, it highlights 16 monitoring indicators across the three key benefit areas (water quality, habitat and biodiversity, and climate change), enabling farmers to track and evaluate their performance over time.

This is grounded in the principles of continuous improvement, and standardised reporting.

Project Scope & Intended Outcomes

This project was delivered in two distinct, but complementary parts. Together, they assess whether oyster aquaculture in NSW aligns with the principles of restorative aquaculture and documents the evidence base supporting environmental outcomes using the established TNC frameworks.

Part 1. Assessment against the TNC Global Principles of Restorative Aquaculture (2021)

The first part of the project assesses the NSW oyster industry against the Global Principles of Restorative Aquaculture (2021), using the three dichotomous flow charts developed by The Nature Conservancy.

The flow-chart assessments were applied from a whole-of-industry perspective, rather than at a discrete, individual farm scale. Robust and credible evidence from peer-reviewed literature, industry reports, and existing studies was gathered and evaluated at each decision point. This approach provided a high-level determination of whether oyster farming in NSW, in general terms, met the criteria for restorative aquaculture, while explicitly acknowledging that outcomes are influenced by site-specific factors such as environmental conditions, species farmed, cultivation methods and other variables.

Part 2. Evidence mapping against the TNC Monitoring, Evaluation and Learning (MEL) Framework (2024)

The second part of the project focuses on documenting and consolidating the evidence base for the environmental benefits and impacts of NSW oyster aquaculture against the criteria and indicators outlined in the TNC Monitoring, Evaluation and Learning (MEL) framework (2024). While Part 1 addresses the overarching question of whether oyster aquaculture in NSW can be considered restorative, Part 2 examines where specific environmental benefits are supported by evidence and where significant knowledge gaps remain.

International examples, including ongoing work in New Zealand led by the Cawthron Institute, demonstrate how MEL frameworks can be effectively supported through long-term, site-based environmental monitoring (The Nature Conservancy, pers. comm.). In these systems, comprehensive baseline data are collected prior to lease establishment and supplemented by regular monitoring throughout farm operation. In contrast, oyster aquaculture in NSW generally lacks equivalent baseline datasets and ongoing monitoring requirements, resulting in limited site-specific information. As a result, the MEL framework is not currently workable as an operational monitoring tool across much of the NSW industry, although two farms are presently collaborating with The Nature Conservancy to pilot comprehensive, farm-level data collection.

Given these constraints, the MEL framework has been applied in this project primarily as a tool for organising and synthesising existing knowledge. Peer-reviewed literature, industry reports, and other credible secondary data sources have been mapped against each MEL criterion and indicator. This approach allowed the project to:

- Identify indicators that were well supported by existing evidence
- Highlight areas where evidence was limited or absent
- Clearly articulate NSW-specific knowledge gaps

Part 1 - Applying The Nature Conservancy's Global Principles

Assessment against TNC Global Principles

The Nature Conservancy identifies six baseline principles that describe the conditions under which aquaculture can move beyond minimising environmental impacts to actively support ecosystem recovery, resilience, and function. Together, these principles address the key elements that influence whether restorative outcomes are plausible. They operate effectively as a high-level screening framework, distinguishing aquaculture systems that are capable of generating restorative outcomes from those that are unlikely to do so.

Principle 1	Site farms where environmental benefits can be generated
Principle 2	Culture species that can provide the environmental benefits intended
Principle 3	Prioritise farming equipment that enhances the delivery of environmental benefits
Principle 4	Adopt farming management practices that can enhance local environmental benefits
Principle 5	Strive to farm at an intensity or scale that can enhance ecosystem outcomes
Principle 6	Recognise the social and economic value of the environmental benefits provided

Table 1. Global Principles of Restorative Aquaculture (The Nature Conservancy 2021).

While this section provides a brief assessment against the six global principles of restorative aquaculture, the primary determination of restorative status is based on application of The Nature Conservancy's three environmental benefit roadmaps:

- Water quality (page 19)
- Habitat and biodiversity (page 28)
- Carbon sequestration (page 37).

The principles are used to establish baseline alignment with the intent of restorative aquaculture, while the roadmaps provide the structured, evidence-based decision pathways required to assess specific environmental outcomes. Accordingly, assessment against the principles is presented only at a high level, to confirm that NSW oyster aquaculture meets the foundational criteria for restorative aquaculture before progressing to more detailed, outcome-specific evaluation.

Principle 1: Site farms where environmental benefits can be generated	Assessment: STRONG ALIGNMENT
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NSW oyster farms are located in estuaries along the NSW coastline. These ecosystems historically supported extensive natural oyster reefs, with early colonial records describing waterways densely covered with reefs spanning many hectares (Ogburn *et al.* 2007). Today, Australia's shellfish reefs are considered functionally extinct (i.e. no longer play a significant role in ecosystem function); less than 1% of Native oyster (*Ostrea angasi*) and 8% of Sydney rock oyster (*Saccostrea glomerata*) reefs remain (Gillies *et al.* 2018). This leaves estuarine systems with greatly reduced natural filtration capacity.

According to the NSW Marine Estate Threat and Risk Assessment (NSW MEMA 2017), the highest-priority environmental threats to the NSW marine estate are urban stormwater discharge and agricultural runoff. Both are significant sources of excess nutrients (particularly nitrogen and phosphorus) and sediments entering estuaries and coastal waters. These inputs drive eutrophication, algal blooms, oxygen depletion and habitat degradation, with impacts on important ecological communities such as seagrass, saltmarsh and mangroves.

Oyster farms are positioned within these receiving environments, where water-quality benefits are needed most. Because farmed oysters filter brackish water, consuming phytoplankton and trapping fine sediments, their location directly overlaps with the estuaries carrying the dominant land-based pollution loads identified in the NSW Marine Estate Threat and Risk Assessment (NSW MEMA 2017). The evidence quantifying these benefits is set out in the indicator assessments in Part 2 of this document, specifically WQ 1.1.1. (quantity of N & P assimilated & extracted), WQ 1.1.2. (rate of denitrification), WQ 1.3.1. (rate of water filtration) and WQ 2.1.1. (chlorophyll a concentration), alongside habitat and biodiversity enhancement indicators (HB 1.1.1. and HB 1.2.1. — abundance and diversity of native fauna).

Lease locations are pre-screened under the NSW Oyster Industry Sustainable Aquaculture Strategy (NSW DPIRD 2021), with Priority Oyster Aquaculture Areas (POAA) selected based on tidal exchange, water quality, circulation and estuary health to ensure environmental benefits are maximised. Importantly, oyster aquaculture is one of the few commercial marine activities sited to deliver both economic value and measurable ecosystem services while supporting a viable coastal industry.

Principle 2: Culture species that can provide the environmental benefits intended	Assessment: STRONG ALIGNMENT
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As reported in the 2024–25 NSW Aquaculture Production Report (NSW DPIRD, 2026), Sydney rock oysters (*Saccostrea glomerata*) account for 86% of the total oyster harvest in NSW. The remaining 14% comprises Pacific oysters (*Magallana gigas*), of which approximately 95% are triploid. Triploid oysters carry an extra set of chromosomes that disrupts the production of viable gametes. As a result, 99% of oysters commercially farmed in NSW are either native species or functionally sterile. Port Stephens is the only NSW estuary where fertile (diploid) Pacific oysters can be cultivated, and this occurs under tightly controlled management arrangements. The historical circumstances that led to this exception are outlined in Clarke (2015).

Both Sydney rock and Pacific oysters are highly effective filter feeders, and it is this characteristic that underpins their primary value in delivering environmental benefits within the estuaries where they are cultivated. Through the removal of phytoplankton, suspended organic matter and fine sediments from the water column, both species contribute to improved water clarity, regulation of phytoplankton biomass, and the uptake and removal of nitrogen and phosphorus. These ecosystem services are particularly important in NSW estuaries affected by nutrient-rich catchment runoff and directly address several of the priority threats identified in the NSW Marine Estate Threat and Risk Assessment (2017). The evidence supporting these benefits is summarised in the indicator assessments presented in Part 2. This includes WQ 1.3.1. (rate of water filtration), WQ 1.1.1. (quantity of N & P assimilated & extracted), and WQ 2.1.1. (chlorophyll a concentration).

Filtration is not the only mechanism by which oyster aquaculture delivers environmental benefits. As calcifying, structure-forming species, oysters introduce hard substrate and structural complexity into environments otherwise dominated by soft sediments, providing habitat that supports associated native species. This habitat contribution is assessed in Part 2 under the Habitat & Biodiversity indicators, including HB 1.1.1. (abundance and diversity of organisms associated with farmed biomass), HB 1.2.1. (mobile fauna associated with the farm site) and HB 2.1.1. (enhancement relative to non-farm areas).

Sydney rock oysters are also among the few estuarine aquaculture species globally being selectively bred for climate-change resilience (Parker *et al.* 2024), ensuring the industry's capacity to continue delivering ecosystem services under future climatic conditions. Where Pacific oysters are used, the reliance on sterile triploids minimises any risk of uncontrolled reproduction or displacement of native species, aligning species selection with broader environmental and biosecurity goals.

Principle 3: Prioritise farming equipment that enhances the delivery of environmental benefits	Assessment: STRONG ALIGNMENT
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The NSW oyster industry operates within some of the most ecologically diverse and dynamic estuarine environments in Australia. Farming infrastructure must withstand continual exposure to tides, salinity, UV radiation, storms, and biofouling, while functioning in close proximity to sensitive habitats such as seagrass meadows, mangroves, and oyster reefs. Within this context, the industry has demonstrably prioritised high-quality farming equipment that both minimises environmental risk and delivers measurable ecological benefits.

Across NSW, oyster farmers employ a range of infrastructure types, including rafts, static post-and-rail systems, floating longlines, and post-supported intertidal longlines. These structures support various trays, bags, and baskets used to house oysters. As oysters grow, they are progressively transferred to containers with larger mesh sizes, improving water flow and enhancing feeding efficiency.

Rather than functioning as passive installations, this equipment introduces hard substrate and three-dimensional structural complexity into predominantly soft-sediment estuaries. It creates habitat in environments where natural oyster reefs have significantly declined. This infrastructure can support a range of fish and invertebrate species, with the type, configuration and placement of farming gear influencing the extent of these ecological benefits. The habitat benefits associated with oyster farming infrastructure are assessed in Part 2 under the Habitat & Biodiversity indicators, including studies showing that farm infrastructure can support biodiversity values comparable to, and in some cases greater than, those of adjacent natural habitats, while substantially exceeding those associated with unvegetated soft sediments (Martínez-Baena *et al.* 2022).

The industry's material choices further reinforce net environmental benefit. Widespread adoption of modern, UV-stable, high-density polyethylene (HDPE) systems, documented by OceanWatch Australia (2024), reflects a voluntary shift away from treated timber and hydrocarbon-based preservatives toward long-life, recyclable, chemically inert materials. With a service life commonly exceeding 10–20 years, this infrastructure reduces waste generation, extends replacement cycles, and supports the development of a circular materials economy, strengthening the environmental performance of oyster farming at a whole-of-system scale.

Principle 4: Adopt farming management practices that can enhance local environmental benefits	Assessment: STRONG ALIGNMENT
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The NSW oyster industry actively applies farming management practices that enhance local environmental benefits, while also improving operational efficiency and worker safety. It is acknowledged that the industry’s increasing adoption of floating longline and post-supported intertidal longlines has been driven primarily by practical considerations, particularly improved mechanisation, reduced manual handling, and better Workplace Health and Safety (WHS) outcomes. However, these operational drivers also reinforce positive environmental outcomes.

Research shows that oyster farming methods interact differently with underlying habitats. Martínez-Baena *et al.* (2022) found that post-and-rail systems, while providing structural habitat (assessed in Part 2 under HB 1.2.1. and HB 2.1.1.), can reduce light penetration and shade seagrass. In contrast, floating and post-supported intertidal longlines generally have lower shading impacts, allowing seagrass to persist while still providing supporting fish communities. International reviews reach similar conclusions: shading effects on seagrass range from negligible to locally significant depending on water clarity and infrastructure type and can be effectively mitigated through appropriate farm placement (Forrest *et al.* 2009).

In response, oyster farming over *Posidonia australis*, listed as an Endangered Ecological Community under the EPBC Act (1999), is now restricted to infrastructure that allows light penetration, namely floating and post-supported intertidal longlines, with tray use prohibited. Aerial survey data from NSW DPIRD indicate that tray coverage over seagrass is minimal and that the industry is voluntarily transitioning toward longline systems as best practice (NSW DPIRD, pers. comm.). Although mechanisation and WHS benefits are likely the primary drivers, this shift also reflects growing awareness of seagrass shading impacts and a commitment to aligning farming practices with habitat values.

This adaptive approach is supported through collaboration with regulators. Oyster farmers on the far south coast of NSW are working with NSW DPIRD to collect data that will inform the development of new best-practice guidelines for floating and post-supported intertidal longline oyster aquaculture over sensitive seagrass meadows, demonstrating a proactive effort to refine farm design and practice based on fine-scale evidence collected by growers on the ground.

The industry also operates within a strong regulatory framework. Under the Fisheries Management Act (1994) and Fisheries Management (Aquaculture) Regulation (2024), farmers must prevent environmental harm, maintain leases in good order, and ensure farming infrastructure does not become debris. Routine inspections and maintenance obligations promote proactive gear management, appropriate siting, and timely replacement of ageing equipment, contributing to long-term environmental outcomes.

Together, adaptive management, collaboration with regulators, and responsiveness to emerging scientific evidence demonstrate that the NSW oyster industry not only selects equipment that delivers environmental benefits, but also actively manages farming practices to enhance local ecological values while maintaining productive, sustainable aquaculture operations.

Principle 5: Strive to Farm at an Intensity or Scale That Can Enhance Ecosystem Outcomes	Assessment: MODERATE ALIGNMENT
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The potential for oyster aquaculture to influence nutrient pollution is scale-dependent. Nutrient loads vary substantially among NSW estuaries due to differences in catchment size, hydrology and land use. Large river-dominated systems such as the Clarence and Richmond rivers receive nutrient inputs measured in the thousands of tonnes of nitrogen and hundreds of tonnes of phosphorus annually, with the majority derived from diffuse catchment sources (Roper *et al.* 2011). In these systems, even substantial oyster production is unlikely to materially reduce total catchment nutrient loads at the scale of the estuary as a whole.

By contrast, in small, low-nutrient estuaries, absolute nutrient loads are much lower. In these settings, oyster aquaculture operates on a comparable order of magnitude to the nutrient pool itself, meaning that filtration, assimilation, and nutrient removal through harvest can measurably influence water column nutrients, algal biomass, and light availability.

Example. Merimbula Lake has a relatively small catchment (approximately 38 km²) comprising a mix of urban, grazing and forested land uses. Long-term monitoring indicates that the estuary maintains generally high water quality, characterised by low chlorophyll concentrations, high water clarity and extensive seagrass habitat, all of which are consistent with a system experiencing relatively low nutrient enrichment.

Supporting these observations, catchment load modelling by Roper *et al.* (2011) identified Merimbula Lake as one of the lowest nutrient-exporting estuaries in NSW, with estimated catchment inputs in 2006 of approximately 7 t nitrogen and 0.9 t phosphorus per year.

Applying nutrient removal factors developed by NSW Farmers (2025), oyster production in 2006/07 (NSW DPIRD 2007) is estimated to have removed approximately 0.8 t nitrogen and 0.1 t phosphorus through harvest - equivalent to approximately 11% of annual catchment nutrient inputs. At this scale, oyster bioextraction is ecologically meaningful relative to total estuary nutrient loading, contributing to maintaining low algal biomass, high water clarity and favourable light conditions.

Oyster production has increased substantially over the past two decades. Applying the same methodology to current production figures suggest harvests could remove nutrients equivalent to 40–50% of the loads modelled by Roper *et al.* (2011). However, this comparison should be treated cautiously, as catchment conditions have changed considerably since 2006 with ongoing urban development and population growth; the 2006 load estimates are unlikely to represent current conditions. An updated assessment of catchment nutrient loads would be required to quantify its present-day contribution with confidence.

Oyster aquaculture is therefore unlikely to function as an effective nutrient-mitigation tool in large, river-dominated estuaries, where nutrient loads are too great for shellfish processes to meaningfully influence system-wide outcomes. However, in small, low-nutrient estuaries, appropriately scaled oyster production can make a significant contribution to ecosystem condition.

Principle 6: Recognise the Social and Economic Value of Environmental Benefits	Assessment: STRONG ALIGNMENT
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NSW Farmers (2025) established a monetary valuation for nutrient removal by the oyster industry using the Queensland Reef Credit Scheme (RCS) as a benchmark. The RCS is a market-based mechanism that incentivises nutrient pollution reduction through tradable credits, providing financial returns while delivering measurable water quality benefits. It demonstrates a practical model for recognising and valuing ecosystem services.

Under the Reef Credit Scheme, one credit represents the removal of 1 kg of nutrient from entering the reef system. While Reef Credit prices are generally negotiated privately between buyers and sellers, a publicly reported transaction in March 2024 valued credits at approximately \$100 (Eco-Markets Australia 2024). The benchmark of \$100 per kilogram of nutrient removed also aligns closely with a European study evaluating the ecosystem services of Ireland’s Pacific oyster industry, which estimated the value of 1 kilogram of nitrogen removal at ~€55 (~\$97 AUD) (Domech et al. 2025). Applying this value to nutrient removal by the NSW oyster industry in 2022/23 gives an estimated ecosystem service value of approximately \$1.74 million.

	Mass removed (kg)	Value of nutrient removal at \$100 / kg (\$)
Nitrogen	15,444	\$1,544,400
Phosphorus	1,909	\$190,900
Total	17,353	\$1,735,300

Table 2. Estimated value of nutrient removal by the NSW oyster industry in 2022/23, based on Reef Credit Scheme (RCS) benchmark pricing.

This approach differs from that adopted by BDO EconSearch (2023), who estimated the value of nutrient removal by benchmarking against the cost of achieving equivalent outcomes using constructed wetland technologies. That analysis relied on a single abatement method with highly variable cost-effectiveness, reporting removal costs ranging from \$45 to \$1,023 per kilogram of total nitrogen. BDO ultimately applied average values of \$507 per kilogram of total nitrogen and \$853 per kilogram of total phosphorus, which would imply a total nutrient-removal value of approximately \$9.5 million based on the harvested oyster biomass reported above. While valid, this approach reflects engineering replacement costs rather than observed market prices and is therefore considered less indicative of potential industry remuneration pathways.

As noted by The Nature Conservancy (2024), both Virginia and Maryland (USA) have implemented nutrient trading programs that allow oyster growers to generate credits through shellfish production. In one case study, Blue Oyster Environmental sold nutrient credits generated by oyster cultivation to the Baltimore Convention Center to offset event-related nutrient discharges. More broadly, the concept of using shellfish nutrient removal to compensate for terrestrial nutrient emissions has been extensively explored, modelled, and piloted in multiple jurisdictions (Lindahl et al. 2005; Bricker et al. 2018).

Assessment against TNC Roadmaps

The Nature Conservancy's three environmental benefit roadmaps provide the primary determination of restorative status. Each roadmap is a dichotomous flow chart that moves through a sequence of yes/no decision points to a likely outcome, covering water quality, habitat and biodiversity, and carbon sequestration respectively.

Roadmap 1: Water Quality

Roadmap 1 provides a structured tool for assessing the likelihood that the NSW oyster industry delivers water quality benefits.

Beginning in the top left corner, the roadmap presents a series of dichotomous (yes/no) questions that guide the user step-by-step toward a likely determination.

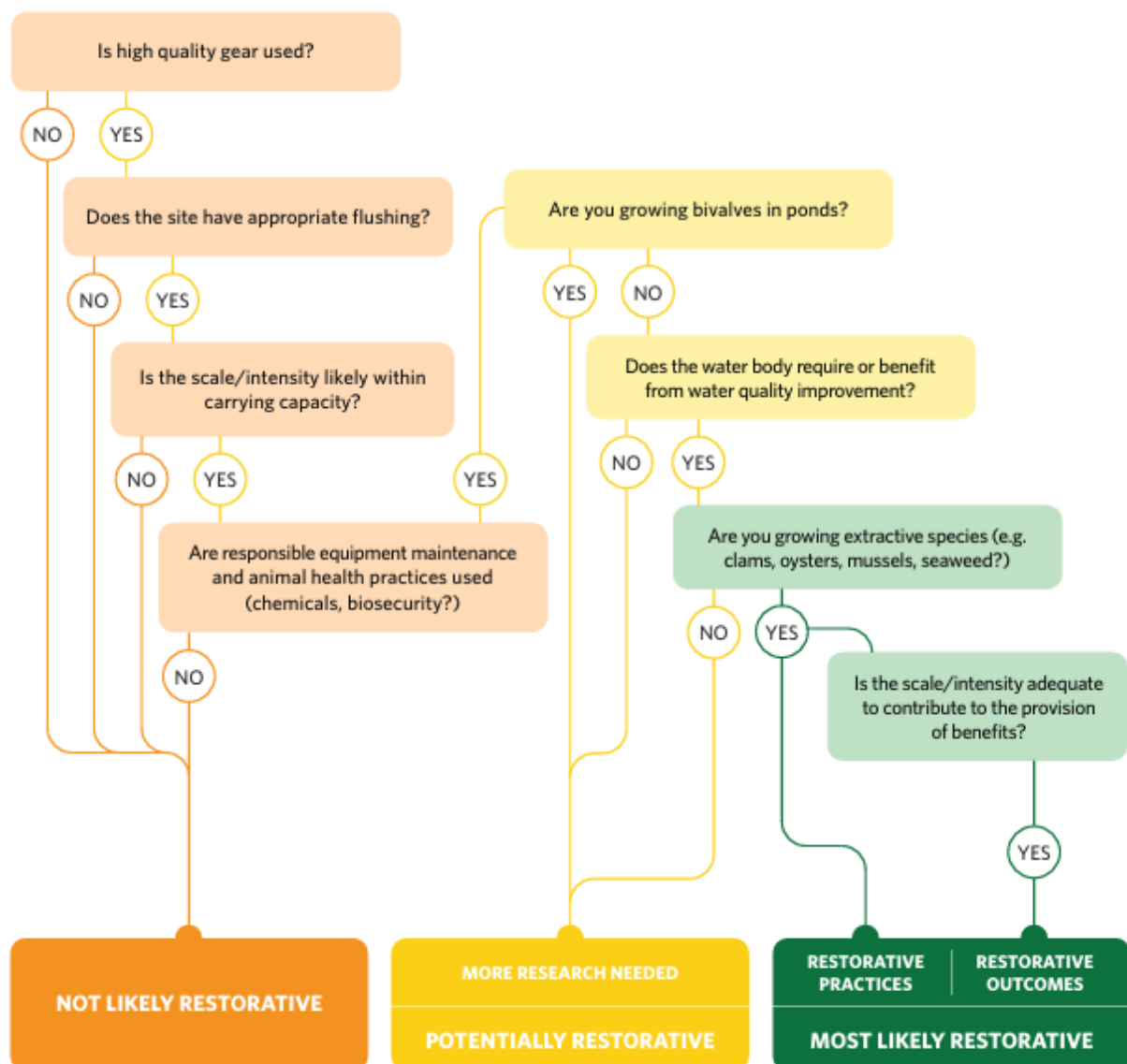


Figure 11. Roadmap 1 – Template for assessing water quality benefits.



There is strong evidence that the industry predominantly relies on high-quality, durable, and purpose-built infrastructure to meet the demands of dynamic, high-energy estuarine environments and support long-term environmental and operational sustainability. This is confirmed independently by OceanWatch Australia's (2024) Oyster and Plastic Recycling Feasibility Study, which found widespread uptake of purpose-built baskets, engineered buoyancy systems and high-holding-power anchors, with most baskets and trays having service lives of 10–20 years or more (see the assessment for Principle 3). Pockets of older or lower-grade gear remain, but these are clear exceptions to a dominant trend toward modern, fit-for-purpose systems.

The materials now in general use, predominantly UV-stable high-density polyethylene (HDPE), offer superior durability, resistance to corrosion and UV degradation, extended service life and reduced maintenance. Collectively, these characteristics lower the risk of gear failure, fragmentation and marine debris while improving farm efficiency and safety.

Much of this equipment was developed in Australia and New Zealand, largely by oyster farmers responding directly to the demands of high-energy estuarine environments. Australasian growers refined the adjustable long-line system and purpose-built HDPE baskets, clips and floating systems. This is reflected in the widespread adoption of systems such as BST, SEAPA, Hexcyl, FlipFarm and Zapco, which are now used across the sector, and regarded internationally as best practice.

Regulatory settings reinforce this: the Fisheries Management Act 1994 and its Aquaculture Regulation effectively require fit-for-purpose gear that is kept in good order, with compliance verified through periodic lease inspections (see Equipment maintenance, page 24).

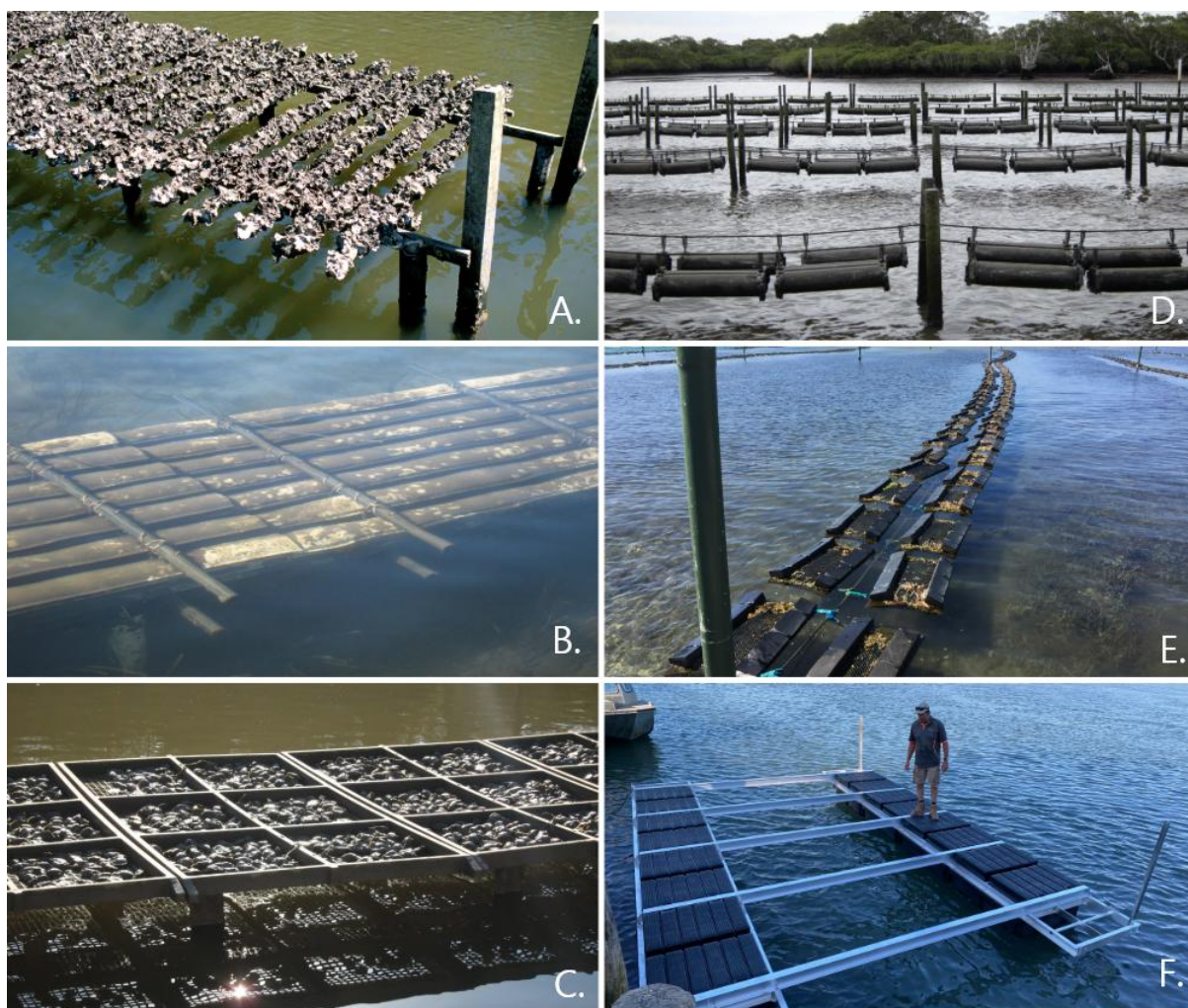


Figure 12. Variety of oyster cultivation. A) Stick cultivation has largely been phased out, B) Catching slats on a post & rail system, C) Trays on a post & rail system, D) Intertidal, post-supported long-lines, E) Floating long-lines, F) Raft culture.

Does the site have appropriate flushing?

NO

YES

NSW oyster aquaculture is confined to designated Priority Oyster Aquaculture Areas (POAA), which are individually assessed and mapped under the NSW Oyster Industry Sustainable Aquaculture Strategy, OISAS (NSW DPIRD 2021). These areas are based on locations with an established history of productive oyster farming and are assessed against environmental, social and economic criteria, including commercial viability. Areas deemed unsuitable for viable oyster production are excluded from consideration.

Commercial oyster production depends on adequate tidal exchange and water movement to deliver planktonic food, remove waste and maintain water quality. Consistent with this, OISAS recognises that estuary morphology, tidal range and entrance condition are key drivers of water circulation, and that reduced flushing and declining water quality are commonly associated

with entrance closure or infilling (NSW DPIRD 2021). As a result, oyster farming in NSW is concentrated in permanently open estuaries, or those that close only infrequently, where water exchange and circulation are maintained.

These conditions are reflected in observed water-quality outcomes. Estuaries supporting long-established oyster industries continue to meet standards for aquatic ecosystem health and shellfish harvest classification, and the NSW Shellfish Program has recorded a trend of harvest-area upgrades over the past 15 years (Figure 13, NSW Shellfish Program, pers. comm.). Similarly, the Healthy Estuaries for Healthy Oysters Guidelines (NSW DPIRD 2023) recognise oyster aquaculture as a land use compatible with maintaining healthy estuarine function.

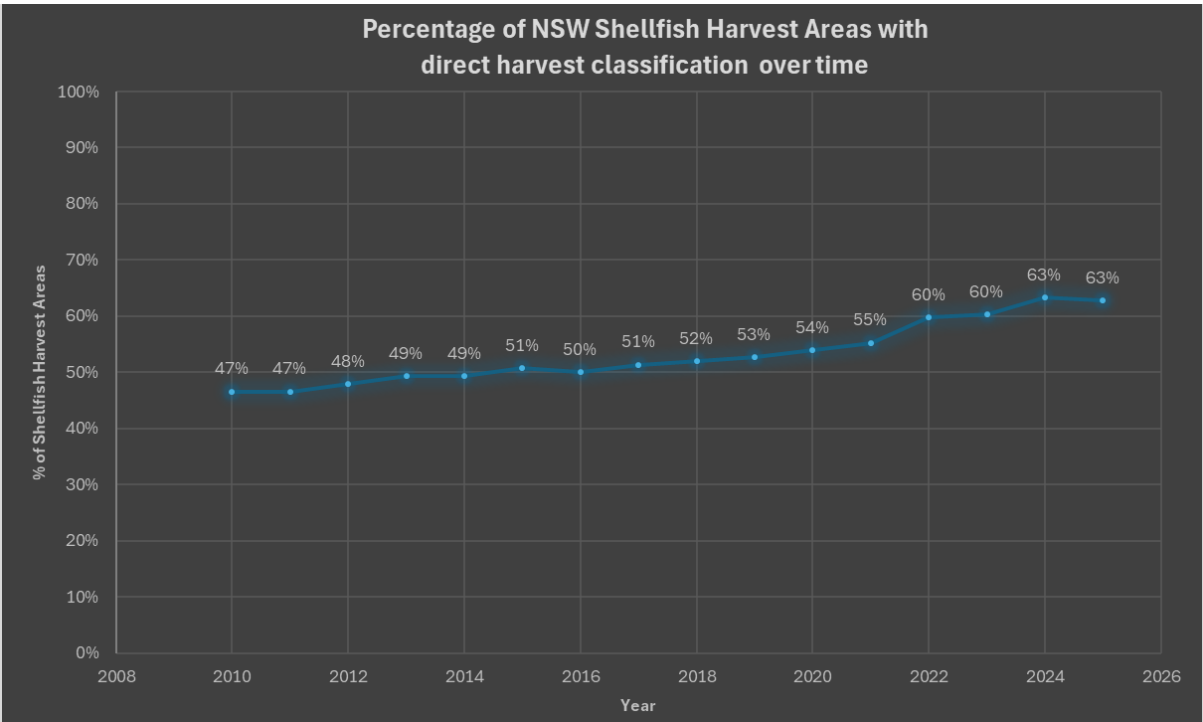
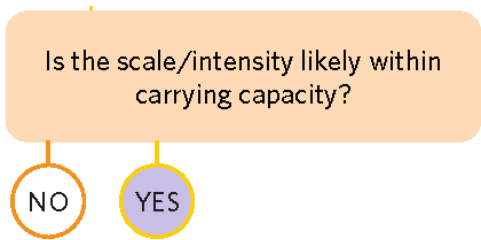


Figure 13. Tracking the percentage of NSW Shellfish Harvest Areas with direct harvest classification over the last 15 years. (Data source: NSW Shellfish Program, pers. comm)



At the statewide scale, strong evidence indicates that the NSW oyster industry operates well within ecological carrying capacity. Oysters feed entirely on naturally occurring phytoplankton, with no addition of feed or fertiliser. NSW DPIRD (2021) estimates the sustainable production of farmed oysters at around 7,500 tonnes, yet annual production sits at around 2,900 tonnes over the three years to 2024/25 (see Table 7), less than half of the assessed capacity.

The NSW Oyster Industry Sustainable Aquaculture Strategy (OISAS, NSW DPIRD 2021) further limits development through a range of spatial and management controls. Oyster cultivation is confined to surveyed and gazetted lease areas, which collectively occupy only around 1% of the surface area of NSW estuaries. OISAS also provides guidance on lease design and stocking intensity, including recommended spacing between cultivation structures. Where stock levels are considered excessive, NSW DPIRD also has the power under the Fisheries Management Act 1994 to require stock management plans or other corrective actions.

The industry's coexistence with healthy estuarine ecosystems for more than 140 years provides strong empirical evidence that production remains compatible with natural processes. As noted by Dame and Prins (1998), sustained bivalve production without ecosystem degradation is consistent with carrying-capacity thresholds not having been breached. If the industry were exceeding these limits, it would manifest in declining water quality, reduced phytoplankton availability, sediment accumulation, or deterioration in harvest classifications, none of which are being observed across NSW oyster estuaries.

That said, there are anecdotal reports of localised overstocking in some estuaries that warrant acknowledgement. Concerns have been raised that dense oyster infrastructure can shade seagrass beds, and that concentrated filtration of large stock volumes could reduce phytoplankton availability for neighbouring farms and other estuarine processes. These concerns are most relevant in low-nutrient-export catchments, where external nutrient inputs are modest and spatial concentration can have proportionally larger local effects before estuary-scale limits are reached.

Nutrient-removal estimates help contextualise these concerns. In some low-nutrient-export estuaries, commercial oyster harvest has been estimated to remove around 11% of both the nitrogen and the phosphorus diffuse loads (see Principle 5). While ecologically meaningful, this level of removal does not imply nutrient depletion at the system scale. These estimates account for catchment-derived nutrients only; estuaries with open entrances also receive substantial marine-derived nutrient inputs via tidal exchange, supporting phytoplankton production, seagrass growth, and broader estuarine processes.

Taken together, these lines of evidence indicate that while localised management issues may arise in some estuaries, they do not undermine the conclusion that the NSW oyster industry operates well within overall carrying capacity. Production remains conservative relative to assessed sustainable limits, spatial expansion is tightly controlled through POAA planning and lease-management frameworks, and long-term environmental monitoring provides a robust mechanism for detecting and responding to emerging issues.

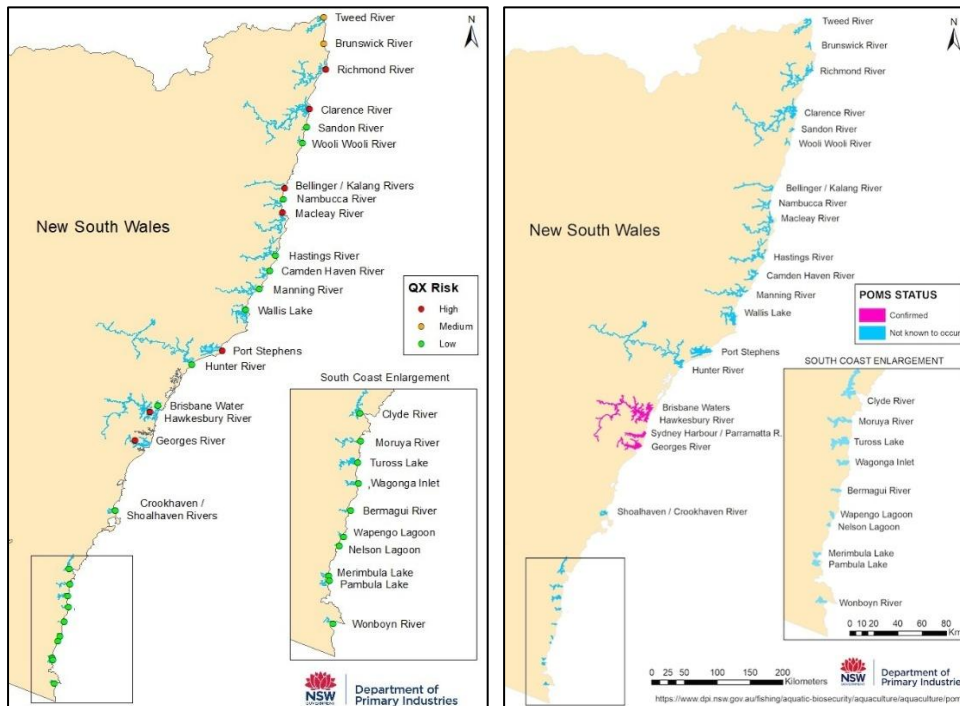
Are responsible equipment maintenance and animal health practices used (chemicals, biosecurity?)



Oyster farming in NSW does not use fertilisers, pesticides, feeds or veterinary chemicals. Chemical use is minimal and tightly controlled, limited to surface disinfectants and epinephrine to induce larval settlement in land-based hatcheries. Both are approved for oyster industry use under an APVMA Minor Use Permit (MUP), used infrequently in small volumes, and in contained settings with no application when oysters are growing in estuaries.

Aquatic animal health is fundamental to survival and growth of oysters, and farmers have strong commercial incentive to maintain it. Day-to-day management is preventative and husbandry-led, including regular inspection of stock, drying regimes to manage biofouling, and using grading schedules and handling practices that minimise stress. Australian-developed farm management platforms (e.g. Mishell, OceanFarmr) increasingly enable farmers to document husbandry practices, track survival and growth, and optimise production.

A robust biosecurity framework underpins disease prevention. The Biosecurity Act 2015 imposes a general duty to manage biosecurity risk, and the Fisheries Management Act 1994 and its Aquaculture Regulation 2024 add specific obligations for disease reporting, stock movement and risk management. Estuary-based biosecurity zones for QX disease and POMS (Figures 14 and 15), mandatory shipment logbooks and unexplained-mortality reporting further support early disease detection and containment.



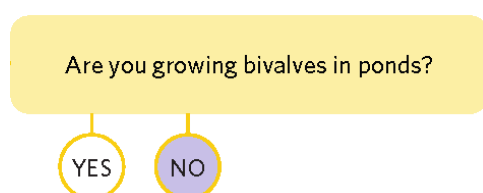
Figures 14 & 15. QX & POMS risk ranking of NSW oyster producing estuaries (NSW DPIRD 2022).

These controls are reinforced by QX- and POMS-resistant breeding programs, and by farm-level biosecurity plans. Research into NSW aquaculture biosecurity (BehaviourWorks 2022) found most farmers regard biosecurity as very important and routinely apply measures such as strict stock-sourcing and movement controls, regular inspection and testing, and engagement with NSW DPIRD. The same study, however, also noted room for improvement, with fewer than half feeling well prepared for a biosecurity event and only about half holding a biosecurity plan.

Equipment maintenance is also embedded in industry practice and regulation. This infrastructure represents major capital investment and is routinely maintained to remain functional and safe in dynamic estuarine environments. OISAS (NSW DPIRD 2021) sets clear expectations for regular maintenance and prompt repair or removal of damaged gear (Table 3). Compliance is verified through DPIRD's Aquaculture Lease Clean-up Program and the Triennial Oyster Lease Inspection Program, which assesses gear condition, lease tidiness, navigation safety and environmental risk every three years.

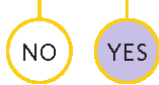
Lease superstructure – markers, cultivation posts and rails.	• Routine once every 12 months. • Repair at any time if it has collapsed, is in danger of imminent collapse or if a marker post or sign is missing.
Catching material or depot blocks	• Routine once every 12 months. • Repair at any time if it has collapsed or is in danger of imminent collapse. • Must not remain continuously on a lease for more than two years before being stripped or nailed out.
Stick cultivation	• Routine once every 12 months. • Repair at any time if it has collapsed or is in danger of imminent collapse. • Must not remain continuously on a lease for more than three years after being nailed out
Trays, baskets and cylinders	• Routine once every 12 months. • Repair at any time if it has collapsed or is in danger of imminent collapse.

Table 3. Maintenance guide for cultivation infrastructure set out in OISAS (NSW DPIRD 2021).



Oyster farmers in NSW do not grow oysters in pond systems. Oysters are extensively farmed in estuarine waters. There are some interstate nursery operations that use land-based raceway systems to grow hatchery seed to a larger size before distribution to farmers for on-growing, but these are not currently used in NSW, where nursery operators typically grow spat in land-based upweller or downweller systems, or estuary-based systems using mesh inserts or socks.

Does the water body require or benefit from water quality improvement?



NSW oyster farms are located in coastal estuaries that historically supported extensive natural oyster reefs. Today, less than 1% of native oyster reefs and 8% of Sydney rock oyster reefs remain (Gillies *et al.* 2018), leaving estuarine systems with greatly reduced natural filtration.

As set out in the assessment for Principle 1, these estuaries receive the state's highest-priority water-quality threats, urban stormwater discharge and agricultural runoff (NSW MEMA 2017), making them the receiving environments where oyster filtration benefits are most needed.

Farmed oysters are extractive, filter-feeding organisms that remove phytoplankton and suspended particles from the water column. Nutrients are assimilated into tissue and shell and permanently removed at harvest, or transferred into biodeposits that promote denitrification, converting bioavailable nitrogen into inert N₂ gas. NSW-specific measurements show that harvested Sydney rock and Pacific oysters remove approximately 5.58 kg N/t and 4.46 kg N/t respectively, with the industry removing ~15.8 tonnes of nitrogen and ~2.0 tonnes of phosphorus annually across NSW estuaries (see Table 7). This has an approximate market value of ~\$1.78m.

While the magnitude of benefit varies by estuary type, evidence shows that oyster-mediated nutrient removal is ecologically meaningful in small to medium, low-nutrient estuaries, where oyster harvest can represent 11% of both the nitrogen and the phosphorus diffuse loads (see Principle 5), helping maintain low chlorophyll levels and clear water. In large river-dominated estuaries, oyster farming cannot provide a significant contribution to nutrient removal, but may still provide localised filtration and habitat benefits without adding nutrients or chemical inputs.

Are you growing extractive species (e.g. clams, oysters, mussels, seaweed?)



Yes. NSW oyster aquaculture is based entirely on extractive, filter-feeding bivalves that remove phytoplankton and suspended particles from the water column. The species permitted to be grown are:

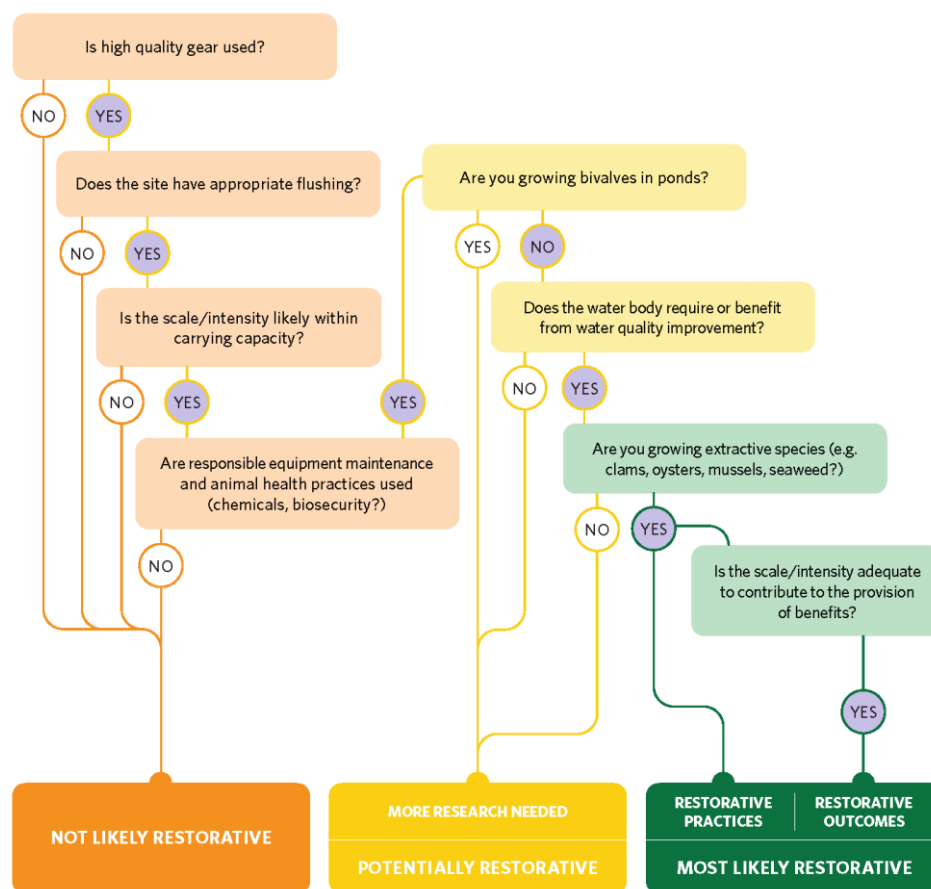
- Sydney rock oysters (*Saccostrea glomerata*)
- Pacific oysters (*Magallana gigas*)
- Native oysters (*Ostrea angasi*)
- Akoya oysters (*Pinctada imbricata fucata*).

Is the scale/intensity adequate to contribute to the provision of benefits?



As indicated in response to Principle 5, the capacity of oyster aquaculture to influence nutrient pollution is scale-dependent. In large, river-dominated NSW estuaries, catchment nutrient loads are too high for oyster farming to materially offset system-wide inputs. In small, low-nutrient estuaries, oyster aquaculture operates on a comparable scale to the nutrient pool, and filtration, assimilation and harvest can measurably reduce nutrients and algal biomass. In Merimbula Lake, for example, oyster harvest is estimated to remove approximately 11% of both the nitrogen and phosphorus diffuse loads entering from land. In the context of restorative aquaculture, this points to expanded production in smaller, nutrient-impacted estuaries as a practical option for mitigating nutrient loads, provided any expansion stays within the carrying capacity of the system.

Final assessment of water quality: MOST LIKELY RESTORATIVE



The NSW oyster industry satisfies all decision points in the water quality flow chart, leading to a **'Most Likely Restorative'** outcome. The assessment is supported by quantitative NSW-specific data for nutrient removal rates, filtration rates, and water quality monitoring.

Roadmap 2: Habitat & Biodiversity Benefits

Roadmap 2 provides a structured tool for assessing the likelihood that the NSW oyster industry delivers habitat and biodiversity benefits.

Beginning in the top left corner, the roadmap poses a series of dichotomous (yes/no) questions that guide the user step-by-step toward a likely determination.

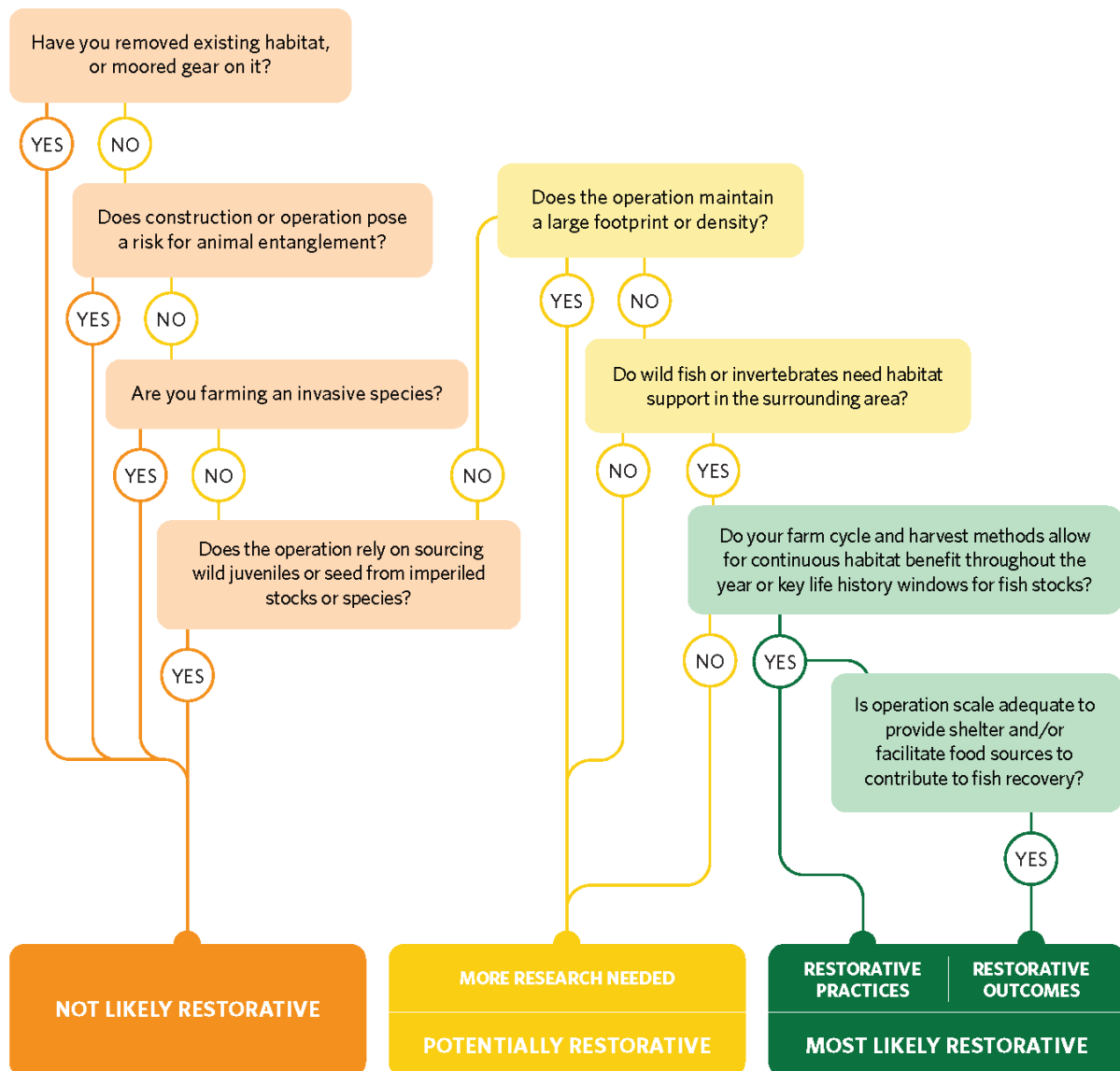


Figure 16. Roadmap 2 – Template for assessing habitat and biodiversity benefits.

Have you removed existing habitat,
or moored gear on it?

YES

NO

Establishing an oyster lease does not involve dredging, excavation, or removal of existing benthic habitat. The only permanent contact with the seabed is from vertical support posts. These posts are typically HDPE-encapsulated recycled timber posts manufactured in 83 mm, 100 mm and 120 mm diameters. This results in a very small footprint on the seabed, with each post occupying approximately 50-115 cm² - about the size of a coffee-cup base. All other components, trays, baskets, longlines, are positioned in the water column, meaning oyster leases are predominantly composed of suspended infrastructure. Importantly, this three-dimensional structure provides additional habitat. The habitat value of this gear is described and quantified in the habitat and biodiversity assessment in Part 2 of this document.

Where infrastructure overlaps with seagrass, potential shading impacts are actively managed. As detailed in the assessment for Principle 4, oyster farming over *Posidonia australis* is restricted to floating and longline systems that allow light to reach the meadow, tray use is prohibited, and aerial survey data indicate that tray coverage over seagrass is minimal and declining as growers voluntarily transition to longline systems.

Shading from non-fixed infrastructure is not uniform but configuration dependent. Factors such as post spacing and line height influence light penetration, and growers on the south coast of NSW are proactively engaging with NSW DPIRD to refine best-practice guidelines over sensitive seagrass habitats (FRDC project 2024-057). This collaboration aims to optimise farm design so that production and seagrass health can be sustained together.

In summary, the industry introduces low-footprint, suspended infrastructure to estuaries rather than removing habitat. Potential shading impacts on sensitive seagrass, particularly *Posidonia australis*, are effectively managed through enforceable restrictions on gear types and an industry-wide shift toward dynamic (non-fixed) cultivation systems.

Does construction or operation pose a risk for animal entanglement?

YES

NO

Neither the construction nor operation of oyster aquaculture in NSW poses a meaningful risk of animal entanglement. Entanglement risk depends on gear type and setting, and NSW oyster aquaculture sits at the low-risk end of both. Farms are located in estuaries, away from the coastal migration routes used by marine mammals such as whales. While whales occasionally enter estuaries, such as a southern right whale recorded in Wallis Lake in June 2021 (Sydney Morning Herald 2021), these events are rare and involve transient animals, not resident populations interacting with farms.

Oyster farming in NSW occurs in shallow, sheltered waters, using trays, baskets and bags with a low profile suspended over the substrate. It does not use slack, vertical deep-water ropes associated with entanglement risk, and the estuarine setting keeps operations separate from open-water migration corridors.

NSW marine wildlife incident data record 62 entanglement events across all marine fauna in 2025 — 50 involving whales, dolphins or dugong; 7 turtles; 4 seals or sea lions; and 1 seabird (NSW Marine Wildlife Dashboard, DCCEEW). Oyster aquaculture has not been implicated in any marine wildlife entanglement recorded or reported in NSW. This is consistent with the low-profile, rope-free nature of oyster gear and its estuarine setting, and with the NSW Marine Estate Threat and Risk Assessment, which attributes entanglement risk to fishing activities and shark nets rather than aquaculture (NSW MEMA 2017). Where the cause of entanglement is known, fishing gear and shark-control programs dominate. On Australia's east coast, fishing gear accounted for around 70% of the 48 humpback whale entanglements documented in 2025, with most of the remainder attributed to shark nets (Meynecke 2025).

This is in alignment with international evidence. The NOAA/NCCOS global review (Bath *et al.* 2023) found entanglements were rare across extensive aquaculture systems, with incidents largely confined to suspended mussel culture using vertical ropes in deep or open water, systems not used in NSW oyster farming.

The documented Australian experience is similar: Kemper *et al.* (2003) found that marine-mammal conflict with aquaculture in Australia was almost entirely confined to fur seal interactions with salmon pens in Tasmania.

The most significant residual risk arises not from gear in operation but from equipment lost during floods and other extreme weather events. Following such events, where feasible farmers actively salvage lost gear to reduce environmental harm and recover valuable assets. This is supported by routine maintenance and regulation, which has been discussed previously in the water quality roadmap assessment (page 24).

Are you farming an invasive species?

YES

NO

Pacific oysters are not native to NSW and are recognised as invasive in Australia. In practice, however, they pose negligible risk of spread from aquaculture. As outlined in the assessment for Global Principle 2, 99% of oysters commercially grown in NSW are either native Sydney rock oysters (~86% of harvest) or functionally sterile triploid Pacific oysters, so almost no farmed non-native stock can reproduce and spread. Fertile diploid Pacific oysters may be grown under tightly controlled conditions in Port Stephens, where a significant naturalised population is already established (NSW DPIRD 2021; Clarke 2015). On this basis, commercial oyster aquaculture in NSW does not propagate an invasive species in a way that creates new establishment or spread risk.

Does the operation rely on sourcing wild juveniles or seed from imperiled stocks or species?

YES

NO

Oyster seed may be sourced either from the wild or purchased from commercial shellfish hatcheries and nurseries; however, the species and associated stocks are not considered imperiled. While the biogenic reef habitat these species once formed has declined substantially (see reef-loss discussion, page 13), the species themselves remain widespread and abundant, and natural spatfall is more than sufficient to support wild spat collection without depleting wild populations. A single female Sydney rock oyster is capable of releasing between 10 and 60 million eggs during a spawning event, while males release hundreds of millions of sperm into the water column (O'Connor *et al.* 2008). Once fertilised, the eggs develop into microscopic, free-swimming larvae that remain in the plankton for approximately 3–4 weeks, with typically less than 0.1% surviving to settlement.

No commercial oyster species farmed in NSW are listed as threatened, endangered, or protected under either NSW or Commonwealth legislation.

There is also a plausible case that commercial oyster aquaculture benefits wild oyster populations. The Sydney rock oyster selective breeding program is increasingly focused on climate resilience traits, selecting for improved tolerance to ocean acidification and rising sea temperatures, while maintaining strong productivity and disease resistance (Parker *et al.* 2024). Because the program works with the same native species, and its breeding stock remains reproductively fertile and spawns alongside wild oysters in the same estuaries, there is a credible biological pathway for these traits to move into wild populations. Indeed, gene flow from farmed to wild stock has recently been documented at low levels in eastern oysters in the

United States (Chen *et al.* 2026b). No such effect has yet been shown for Sydney rock oysters, with one study finding that wild and farmed populations in the Georges River remain genetically distinct after roughly 30 years of selectively bred oysters being farmed there (Thompson *et al.* 2017).

Does the operation maintain a large footprint or density?

YES

NO

The oyster industry spans a wide geographic area, with commercial oyster production occurring across ~36 estuaries from the Tweed River in the north, to Wonboyn Lake in the south. Of the roughly 135 estuaries in NSW, covering a combined surface area of 3,000–3,500 km², oyster cultivation takes place in about 27% of these systems. However, Priority Oyster Aquaculture Areas (POAA) account for only around 1% of the total estuarine surface area. Many of these POAA are also not in production, with ~20% currently available for lease (NSW DPIRD pers. comm. 2026). Furthermore, the physical infrastructure used in oyster farming occupies only a small proportion of each lease, as adequate spacing between rows is needed to allow vessel access (see Figure 17).

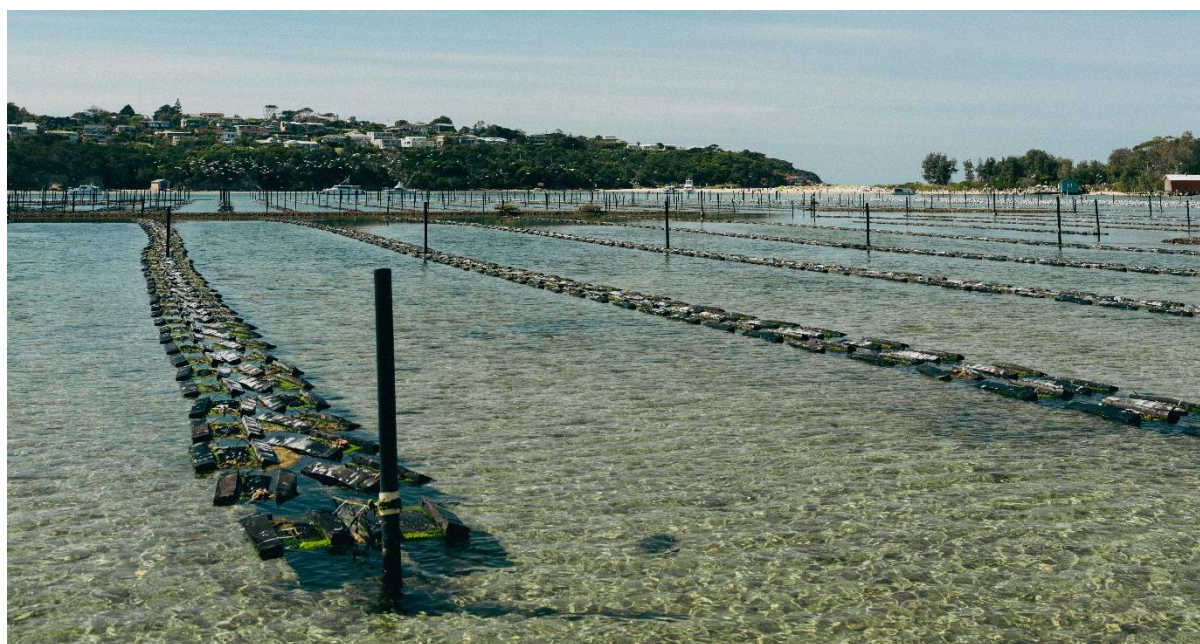


Figure 17. A typical oyster lease established with floating longlines, showing spacing between rows to enable vessel access.

Despite this broad footprint, recorded harvest is concentrated within a relatively small number of estuaries rather than being evenly distributed along the coast. In the 2024/25 production year, more than 50% of total oyster harvest was recorded from just four systems, Merimbula Lake, Port Stephens, Wallis Lake, and the Clyde River (Table 4).

Estuary	Oyster harvest volume in 2024/25	% of state production	Cumulative % of production
Merimbula Lake	1,109,003	20%	20%
Port Stephens	690,471	13%	33%
Wallis Lake	557,320	10%	43%
Clyde River	519,620	10%	53%
Others	2,595,077	47%	100%

Table 4. Recorded oyster production by estuary of final harvest, NSW 2024/25 (all species, all sizes), ranked by volume (NSW DPIRD 2026).

These figures should be read with an important caveat: production is recorded against the estuary of final harvest, which is not necessarily where an oyster spent most of its life. Several estuaries, Port Stephens included, are recognised as "finishing" estuaries, where farmers relay stock in the months before sale to improve condition and meat quality. Because a Sydney rock oyster typically grows for 2.5–4 years but may be finished and harvested in a different estuary from where it was grown out, harvest statistics overstate the concentration of farming activity in these locations and understate the more dispersed grow-out effort across the coast. Active lease area is correspondingly less concentrated than the production figures imply, and the industry's overall spatial footprint remains comparatively small and widely distributed.

The regulatory framework is also designed to deliberately limit and manage spatial expansion to protect environmental values. All existing and potential lease areas are individually assessed against location, environmental and socio-economic criteria, with only suitable areas designated for aquaculture. This approach confines the industry to a pre-vetted portion of each estuary and prevents encroachment into sensitive or unsuitable habitats. At the lease scale, boundaries are formally surveyed and gazetted, and all infrastructure must remain within these fixed limits.

The Oyster Industry Sustainable Aquaculture Strategy (OISAS) sets standards for cultivation practices and infrastructure, including guidelines on layout, type and density. These include a recommended minimum 8m spacing between rack-and-rail / tray rows to maintain access and up to 2.5km of longlines per hectare. The strategy also recognises over-stocking as a risk. Under the Fisheries Management Act (1994), NSW DPIRD can implement stock management plans in situations where excessive biomass can be attributed to poor growth, disease, or mortality.

Together these provisions function as de facto stocking and density controls, keeping infrastructure density and biomass within limits consistent with the carrying capacity and environmental health of the estuary.

Do wild fish or invertebrates need habitat support in the surrounding area?

NO

YES

The estuaries in which NSW oyster leases sit are structurally impoverished relative to their historical natural state. Extensive shellfish reef systems, once a dominant biogenic habitat of Australia's bays and estuaries, have undergone near-complete loss and are now considered functionally extinct (Beck *et al.* 2011; Gillies *et al.* 2018). The IUCN Red List of Ecosystems similarly recognises oyster reefs as key habitat-forming ecosystems whose complex biogenic structures historically underpinned estuarine communities, but which have now largely disappeared.

Other key habitat-forming systems, including seagrass meadows, saltmarsh and mangroves, have also declined or been substantially altered. Seagrasses have been reduced in many estuaries due to turbidity, nutrient enrichment and physical disturbance. Saltmarsh has been heavily impacted by reclamation and coastal urbanisation, often being replaced by mangroves or built infrastructure. While mangroves have expanded in some areas, their distribution has also been modified by changes to hydrology and land use. As a result, large areas of many estuaries are now dominated by unstructured bare sediment, which supports markedly lower abundance and diversity of fish and mobile invertebrates than structured habitats. Against this degraded baseline, there is a clear deficit of structurally complex habitat for estuarine fauna.

Do your farm cycle and harvest methods allow for continuous habitat benefit throughout the year or key life history windows for fish stocks?

NO

YES

The structural components of an oyster lease (e.g. rack and rail, posts, longlines) are permanently installed and remain in place year-round. In contrast, the containers used to hold oysters (e.g. baskets, bags, and trays) may be moved on or off the lease periodically, depending on factors such as harvest timing, stock size, and water conditions. Despite this movement, the overall habitat structure, whose biodiversity value is quantified in the habitat and biodiversity assessment in Part 2, remains effectively continuous.

Because Sydney rock oysters require approximately 2.5–4 years and Pacific oysters 1–2 years to reach market size, farmers maintain multiple overlapping crops at different stages of maturity to ensure an annual harvest. While sales peak around Christmas, Easter, and during the summer months, each crop contains "front runners" (fast-growing) and "runts" (slow-growing) oysters, ensuring a constant presence of stock, and structural components, in the water.

As a result, only a small portion of the infrastructure is disturbed at any given time, and because the permanent structure (i.e. posts, longlines) stays in place, the habitat remains available

continuously, regardless of season or harvest cycle. This continuity matters because estuarine fish use nursery habitat on species-specific schedules that collectively span the year — spring and summer for recruits such as sand whiting, luderick and prawns, and autumn and winter for yellowfin bream, dusky flathead and sea mullet. Continuous, rather than seasonal, habitat availability is therefore what aligns with the life histories of the broader fish community.

Is operation scale adequate to provide shelter and/or facilitate food sources to contribute to fish recovery?

YES

The spatial extent of the industry is well defined. NSW currently has 2,417 oyster leases covering 3,016 hectares of estuarine water across 36 estuaries, an average lease size of approximately 1.25 hectares (NSW DPIRD, pers. comm). Leases are not distributed as isolated units. They are typically clustered within the mid to lower reaches of each estuary, so the structural habitat available to mobile fauna is the aggregate of adjacent leases rather than a single 1.25 hectare patch. Scale should also be read in three dimensions. Racks, rails, baskets, lines and the oysters themselves present a surface area well in excess of the two-dimensional footprint, and that structure sits over soft sediment which otherwise offers little shelter.

On a per-unit-area basis, oyster farming infrastructure provides habitat value equivalent to natural biogenic habitats (seagrass, mangrove, remnant reef) and well above bare sediment, helping offset the documented deficit of structurally complex habitat. Remote underwater video surveys of oyster leases in Port Stephens recorded 90 fish species from 51 families, with both rack-and-rail and basket systems supporting species richness comparable to adjacent seagrass, mangrove and remnant reef habitats, and well above bare sediment (Martínez-Baena *et al.* 2022). More broadly, a 65-study global meta-analysis found that bivalve and seaweed aquaculture supported a median of ~1.95 times the mobile-fauna abundance and ~1.14 times the species richness of reference sites, with the largest increases coming from suspended and elevated oyster and mussel culture (Theuerkauf *et al.* 2022).

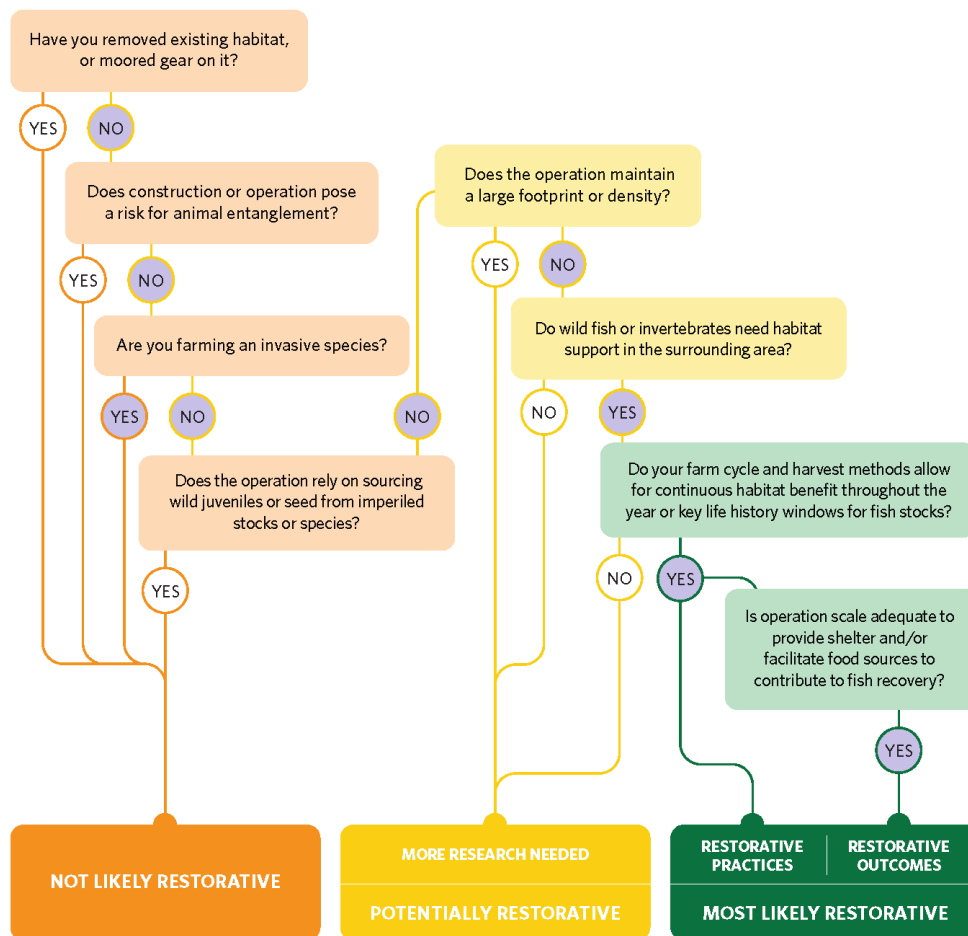
What remains unresolved is whether the footprint is large enough to convert habitat provision into population-level fish recovery. Most studies measure abundance and richness at farms (attraction) rather than the net production of new fish, and there is no NSW industry-scale estimate of fish output. So, while the industry is demonstrably of sufficient scale to contribute to the shelter and food base for estuarine fauna, its quantitative contribution to fish recovery at the estuary or stock scale has not yet been established.

Oyster filter feeding may provide a further benefit by reducing waterborne disease transmission. In paired field and laboratory experiments in the US, Chen *et al.* (2026a) found that eastern oysters (*Crassostrea virginica*) removed the free-swimming infective stages of the parasitic dinoflagellate (*Hematodinium perezii*), the agent of "bitter crab disease", cutting infection in juvenile blue crabs by roughly one-third. Laboratory trials confirmed the pathway, with oysters clearing parasite dinospores from the water at rates comparable to their normal

phytoplankton food, removing the majority of infective particles within an hour. This reframes a filter-feeding oyster lease as not only a structural refuge and a feeding ground but also a biological filter that lowers ambient pathogen loads for fish and crustaceans.

Oysters in NSW are also effective filter feeders, which makes the pathway biologically plausible for NSW estuaries. The caveat is that this evidence is a proxy, and that parasites, hosts and magnitudes relevant to NSW fish and crustacean recovery have not been measured in the state.

Final assessment of Habitat and Biodiversity: MOST LIKELY RESTORATIVE



The NSW oyster industry satisfies all habitat and biodiversity flow chart decision points. It avoids habitat removal, poses negligible entanglement risk, farms predominantly native species, operates at low density across many estuaries, and provides documented habitat benefits to fish and invertebrate communities. Direct NSW evidence from Martínez-Baena *et al.* (2022) confirms that farm infrastructure functions as effective habitat comparable to natural biogenic structures.

Roadmap 3: Carbon Sequestration

Roadmap 3 provides a structured tool for assessing the likelihood that the NSW oyster industry delivers carbon sequestration benefits.

Beginning in the top left corner, the roadmap poses a series of dichotomous (yes/no) questions that guide the user step-by-step toward a likely determination.

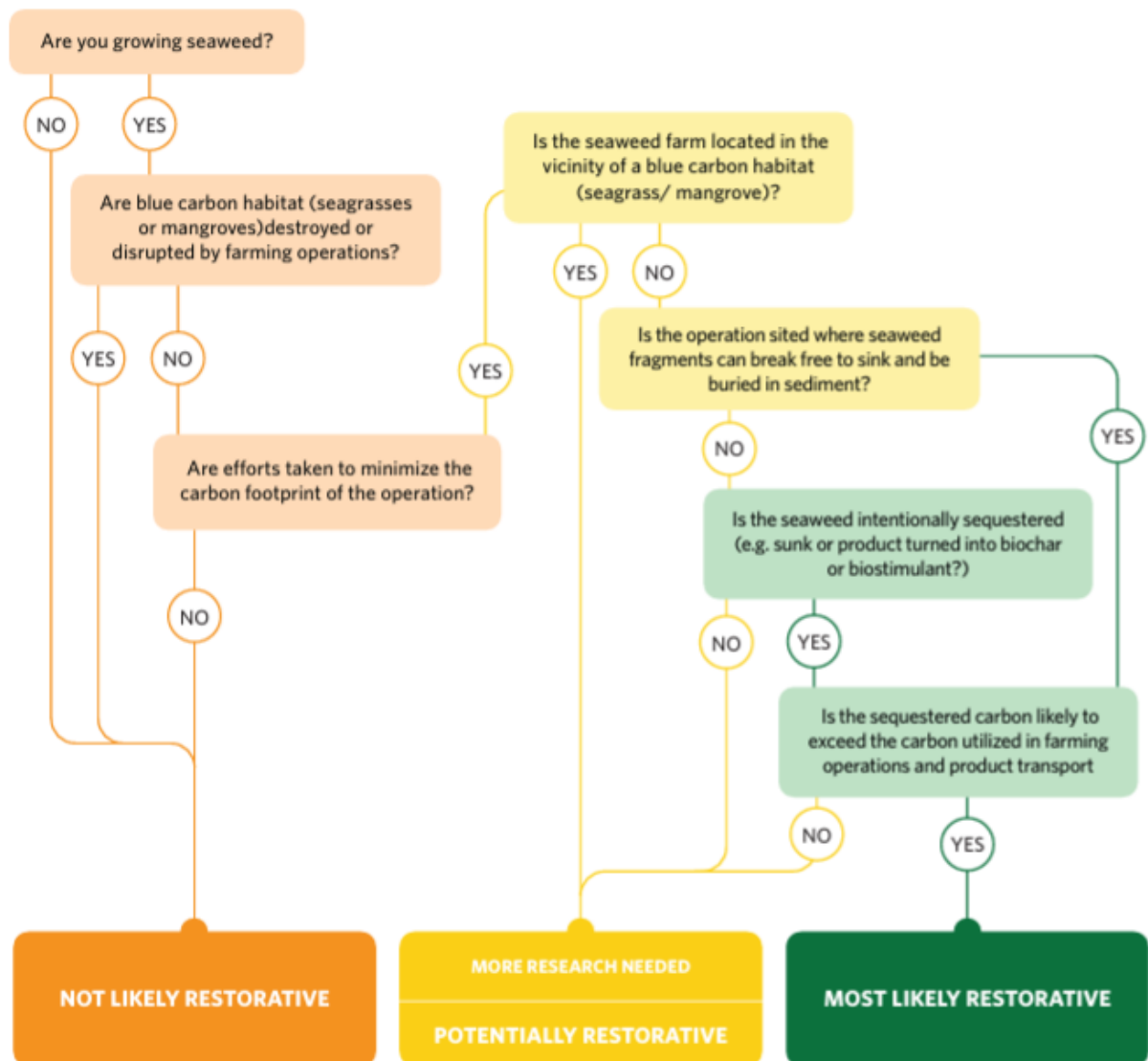
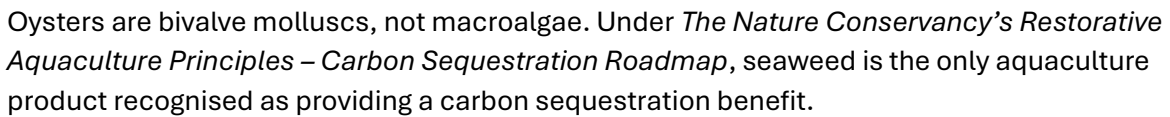


Figure 18. Roadmap 3 – Template for assessing carbon sequestration benefits.



Summary of Flow Chart Outcomes

Roadmap	Outcome	Note
Water Quality	Most Likely Restorative	The NSW oyster industry satisfies all decision points in the water quality flow chart, supported by quantitative NSW-specific data for nutrient removal rates, filtration rates, and long-term water-quality monitoring.
Habitat & Biodiversity	Most Likely Restorative	The NSW oyster industry satisfies all habitat and biodiversity flow chart decision points. The industry avoids habitat removal, presents negligible entanglement risk, farms predominantly native species at low density across many estuaries, and delivers documented habitat benefits to fish and invertebrates. Direct NSW evidence (Martínez-Baena <i>et al.</i> 2022) shows farm infrastructure functions as habitat comparable to natural biogenic structures.
Carbon Sequestration	Not Likely Restorative	Under the current roadmap, seaweed is the only aquaculture product recognised as providing a carbon-sequestration benefit, so on this measure oyster aquaculture is "Not Likely Restorative."

Table 5. Summary of flow-chart outcomes when assessing NSW oyster aquaculture against The Nature Conservancy (2021) roadmaps.

Carbon discussion relevant to NSW oyster aquaculture:

The NSW oyster industry has a very small carbon footprint compared to other farmed proteins. NSW Farmers (2025) calculated that in 2022/23, total NSW oyster industry emissions were approximately 2,640 tonnes of CO₂e (carbon dioxide equivalent). This is equivalent to:

- 0.93 kg CO₂e per kg of product harvested, or
- 3.75 kg CO₂e per 100 g of protein.

These figures are comparable to live mussels and frozen oysters farmed in New Zealand (Thinkstep 2021). Offsetting the industry's entire annual emissions would cost under \$100,000, or around 1.5 cents per dozen oysters if spread across the sector.

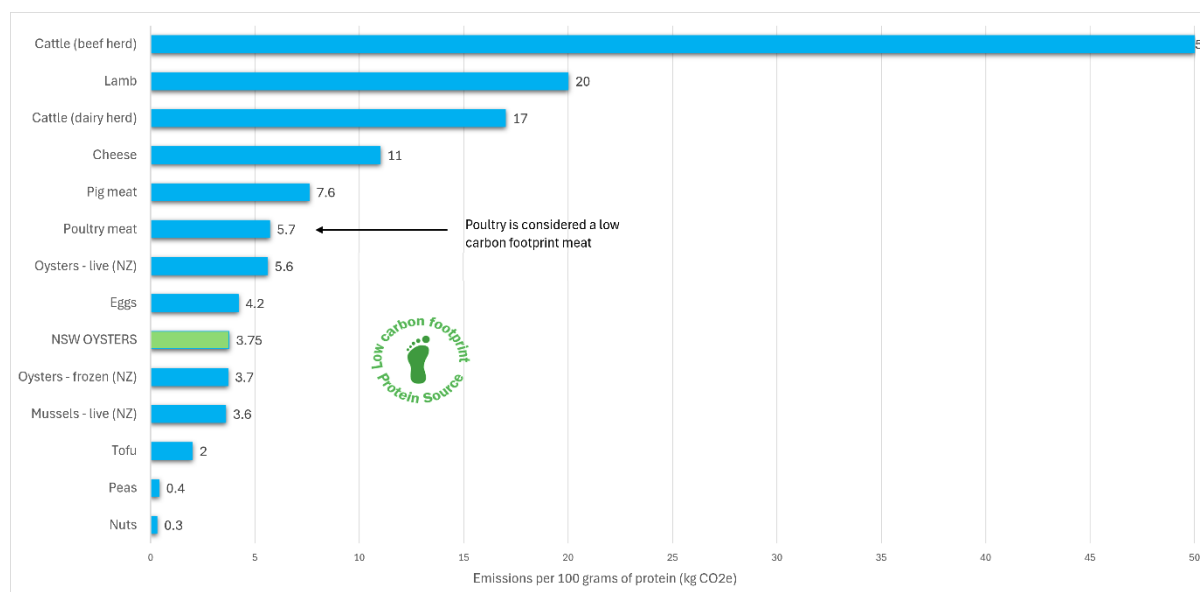
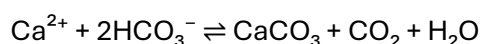


Figure 19. Carbon emissions per 100g of protein across common farmed foods (NSW Farmers 2025).

Do oyster shells lock up carbon?

It is tempting to assume that because oyster shells are made largely of calcium carbonate, growing oysters must sequester carbon. The chemistry is less favourable than it looks. When an oyster builds its shell it combines calcium and bicarbonate from the water, but that same reaction releases carbon dioxide as a by-product:



Shell-building therefore stores carbon in the shell and releases CO₂ into the water at the same time. Pernet *et al.* (2025) add two further points. First, most of the bicarbonate oysters use comes from the slow, natural weathering of rocks over tens of thousands of years. They estimate only about 6% is of recent, human-caused origin. Shell-building therefore does little to draw down atmospheric CO₂. Second, the CO₂ released during shell formation raises the partial pressure of CO₂ in the surrounding water, which slightly reduces the ocean's ability to absorb CO₂ from the atmosphere. So while a shell physically contains carbon, forming it does not

remove CO₂ from the atmosphere — the process scientists call marine carbon dioxide removal, or mCDR.

The “biological pump” (a contested pathway):

Shell chemistry is only part of the story. A recent study looked beyond the individual oyster to the wider farm ecosystem and proposed a second, indirect way oysters might influence carbon. Chen *et al.* (2025) argue that oysters can act as a “biological pump”. By recycling nutrients through their waste, grazing heavily on phytoplankton (which keeps the algae in a fast-growing, high-turnover state), and clearing particles so more light penetrates the water, oysters can stimulate more photosynthesis. More photosynthesis produces more organic carbon, some of which settles into the sediment. In their experiment this shifted the system toward being a net absorber of CO₂, and they estimated the carbon produced this way was 2.39 times the amount stored in the shells. On that basis they described oyster farming as a scalable, nature-based climate solution.

This study has, however, recently been contested by Pernet *et al.* (2026). Several issues are raised in the rebuttal, but the core issue is that the experiments undertaken by Chen *et al.* (2025) were conducted in enclosed, experimental tanks (mesocosms), and that their own paired field measurements did not show the same enhancement of photosynthesis. The paper also counted biodeposits as ‘stored carbon’, whereas these nutrient-rich particles are often remineralised and released in the estuarine environment.

Summary:

On the current evidence, oyster farming cannot be treated as a carbon-sequestration or CO₂ removal strategy, and it is not recognised as one under the TNC framework. The climate story for the NSW industry is not carbon removal but carbon efficiency. Oysters are among the lowest-emission animal proteins available, needing no feed, fertiliser, or fresh water, and the industry's total footprint is small and inexpensive to offset.

Part 2 - Mapping Evidence Base to The Nature Conservancy's Monitoring, Evaluation & Learning (MEL) Framework

Part 2 is the evidence chapter. It works systematically through the 16 indicators of the TNC MEL Framework, organised by the framework's three benefit areas — water quality, habitat and biodiversity, and climate change. For each indicator it sets out what the framework asks for, what evidence exists (NSW-specific where available, interstate or global proxies where not), the confidence in that evidence, and the gaps that remain.

Each indicator is classified as either:

- **Well Supported** (quantitative data exists including NSW-specific research),
- **Partially Supported** (evidence from comparable contexts; NSW data would help), or
- **Not Yet Supported** (insufficient evidence).

In some international settings (e.g. NZ), MEL frameworks are underpinned by long-term, site-level environmental monitoring. NSW oyster farming has no comparable environmental baseline or ongoing ecological monitoring requirements, so site-specific data is limited and the framework is not currently workable as an operational monitoring tool for much of the industry. This project therefore used the framework differently, as a tool to organise and synthesise existing evidence.

Peer-reviewed research, industry studies, and credible secondary sources were mapped against each MEL criterion and indicator to identify indicators that are well supported, highlight where evidence is limited or absent, and articulate the NSW-specific knowledge gaps relevant to restorative aquaculture.

Water Quality Indicators

WQ 1.1.1. Quantity of N & P assimilated & extracted

Goal 1	Mollusc farming contributes to a reduction of excess organic nutrients in the local environment.
Objective 1.1	Farmed bivalve biomass takes up more N and P than is released.
Indicator WQ 1.1.1.	Quantity of N and P assimilated and extracted.
Metric	N and P (kg) in harvested biomass.
WELL SUPPORTED	

One of the most tangible water-quality (WQ) benefits provided by oyster farming is nutrient bioextraction — the permanent removal of nitrogen (N) and phosphorus (P) from an estuary when oysters are harvested. Oysters filter particulate organic matter and phytoplankton from the water column (Figure 20) and assimilate the bound nutrients into their tissue and their shell. When oysters are harvested, those nutrients are physically removed from the waterway along with the biomass. As a result, the nutrient content of the harvested crop can be treated as a direct nutrient-removal service, independent of other processes such as denitrification occurring within the estuary (Barrett *et al.* 2022).



Figure 20. Oyster filtration (photo credit Celeste Boonaerts)

Research conducted in NSW confirms that oysters actively remove nutrients under local conditions. Biofiltration trials undertaken by Jones and Preston (1999) and Jones *et al.* (2002) found that Sydney rock oysters reduced total nitrogen concentrations in static wastewater by 20% and total phosphorus by 33%. Under flow-through conditions, reductions increased to 34% for nitrogen and 44% for phosphorus. While these studies measured reductions in water-column concentrations rather than nutrient mass removed at harvest, they clearly demonstrate the biological mechanism underpinning nutrient bioextraction.

To estimate harvest-based nutrient removal, NSW Farmers (2025) combined oyster meat composition data from Food Standards Australia New Zealand (FSANZ) with shell nutrient composition data from de Roover (2024). Applying these nutrient concentrations to species-specific shell-to-meat ratios resulted in estimated removal rates of 5.58 kg N and 0.69 kg P per tonne of Sydney rock oysters harvested, and 4.46 kg N and 0.55 kg P per tonne of Pacific oysters

	Sydney rocks	Pacific oysters	Source
Moisture	84%	81.7%	FSANZ
Tissue N (wet)	16.9 g N/kg (1.7%)	17.4 g N/kg (1.7%)	FSANZ
Tissue P (wet)	1.83 g P/kg (0.2%)	1.74 g P/kg (0.2%)	FSANZ
Tissue N (dry)	106 g N/kg (10.6%)	95 g N/kg (9.5%)	Derived
Tissue P (dry)	11.4 g P/kg (1.1%)	9.5 g P/kg (1.0%)	Derived
Shell N	1.963 g N/kg (0.2%)	1.963 g N/kg (0.2%)	de Roover (2024)
Shell P	0.32 g P/kg (0.03%)	0.32 g P/kg (0.03%)	de Roover (2024)
Shell : Meat ratio	Shell 75.6% Meat 24.4%	Shell 83.8% Meat 16.2%	For SRO (Nine-Squared 2022) For PAC (Hickey 2008)
Total N removal (whole live weight)	5.58 kg/tonne	4.46 kg/tonne	NSW Farmers (2025)
Total P removal (whole live weight)	0.69 kg/tonne	0.55 kg/tonne	NSW Farmers (2025)

Table 6. Summary of nutrient composition and harvest-based nutrient-removal factors for Sydney rock and Pacific oysters.

Applying these factors to reported NSW production gives industry-wide nutrient removal for each of the past three production years (Table 7). Removal has ranged from 15.3 to 16.8 tonnes of nitrogen and 1.9 to 2.1 tonnes of phosphorus, averaging 15.8 tonnes of nitrogen and 2.0 tonnes of phosphorus. Variation between years reflects harvest volume and species mix, not any change in the removal factors themselves, which are set by tissue and shell composition. Because removal scales directly with harvest, the factors in Table 6 are the durable measure and the annual totals will move with production in any given year.

Year	Sydney rock oysters		Pacific oysters		Nutrient removal	
	Dozen	Tonnes	Dozen	Tonnes	N (t)	P (t)
2022/23	5,159,666	2,484.4	393,238	354.5	15.4	1.9
2023/24	5,153,160	2,534.7	624,924	588.2	16.8	2.1
2024/25	4,726,732	2,217.8	744,199	657.4	15.3	1.9
Average	5,013,186	2,412.3	587,454	533.4	15.8	2.0

Table 7. NSW oyster harvest and estimated nutrient removal, 2022/23 to 2024/25. Removal calculated by applying the species-specific factors in Table 6 to reported harvest tonnage (NSW DPIRD 2024a, 2025a, 2026). Sydney rock and Pacific oysters only.

Further support comes from field measurements undertaken by Gifford *et al.* (2005) at a commercial oyster farm in Port Stephens. The study estimated nutrient removal of 7.45 kg N and 0.55 kg P per tonne of harvested oyster material. While the work was undertaken on pearl oysters (*Pinctada imbricata*) rather than Sydney rock or Pacific oysters, it provides additional evidence that harvested oyster biomass represents a meaningful pathway for nutrient removal.

The NSW estimates are broadly consistent with international findings. Domech *et al.* (2025) reported average nutrient-removal rates of 3.05 kg N and 0.35 kg P per tonne of harvested Pacific oysters in Ireland. While the NSW values are somewhat higher, both studies are of a similar order of magnitude and support the conclusion that oyster harvest provides a measurable nutrient-removal service. Differences are likely to be attributed to geographic conditions, oyster size, harvest composition, analytical methods, or natural variation in nutrient content.

A robust cross-check comes from the dataset underpinning NOAA's Aquaculture Nutrient Removal Calculator (Rose *et al.* 2024), which compiled nitrogen and morphometric data from over 1,300 eastern oyster (*Crassostrea virginica*) samples across the US Northeast. It reports a mean tissue nitrogen concentration of 7.70% of dry weight and a mean shell nitrogen concentration of 0.19% of dry weight, with low variability. These align with the NSW factors. The NSW shell nitrogen value (0.20%) is almost identical, and the SRO and Pacific tissue nitrogen (10.6% and 9.5% respectively of dry weight) falls in the same range. This broad agreement across different species and hemispheres supports the reliability of the NSW composition factors.

Notably, Rose *et al.* (2024) found nitrogen concentration varied little with location, ploidy or gear; the dominant driver of per-oyster removal was the relationship between oyster size and the dry weight of tissue and shell.

The critical variable for NSW is condition. Tissue carries roughly forty times the nitrogen concentration of shell, so despite making up only a few percent of an oyster's dry weight it accounts for the majority of the nitrogen removed at harvest.

Developing a NSW nutrient removal calculator:

Internationally, nutrient accounting for shellfish aquaculture is becoming increasingly sophisticated, and a similar tool could be developed for NSW using the nutrient-removal factors presented here. Delivering it is a two-stage process.

Stage 1. Establishing the underlying relationships.

The first stage is a research task. It requires sampling oysters from commercial leases to establish, for each species, how shell length relates to the dry weight of tissue and shell, and how that relationship shifts with location and time of year. Sampling would need to cover the main producing estuaries, span the full harvest size range, and be repeated through the year to capture the seasonal condition cycle. Rose *et al.* (2024) caution that shell data drawn from wild or restored oysters overstates removal by farms, as farmed oysters carry lighter shells at a given size, so sampling must come from commercial stock. Ploidy warrants separate treatment from the outset.

Stage 2. Applying the program.

Once those relationships are established, the complexity sits inside the calculator rather than in front of the grower. Routine use requires only the shell length of the oysters harvested (the grade) and the number harvested, both of which growers already record. The tool selects the appropriate species, seasonal and regional relationship, converts size to tissue and shell dry weight, applies the nutrient composition factors, and scales the result by the harvest quantity.

Such a tool would give growers a practical means of estimating and communicating the water-quality benefit of their own production and would provide government and market participants with a defensible, locally derived basis for recognising that service.

Summary of key knowledge gaps:

- **Seasonal and spatial variation in condition**— The dominant uncertainty in the whole-weight removal factors is not the nutrient concentrations but the tissue dry weight of the animal, which varies with condition and therefore with time of year, estuary and stage of the spawning cycle. Because tissue carries the great majority of the nitrogen, this variation flows directly through to removal estimates. Establishing shell length to tissue and shell dry weight relationships across seasons, estuaries and both species is the highest-value investment for improving NSW estimates.
- **Nutrient removal calculator** – No NSW tool currently exists. Building one is a two-stage task, comprising a sampling program to establish size, condition and shell relationships across species, estuaries and seasons, followed by development of a calculator that growers can run from harvest size and quantity alone.

WQ 1.1.2. Rate of denitrification

Goal 1	Mollusc farming contributes to a reduction of excess organic nutrients in the local environment.
Objective 1.1	Farmed bivalve biomass takes up more N and P than is released.
Indicator WQ 1.1.2.	Rate of denitrification.
Metric	Net N ₂ flux ($\mu\text{mol} / \text{m}^2 / \text{hr}$) and/or total N removed ($\text{mg N} / \text{yr}$).
PARTIALLY SUPPORTED	

Denitrification is the microbial process that permanently removes nitrogen from an estuary, converting biologically reactive nitrate into inert nitrogen gas (N₂), which is then released harmlessly into the atmosphere. For oyster farming, it is one of two nitrogen-removal pathways recognised by the framework, alongside the physical removal of oysters at harvest (see previous indicator, WQ 1.1.1.).

The role of oysters in enhancing denitrification is well established and consistent across global studies. As they feed, oysters drop a steady supply of organic material (i.e. faeces and pseudofaeces) onto the seabed beneath the farm. That material feeds sediment bacteria which strip oxygen from the nitrate and convert it to nitrogen gas (N₂) through a series of chemical reductions:

- Nitrate (NO₃⁻) → Nitrite (NO₂⁻) → Nitric oxide (NO) → Nitrous oxide (N₂O) → Nitrogen gas (N₂)

Once it reaches its final state, the nitrogen gas forms microscopic bubbles that float up out of the sediment, eventually escaping into the atmosphere. Nitrogen-cycling bacteria also live on oyster shells and within the animals' digestive systems, so oysters can influence nitrogen transformation beyond the sediment as well (Caffrey *et al.* 2016; Smaal *et al.* 2019), though whether this adds to or offsets net removal varies by site.

The international evidence for this enhancement is strong and directly measured. Using in situ measurements in the US, Humphries *et al.* (2016) recorded denitrification rates of $346 \pm 169 \mu\text{mol N}_2\text{-N} / \text{m}^2 / \text{hr}$ under oyster aquaculture and $582 \pm 164 \mu\text{mol N}_2\text{-N} / \text{m}^2 / \text{hr}$ over restored reefs, among the highest rates recorded for oyster-dominated systems, and roughly an order of magnitude above the bare-sediment control ($24 \pm 10 \mu\text{mol N}_2\text{-N} / \text{m}^2 / \text{hr}$). Aquaculture and restored reefs removed nitrogen at comparable rates, indicating that working farms can deliver a denitrification benefit similar to restoration. A global meta-analysis of 45 studies (Ray & Fulweiler 2021) confirms the general pattern. Oysters enhance nitrogen removal by stimulating denitrification, with reefs and oyster aquaculture functioning similarly. Some researchers argue that this level of removal is substantial and reliable enough to be incorporated into formal nitrogen management and nutrient trading frameworks (Ayvazian *et al.* 2021; Ray *et al.* 2025).

The difficulty in applying this to NSW is twofold. First, the meta-analytic evidence base in Ray & Fulweiler (2021) is geographically narrow, with 28 of the 45 studies focusing on the Atlantic coast of North America, and none from Australia, so rates measured elsewhere cannot be assumed to hold for oysters in sub-tropical NSW estuaries. Second, and more importantly, the single directly relevant NSW study points the other way. Beneath an active suspended Sydney

rock oyster farm in Wallis Lake, Erler *et al.* (2017) found that dissimilatory nitrate reduction to ammonium (DNRA) accounted for 98% of nitrate reduction, with denitrification contributing very little. DNRA is an alternative pathway to denitrification that recycles nitrogen back into the water column as ammonium rather than removing it as N_2 . That system therefore favoured nitrogen retention over nitrogen loss.

In summary, while the capacity of oyster aquaculture to enhance denitrification is well supported globally, its effectiveness as a net nitrogen sink in NSW remains unquantified. The underlying chemistry suggests that lower stocking densities and well-oxygenated, well-flushed conditions should favour permanent removal (denitrification) over retention (DNRA), but the Wallis Lake study (Erler *et al.* 2017), shows that warm, nutrient-rich conditions can still tip the balance toward retention. Outcomes are likely to vary across locations, stocking densities, and seasons.

Summary of key knowledge gaps:

- **Lack of NSW specific denitrification data** – The local nitrogen-cycling evidence rests on a single Wallis Lake study (Erler *et al.* 2017), which found nitrogen retention (DNRA) dominating over permanent removal (denitrification). Whether NSW oyster farming is a net nitrogen sink or source therefore remains unresolved. What is needed is direct measurement of denitrification rates beneath Sydney rock and Pacific oyster leases, using site-specific, seasonally resolved sampling of paired farm and reference sediments across a range of NSW growing estuaries.

WQ 1.2.1. Dissolved oxygen concentration at the farm site

Goal 1	Mollusc farming contributes to a reduction of excess organic nutrients in the local environment.
Objective 1.2	Unfed farmed molluscs support a reduction in symptoms of eutrophication.
Indicator WQ 1.2.1.	Dissolved oxygen concentration at the farm site.
Metric	Dissolved oxygen concentration (mg/L)
PARTIALLY SUPPORTED	

Eutrophication occurs when excess nutrients, particularly nitrogen and phosphorus, stimulate rapid algal growth. This leads to turbid water, reduced light penetration, and shading of seagrass. As algal biomass accumulates and subsequently decomposes, microbial processes consume oxygen, often resulting in hypoxia that can stress or kill aquatic organisms. Dissolved oxygen (DO) is therefore an effective integrative indicator of eutrophication, reflecting the balance between oxygen-consuming processes, such as decomposition and respiration, and oxygen-producing processes, such as photosynthesis. In eutrophic systems, this balance becomes unstable, with large daily fluctuations in DO and low night-time minimums.

Seagrass and dissolved oxygen:

Seagrass plays an important role in regulating dissolved oxygen (DO) in estuarine systems by acting as a major site of photosynthesis.

- During daylight hours, seagrass photosynthesise, absorbing carbon dioxide and releasing oxygen into the surrounding water. This increases DO levels and helps counteract oxygen depletion associated with eutrophication.
- At night, photosynthesis stops but respiration continues. The plant breaks down the sugars made during the day, using oxygen and releasing carbon dioxide.

Studies on NSW seagrass (e.g. *Zostera muelleri*) by Ferguson *et al.* (2017) show that oxygen production during the day is closely balanced by oxygen consumption through respiration over a full 24-hour cycle, resulting in near-neutral net metabolism. Despite seagrass meadows functioning as metabolically balanced systems, their high photosynthetic rates elevate DO during the day and help stabilize oxygen dynamics.

As efficient filter feeders, oysters remove phytoplankton and suspended organic particles from the water column, reducing the amount of organic matter available for decomposition and thereby lowering oxygen demand. By improving water clarity, this same filtration can also support oxygen-producing marine vegetation and shift systems toward greater autotrophy (i.e. more oxygen being produced than consumed); the “clarity effect” and its benefits for seagrass are detailed under WQ 2.1.1.

These benefits are not uniform. At individual lease scales, particularly in densely stocked or poorly flushed environments, oysters can locally reduce DO through respiration and through microbial activity associated with their biodeposits. These processes can lead to short-term

reductions in oxygen, especially at night or near the water-sediment interface (Ray *et al.* 2025). However, these localised effects are generally transient and outweighed at the scale of the estuary by the broader filtration-driven improvements in water quality.

The wider body of evidence is consistent with this interpretation. Oyster filtration can suppress phytoplankton even under elevated nutrient loads, while global studies and restoration programs (e.g. Chesapeake Bay) link increased oyster biomass with reduced turbidity, lower chlorophyll a, and improved oxygen conditions (Smaal *et al.* 2019). Bench-scale filtration experiments with Sydney rock oysters reduced suspended solids in prawn-pond effluent by up to 51%, alongside reductions in bacteria (42%), total phosphorus (33%) and total nitrogen (20%), with the highest oyster density having the most pronounced effect (Jones & Preston 1999). While conducted on concentrated aquaculture effluent rather than ambient estuary water, this demonstrates the same filtration mechanism that Sydney rock oysters exert.

NSW also provides strong observational evidence through extensive long-term monitoring. The NSW Shellfish Program generates up to 20,000 observations annually, with real-time sensors and records spanning five decades (Dove *et al.* 2025). Over this period, shellfish harvest area classifications have generally improved, indicating stable or improving water quality. Additional monitoring using handheld DO meters in multiple estuaries allows growers to track oxygen dynamics during “blackwater” episodes, where rapid decomposition of terrestrial organic matter can cause severe oxygen depletion.

Independent monitoring by government and councils further support these findings. Dissolved oxygen is a standard variable in estuary health assessments under the Marine Estate Management Strategy, alongside indicators such as chlorophyll a and turbidity, with most NSW estuaries generally rated in good condition. Changing dissolved oxygen is formally recognised as a key stressor in these systems (NSW Marine Estate Threat and Risk Assessment 2017), reinforcing its relevance as an indicator.

Overall, the evidence is consistent and robust at the estuary scale. Eutrophication reduces dissolved oxygen, while oyster aquaculture counteracts this by removing phytoplankton, improving water clarity, and supporting oxygen-producing systems such as seagrass. This results in generally stable and healthy DO conditions across oyster-growing estuaries in NSW. However, the specific indicator defined here, dissolved oxygen at the farm site, has not yet been systematically measured using paired farm and control sites at the fine spatial and temporal resolution required to isolate farm-scale effects.

Summary of key knowledge gaps:

- **The farm-scale effect is unmeasured in NSW** - There is no paired, high-frequency monitoring comparing dissolved oxygen at within-lease versus non-farm control sites (particularly capturing the critical pre-dawn minimum), and the underlying "clarity effect" is equally unquantified, with no systematic comparison of chlorophyll a, turbidity, or light inside versus outside farmed areas. Together this makes it impossible to isolate the farm's specific contribution to DO.
- **Existing data is fragmented** - Industry, council and state programs all record water quality data independently. Pooling them would give a single, highly useful estuary-by-estuary picture.

WQ 1.3.1. Rate of water filtration

Goal 1	Mollusc farming contributes to a reduction of excess organic nutrients in the local environment.
Objective 1.3	Farmed biomass contributes to water filtration within the estuary that improves light penetration and reduces hypoxia
Indicator WQ 1.3.1.	Rate of water filtration.
Metric	Filtration rate (L/hr)
WELL SUPPORTED	

Water filtration underpins almost every water-quality benefit oysters deliver. As filter feeders, they pump large volumes across their gills to extract phytoplankton and suspended particles. This process drives multiple ecosystem services across the framework. It underlies nutrient removal (WQ 1.1.1.), contributes organic material to sediments through biodeposition that fuels denitrification (WQ 1.1.2.), and improves water clarity and quality metrics such as chlorophyll a and dissolved oxygen (WQ 2.1.1. and WQ 1.2.1.). In practical terms, filtration is the “engine” that links oyster biomass to measurable improvements in estuarine condition.

The most direct way to quantify this process is through the filtration (or clearance) rate, typically expressed in litres per hour. This can be measured per individual oyster, but for management and reporting purposes it is far more useful when scaled to a farm, estuary, or industry.

A key strength of this indicator is that it is grounded in empirical measurements for Sydney rock oysters (SRO) under NSW conditions. Foundational feeding-physiology studies by Bayne *et al.* (1999) measured a clearance rate for a market-size adult Sydney rock oyster to be approximately 3 litres per hour. Follow up work by the same author in 2002 (Bayne 2002), comparing Sydney rock and Pacific oysters in the same estuary, reported daily filtration volumes exceeding 100 litres per adult SRO. These values remain the accepted reference points for NSW and have been reaffirmed in recent synthesis work (e.g. Dove *et al.* 2025).

Comparable feeding data also exist for Pacific oysters. Working in Port Stephens, Bayne (2002) measured the feeding physiology of Pacific oysters and Sydney rock oysters side-by-side and confirmed that, under NSW conditions, Pacific oysters feed faster. Bayne expressed filtration as particle processing and ingestion rates rather than as a volumetric clearance rate. For the purposes of this assessment, the filtration rate adopted for Pacific oysters, approximately 5 - 8 litres per hour, derives from international laboratory and field studies (Bougrier *et al.* 1995). Together these provide relevant filtration benchmarks for both of the state's primary cultured species.

When scaled up to industry production, the magnitude of filtration becomes substantial. Using harvest volumes for the 2024/25 production year and representative filtration rates, the total annual filtration capacity of harvested stock can be estimated (Table 8). Sydney rock oysters account for approximately 1.49 trillion litres of water filtered each year, while Pacific oysters contribute a further ~508 billion litres. Combined, this equates to ~2 trillion litres of water processed per year by harvested oysters alone. This is the equivalent of emptying and cleaning

Sydney Harbour 4 times annually (or 800,000 Olympic-sized pools). This figure is also exclusive of the ~200 million juveniles that are being concurrently grown for future harvests.

Species	Harvest in 24/25 (dz)	Harvest in 24/25 (#)	Filtration rate	Total filtration (litres per year)
Sydney rock oysters	4,726,732	56,720,784	3 litres / hr	1,490,622,203,520 (1.49 trillion litres)
Pacific oysters	744,199	8,930,388	6.5 litres / hr	508,496,292,720 (508 billion litres)
Combined				1,999,118,496,240 (~2 trillion litres)

Table 8. Estimated potential water filtration by harvested oyster stock in NSW, 2024/25. Figures are indicative - they assume oysters filter continuously over a full year and therefore represent a potential upper bound rather than realised filtration (see below).

An important nuance is that the filtration rate is not constant. Clearance rate responds dynamically to environmental drivers. It generally increases with temperature but declines sharply in turbid water when oysters reduce feeding activity (Suplicy *et al.* 2025). In a related tropical Blacklip oyster species (*Saccostrea echinata*), it's has also been found that filtration varies with salinity, food availability and quality, and the size and physiological condition of the animal (Rennie 2022).

Farming method also affects how much filtration actually occurs. Oysters in NSW are grown intertidally on racks and adjustable longlines, and are often exposed to air for a number of hours during tidal cycles or for routine drying. This means they are not feeding continuously. As a result, laboratory or fully submerged filtration rates represent an upper limit ("potential filtration"), while real-world ("realised") filtration will be lower. For NSW applications, it is therefore best to report filtration as a range that distinguishes between these two scenarios.

To handle this complexity, researchers overseas have developed models like ShellSIM and FARM that estimate oyster filtration more realistically. These models factor in parameters like temperature, food levels, water quality, oyster size, and stocking density, rather than relying on a single filtration rate per oyster. These models are widely used in Europe to estimate the environmental benefits of Pacific oysters and mussels but have not yet been contextualised for Sydney rock oysters in NSW. This makes it harder to scale simple per-oyster filtration rates into accurate, whole-of-estuary or industry estimates.

Summary of key knowledge gaps:

- **Dated and limited filtration data** — The accepted rates rest on a small number of older studies. Neither species has a volumetric clearance rate (L/hr) measured across the range of NSW estuaries, environmental conditions (temperature, salinity, turbidity), or different size and age classes, leaving industry-scale estimates reliant on a few reference values.
- **Lack of calibrated dynamic models for SRO** - While modelling frameworks such as ShellSIM and FARM provide a robust, process-based way to estimate filtration and related ecosystem services, they have not yet been calibrated for Sydney rock oysters.

WQ 2.1.1. Chlorophyll a concentration on the farm site

Goal 2	Mollusc farming improves / enhances local ecosystem primary production
Objective 2.1	Farming of molluscs supports regulation of phytoplankton arising from eutrophication, chlorophyll-a concentrations are lower, and microorganism communities similar to or more productive on the farm site without negatively impacting carrying capacity and feed available for wild populations or other farms.
Indicator WQ 2.1.1.	Chlorophyll a concentration on the farm site.
Metric	Chlorophyll a concentration ($\mu\text{g/L}$), as a primary indicator of eutrophication.
PARTIALLY SUPPORTED	

Chlorophyll a is a standard proxy for phytoplankton biomass and a widely used indicator of eutrophication, so a measurable reduction in it represents a real water-quality benefit. The mechanism is the same one behind two related indicators, filtration (WQ 1.3.1.) and nutrient extraction (WQ 1.1.1.). Oysters are filter feeders that continuously filter water, removing particulate material including phytoplankton. Where filtration outpaces the combined effect of algal growth and physical replenishment, chlorophyll a declines. This indicator is, in effect, the water-column expression of the filtration process captured in those related indicators.

Controlled Australian work shows oysters can substantially reduce chlorophyll a under high-nutrient conditions. In tank-based prawn-effluent trials, settlement and Sydney rock oyster filtration cut chlorophyll a to 8% of its initial value (Jones & Preston 1999), though chlorophyll a was only a minor component of that particular effluent. The related Blacklip rock oyster *Saccostrea echinata*, reduced chlorophyll a by 39% at high stocking density (Rennie 2022).

Field studies internationally report lower chlorophyll a levels within shellfish farming areas. At a long-line mussel farm in Denmark, chlorophyll a was depleted by 27–44% within the narrow feeding zone around the ropes, with farm-scale depletion averaging 22% (Cranford 2019), and Jiang *et al.* (2016) recorded a 60% reduction in chlorophyll a in an intense oyster farming zone relative to a reference site. Across species, designs and environments, the direction of effect is consistent, oyster filtration reduces phytoplankton biomass locally.

Lower chlorophyll a also means clearer water. By reducing phytoplankton, oyster filtration improves light penetration, which can enhance seagrass photosynthesis and shift systems toward greater autotrophy — a mechanism often referred to as the “clarity effect”. In US mesocosm experiments, DuBois *et al.* (2024) found oysters facilitated eelgrass (*Zostera marina*) leaf growth and clonal reproduction by 35% and 38% respectively, likely through nutrient provision and improved local conditions rather than light alone. That facilitation weakened and reversed under experimental warming and acidification, so the benefit is condition dependent. These findings require local validation but are notable because *Zostera* also occurs in NSW estuaries (albeit a different species), and they illustrate how oyster filtration-driven reductions in chlorophyll a can reinforce, rather than compete with, seagrass condition where the two co-occur.

The effect is spatially variable and not always in the expected direction. In a paired upstream–downstream study of two Rhode Island farms, chlorophyll a change ranged from a 64% reduction to a 74% increase downstream, with elevated chlorophyll a inside oyster bags (Ayvazian *et al.* 2026). This partly reflects selective filtration with oysters preferentially removing larger phytoplankton, releasing smaller picophytoplankton from grazing pressure and allow them to increase locally (Jiang *et al.* 2016, see WQ 2.1.2.). Nutrient recycling from oyster excretion can likewise support localised primary production at farm margins.

The magnitude of the effect is fundamentally constrained by system dynamics, chiefly the balance between clearance time (how long oysters need to filter the water body), residence time (how fast tidal flushing exchanges that water) and the phytoplankton growth rate.

- Where filtration is rapid relative to flushing and growth, chlorophyll a levels drop;
- Where flushing or growth dominates, the impact of filtration is diluted or lost.

At larger spatial scales, including whole estuaries, both empirical and modelling studies indicate that the effect on chlorophyll a is small. For example, modelling of Chesapeake Bay (US) suggested that even a ten-fold increase in oyster biomass would only lower annual mean chlorophyll a by only about 6% across the northern Bay (Cerco & Noel 2007). A subsequent multispecies model concluded that oyster restoration alone is unlikely to produce more than a marginal bay-wide reduction, with effects concentrated in tributaries (Fulford *et al.* 2010).

In the NSW context, several factors suggest the observable chlorophyll a signal will be modest. Oyster aquaculture here is typically low-density, often farmed intertidally, and within well-flushed estuaries. These conditions limit the residence time of water within farms and therefore the cumulative effect of filtration. Reductions in chlorophyll a are consequently expected to be localised, temporally variable and smaller in magnitude than those observed in high-density or poorly-flushed systems. The large reductions reported in controlled or intensive settings should therefore be read as demonstrations of biological capacity rather than realistic expectations for commercial leases (Jones & Preston 1999; Smaal *et al.* 2019).

A further complication is that where diffuse catchment nutrient loads are high, chlorophyll a can stay elevated regardless of oyster filtration, masking the farm signal. Elevated chlorophyll a at a farm site may therefore reflect catchment inputs rather than weak filtration. Isolating the oyster farm effect requires carefully matched control sites.

Taken together, the evidence supports oyster aquaculture reducing chlorophyll a at the farm scale, consistent with its role as a biological filter. The uncertainty is magnitude under typical NSW conditions. Capacity is clear, but no paired farm-versus-control chlorophyll a measurements exist from commercial estuaries capturing stocking density, tidal exchange and intertidal exposure. The effect is, in short, highly context-dependent.

Summary of key knowledge gaps:

- **No NSW farm-versus-control chlorophyll a dataset exists** – This indicator is unmeasured in NSW. The magnitude of the effect is unqualified.

WQ 2.1.2. Microorganism & plankton community on the farm site

Goal 2	Mollusc farming improves / enhances local ecosystem primary production
Objective 2.1	Farming of molluscs supports regulation of phytoplankton arising from eutrophication, chlorophyll a concentrations are lower, and microorganism communities similar to or more productive on the farm site without negatively impacting carrying capacity and feed available for wild populations or other farms.
Indicator WQ 2.1.2.	Microorganism and plankton community on the farm site.
Metric	Microorganism and plankton species presence, abundance, and change over time.
PARTIALLY SUPPORTED	

Where the previous indicator (WQ 2.1.1.) measures how *much* phytoplankton is in the water, this one asks *what* is there, and whether oyster farming influences the community in a healthy way. The two indicators are complementary rather than competing. Reducing excess phytoplankton biomass is the benefit captured under WQ 2.1.1., while this indicator evaluates whether that outcome is ecologically sound - that the plankton community stays diverse and functional, that harmful or bloom-forming species do not come to dominate and that grazing does not exceed the estuary's carrying capacity by removing food from wild filter-feeders or neighbouring farms.

The two indicators reinforce one another. For example, reducing a phytoplankton bloom lowers total chlorophyll a concentration while stripping out a single dominant species, resulting in a more even and diverse community. A restorative outcome is therefore one in which excess biomass declines while the phytoplankton and microbial community remains diverse, functional and resilient. In practice, this would be shown by fewer harmful algal blooms (*Pseudo-nitzschia*, *Dinophysis*, *Alexandrium*), retention of the large diatoms that underpin the food web, any size-structure shift being small and reversible, and a microbial community that stays diverse and functional.

This matters for two main reasons. Ecologically, the plankton community is the base of the estuarine food web and the oyster's own food supply. Practically, it is also where harmful algal blooms and biotoxin risk sit, so in NSW this indicator overlaps directly with the food-safety monitoring the industry already runs.

The underlying mechanism is well understood. Oysters are not indiscriminate filters. Oyster gills carry only small laterofrontal cirri, which makes them less efficient at capturing fine particles than mussels and clams. In the European flat oyster, retention efficiency falls to around 30% for 2 µm particles and about 5% for 1 µm particles (Møhlenberg & Riisgård 1978, reviewed in Riisgård & Larsen 2026), so grazing acts mainly on diatoms and large flagellates while most of the picoplankton and free-living bacteria passes through. The strongest Australian test of this mechanism comes from FRDC project 2014/027, which exposed Pacific oysters to natural seston from Coffin Bay in South Australia across four seasons. Removal was concentrated on particles larger than 2 µm, while free-living bacteria and virus-like particles were not reduced at all (Miller-Ezzy *et al.* 2024). The microbial base of the food web therefore

passes through a farm substantially intact, and the grazing signal sits on the larger cells that drive bloom biomass.

The same trials speak to whether farmed oysters compete with wild filter-feeders for food. Pacific oysters, blue mussels and mud cockles were found to filter different parts of the particle spectrum and not necessarily to compete, with cockles feeding efficiently on the small particles oysters leave behind (Miller-Ezzy *et al.* 2024). Co-occurring filter-feeders appear to partition the food resource rather than contest it, though this has not been tested in NSW.

Species matters in applying this to NSW. South Australia farms Pacific oysters, while NSW production is predominantly Sydney rock oyster with a smaller Pacific oyster component. The only direct comparison of the two species, run in Port Stephens, found Pacific oysters filtered faster and absorbed more efficiently, while Sydney rock oysters fed more slowly and adjusted their sorting of particles to the quality of the food, which Pacific oysters did not (Bayne 2002). Sydney rock oysters therefore appear to be the more responsive feeder, adjusting what they ingest to the quality of what is available, with Pacific oysters the higher-throughput feeder.

Clear evidence of community change comes mainly from overseas studies that compare farm and non-farm areas directly. In Daya Bay, China, pigment analysis showed that intensive oyster farming substantially reduced phytoplankton biomass, with the strongest depletion occurring in larger (>20 µm) fractions. Community composition differed significantly from adjacent non-farm areas and shifted toward smaller taxa, particularly prasinophytes, consistent with selective grazing by oysters (Jiang, T. *et al.* 2016).

The change is not always a loss of diversity. A separate paired farm-versus-control study, in a different Chinese bay made warmer and more eutrophic by power station discharge, found that oyster farming raised phytoplankton species richness (+26%), Shannon–Wiener diversity (+38%) and evenness (+29%) relative to control areas, while suppressing a bloom. Phytoplankton abundance and chlorophyll *a* were 46% and 28% lower on the farm. Every one of these differences disappeared once the culture rafts were removed, showing the community change is real, positive and reversible (Jiang, Z. *et al.* 2019).

In NSW, there are no direct studies comparing plankton communities inside and outside oyster leases. There is, however, a large, long-term dataset collected within farms themselves. This comes from two main programs.

The first is the NSW Shellfish Program, run by the NSW Food Authority. Under it, each local shellfish committee must follow a sampling plan that specifies the frequency of water and shellfish sampling for phytoplankton, marine biotoxins, microbiological indicators and heavy metals, with samples collected by trained samplers from designated test sites and analysed at NATA accredited laboratories (NSW Food Authority 2025). It is a mandatory, food-safety-driven surveillance program, with phytoplankton counts and biotoxin results triggering harvest-area closures. Aggregated, it generates up to ~3,000 phytoplankton and biotoxin tests and about 20,000 environmental data points a year, the largest and longest running harmful-algal-bloom dataset in Australia (Dove *et al.* 2025).

The second is the “Transforming Australian Shellfish Production” project (Ajani *et al.* 2024). This project expanded on the monitoring by analysing plankton communities in much greater detail and linking them to environmental conditions. It combined real-time sensors (salinity, temperature, depth) with DNA-based tests (eDNA and qPCR) targeting harmful algae, as well as *E. coli*. Farmers collected weekly samples, producing about 11,803 DNA samples and 3,222 oyster growth records.

Overall, NSW has strong capability to measure this indicator, supported by extensive monitoring and advanced analytical tools. None of it however currently compares the plankton or microbial community on a farm against a matched non-farm site in the surrounding estuary. Based on known mechanisms and overseas evidence, low-density, well-flushed, off-bottom Sydney rock oyster farming is expected to cause modest, reversible shifts toward smaller phytoplankton, though this remains a prediction until measured locally.

Summary of key knowledge gaps:

- **No NSW farm-versus-control community study** - The core metric, plankton and microbial species presence, abundance and change over time, measured inside a lease versus a matched non-farm site, has not been collected in NSW. The method is not the obstacle. FRDC 2014/027 ran 13 months of monthly sampling at lease and non-lease sites in two South Australian bays. Applying that design in NSW, with properly matched controls, would close this gap directly.
- **Feeding behaviour of Sydney rock oyster is not resolved** - Particle-size selectivity has been measured on natural plankton assemblages for Pacific oysters but not for Sydney rock oysters, and the only direct comparison of the two species measured food quality rather than particle size. The grazing signature of the dominant NSW species against natural estuarine seston therefore remains inferred.

Habitat & Biodiversity (HB) Indicators

HB 1.1.1. Abundance & diversity of organisms directly associated with farmed biomass

Goal 1	Mollusc are farmed in a way that supports an abundance and diversity of associated native species.
Objective 1.1	Farming of molluscs supports an abundance and diversity of native epibiota (organisms that live on the surface of another living organism).
Indicator HB 1.1.1.	Abundance and diversity of organisms directly associated with farmed biomass.
Metric	Abundance – Number of individuals or total mass per species / species groups. Diversity – Shannon Diversity Index, or number of species, genus, families and/or functional groups.
WELL SUPPORTED	

This indicator focuses on epibiota, the sessile organisms that live attached to oyster shells and farming gear. These include barnacles, mussels, wild oyster spat, ascidians (sea squirts), bryozoans, sponges, hydroids, tube-building worms, anemones and macroalgae.

A distinctive feature of the NSW industry makes this question particularly relevant: Sydney rock oyster production relies heavily on wild-caught native spat. Growers deploy tens of thousands of catching slats each year, with an estimated 85–90% of production sourced this way rather than from hatcheries (NSW DPIRD 2024b). Against an annual harvest of around 57 million and 30% production-cycle mortality, this implies roughly 70–75 million Sydney rock oysters are recruited from the wild each year. Combined with extensive farm infrastructure, this creates a large area of hard substrate within an otherwise soft-sediment environment.

The mechanism is well established, and the direction of effect is clear; added structure is rapidly colonised. In Port Stephens, Martínez-Baena *et al.* (2022) showed that cultivation equipment introduces hard, three-dimensional surfaces into soft-bottom estuaries that are colonised by fouling organisms and macroalgae, with greater-surface-area systems, such as post-and-rail, supporting higher epibiont biomass. Beyond working gear, McLeod *et al.* (2019) found Sydney rock oyster reefs supported roughly fivefold higher density, biomass and productivity of mobile macroinvertebrates than adjacent bare sediment. This study looked at reef and mobile fauna rather than gear and epibiota, but it is a clear demonstration that oyster structure converts bare substrate into productive habitat.

This is consistent with the broader literature. Reviews by van der Schatte Olivier *et al.* (2020) and Smaal *et al.* (2019) confirm that racks, cages, nets, ropes and the shells themselves all act as substrate for diverse fouling assemblages, and that bivalve aggregations function as biodiversity hotspots. A global biofouling review documents shellfish gear colonised by tunicates, bryozoans, hydroids, sponges and algae (Bannister *et al.* 2019), and a Black Sea study of a Pacific oyster longline recorded barnacles, bryozoans, ascidians, hydrozoans,

mussels and polychaetes across the cages, ropes and shells, shifting seasonally with temperature and larval supply (Niță *et al.* 2026). The closest Australian analogue is South Australian habitat, where introduced, reef-forming Pacific oysters supported roughly twice the invertebrate richness and about eight times the biomass of adjacent mangrove and bare sediment (Martin *et al.* 2025). Again, this is a reef-structure analogue rather than oyster farming gear, and one that also harboured several non-native species.

Two limitations apply in NSW. First, most local studies have measured mobile fauna (HB 1.2.1) and infauna rather than the sessile epibiota itself, so the specific metric here, epibiont abundance or biomass and diversity (e.g. Shannon index) per unit of farmed biomass, has not been directly reported for NSW farms. The colonisation pathway is well evidenced, but the epibiotic community has not been quantified in the framework's terms.

Second, biofouling is actively managed. Husbandry practices such as drying and heat-treatment are specifically designed to kill fouling organisms that harm oyster health or reduce marketability, introducing regular disturbance so that standing epibiont biomass and diversity on working farms are likely lower than on comparable unmanaged structures. The effect is real and directionally certain, but under-quantified for NSW and strongly shaped by farm practice.

This husbandry effect is being investigated by a current overcatch-management project on Sydney rock oysters in Moreton Bay, Queensland (Cawthorn *et al.* 2026), which is recording the fouling community on the stock itself; direct data on epibiont abundance and composition under commercial conditions. Preliminary results from untreated control stock ~30 months old show an abundant, diverse native assemblage averaging just over seven organisms per oyster (7.05/oyster), dominated by wild oyster spat (2.26/oyster, presumably SRO) and barnacles (1.55/oyster), with tubeworms, pearl oysters, tunicates, ascidians, bryozoans and macroalgae. The baskets themselves further supported tunicates and spat, and habitat for small fishes and crabs. As untreated stock, these figures represent the epibiotic load before husbandry suppression. Being the same species under commercial conditions, this represents a close proxy for NSW, though this information is preliminary and unpublished (Cawthorn *et al.* 2026, unpubl. data).

In summary, there is strong and consistent evidence that oyster farming structures in NSW act as habitat for epibiotic communities, supported by both local studies and global literature. The effect is clear in direction, oyster farms support biodiversity, but remains incompletely quantified for NSW in the specific terms required by this framework, particularly once routine husbandry is accounted for.

Summary of key knowledge gaps:

- **No NSW epibiont dataset in the framework's terms** - No NSW study reports epibiont abundance/biomass or a diversity index. Work to date has measured fish and infauna rather than the sessile epibiotic community, and the closest direct measurement (Cawthorn *et al.* 2026, unpubl.) is in Moreton Bay, Queensland, and is expressed as organisms per oyster rather than a Shannon index. Any NSW figure would also need to account for routine husbandry (drying, heat-treatment, gear maintenance), which suppresses fouling and likely lowers measurable epibiota relative to unmanaged structures, and for significant estuary-to-estuary variation.

HB 1.2.1. Abundance & diversity of mobile fauna associated with farm site (e.g. fish, crustaceans, birds, marine mammals)

Goal 1	Mollusc are farmed in a way that supports an abundance and diversity of associated native species.
Objective 1.2	Farming of molluscs supports an abundance and diversity of native mobile fauna, such as fish and crustacea, without increasing negative impacts, such as fishing pressure.
Indicator HB 1.2.1.	Abundance and diversity of mobile fauna associated with farm site (e.g. fish, crustaceans, birds, marine mammals)
Metric	Abundance – Number of individuals or total mass per species / species groups. Diversity – Shannon Diversity Index, or number of species, genus, families and/or functional groups.
WELL SUPPORTED	

Mobile fauna are the most visible expression of the “farm as habitat” concept. If oyster gear works like a constructed reef, it should attract and support the same fish and invertebrates that use natural reef systems, including commercially and recreationally valuable species. This indicator asks whether NSW farms support their abundance and diversity, while also considering whether they introduce unintended impacts, such as increased fishing pressure.

The clearest NSW test is Martínez-Baena *et al.* (2022), which used remote underwater video (RUV) at oyster farms in Port Stephens, comparing fish among farm gear with adjacent natural habitats (reef, seagrass, mangrove, bare sediment). Across 510 deployments (586.5 hrs), 90 species from 51 families were recorded. Both farm types, post-and-rail and intertidal longlines, supported fish richness comparable to natural biogenic habitats and far above bare sediment (50 species at racks, 54 at remnant reef, 11 shared across all habitats). The assemblage was dominated by harvested species; yellowfin bream (42%), luderick (24%) and sand whiting (3%). Importantly, fish use was functional rather than incidental: 84 species were observed actively moving through the structures and 40 were recorded feeding.

The same study highlighted that post-and-rail systems supported higher fish abundance and species richness than floating basket systems, which suggests that structural complexity, not just the presence of oysters, is the key driver of habitat value. However, that benefit comes with a trade-off. Rack systems cast greater shade over underlying seagrass, whereas floating baskets reduce seagrass impact but provide somewhat lower fish habitat value.

A NSW field experiment quantified this trade-off with Ferretto *et al.* (2022) finding that trays over *Posidonia australis* reduced light availability to the seagrass by 90.8% and drove roughly four-fold declines in shoot density within three months, whereas floating bags caused no measurable loss of shoot density or leaf length. Gear selection is therefore a practical lever for reconciling fish-habitat value with seagrass protection: matching system type to the sensitivity of the underlying seabed lets farms retain structural complexity over bare sediment while limiting shading where seagrass is present.

Global literature provides strong support for the NSW fish findings. In a synthesis of 65 studies, Theuerkauf *et al.* (2022), found that bivalve aquaculture is generally associated with increased abundance (median ~2x, though ranging widely from 0.05 to 473 times reference sites) and higher species richness of mobile macrofauna. Suspended culture systems, those most similar to NSW longline systems, showed the largest gains. However, the wide range in outcomes highlights a key point: while the direction of effect is positive, the magnitude is highly context dependent, varying with gear type, estuary characteristics, season and surrounding habitat.

Beyond fish, the NSW evidence base becomes thinner and more indirect. For mobile invertebrates, McLeod *et al.* (2019) found that remnant Sydney rock oyster reefs supported around five times the density, biomass and productivity of mobile macroinvertebrates compared with bare sediment, with crustaceans a major component. While this is not a direct farm-gear study, it provides a strong within-NSW analogue for the structured-habitat effect.

For birds, NSW oyster estuaries support foraging by threatened shorebirds including the Pied Oystercatcher, Sooty Oystercatcher, Beach Stone-curlew and Eastern Curlew, and OISAS notes that leases overlap intertidal foraging and roosting habitat, though no NSW farm-versus-non-farm comparisons exist. International research offers a useful reference point. A study in Delaware Bay in the US (Maslo *et al.* 2020) found that oyster farming activity around intertidal rack structures reduced the probability of shorebird presence by only 1–7%, while untended aquaculture structures had no detectable effect. The authors concluded that farm activity had little measurable effect and only resulted in modest short-term reductions in bird occurrence.

There is also emerging evidence of an indirect ecosystem benefit. In the US, Chen *et al.* (2026) found that live oysters lowered the probability of juvenile blue crabs being infected by *Hematodinium perezii*, the agent of Bitter Crab Disease in blue crabs, by 32.7%. This indicates a potential disease-regulation service that acts on mobile crustaceans through water-column filtration. A closely related parasite, *Hematodinium australis*, causes the same disease in Australian blue swimmer/sand crabs. Because the mechanism, oyster filtration of free-living, waterborne parasite spores, is general to the genus, it is plausible, that oyster farming could similarly dampen transmission where farms and blue swimmer crabs overlap in NSW estuaries.

Taken together, the evidence provides strong support for the fish and mobile-invertebrate components of this indicator in NSW. Direct measurements from working farms, using appropriate methods, align with a consistent global pattern showing increased use of aquaculture structures by mobile fauna.

Summary of key knowledge gaps:

- **Broader NSW evidence is need** - Direct farm-versus-non-farm studies of mobile-fauna abundance and diversity are lacking across NSW estuaries, gear types and seasons, particularly for invertebrates, birds and marine mammals.
- **Oyster-mediated disease regulation is untested in Australia** - Chen *et al.* (2026a) show that US oysters reduce transmission of *Hematodinium perezii* to blue crabs, and a congeneric parasite (*H. australis*) causes Bitter Crab Disease in Australian blue swimmer/sand crabs. Whether oyster filtration delivers a comparable disease-dampening service where farms and blue swimmer crabs co-occur in NSW estuaries has not been investigated.

HB 1.3.1. Abundance & diversity of infauna associated with the benthic habitat under the farmed biomass

Goal 1	Mollusc are farmed in a way that supports an abundance and diversity of associated native species.
Objective 1.3	Farming of molluscs supports an abundance and diversity of native benthic infauna
Indicator HB 1.3.1.	Abundance and diversity of infauna associated with the benthic habitat under the farmed biomass.
Metric	Abundance – Number of individuals or total mass per species / species groups. Diversity – Shannon Diversity Index, or number of species, genus, families and/or functional groups.
PARTIALLY SUPPORTED	

This indicator assesses whether benthic infauna, small sediment dwelling animals such as worms, small crustaceans and molluscs, are more or less abundant and diverse beneath NSW oyster farms compared with unfarmed areas. Two processes drive the answer: the organic matter oysters add to the seabed, and the physical disturbance of the farm itself.

The first and best-studied process is biodeposition. As they filter, oysters package fine particles into faeces and pseudofaeces that fall to the sediment, enriching it with organic matter. How the bottom-dwelling animals respond follows a long-established pattern - the *Pearson-Rosenberg Organic Enrichment Model*, restated for shellfish farms by McKindsey *et al.* (2011). At low-to-moderate levels, organic enrichment raises the abundance and variety of infauna; but too much, typically where stocking is heavy and water exchange poor, it can smother the sediment, strip its oxygen, and replace sensitive species with a few opportunistic, pollution-tolerant taxa such as capitellid polychaete worms (McKindsey *et al.* 2011).

The outcome therefore sits on a gradient set by how much organic matter arrives versus how well the system can flush and process it. Well-flushed systems tend to disperse and assimilate biodeposits, supporting productive and diverse infaunal assemblages. This positive effect is highlighted in global syntheses, which show that shellfish biodeposits can act as a food subsidy supporting diverse benthic invertebrates (van der Schatte Olivier *et al.* 2020). Conversely, poorly flushed or heavily stocked systems are more likely to experience reduced diversity and simplified community structure.

In addition to biodeposition, physical processes associated with farming can influence benthic communities. Reviewing intertidal oyster culture, Forrest *et al.* (2009) report that sedimentation rates directly beneath rack structures can be up to three times those at control sites, accompanied by localised changes in seabed elevation, and that such effects are highly localised. Routine farm activity adds to this: propeller wash, harvesting and gear maintenance physically disturb the soft sediment leading to resuspension. Both effects tend to push the community the same way as heavy organic loading - favouring the hardier opportunists. The review emphasises that the impacts are localised and minor by comparison with fish farming.

The realised state of the seabed therefore reflects a combined gradient - the total pressure from organic loading and physical disturbance together, set against the estuary's capacity to flush, dilute and recover. At the gentle end of that gradient communities are unchanged or even enriched; at the harsh end, more sensitive species give way to opportunists.

The key point is that the effect is context-dependent, and the Australian evidence is reassuring. Crawford *et al.* (2003) monitored three long-established Tasmanian shellfish farms and found no significant difference in sediment deposition, oxidation state, sulphide, organic carbon or turbidity between farmed and unfarmed areas. They concluded shellfish farming had little benthic impact. This matches NSW's dominant practice: intertidal, post-supported longlines and trays in generally well-flushed estuaries, stocked at a moderate density. These conditions sit at the low-impact end of the combined gradient where benthic communities are unchanged for even enriched.

Where oyster structure sits on or near the bottom, the evidence points to enrichment rather than harm. The one NSW-relevant dataset, McLeod *et al.* (2019), sampled under eight remnant Sydney rock oyster reefs and found infaunal productivity about twice as high under the reefs as in bare sediment, within a broader community that was roughly five times denser, heavier and more productive (crustaceans were about thirteen times more productive). Internationally, Chan *et al.* (2022) recorded 61 species (Shannon diversity 1.85) on abandoned benthic oyster farms in Hong Kong versus 26 species (1.35) on neighbouring mudflat. The caveat is that these describe oysters resting on the bottom - a strong analogue for reef-like culture rather than suspended gear.

Taken together, the available evidence suggests that effects on benthic infauna are most likely neutral to positive for off-bottom systems typical of NSW oyster farming using moderate stocking densities in generally well-flushed estuaries. Moderate organic enrichment from oyster farms can enhance food availability and support greater abundance and productivity, while hydrodynamic conditions limit excessive accumulation. The primary risk, declines in diversity and dominance by opportunistic species, appears to be associated with conditions of high organic loading, poor flushing, or significant physical disturbance, which are not characteristic of most NSW oyster farming operations.

While this points to a neutral-to-positive interpretation, there is a lack of direct, systematic measurement of infaunal abundance and diversity beneath commercial oyster farms in NSW. Further site-specific monitoring (e.g. abundance, biomass, and diversity indices such as Shannon diversity) would therefore provide valuable validation of these patterns.

Summary of key knowledge gaps:

- **No NSW infaunal data under oyster gear** - No abundance, mass or Shannon-diversity counts have been taken in sediment cores or grabs beneath NSW oyster leases, and no NSW dose-response has measured how infauna change with stocking density, gear type, estuary flushing or sediment type.

HB 1.4.1. Sediment characteristics & biogeochemistry and similarity to nearby sediment characteristics

Goal 1	Mollusc are farmed in a way that supports an abundance and diversity of associated native species.
Objective 1.4	Farming of molluscs maintains sediment characteristics and biogeochemistry comparable to or better than surrounding non-farm areas.
Indicator HB 1.4.1.	Sediment characteristics and biogeochemistry and similarity to nearby sediment characteristics
Metric	Sediment profile encompassing a range of biogeochemical characteristics (e.g. organic content, oxygen concentrations, hydrogen sulphide concentrations, ammonia).
PARTIALLY SUPPORTED	

This indicator asks whether oyster farming keeps the seabed underneath it, in a comparable condition to off-farm sites. This covers physical characteristics (grain size, settlement rate) as well as biogeochemistry (organic content, oxygen, ammonia and hydrogen sulphide).

The best-known process is biodeposition. As oysters filter water, they bundle material into faeces and pseudofaeces that settle on the seabed, adding a pulse of easily broken-down organic matter and nutrients. But the farm structures themselves also reshape the seabed, independently of oyster biology. Oyster infrastructure slows water flow, which allows fine particles like silt and clay to drop out and accumulate. Routine farming activities (e.g. harvesting, drying, maintenance), can also disturb and rework the sediment. These structural effects can be substantial, with work in NZ showing that sedimentation rates under racks can increase markedly, up to around three times higher than at unfarmed sites, shifting the seabed towards finer, siltier sediment (Forrest *et al.* 2009).

The sediment under a lease therefore responds to a combination of biological inputs, farm infrastructure, management activities and ambient environmental conditions. If the added organic matter and trapped fine sediment are dispersed and processed, the seabed can remain healthy and even become more biogeochemically active. Conversely, if the organic matter accumulates faster than it's broken down, oxygen is depleted, hydrogen sulphide builds up, and the sediment becomes over-enriched and stressed.

Globally, the evidence is consistent on direction but highly dependent on local conditions. A meta-analysis by Ray & Fulweiler (2021) shows that oyster presence increases sediment oxygen demand, ammonium and phosphate release, and denitrification compared to bare sediment — signalling nutrient cycling and biological activity in these biogeochemical “hot spots.”

Australian and international studies confirm the same enrichment pathway, with oyster farming increasing sediment organic matter through biodeposition (Domech *et al.* 2025). Whether this enrichment results in degradation or a more active seabed depends on local conditions.

For intertidal or floating systems (like those used in NSW), impacts are generally found to be minor and localised. Studies from Australia and New Zealand indicate that any effects associated with shellfish biodeposition are typically localised beneath or immediately adjacent to farming structures. Sediment changes, including increased fine particles, elevated organic matter and reduced sediment redox potential, have been shown to diminish rapidly with distance from farms in well-flushed environments (Crawford *et al.* 2003; Forrest *et al.* 2009).

Where impacts become severe is largely a function of poor water exchange. At a poorly flushed site in France, dense oyster culture turned the sediment foul, with very high levels of toxic hydrogen sulphide in the mud beneath the oysters, while a nearby well-flushed site showed almost no such effect (Andrieux-Loyer *et al.* 2014).

This context explains why the same measurements can indicate either benefit or harm. Increased oxygen demand and ammonium release beneath oyster farms can coincide with enhanced denitrification and nutrient cycling (a recognised water-quality benefit (WQ 1.1.2)), or, under high stocking densities and poor flushing, lead to hypoxia. Which outcome prevails depends largely on stocking density and water movement (McKindsey *et al.* 2011).

In NSW, only one study has looked at the seabed chemistry under a Sydney Rock oyster farm (Erler *et al.* 2017). It found slightly more organic matter beneath farms, a small increase in sediment oxygen demand, and conditions were slightly more oxygen-poor than at a nearby reference site, but only modestly so. Nitrate reduction was dominated by DNRA (see section WQ 1.1.2), while nitrous oxide production remained low and the system acted as a net N₂O sink. This points to a subtle change, not the strongly anoxic or sulfidic conditions seen in overloaded systems.

Comparable Australian work supports this interpretation. At long-established shellfish farms in Tasmania, seabed impacts were minor, localised and recovered quickly wherever flushing was good (Crawford *et al.* 2003). NSW restoration studies also show that structured Sydney rock oyster habitat can trap fine sediment while maintaining oxygenated conditions and supporting productive benthic communities (McLeod *et al.* 2019). The NSW Marine Estate Threat and Risk Assessment does not list oyster aquaculture as a major driver of sediment degradation.

Most Australian and international studies, including Erler *et al.* (2017) and Crawford *et al.* (2003), therefore suggest that low-intensity, off-bottom oyster farming in well-flushed environments keeps sediment conditions close to those of unfarmed areas, with impacts largely confined to the footprint of the gear. However, the data for NSW remains incomplete. No one has yet done a full side-by-side comparison of farmed and unfarmed seabed measuring a full suite of physical and chemical indicators. Critically, the main risk case, poorly flushed leases tipping into oxygen-starved, sulphide-rich conditions, has not been directly tested in NSW systems.

Summary of key knowledge gaps:

- **No NSW farm-verses-control sediment study** - No NSW study has measured a full physical and biogeochemical sediment profile at oyster leases alongside matched non-farm sites, and the key risk case, poorly flushed leases tipping into oxygen-starved, sulphide-rich conditions, has not been tested in the state.

HB 2.1.1. Abundance & diversity of organisms directly associated with farmed biomass and the farm site

Goal 2	Molluscs are farmed in a way that enhances the abundance or diversity of associated native species.
Objective 2.1	Farming of molluscs enhances (promotes, increases) the abundance and diversity of associated native species in comparison to nearby, similar non-farm areas.
Indicator HB 2.1.1.	Abundance & diversity of organisms directly associated with farmed biomass and the farm site.
Metric	Profile of community biodiversity (includes data on a range of characteristics, e.g. abundance, species richness, diversity, age classes, functional groupings).
WELL SUPPORTED	

This indicator sits under Goal 2 of the framework, which is about *enhancement*. The earlier “support” indicators (HB 1.1.1. Epibiota, HB 1.2.1. Mobile Fauna, HB 1.3.1. Infauna) ask a fairly simple question: do plants and animals live on or around the farm? This one asks a harder question: does the farm carry **more** abundance and diversity than a similar patch of estuary with no farm on it? This requires paired farm vs. non-farm comparisons to show a net positive difference.

For NSW this indicator is anchored by a study built around exactly that comparison. Martínez-Baena *et al.* (2022) deployed remote underwater video at commercial oyster leases in Port Stephens and filmed the fish communities of post-and-rail and intertidal, post-supported longline alongside four adjacent non-farm habitats, remnant oyster reef, seagrass, mangrove and bare sediment. Across 510 deployments (587 hours of footage) they recorded 90 fish species from 51 families. Both farm types supported at least as many fish species as the natural biogenic habitats they sit within, and far more than bare sediment. The farms also drew in commercially valuable fish usually tied to wild oyster reefs, and the fish used the gear to feed and shelter just as they would use natural structure. Read against this indicator, the result is a qualified 'yes': the farm enhances the fish community relative to the soft-sediment matrix that dominates the estuaries where leases sit, while roughly matching biogenic habitat.

This distinction is the crux of an enhancement assessment. Less than 5% of aquaculture leases in NSW have dense seagrass (NSW DPIRD, pers. comm), and therefore the realistic alternative to a farm is bare soft sediment. Measured against that baseline, the boost is large and consistent. McLeod *et al.* (2019) found remnant Sydney Rock oyster reef carried roughly five times the density, biomass and productivity of mobile macroinvertebrates of bare sediment, and in Hong Kong, Chan *et al.* (2022) recorded 61 macrobenthic species on abandoned oyster-farm habitat versus 26 on the surrounding mudflat. In South Australia, Martin *et al.* (2025) found introduced Pacific oyster habitat supported about double the invertebrate richness and eight times the invertebrate biomass of comparison habitats, with greater fish richness, abundance and foraging and a clear preference by fisheries-targeted black bream.

Where aquaculture overlaps with high-value habitats such as seagrass or natural reef, however, the expectation of straightforward enhancement no longer applies. In these cases, the evidence tends to show comparable ecological values rather than clear gains, and assessment shifts to evaluating trade-offs between habitat types. For example, the assessment then weighs the potential for post-and-rail with trays to shade underlying seagrass, rather than measuring a simple net biodiversity increase.

The wider literature backs up the NSW picture. The global meta-analysis of Theuerkauf *et al.* (2022) pooled 65 farm-versus-reference studies worldwide. On average, farms held about 1.95 times the abundance and 1.14 times the species richness of reference sites, with suspended and elevated oyster and mussel systems - the closest match to NSW's post-supported longline culture - showing the biggest gains. The ranges are however wide and sometimes dip below the reference (abundance ran from 0.05x to 473x; richness from 0.68x to 4.3x). Hence, enhancement is the average result, not a guarantee: a minority of farm-reference pairs show no difference or a deficit, and the direction is context-dependent on gear, estuary, season and the surrounding habitat. Barrett *et al.* (2022) translate the central tendency into a fisheries-relevant figure, an estimated extra 348–1,110 kg of fish per hectare per year relative to reference habitats but explicitly flag that this assumes equal mortality at farms and natural habitats.

That assumption points to the principal caveat for any enhancement claim: attraction versus 'real' production. Elevated abundance at the farm may reflect genuine added production, or merely the redistribution of mobile animals that would otherwise occupy nearby habitat. No NSW study has yet partitioned the two for oyster farms. For this indicator, that means the increases in abundance and species richness at farm structures are robust, but the inference that this translates to a net increase in populations at the estuary scale remains untested.

Summary of key knowledge gaps:

- **No complete NSW community profile** - No NSW study has measured the full community profile the indicator asks for - abundance, richness, diversity, age classes and functional groups, in a matched farm-versus-non-farm comparison.
- **Attraction vs. production** – Comparative abundance at the gear has not been partitioned into net production versus redistribution, so 'enhancement of the estuary' remains inferred rather than measured. Martínez-Baena *et al* (2022) outlines the methods needed to resolve this question.

HB 2.2.1. Species using & extent of spawning or recruitment at the farm site.

Goal 2	Molluscs are farmed in a way that enhances the abundance or diversity of associated native species.
Objective 2.2	Farming of molluscs enhances the abundance of associated native fauna (fish, invertebrates or algae) by supporting spawning or recruitment.
Indicator HB 2.2.1.	Species using & extent of spawning or recruitment at the farm site.
Metric	Presence of spawning or recruitment of fauna or algae.
PARTIALLY SUPPORTED	

This indicator asks whether the farm actively supports two early life processes – spawning and recruitment.

The clearest place to start is with the oyster itself, because NSW has an enormous, directly measured recruitment signal hiding in plain sight: the wild spat catch. The Sydney rock oyster is native to NSW, and the industry still runs mostly on wild-caught spat. Growers put out tens of thousands of catching slats each year, timed to the natural spawning and settlement pulse from February onwards. An estimated 85-90% of production comes from larvae that settle naturally onto this gear rather than from hatcheries (NSW DPIRD 2024b). Scaled against the annual Sydney rock oyster harvest, it's estimated that 70-75 million Sydney rock oysters recruit from the wild onto farm structures each year. The spawning side is just as concrete: a single female Sydney rock oyster is capable of releasing approximately 10-60 million eggs per spawning event (O'Connor *et al.* 2008). Hence, both processes the indicator names, spawning in the estuary and recruitment onto farm gear, demonstrably happen at the farm scale, for a native species, in very large numbers.

The qualifier is that this is the farmed species itself and therefore sits on the boundary with indicator 3.1.1. (farmed larvae supporting wild populations), and on its own doesn't tell us whether the wider community of associated animals and plants - the fish, other invertebrates and algae the indicator is really aimed at - is also spawning and recruiting at farms. That broader question is where the evidence starts to thin out.

Oyster spat is not the only thing settling on the gear. In otherwise bare, muddy substrate, the same hard surfaces provide somewhere to settle for barnacles, tube worms, bryozoans, sponges, ascidians and seaweeds. The mechanism is set out in detail under HB. 1.1.1. An important practical caveat, however, is that growers actively work against this. Fouling organisms compete with the crop, add weight and drag to infrastructure and downgrade product quality, so growers deliberately suppress them through routine husbandry such as air-drying, and heat treatment, with these biofouling control methods currently being optimised through a Fighting Food Waste / FRDC project (Cawthorn *et al.* 2026). Such management is undertaken to protect the structural integrity of the farming gear and the quality of the product.

For associated fish, the strongest NSW evidence is about nursery function (recruitment). Martínez-Baena *et al.* (2022) showed that post-and-rail and post-supported intertidal longline

leases in Port Stephens host fish assemblages at least as rich as nearby reef, seagrass and mangrove, confirming that farm infrastructure is used by the same fauna pool that recruits to natural estuarine nurseries. Fish use was functional rather than incidental: 84 species were seen actively moving through the gear and 40 were recorded feeding, but no spawning was observed.

More directly on recruitment, Pine *et al.* (2022) filmed juvenile Eastern Blue Groper (*Achoerodus viridis*), the NSW state marine emblem, on remnant Sydney rock oyster reefs in NSW. Juveniles appeared in 29.8% of summer videos overall (up to 56–65% at Crookhaven and Bermagui), direct evidence that Sydney rock oyster biogenic structures function as recruitment / nursery habitat for an iconic NSW reef fish. The caveat is that this was measured on remnant reef, not on commercial farming gear. The transfer to leases is reasonable (same species, same structural mechanism) but not yet demonstrated on farms.

The proxy studies that best match the framework's recommended methods are encouraging. Underwood & Jeffs (2023) deployed SMURFs, the recruitment collectors the framework names, in New Zealand mussel farms and adjacent natural habitats, catching 730 fish of 9 species, with recruitment to the farms broadly similar to natural reef and soft sediment. In the US, Mercaldo-Allen *et al.* (2021) describe eastern-oyster cages as a possible “focal habitat for courtship and mating activity,” and observed newly-settled young-of-year black sea bass and scup at the cages. Veggerby *et al.* (2024) found shellfish aquaculture farms in Washington State (US) functioned as foraging habitat for a range of nearshore fishes and crabs.

Taken together, the evidence supports a measured conclusion. Sydney rock oysters demonstrably spawn in NSW estuaries and recruit onto farm gear in very large, well-quantified numbers. Sydney rock oyster farms almost certainly provide a nursery and recruitment function for at least some associated fish and invertebrates, consistent with strong NSW reef data and method-matched overseas proxies; algal and invertebrate settlement on shell / gear is mechanistically expected, even though growers suppress it in practice. What is still missing is direct measurement of spawning and recruitment for the wider associated community. Spawning by associated fauna is only hinted at, and only from overseas courtship behaviour; direct observation of fish spawning on NSW farm infrastructure has not been recorded and remains a specific research need.

Summary of key knowledge gaps:

- **No direct NSW measurement of spawning or recruitment by associated fauna** – No NSW oyster-farm study has measured spawning or recruitment of associated fish, invertebrates or algae. The nursery/recruitment role is inferred from reef data and overseas proxies rather than measured on NSW farms, and spawning by associated fauna is essentially unmeasured anywhere, hinted at only from overseas courtship footage (Mercaldo-Allen *et al.* 2021).

HB 3.1.1. Abundance of larvae or recruits released from farm stock

Goal 3	Molluscs are farmed in a way that can support native wild populations that have declined or are under stress.
Objective 3.1	Where native species populations have declined or are at risk of decline, larvae from farming these species increases larval abundance and recruitment in local wild populations, with stock that has an appropriate genetic structure (i.e. supports diversity in wild populations or supports effective restoration through stock with higher thermal tolerances for climate change resilience).
Indicator HB 3.1.1.	Abundance of larvae or recruits released from farm stock.
Metric	Detection of spawning and recruitment of farmed stock in wild populations.
PARTIALLY SUPPORTED	

Goal 3 is about restoration. Where a native species has declined, larvae spawned by farmed stock should measurably boost larval supply and recruitment in the surrounding wild population, using stock of appropriate genetic structure. The required evidence is not that the species recruits in the estuary generally, but that larvae or recruits of farm origin can be detected in the wild. No such study has been conducted for any oyster species in NSW, so the indicator is therefore a data gap. The surrounding context, however, is supportive of the underlying mechanism for the Sydney rock oyster.

NSW's natural oyster reefs have all but disappeared. Studies estimate that less than 1% of Native oyster (*Ostrea angasi*) and 8% of Sydney rock oyster (*Saccostrea glomerata*) reefs remain (Gillies *et al.* 2018). The ecosystem is considered functionally extinct and is recognised on the IUCN Red List of Ecosystems (Ogburn *et al.* 2007; Gillies *et al.* 2018; Dove *et al.* 2025). This is the "declined population" situation Goal 3 is written for.

Farmed SRO are predominantly fertile diploids and are prolific broadcast spawners, with a single female releasing 10–60 million eggs per spawning event (O'Connor *et al.* 2008), with larvae drifting in the plankton for three to four weeks. Genetic work shows the eastern-Australian population functions as a single, well-connected group, its gene flow following the East Australian Current, and with no sign of genetic bottlenecks (O'Hare *et al.* 2021). Crucially, around 85–90% of the spat that stocks NSW farms is still captured from natural settlement (NSW DPIRD 2024b). This is direct, industry-scale evidence that abundant larval supply and wild recruitment occur in exactly the estuaries where farming takes place. It's therefore undeniable that the standing biomass of farmed stock adds to the larval pool.

There is also unambiguous proof that farm-origin oyster larvae can recruit into the NSW environment, although it is not a positive story. Following the introduction of diploid Pacific oysters to Port Stephens in the mid-1980s, escapees from cultivation established self-recruiting feral populations that are now endemic in NSW estuaries south of and including the Hastings River (NSW DPIRD 2021). This shows the disperse-and-recruit mechanism plainly works, but for an invasive species, so it is a biosecurity problem to be managed rather than the native benefit Goal 3 seeks. It is largely to contain this risk that about 95% of NSW Pacific oyster

production is sterile triploid stock (bred with an extra chromosome set so they cannot reproduce), which by design releases no viable larvae (NSW DPIRD 2026).

Goal 3 also asks for stock of "appropriate genetic structure," and here NSW actually has direct evidence, although it complicates the simple enhancement story. The NSW Sydney rock oyster breeding program produces fertile lines selected for QX-disease resistance and, more recently, for resilience to ocean acidification and warming (Parker *et al.* 2024). These lines are now being trialled in oyster reef restoration, the most direct expression of Goal 3. It is tempting to assume their beneficial traits will flow into wild populations, but the one study to test this found the opposite: after roughly 30 years of selectively-bred oysters being farmed in the Georges River, wild and farmed populations remained strongly genetically distinct, with no detectable gene flow between them (Thompson *et al.* 2017). That same study found the bred line carried higher genetic diversity than the wild population, so the loss-of-diversity and domestication concerns raised by some overseas oyster studies (Sutherland *et al.* 2020; Hornick & Plough 2019) are not evident here. The broader question stays open. In the US, farm genes have been shown to cross into wild eastern oysters at low levels (Chen *et al.* 2026b), yet the NSW evidence so far points to farmed and wild Sydney rock oysters staying separate rather than mixing.

In short, the mechanism is real and the connectivity context is strong, and the methods to measure it exist. The strongest demonstration is in New Zealand green-lipped mussels, where Norrie *et al.* (2020) combined trace-element fingerprinting of larval shells with biophysical modelling and found a well-mixed larval pool, with larvae from aquaculture sites capable of settling throughout the study area. For oysters the technique is less advanced. Hintz *et al.* (2025) separated three regions of Puget Sound by larval shell chemistry with around 75% accuracy, but could not assign settlers of unknown origin back to a source, leaving it a proof of concept. Applying it in NSW would mean building a reference library of estuary signatures first.

That library would have a second use. Trace-element fingerprinting has separated cockles harvested from sites less than a kilometre apart with 92% accuracy, which its authors propose as a tool for seafood traceability and fraud detection (Ricardo *et al.* 2015). The signature is laid into the shell as it grows, so it records the water an oyster has lived in. Stock relayed between estuaries carries a signature from each, making it a record of where an oyster has been rather than a single point of origin or harvest.

Summary of key knowledge gaps:

- **No direct measurement of oyster farm contribution to wild stocks** – Farm-origin larvae and recruits have never been traced in NSW (no local trace-element reference library exists), so how much farmed stock adds to wild populations is unknown. That library would also underpin provenance claims for NSW oysters.
- **Genetic evidence is limited to one line and estuary** - The only farmed-versus-wild Sydney rock oyster genetic comparison (Thompson *et al.* 2017) covered a single breeding line in one estuary and found no gene flow to the wild. It has not been repeated for the newer climate-resilient lines now entering restoration, or across other estuaries.

Climate Change Indicators (CC) Indicators

CC 1.1.1. Cradle to grave GHG emissions

Goal 1	Mollusc farming occurs in a way that can support mitigation of CO ₂ by providing a comparatively low or net neutral GHG emissions product
Objective 1.1	Farmed molluscs are produced with fewer GHG emissions than similar products (e.g. other seafood) produced in comparable systems and geographies, and emissions continue to decrease over time.
Indicator CC 1.1.1.	Cradle to grave GHG emissions
Metric	Life Cycle Analysis (LCA) impact indicators of Global Warming Potential or Climate Change (kg CO ₂ equivalent)
WELL SUPPORTED	

This indicator measures the greenhouse gas emissions required to produce one kilogram of oysters, expressed as kilograms of CO₂ equivalent (CO₂e). For NSW, this is supported by direct data. A statewide industry audit undertaken by NSW Farmers in 2025 found emissions of just 0.93 kg CO₂e per kg of oysters, placing them among the lowest of any animal protein. On that basis, the indicator is rated as being well supported.

Oysters achieve such a low footprint for a simple reason: they are not fed. In contrast to fish, poultry and livestock, where a large share of emissions comes from growing and processing feed, oysters obtain their food directly from the water column. This removes an entire emissions source. As a result, the remaining footprint is largely driven by energy use, particularly fuel. In the NSW audit, more than three-quarters of total emissions came from fuel combustion: petrol outboards (42%) and diesel (34%). Purchased electricity contributed 19%, and transport to market just 2% (Table 9).

	Scope 1			Scope 2	Scope 3	Total
	Unleaded	Diesel	LPG	Purchased electricity	3 rd party transport to markets	
kg CO ₂ e per kg of oysters harvested	0.39	0.32	0.02	0.18	0.02	0.93
% of emissions	42%	34%	2%	19%	2%	99%

Table 9. Average greenhouse gas emissions by source (NSW Farmers 2025). Percentages do not sum to 100% due to rounding.

Because oyster farming involves a fixed set of activities (tending leases, drying, grading) regardless of output, higher production spreads these emissions across more product. As a result, across the audit, results ranged from 0.09 to 5.52 kg CO₂e per kg, demonstrating the strong influence of scale of production and efficiency.

The NSW result can be compared with other Australian marine proteins. In 2022, Blueshift Consulting assessed carbon emissions across a range of Australian fishing and aquaculture sectors. The NSW Farmers (2025) result is compared with those figures, as shown in Figure 21.

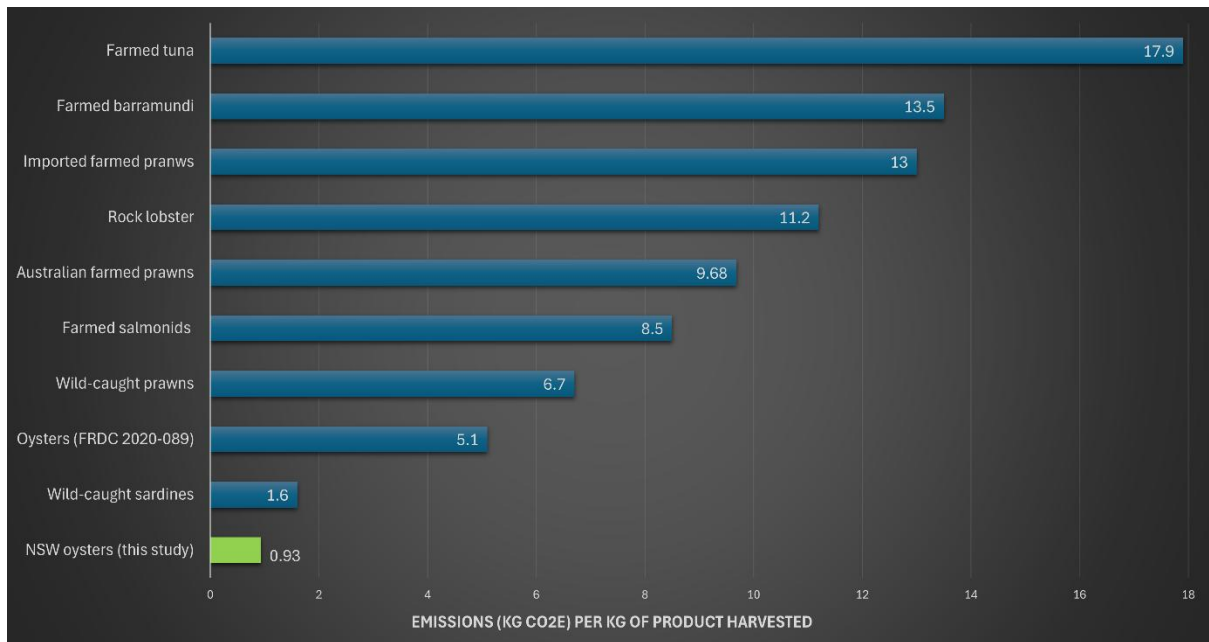


Figure 21. Greenhouse gas emissions per kilogram of product harvested for different Australian marine proteins (Blueshift Consulting 2022; NSW Farmers 2025).

On a per-protein basis, emissions rise to 3.75 kg CO₂e per 100 g of protein, similar to eggs and tofu. This reflects the fact that much of an oyster's total weight is shell rather than edible product (Figure 22). Either way, oysters clearly pass the indicator's test of producing fewer emissions than comparable foods.

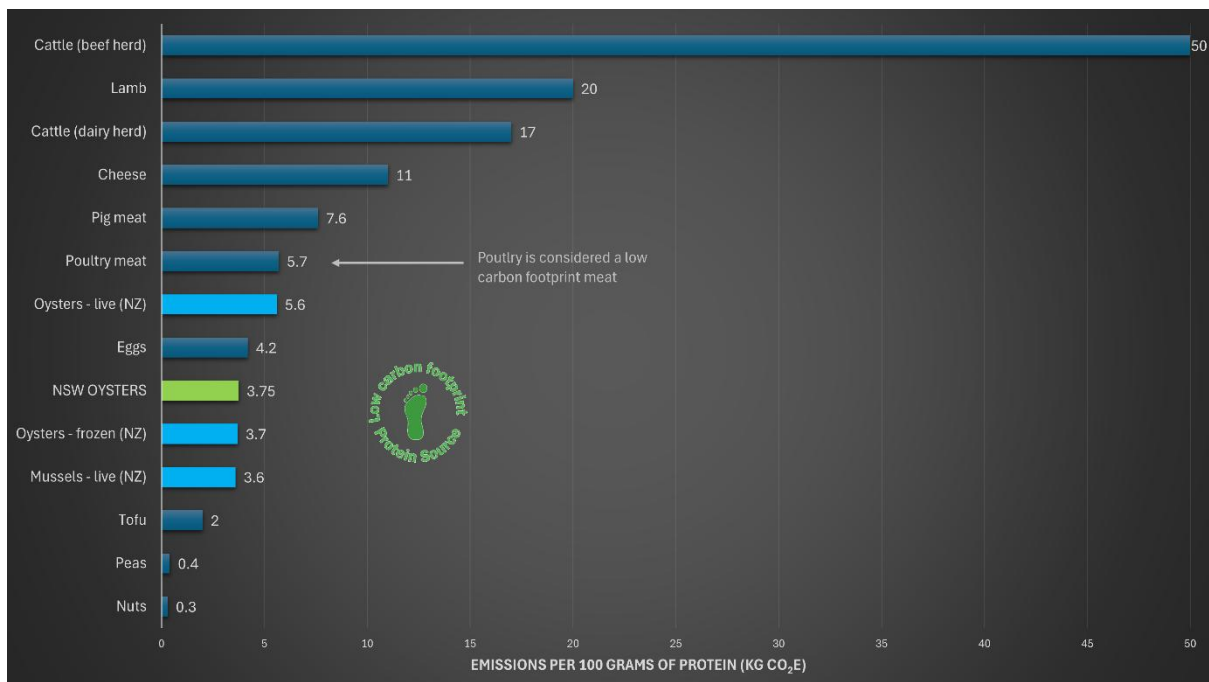


Figure 22. Carbon emissions per 100g of protein across common farmed foods (NSW Farmers 2025).

The footprint is also small enough to offset cheaply. Neutralising the entire NSW oyster industry's emissions with carbon credits would cost less than A\$100,000 per year, equivalent to around A\$370 per farm, or approximately 1.5 cents per dozen oysters.

The NSW findings are consistent with international evidence for this style of aquaculture. An Irish life cycle assessment of Pacific oysters (Domech *et al.* 2025) reported 0.37 kg CO₂e per kg, with electricity use almost identical to NSW (0.20 vs 0.18 kg CO₂e per kg). Similarly, a New Zealand study (Thinkstep 2021) found farmed oysters and mussels to have lower emissions per 100 g of protein than any other animal protein.

There are, however, two key caveats. First, the NSW audit is a “farmgate to first receiver” assessment rather than a full cradle-to-grave analysis. It excludes hatchery inputs, equipment manufacture, and downstream consumer stages. These are considered minor but remain unquantified. Second, the results cover a single year, one greatly affected by flooding and below-average harvests, which would have inflated standardised emissions.

A longer-term trend is not yet available to show whether emissions are falling over time, and the picture pulls in two directions. The growing uptake of solar and battery systems and the continued evolution of electric and hybrid outboards should push emissions down; but increasing on-farm technology and mechanisation will tend to push energy use up.

Looking ahead, the pathway to further reductions is clear. The NSW Farmers (2025) audit identifies practical measures such as shed-roof solar (with an estimated three-year payback), battery storage, and the transition to electric or hydrogen outboards, targeting the dominant fuel-related emissions. Repeating the audit over time will be critical to track progress and demonstrate a sustained downward trend.

Summary of key knowledge gaps:

- **Hatchery emissions data** – No greenhouse-gas data exist for Australian shellfish hatcheries, yet these are needed to extend the NSW footprint toward a full cradle-to-grave assessment.
- **Multi-year audits** – Repeat audits across several years are needed so the distortions of floods and other natural disasters average out, giving a representative long-run emissions figure and revealing the trend over time.

CC 2.1.1. Quantity of shell, pearls, and other materials directed toward appropriate storage or disposal pathways

Goal 2	Mollusc farming enhances carbon cycling in the water and shells, pearls, and other hard materials with a long-life span are directed toward circular solutions for carbon management.
Objective 2.1	Farmed shell, pearls and other materials retain more carbon that is respired by bivalves during farming.
Indicator CC 2.1.1.	Quantity of shell, pearls, and other materials directed toward appropriate storage or disposal pathways
Metric	Quantity of carbon (kg) assimilated and retained in farmed biomass
PARTIALLY SUPPORTED	

This indicator asks two things: how much carbon is stored in oyster shell, and whether that storage delivers a real climate benefit. The answers diverge. The carbon itself is measurable, and NSW has already done that work, so the inventory side is solid. But the climate value of shell storage is still contested, with major papers reaching opposite conclusions within a year of each other. The most appropriate rating is therefore Partially Supported: the carbon pool is real and well-quantified, but its overall climate benefit is unresolved.

Take the accounting first. Oyster shell is ~92% calcium carbonate (de Roover 2024), so 1kg of shell is 920g CaCO₃. By weight about 12% of calcium carbonate is carbon, so each kilogram of shell holds roughly 110 g of carbon (~0.40 kg CO₂ on a simple conversion basis). Applying this to the NSW Farmers carbon audit (2025), the NSW oyster industry landed 2,175,228 kg of shell across the 22/23 production year, which would have contained about 237 tonnes of carbon, or roughly 870 tonnes of CO₂ on paper. This is exactly what the framework asks for, carbon content multiplied by harvested biomass.

The complication is chemistry. Calcification, the building of shell, sees oysters take up calcium and bicarbonate ions to form calcium carbonate.



If the carbon sequestered into the shell originated from rapidly cycled carbon pools (such as atmospheric CO₂), there would be a strong case that shell carbon could be considered a carbon sink. Unfortunately, however, this is not the case. Pernet *et al.* (2025) claims that the carbon trapped in shell originates from the bicarbonate ions, which are predominantly formed by the chemical weathering of sediments and rocks over tens of thousands of years. Therefore, incorporating this carbon into shell does not prompt short-term CO₂ compensation. Indeed, Pernet *et al.* (2025), goes on to calculate that only 6% of the bicarbonate pool available to bivalves originate from anthropogenic CO₂.

The equation above also reveals that carbon dioxide is released as a by-product of shell biomineralisation. This release of CO₂ serves to increase the partial pressure of carbon dioxide (pCO₂) in the water, which in turn slows the movement of CO₂ from the atmosphere into the ocean.

Oysters also release carbon throughout their lives, through respiration and shell erosion (Figure 23), although respiration is generally not counted as an emission in carbon footprint accounting.

There is a research gap concerning the quantitative flow of carbon in relation to oysters in NSW however work elsewhere suggests that once respiration is included, oysters can release more CO₂ than they store (Han *et al.* 2017), and a New Zealand life-cycle assessment found shellfish release about 0.29 kg CO₂ for every kilogram of shell formed (Thinkstep 2021).

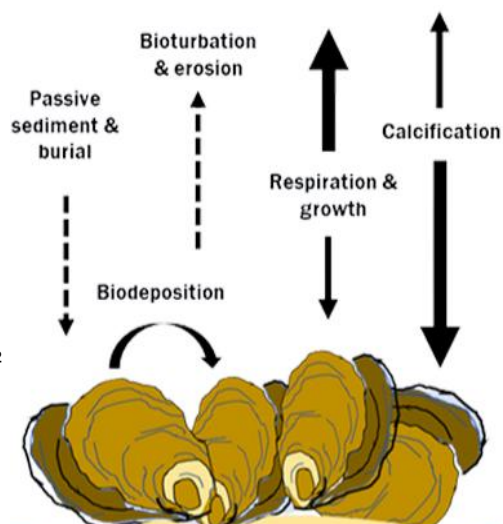


Figure 23. Movement of carbon, showing deposition (downward arrows) and release (upward arrows). (Fodrie *et al.* 2017).

That is not the end of the story, and it is why the debate is still live. Chen *et al.* (2025) argues that at the farm scale, filter-feeding redirects substantial carbon into organic pathways, particles, dissolved pools, and sediment burial, well beyond what ends up in shells. In their experiment, the organic-carbon pathway captured ~2.4x more carbon than shell, with sediment organic carbon alone contributing more than half, and the system shifted toward net CO₂ uptake. They describe oyster farming as a carbon-removal “hotspot.” But this was a short (120-day) tank study on Pacific oysters at moderate stocking density, not field-validated, and it drew a formal rebuttal the following year (Pernet *et al.* 2026) arguing it does not establish oyster farming as a removal strategy. Other studies also split: Domech *et al.* (2025) treat shell as a short- to medium-term store, while Fodrie *et al.* (2017) show reefs can be net sinks or sources depending on tidal position. In short, the scientific community does not agree.

For NSW, the important point is that this has already been handled carefully. The NSW oyster carbon-footprint assessment (NSW Farmers 2025) calculated shell carbon, then deliberately excluded it from the headline footprint, citing Pernet *et al.* (2025). The distinction is clear: shell is a carbon store, but not necessarily a CO₂ removal mechanism, and claiming it as a sink would be premature without direct measurements of carbon fluxes in NSW estuaries. The assessment shows transparently that including shell would reduce the footprint by about a third (0.93 to 0.62 kg CO₂ per kg of oysters) but also flags the accounting trade-off: if shell is credited as a sink, the associated dissolution emissions must be carried somewhere in the ledger. That is a more rigorous treatment than most jurisdictions, and it supports a cautious NSW position—lead with the genuinely low-emissions production story (CC 1.1.1), and keep shell carbon as a separate, clearly labelled inventory item rather than a sequestration claim until the science settles.

Summary of key knowledge gaps:

- **Sink vs source remains unresolved (Chen vs Pernet)** - There are no in-situ measurements of CO₂ flux, alkalinity, or dissolved carbon on NSW leases, so whether oyster farming is a net sink or source cannot yet be determined locally.

CC 3.1.1. Wave attenuation or decay across the footprint of farming infrastructure and stock

Goal 3	Nearshore mollusc farms support broader efforts to reduce the threat of coastal erosion and storm damage
Objective 3.1	Mollusc farms contribute to reducing wave energy and coastal erosion during severe weather events.
Indicator CC 3.1.1.	Wave attenuation or decay across the footprint of farming infrastructure and stock
Metric	Wave decay coefficients (k_D)
PARTIALLY SUPPORTED	

This indicator measures the potential coastal protection benefit provided by oyster farming. The underlying premise is that the physical structure of a nearshore farm, both the cultivation infrastructure and the standing crop, increases hydraulic roughness and drag within the water column, dissipating wave energy and reducing the amount that reaches the shoreline behind the farm. The metric is the wave decay coefficient, which describes the rate at which wave height, energy or amplitude decreases as a wave moves across an area.

The wave attenuation mechanism itself is well established, although the strongest evidence currently comes from oyster reefs rather than commercial oyster farms. Oyster reefs function as low, permeable breakwaters, reducing wave energy before it reaches the shore. For example, a natural oyster reef in Texas was found to attenuate wave heights by approximately 77% (Lunt *et al.* 2017), while Grabowski *et al.* (2012) found shoreline protection to be among the largest economic benefits of oyster reef restoration.

Closer to home, UNSW Water Research Laboratory undertook physical modelling of living Sydney rock oyster clumps and oyster-shell-filled coir-mesh bags designed to reduce foreshore erosion from boat wake and wind-generated waves in Sydney estuaries. These structures reduced wave heights by anything from negligible amounts up to around 85%, with the highest attenuation achieved by shallow, emergent and multi-tiered structures. Performance declined as the structures became increasingly submerged under deeper water conditions (Coghlan *et al.* 2016; Howe *et al.* 2019). These studies confirm that oyster-based structures can effectively attenuate wave energy in NSW estuaries, while also highlighting a key principle: attenuation depends on how much of the structure remains within the active wave zone.

Direct evidence from commercial oyster farms is much more limited and suggests that attenuation benefits are highly dependent on infrastructure type and tidal stage. At an oyster farm in New Jersey, wave energy behind floating-bag and bottom-cage systems was reduced by about 75% at low tide but showed no measurable reduction at high tide. The authors described shoreline protection as perhaps the most poorly studied ecosystem service associated with oyster farming and emphasised the need for field data (Munroe *et al.* 2026).

This high tide result matters because foreshore and bank erosion is largely a high-water process. At high tide, waves can directly reach and scour erodible banks, whereas at low tide much of their energy is dissipated across mudflats or stands of mangroves. A farming system

that attenuates wave energy only at low tide may therefore contribute relatively little to shoreline protection.

Two aspects of NSW estuaries nonetheless work in the industry's favour. First, most oyster-producing estuaries in NSW are barrier estuaries, coastal lagoons and drowned river valleys with relatively limited fetch. Consequently, the waves responsible for much of the local foreshore erosion are typically short-period wind waves and vessel wake rather than long-period ocean swell. This is important because modelling by Zhu *et al.* (2020) shows that suspended and floating aquaculture are particularly effective at attenuating shorter-period, higher-frequency waves - the same wave types that dominate many NSW estuaries.

Second, there are reasons to expect different oyster farming systems to behave differently across the tide. Zhu *et al.* (2020) modelled suspended and floating aquaculture and found that these structures are less sensitive to changing water levels than submerged structures because they remain within the active wave field as water depth increases. The implication is that floating longline systems, which rise and fall with the tide and remain on the water surface where wave energy is concentrated, may continue attenuating waves during high tide, storm surge and sea-level-rise conditions.

By contrast, intertidal suspended systems become progressively more submerged as the tide rises. In principle, this may reduce their attenuation capacity in a similar way to the oyster-based living shoreline structures tested by UNSW WRL, where performance declined as water depth increased (Coghlan *et al.* 2016; Howe *et al.* 2019). Whether this occurs in practice for commercial oyster infrastructure has not been tested.

For NSW oyster farming specifically, there are currently no measurements of wave attenuation associated with commercial leases. Nevertheless, some growers deliberately deploy robust floating longline systems, such as FlipFarm infrastructure, along the exposed outer margins of a lease to reduce wave and flow energy reaching infrastructure further inshore. This represents a practical, on-farm application of wave-energy management, although it is aimed at protecting farming infrastructure rather than a quantified shoreline-protection service.

Taken together, the evidence supports the possibility of coastal-protection benefits: reefs, reef-style living shorelines and modelling of intertidal aquaculture all show mechanisms capable of dissipating wave energy (Coghlan *et al.* 2016; Howe *et al.* 2019; Zhu *et al.* 2020). The question is no longer whether attenuation can occur, but how much commercial NSW farms deliver and whether it reduces foreshore erosion.

Summary of key knowledge gaps:

- **No NSW oyster farm wave attenuation data exists** - No wave decay coefficients or transmission coefficients have been measured at commercial leases, and attenuation has not been quantified by farming configuration (e.g. floating longlines versus intertidal suspended systems) or tidal stage. As a result, it remains unclear how much wave attenuation NSW oyster farms provide, how performance varies across the tidal cycle, or which farming systems deliver the greatest effect.

Summary of Indicator Status

The evidence review found that NSW oyster aquaculture has a strong scientific foundation for demonstrating restorative outcomes. Of the 16 MEL indicators assessed, 6 were classified as Well Supported, 10 were Partially Supported, and none were unsupported. Overall, the strongest evidence relates to water filtration, nutrient bioextraction, biodiversity enhancement and greenhouse gas performance, while the principal knowledge gaps relate to denitrification, sediment processes, recruitment dynamics and wave attenuation.

Water Quality Indicators

Indicator	Status	Evidence Summary
WQ 1.1.1. Quantity of N & P assimilated & extracted	Well Supported	Strong NSW-specific evidence demonstrates that oyster harvest permanently removes nitrogen and phosphorus from estuaries through bioextraction. Current estimates indicate removal of approximately 15.8 tonnes N and 2.0 tonnes P annually, providing one of the clearest and most quantifiable restorative benefits delivered by the industry.
WQ 1.1.2. Rate of denitrification	Partially Supported	International studies consistently demonstrate enhanced nitrogen processing around shellfish habitats; however, denitrification has been measured only once in NSW and results suggested nitrogen retention through DNRA rather than removal. Further NSW research is required before the scale of this benefit can be confidently quantified.
WQ 1.2.1. Dissolved oxygen concentration	Partially Supported	Multiple lines of evidence suggest oyster filtration supports healthy oxygen dynamics by reducing phytoplankton biomass and improving water clarity. However, farm-scale monitoring capable of isolating oyster aquaculture effects from broader estuary processes has not yet been undertaken.
WQ 1.3.1. Rate of water filtration	Well Supported	Filtration is the primary mechanism through which oyster aquaculture delivers water-quality benefits. Individual Sydney rock oysters filter around 3 L/hr and Pacific oysters 5–8 L/hr, resulting in an estimated industry-wide filtration capacity of approximately 2 trillion litres annually. This provides strong evidence that the industry delivers ecosystem-scale filtration services.
WQ 2.1.1. Chlorophyll a concentration	Partially Supported	The biological mechanism is well established, and international studies demonstrate reductions in phytoplankton biomass around shellfish farms. However, no NSW farm-versus-control studies have directly quantified chlorophyll reductions under local conditions.
WQ 2.1.2. Microorganism & plankton communities	Partially Supported	NSW possesses extensive phytoplankton monitoring datasets and strong analytical capability. While oyster filtration is expected to influence plankton composition, direct evidence of community-level changes attributable to farming remains unavailable.

Habitat & Biodiversity Indicators

Indicator	Status	Evidence Summary
HB 1.1.1. Epibiota abundance & diversity	Well Supported	Oyster infrastructure creates extensive hard substrate that supports diverse fouling communities and associated invertebrates. While the exact magnitude varies with husbandry practices, evidence consistently shows farms increase habitat availability in structurally simplified estuaries.
HB 1.2.1. Mobile fauna abundance & diversity	Well Supported	Direct NSW research confirms oyster farms function as important fish habitat. Studies recorded 90 fish species associated with farm infrastructure, with biodiversity values comparable to natural reefs, mangroves and seagrass habitats.
HB 1.3.1. Infauna abundance & diversity	Partially Supported	Available evidence suggests oyster farming generally supports neutral-to-positive benthic outcomes in well-flushed estuaries. However, comprehensive NSW datasets comparing farm and non-farm sediments are limited.
HB 1.4.1. Sediment characteristics & biogeochemistry	Partially Supported	Existing studies indicate sediment effects are generally localised and minor under typical NSW farming conditions. Nevertheless, a complete assessment of sediment health indicators across multiple estuaries has not yet been undertaken.
HB 2.1.1. Enhancement relative to non- farm areas	Well Supported	Strong evidence demonstrates that oyster farms support substantially greater biodiversity than adjacent soft-sediment habitats and perform similarly to many natural structured habitats. This is one of the strongest biodiversity findings in the assessment.
HB 2.2.1. Spawning & recruitment at farm sites	Partially Supported	Oyster recruitment onto farm infrastructure is well documented, particularly for Sydney rock oysters. However, the extent to which farms enhance recruitment of broader fish and invertebrate communities remains largely unquantified.
HB 3.1.1. Larval contribution to wild populations	Partially Supported	Farmed Sydney rock oysters spawn prolifically, but no NSW study has traced how much farm-origin larvae contribute to wild populations. The only genetic comparison found farmed and wild oysters remained genetically distinct after ~30 years, with no detectable gene flow, so both the magnitude of any larval contribution and its genetic appropriateness remain to be established.

Climate Change Indicators

Indicator	Status	Evidence Summary
CC 1.1.1. Cradle-to-grave GHG emissions	Well Supported	NSW oyster aquaculture has one of the lowest greenhouse gas footprints of any animal protein system (approximately 0.93 kg CO ₂ e / kg product). The industry's climate value is therefore strongly supported as a low-emissions food production sector.
CC 2.1.1. Carbon retained in shell & biomass	Partially Supported	Carbon stored within oyster shells can be quantified, but whether shell formation provides a net climate-change mitigation benefit remains scientifically contested. Current evidence supports accounting for shell carbon, but not claiming atmospheric CO ₂ reduction.
CC 3.1.1. Wave attenuation & coastal protection	Partially Supported	International studies and analogue oyster-reef research demonstrate clear potential for wave attenuation and coastal protection benefits. However, these services have not yet been directly measured at commercial NSW oyster farms.

Key Knowledge Gaps and Future Research Priorities

Across the indicators, the principal knowledge gaps are not whether benefits occur, but rather quantifying their magnitude, variability and ecological significance under NSW conditions. The six priority areas that follow are presented by theme, not in order of importance.

1. Nitrogen Cycling & Denitrification

While nutrient removal through harvest is well quantified, less is known about nutrients once deposited beneath farms. International evidence suggests oyster farms can enhance denitrification and permanently remove nitrogen from estuaries, yet the only NSW study found nitrogen processing was dominated by DNRA, a pathway that retains nitrogen within the ecosystem. Additional research across multiple estuaries and seasons is needed to determine under what environmental conditions denitrification or DNRA becomes the dominant pathway.

Priority actions:

- Direct measurement of denitrification and DNRA across different NSW estuaries, and across seasons.

2. Farm-Scale Water Quality Benefits

While oyster filtration and nutrient bioextraction are strongly supported, the downstream responses expected from these processes remain poorly quantified under NSW conditions. In particular, there is a lack of paired farm-versus-control studies examining chlorophyll a, dissolved oxygen, turbidity and plankton community responses. NSW already has one of the largest plankton / biotoxin datasets in the country, so this is partly an analysis gap rather than a lack of data. Understanding these relationships would provide direct evidence linking oyster filtration to measurable water quality improvements.

Priority actions:

- Establish paired monitoring sites within and adjacent to commercial farms.
- Quantify chlorophyll a, turbidity, dissolved oxygen and light penetration responses.
- Investigate the "clarity effect" and links to seagrass condition and productivity.

3. Biodiversity, Recruitment and Fish Production

NSW studies clearly show oyster farms support diverse fish and invertebrate communities; however, important questions remain about the ecological significance of this habitat. Current research primarily demonstrates attraction and habitat use, rather than whether farms increase recruitment, survival or population-level production of native species.

Priority actions:

- Expand biodiversity assessments across multiple estuaries and farming systems.
- Quantify spawning, recruitment and nursery habitat functions.
- Resolve the attraction vs. production question for commercially significant species.
- Assess the contribution of farm-derived larvae to wild Sydney rock oyster populations
- Extend farmed-versus-wild genetic comparisons, including the climate-resilient breeding lines now being used in restoration projects.

4. Sediment Process

Existing evidence suggests sediment impacts beneath NSW oyster farms are generally localised and minor, but comprehensive assessments remain limited.

Priority actions:

- Undertake comprehensive sediment health assessments across farm types.
- Assess sediment biogeochemistry under a broader range of environmental conditions.

5. Ecosystem Service Accounting & Valuation

One of the most significant opportunities emerging from this assessment is the development of robust ecosystem-service accounting frameworks. Nutrient removal, water filtration and habitat enhancement are increasingly being recognised within environmental markets; however, methodologies for quantifying and verifying these services remain underdeveloped in Australia. For nutrient removal specifically, the main source of uncertainty is not the nutrient concentrations, which are well constrained internationally, but the proportion of a harvested oyster that is nitrogen-rich meat rather than nitrogen-poor shell. That ratio varies by size, estuary, ploidy and season, and must be resolved before farm-scale accounting is possible.

Priority actions:

- Establish shell length to tissue and shell dry weight relationships for SRO and PAC oysters across major estuaries and seasons.
- Build a NSW nutrient-removal calculator so growers can estimate nitrogen and phosphorus removal from shell length and harvest volume.
- Establish consistent methods for valuing ecosystem services delivered by oyster farming.
- Explore opportunities associated with nutrient credits and Payments for Ecosystem Service (PES) schemes.

6. Climate Change & Coastal Protection

The climate-related benefits of oyster farming remain one of the least resolved areas of the evidence base. While oysters from NSW have been assessed as a low-emissions food source, substantial uncertainty remains regarding shell carbon accounting, marine carbon cycling and coastal protection services.

Priority actions:

- Measure wave attenuation and shoreline-protection benefits of commercial farms.
- Compare the performance of floating and intertidal cultivation systems under different tidal and storm conditions.
- Quantify carbon fluxes associated with commercial oyster leases.
- Continue evaluating emerging research on oyster aquaculture and marine carbon dioxide removal.
- Update existing industry climate-adaptation assessments with current POMS/QX distribution and marine-heatwave evidence.

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