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Tini a Tangaroa

2026 Overview of Ecological Effects of Aquaculture

New Zealand Aquatic Environment and Biodiversity Report No. 375

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PLAIN LANGUAGE SUMMARY

This document provides an update to the 2013 *Overview of Ecological Effects of Aquaculture*. It focuses on areas where there have been significant increases in understanding or new developments since the original overview was published.

Since 2013, New Zealand's aquaculture industry has expanded and diversified, including increased interest in offshore farming and emerging species. Research over the past decade has improved understanding of aquaculture effects on water quality, seabed habitats, marine mammals, seabirds, wild fish, biosecurity and hydrodynamic processes. Advances in monitoring tools, modelling approaches and industry guidelines have also strengthened the ability to predict, monitor and manage environmental effects through adaptive management approaches. Despite these advances, important knowledge gaps remain, particularly in relation to open ocean aquaculture, climate change interactions and emerging industries.

This updated Overview also recognises increasing interest in restorative aquaculture, where farming activities may provide environmental benefits alongside food production. Shellfish and seaweed farming, for example, may contribute to habitat creation, nutrient cycling and water filtration in some environments. Overall, the ecological effects of aquaculture are highly site-specific and influenced by farm design, scale, location and management practices, highlighting the importance of careful planning, monitoring and ongoing research to support sustainable aquaculture development in New Zealand.

EXECUTIVE SUMMARY

McGrath, E.[1]; Knight, B.[1]; Elvines, D.[1]; Clement, D.[1]; Bull, L.[2]; Sneddon, R.[1]; Atalah, J.[1]; Hutson, K[1]; Symonds, J.[1]; Costilla, R.[1]; Scholtens, M.[1]; Millar, R.[1]; Alder, A.[1] (2026). 2026 Overview of Ecological Effects of Aquaculture.

***New Zealand Aquatic Environment and Biodiversity Report No. 375*. 100 p.**

This document provides an update to the 2013 *Overview of Ecological Effects of Aquaculture* (the Overview). It focuses on areas where there have been significant increases in understanding or new developments since the original overview was published. It draws primarily on New Zealand research, supported by international literature where relevant, and is intended as a strategic overview rather than a comprehensive evidence review. A supplementary bibliography document outlining these updates and listing newly cited references is published as a separate document.

Since 2013, New Zealand's aquaculture sector has undergone substantial strategic and regulatory change. Government production targets have increased from $1 billion by 2025 to $3 billion by 2035 under the Aquaculture Development Plan, with expansion into open ocean environments and diversification into new species identified as key pathways for economic growth.

Major advances in understanding ecological effects associated with aquaculture are highlighted, including benthic processes, hydrodynamics, marine wildlife interactions, biosecurity, cumulative effects and climate-related pressures. Developments in environmental monitoring and predictive modelling, including eDNA techniques, remote sensing and adaptive management frameworks, have improved the capacity to assess and manage ecological risk. However, significant uncertainty remains, particularly for open ocean aquaculture, cumulative effects, climate change interactions and emerging industries where empirical data are limited and farms are not yet operational.

The revised Overview also recognises increasing interest in restorative aquaculture and the potential for some aquaculture activities to provide ecosystem services alongside food production. Shellfish and seaweed farming may contribute to habitat provision, nutrient cycling and water filtration under some conditions, although outcomes remain highly site- and context-specific. Overall, the Overview emphasises that ecological effects are strongly influenced by farm location, scale, design and management practices, reinforcing the importance of monitoring and continued research to support sustainable aquaculture development in New Zealand.

[1] Cawthron Institute.
[2] BlueGreen Ecology Ltd.

1. INTRODUCTION

1.1 Aquaculture Ecological Guidance

Aquaculture planning needs to be underpinned by accurate science-based information on ecological effects. This information is critical for appropriate, robust decision-making on aquaculture development.

The Ministry for Primary Industries (MPI) provides current and science-based information and advice on ecological effects of marine-based aquaculture at a national level to assist local authorities, the aquaculture industry, and other stakeholders with their planning for and management of aquaculture. These generally take the form of guidance documents, which currently include:

- *Literature Review of Ecological Effects of Aquaculture* brings together existing scientific knowledge on the main potential ecological effects of aquaculture in New Zealand
- *Overview of Ecological Effects of Aquaculture* – summarises the key messages and content from the literature review
- Best practices and technologies available to minimise and mitigate the interactions between finfish open ocean aquaculture and seabirds[3]
- Best practices and technologies available to minimise and mitigate the interactions between finfish open ocean aquaculture and marine mammals[3]
- Best practice guidelines for benthic and water quality monitoring of open ocean finfish culture in New Zealand[3]

These documents have been developed through a collaborative working group process with iwi, industry and stakeholders.

The Aquaculture Ecological Guidance is primarily focused on informing aquaculture planning and management, including:

- for marine farmers scoping potential ecological issues prior to lodging a resource consent application;
- for the aquaculture industry to inform codes of practice;
- for councils processing resource consent applications and for informing coastal planning;
- for research providers as a resource of information; and
- for the public seeking an unbiased assessment of ecological effects.

Our scientific understanding of the ecological effects of aquaculture continues to grow. For this reason, the Aquaculture Ecological Guidance Package was originally web-based so that it could be updated to reflect current thinking and research.

The *Literature Review of Ecological Effects of Aquaculture* was originally compiled in 2013 by two of New Zealand's main science providers in aquaculture – the National Institute of Water and Atmospheric Research (NIWA) and Cawthron Institute (Cawthron). The review brought together existing scientific knowledge on the main potential ecological effects of aquaculture in New Zealand and identified uncertainties and knowledge gaps.

The 2013 *Overview of Ecological Effects of Aquaculture* (the Overview) summarised the key potential ecological effects of aquaculture in New Zealand, provided commentary on their likely significance, and outlined management and mitigation options. It was intended to communicate the key technical details of the literature review in an accessible format.

[3] https://www.mpi.govt.nz/fishing-aquaculture/aquaculture-fish-and-shellfish-farming/sustainable-aquaculture

Since publication of the 2013 Overview the New Zealand government has increased its aquaculture production targets from $1 billion by 2025 to $3 billion by 2035 under the Aquaculture Development Plan. This plan identifies aquaculture extension into the open ocean as a key pathway to meet these production goals, alongside diversification of aquaculture species as a strategic priority.

This document provides an update to the 2013 *Overview of Ecological Effects of Aquaculture* (the Overview). It focuses on areas where there have been significant increases in understanding or new developments since the original overview was published. A supplementary bibliography document outlining these updates and listing newly cited references is published as a separate document (McGrath et al. 2026).

The Overview focuses on the potential ecological effects of existing commercial aquaculture species in New Zealand, and those species projected to have short-term development potential over the next five years (see Table 1.1). One of the most significant changes since the 2013 Overview is that the list of marine aquaculture species in New Zealand has been updated to reflect interest in diversification, with the inclusion of pāua, snapper, flat oysters and native seaweed species. Hāpuku has been removed from the updated Overview.

Not all species listed are discussed in detail; however, species within the same trophic group are expected to exhibit broadly similar ecological effects. Species discussed include:

- shellfish – green-lipped mussels[4] and oysters (referred to as *filter-feeder* in the literature review);
- finfish – Chinook salmon and kingfish (referred to as *feed-added* in the literature review); and
- lower trophic levels – seaweeds (*Undaria pinnatifida* and native seaweeds) and sea cucumbers.

Table 1.1: Marine aquaculture species in New Zealand with their farming status and feeding requirements (trophic level).

Species	Farming status	Feeding requirements (trophic level)
Green-lipped mussels (*Perna canaliculus*)	Current	Filter-feeder (low)
Pacific oysters (*Magallana gigas*)	Current	Filter-feeder (low)
Flat oysters (*Ostrea chilensis*)	Current	Filter-feeder (low)
Chinook salmon (*Oncorhynchus tshawytscha*)	Current	Feed-added species (high)
Yellowtail kingfish (*Seriola lalandi*)	Current	Feed-added species (high)
Snapper (*Chrysophrys auratus*)	Short-term potential / research scale	Feed-added species (high)
Pāua (*Haliotis iris*)	Current	Feed-added species (low)
Native seaweeds	Short-term potential / research scale	Nutrient and light required (very low)
Sea cucumber (*Australostichopus mollis*)	Short-term potential / research scale	Benthic organic matter (low)
Undaria (*Undaria pinnatifida*)	Short-term potential / research scale	Nutrient and light required (very low)

[4] The commercial trademark for New Zealand's green-lipped mussels produced through aquaculture is Greenshell™.

1.2 Overview of the Ecological Effects of Aquaculture

1.2.1 Structure of the Overview

The Overview is structured for readers' ease-of-use by separating the feeding types (shellfish, finfish, or seaweeds and sea cucumbers) into different sections:

Section 1. Introduction
Section 2. Ecological effects of farming shellfish
Section 3. Ecological effects of farming finfish
Section 4. Ecological effects of farming seaweeds and sea cucumbers
Section 5. Cumulative effects associated with aquaculture
Section 6. Monitoring the effects of aquaculture
Section 7. Restorative aquaculture

This separate grouping of shellfish and finfish (Sections 2 and 3) is because there are common ecological effects that typically arise with organisms that feed in the same manner (such as filter-feeding shellfish), some of which also share similar farming structures (for example, all finfish species are likely to be enclosed in cages). The third grouping (seaweeds and sea cucumbers) covers emerging species that do not fit within the previous two groups.

Within Sections 2 to 4, the potential ecological effects are presented in the same order as the literature review:

- water column effects;
- benthic effects;
- marine mammal interactions;
- effects on wild fish;
- effects on seabirds;
- biosecurity;
- escapee and genetic effects;
- effects from additives; and
- alteration of hydrodynamic flows.

Note that there is some necessary repetition between the sections. For example, the shellfish and finfish sections will repeat some ecological effects, because in many cases, the effects from aquaculture activities, and the associated mitigation options, will be similar with finfish farms and shellfish farms.

1.3 Aquaculture in New Zealand

1.3.1 Background

Aquaculture is the world's fastest expanding production of animal protein for human consumption. The United Nations Food and Agriculture Organization (FAO) reports that aquaculture supplies nearly half of all seafood consumed globally. As the global supply of seafood from wild fisheries is limited, aquaculture has the opportunity to meet the growing world demand for seafood through increased production.

In New Zealand, aquaculture is a growth industry that brings opportunities and benefits to national and regional economies. The New Zealand government supports well-planned and sustainable aquaculture development and is committed to enabling this industry to achieve its goal of $3 billion in

annual sales by 2035[5]. Currently, the majority of aquaculture activities are located in the inshore coastal marine environment, and the main aquaculture locations are shown in Figure 1.2. The Aquaculture Development Plan identifies the extension of aquaculture into more exposed open ocean[6] locations as a key pathway to meet these production goals.

An essential part of growing the aquaculture industry is ensuring that expansion takes place within acceptable environmental limits while taking into account the effects on other users and values of our waterways and marine environment. As operations extend into new environments, there is opportunity to reduce environmental impacts and potentially deliver ecological benefits and consideration of environmental or ecological effects and benefits may be necessary. Planning for sustainable aquaculture development needs to be supported by science-based information on ecological effects.

Aquaculture production in New Zealand is currently dominated by three species: green-lipped mussels, Chinook salmon and Pacific oysters. However, the Aquaculture Development Plan has identified the potential to diversify in order to target the best opportunities to enable sector growth. Identifying and implementing the best new opportunities, including a limited number of new species, is being investigated for future development.



Figure 1.2: Spatial distribution and production of main aquaculture species in New Zealand. Source: Ministry for Primary Industries (2025)[7].

1.3.2 How are the ecological effects of aquaculture managed in New Zealand?

Aquaculture planning and consenting processes in New Zealand are governed by an integrated framework of national legislation and regional planning instruments. The Resource Management Act

[5] View the New Zealand Aquaculture Development Plan (2025–2030) for full details surrounding the key pathways for development.
[6] Exposed or dynamic environments, often in offshore locations.
[7] Ministry for Primary Industries. 2025. New Zealand Aquaculture Development Plan 2025–2030. Wellington: MPI. https://www.mpi.govt.nz/dmsdocument/67776-NZ-Aquaculture-Development-Plan-2025-2030

1991 (RMA) currently provides the primary statute for the sustainable management of natural and physical resources in New Zealand, including the requirement to avoid, remedy or mitigate any adverse environmental effects of aquaculture[8]. Under the RMA, regional councils and unitary authorities manage aquaculture within their coastal marine area, defined as the zone between the mean high water springs and the 12 nautical mile limit. Reforms to the RMA are underway and are expected to introduce clearly defined environmental limits and streamlined planning processes, which may affect how aquaculture activities are assessed and consented in the near future.

Alongside the RMA, the Fast-track Approvals Act 2024[9] established a parallel approvals pathway for projects considered to deliver significant regional or national benefits, providing an alternative, streamlined consenting process in certain circumstances.

National direction issued under the RMA plays a significant role in shaping aquaculture regulation. The National Environmental Standards for Marine Aquaculture (NES-MA) provides nationally consistent rules for specific activities, particularly through the reconsenting, replacement, and extension of existing marine farms, and mechanisms to enable aquaculture through plan changes in appropriate areas. The NES-MA were introduced to reduce regulatory uncertainty and streamline decision-making while maintaining environmental safeguards. Regional councils[10] must comply with NES-MA when preparing plans and assessing resource consent applications.

While regional councils are responsible for managing the environmental effects of aquaculture under the RMA, the sustainability and allocation of fisheries resources are addressed under the Fisheries Act 1996, administered by central government. The interaction between aquaculture and fisheries is therefore managed through an interface between the RMA's effects-based environmental management framework and fisheries legislation, rather than through a specific fisheries-control function within the RMA.

Any person wishing to establish a marine farm must obtain approval under the applicable statutory framework. In most cases this requires a resource consent from the appropriate regional council under the RMA, unless the proposal is approved through an alternative pathway such as the Fast-track Approvals Act 2024. Under the RMA, applications for a resource consent for marine farms may be made, subject to the provisions of the relevant regional coastal plan, and must include an assessment of environmental effects (AEE) prepared by the applicant. The AEE identifies the effects of the proposed activity and considers those effects against the purpose and principles of the RMA to promote the sustainable management of natural and physical resources. Regional coastal plans may specify additional information requirements.

Where assessed under the RMA, a regional council can grant a coastal permit for aquaculture for a maximum duration of 35 years. While there is no longer a universal statutory minimum term, longer durations are typical in practice. Consent conditions are imposed to ensure that the aquaculture activity is carried out in a manner that avoids, remedies, or mitigates any adverse effects on the environment, and councils are responsible for monitoring compliance with those conditions.

Decision-making under the RMA must also consider a range of additional matters, including effects on tangata whenua values, other marine users, natural character, landscape, public access and

[8] Sustainable management is defined in section 5 of the RMA as: managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while –
(a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations;
(b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and
(c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.

[9] View the Fast-track Approvals Act.

[10] In this document, the term "regional council" includes both regional councils and unitary authorities.

navigation, as relevant. These matters will need to be considered when preparing a consent application[11].

1.3.3 Other roles and responsibilities

MPI, through Fisheries New Zealand, is responsible for determining whether proposed aquaculture activities will have adverse effects on fishing under the Fisheries Act 1996. This assessment, known as the undue adverse effects (UAE) test, evaluates potential impacts on commercial, recreational and customary fishing. The UAE assessment is undertaken once a regional council has granted the resource consent under the RMA (or alongside alternative approval processes, where applicable). A proposed marine farm cannot proceed if it would have undue adverse effects on recreational or customary fishing. Where undue adverse effects on commercial fishing are identified, an aquaculture agreement or equivalent arrangement must be reached before the activity can proceed. More information about the UAE test is available on MPI's website.

Biosecurity management of aquaculture activities currently occurs at multiple levels from national to regional to on-farm practices. MPI leads New Zealand's biosecurity system under the Biosecurity Act 1993, working with industry, iwi and regional councils to prevent, detect, and respond to pests and diseases. Regional councils implement regional pest management plans under the Biosecurity Act 1993 and may also address biosecurity risks through RMA plan provisions and consent conditions. At the farm level, operators are expected to implement biosecurity practices encompassing prevention, surveillance, and response measures, often guided by industry codes of practice through initiatives such as the A+ programme and the development of industry biosecurity standards developed in collaboration with MPI.

The Department of Conservation (DOC) has statutory functions under the Conservation Act 1987 and related legislation, including the National Parks Act 1980, the Marine Reserves Act 1971, the Reserves Act 1977, the Wildlife Act 1953 and the Marine Mammals Protection Act 1978. DOC manages land, freshwater, coastal area waters, and historic sites protected for conservation purposes. Many of these areas are coastal and are valued for their biodiversity, naturalness and recreational amenity.

DOC also supports the Minister of Conservation's role under the RMA, including the preparation of the New Zealand Coastal Policy Statement 2010 (NZCPS) and approval of regional coastal plans. The NZCPS sets national policies for sustainable management of the coastal environment and promotes strategic planning and zoning for coastal activities, including aquaculture. Policy 8 recognises that aquaculture can contribute significantly to the economic and cultural well-being of people and communities, while other policies emphasise protection of natural character, biodiversity and water quality.

1.3.4 Aquaculture in a changing environment

The influence of climate change on the ecological effects of aquaculture is complex and remains poorly understood globally, with considerable uncertainty in the New Zealand context. Effects are likely to be highly location-specific, reflecting regional environmental conditions, changes in ecological function and interactions between species. Where available, relevant information has been incorporated in this document; however, significant knowledge gaps remain, and further research is required both in New Zealand and internationally.

1.3.5 Considerations for marine farmers on managing ecological effects

Marine farmers should take into account the following to manage and mitigate the ecological effects of aquaculture.

[11] View information on applying for a resource consent.

1.3.5.1 Location, location, location

Appropriate siting of a new aquaculture development is critical to avoiding and reducing many potential adverse ecological effects, and may also result in enhancing the positive effects of an aquaculture activity. However, site selection must first consider the requirements of the species to be farmed and the applicable statutory planning framework (including regional coastal plans and any relevant national direction). Siting considerations may include:

- Avoiding sensitive, at-risk, rare or endangered habitats, species and communities, including areas identified in regional plans or the NZCPS as having significant ecological values (Policy 11).
- Diluting and diffusing outputs: Locate your activity in an environment that can tolerate changes resulting from the activity (such as nutrient additions, extractions or farm-derived wastes deposited on the seabed). Deep water with strong currents reduces localised effects on the seabed and water column.
- Selecting assimilative sites such as soft, muddy sediments without any significant benthic community. These habitats are generally more suitable for aquaculture as they are usually more tolerant of deposition. These habitats also tend to be much more common or abundant, especially in offshore areas.
- Researching your site first. Know what is in the "effects footprint" of your activity and if there is the potential for cumulative effects, including effects in combination with other existing or consented activities.

1.3.5.2 Talk to your regional council

Regional councils have specific policies on marine farming stated in regional coastal plans. Contact your regional council as early as possible to discuss how you can best prepare your application (e.g. a resource consent under the RMA or approval under alternative statutory pathways, where applicable). Regional councils hold information on ecology in the coastal area that can be made available to you to help you assess the suitability of potential locations and prepare your AEE or equivalent supporting documentation. Regional council staff may have expertise in the ecological effects of aquaculture and can refer you to research providers. They can also refer you to additional information, such as relevant scientific papers and reports.

1.3.5.3 Do your homework

Every aquaculture application for statutory approval requires a site assessment to describe the environment and predict likely ecological effects (along with other effects, such as cultural, visual amenity and navigation). Use existing information and resources available (including the Aquaculture Ecological Guidance Package) to target research to the most relevant or greater risk issues and to avoid duplication of effort and costs.

1.3.5.4 Aquaculture science review

Fisheries New Zealand (within MPI) convenes Aquatic Environment Working Groups (AEWGs) to provide scientific feedback and review of new research, including aquaculture. Regional councils and private applicants can request that their projects are reviewed by AEWG. Although not a statutory requirement, a science review could be worthwhile particularly for large, novel research[12].

[12] Fisheries research processes | NZ Government

1.3.5.5 Think effects, not species

When applying for or issuing statutory approvals for an aquaculture activity, consider species groupings (such as shellfish and finfish) rather than individual species, as the environmental effects are very similar and this approach provides more flexibility for innovation. For example, filter-feeding shellfish gives flexibility to farm blue mussels, green-lipped mussels, oysters and scallops.

1.3.5.6 Adopt best practice

Follow industry environmental codes of practice and look for continual improvement. There are opportunities for market gains by demonstrating sustainability and environmental performance, including internationally recognised certifications. Aquaculture New Zealand and other industry bodies maintain environmental codes of practice for the oyster, mussel and finfish farming industries.

1.3.5.7 Be innovative

Trials of new species and technologies and integrated multi-trophic aquaculture (IMTA) could bring gains to the industry in the future and potentially assist to minimise ecological effects (for example, farming of sea cucumbers, native seaweeds and *Undaria*). Experimental aquaculture, by its nature, may have greater uncertainties in terms of ecological effects; however, these risks will likely be tempered by the typically limited duration and scale of such activities and appropriate monitoring and adaptive management conditions[13].

1.3.5.8 Consult

As with other aspects of the resource consent application, consultation with potentially affected parties may provide information on habitats and fisheries resources of value to iwi and interest groups at the application site and in the local waterbody. Early engagement with tangata whenua is strongly encouraged and, in many cases, expected by decision-makers. Regional councils should encourage applicants to consult with relevant groups during the preparation of the AEE or equivalent documentation.

1.3.5.9 Monitoring

Monitoring is crucial to assessing the effects of a marine farm on the surrounding environment. A monitoring plan needs to be thought about early on, including whether and what baseline monitoring is needed, and how any ongoing monitoring is undertaken. It is important to look at what monitoring already exists to see whether that can be used.

[13] The scope, definition and consenting pathways for research and experimental aquaculture activities may require further refinement pending updates to the National Environmental Standards for Marine Aquaculture (NES-MA)

2. ECOLOGICAL EFFECTS OF FARMING SHELLFISH

2.1 Introduction

This section provides an overview of the ecological effects associated with farming New Zealand's two main shellfish species: green-lipped mussels (*Perna canaliculus*) farmed using subtidal long-lines, and Pacific oysters (*Magallana gigas*) grown on intertidal racks or in baskets (see Figure 2.1 and Figure 2.2). The discussion is also broadly relevant to other shellfish species farmed using suspended culture methods.

This section summarises information from the *Literature Review of Ecological Effects of Aquaculture*. While the literature review remains a key reference, it has not been reviewed since 2013 and some information may now be outdated. To address this, a new appendix for the literature review has been prepared, comprising a bibliography that summarises the principal additions to the original review, alongside an abbreviated list of references most relevant to those updates. Readers can refer to the literature review for additional background; however, this document provides the most current context on regulatory, policy, technological and research developments relevant to the ecological effects of shellfish aquaculture.

Aquaculture effects occur within the context of (and potentially interacting with) other natural and human-influenced processes. These interactions and possible cumulative effects are discussed in Section 5 of this document.

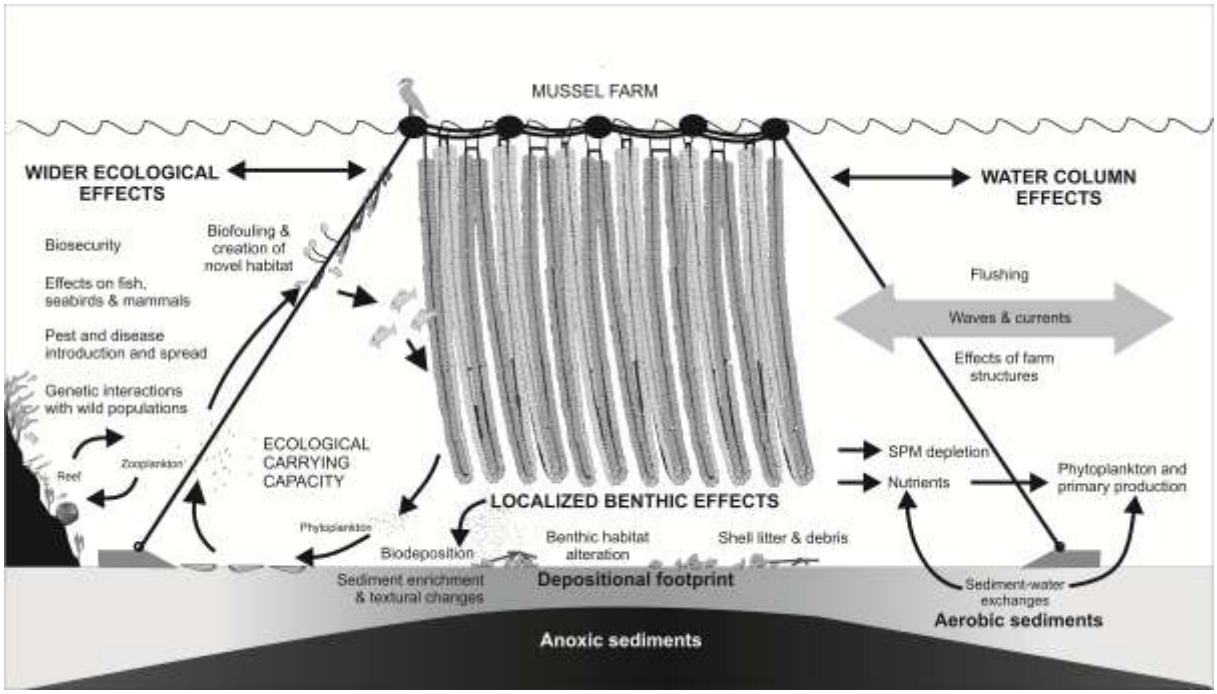


Figure 2.1: The actual and potential ecological effects from longline mussel farming. Source: Keeley et al. (2009).

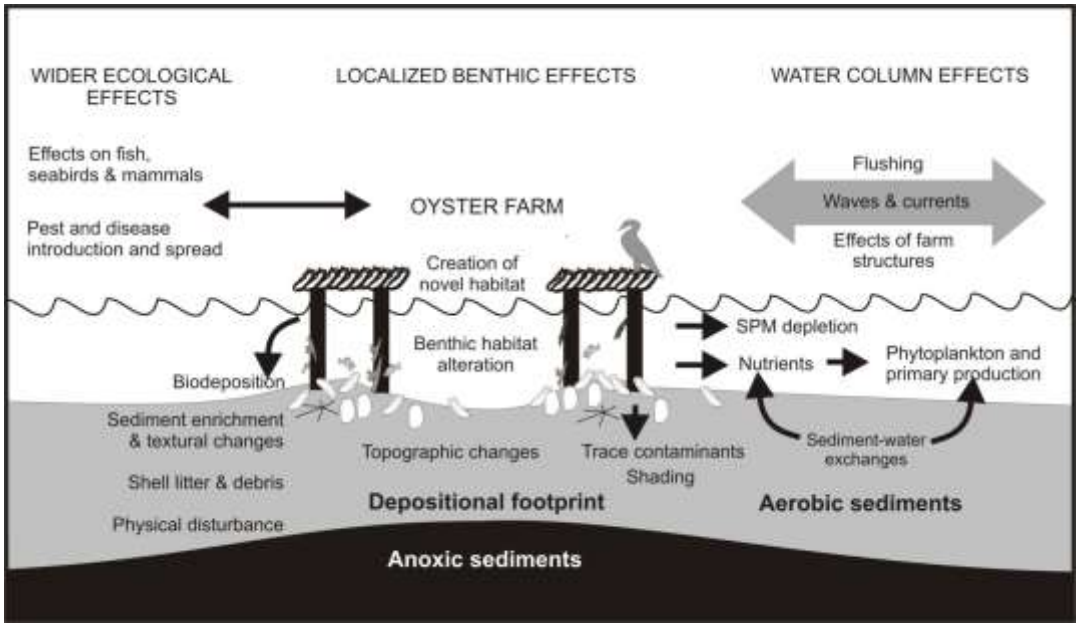


Figure 2.2: The actual and potential effects from elevated intertidal oyster cultivation. Source: Forrest et al. (2007). Note: this diagram does not include floating basket oyster growing technology, which is expected to have a reduced ecological impact compared to elevated intertidal oyster cultivation.

2.2 Water column effects

Table 2.1: Overview of potential water column effects of shellfish farming.

Definition	Effects of shellfish aquaculture on the water column at approximately the scale of the farm
Summary of potential effects	• Phytoplankton depletion and changes in planktonic community composition • Dissolved nutrient and particulate release into the water column • Effects from biofouling communities
Management and mitigation options	• Careful site selection • Farm design, orientation and stocking rates • Monitoring for key plankton and nutrient parameters • Adaptive management • Integrated multi-trophic aquaculture
Knowledge gaps	• Baseline water quality data in many regions • Carrying capacity of estuaries, harbours, embayments and coastal regions for shellfish farming • Effectiveness of integrated multi-trophic aquaculture • Effects of climate changes on phytoplankton resources supporting shellfish aquaculture and marine food webs
Key terms defined in glossary	Adaptive management, bay-wide, biofouling, biomass, carrying capacity, chlorophyll-a, cumulative effect, depletion footprint, IMTA, intertidal, meroplankton, nutrient enrichment, phytoplankton, pseudofaeces, stratification, water column

2.2.1 Summary of potential effects

This section summarises the potential ecological effects to the water column at approximately the scale of the marine farm. Bay-wide effects on the water column and wider ecosystem are discussed in Section 5.

2.2.1.1 Phytoplankton depletion

The main effect on the water column from the farming of shellfish is the extraction of phytoplankton and organic particulates by the farmed shellfish. Phytoplankton depletion can be substantial and has been observed to alter the biomass and size structure of phytoplankton communities in sheltered bays with intensive farming. Shellfish grazing may also filter larger particles, including zooplankton and fish eggs. However, long-term monitoring of the water column around mussel farms in both the Firth of Thames and the Marlborough Sounds has not detected sustained changes in nutrients or chlorophyll-*a*, the pigment commonly used as an indicator of phytoplankton biomass. Consequently, the ecological effects of current shellfish aquaculture on water column properties appears to be small in New Zealand farming areas.

The theoretical phytoplankton depletion footprint is shaped by site-specific physical characteristics (such as flushing rates, currents, depth, wind, ambient nutrients and plankton concentrations), as well as farm stocking densities. Figure 2.3 shows an example of modelled phytoplankton depletion footprints for offshore mussel farms in Golden Bay, generated using a biophysical and hydrodynamic model.

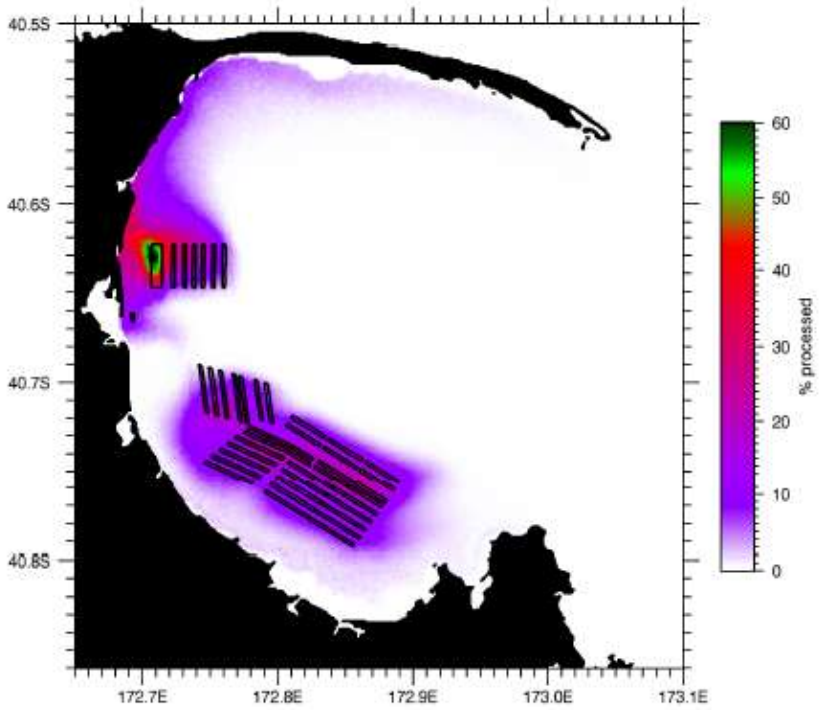


Figure 2.3: Model-based prediction of a phytoplankton depletion footprint around proposed mussel farms in Golden Bay expressed as percentage of seawater processed by mussels. Source: Morrisey et al. (2006).

Short, day-long synoptic water column surveys using profiling sensor and sampling instruments provide useful snapshots of phytoplankton abundance (as indicated by chlorophyll-*a*) and can offer a means to provide evidence of localised phytoplankton depletion. Increasingly, long time-series from satellite sensors, often spanning a decade or more, also allow assessment of pre- and post-farming surface chlorophyll-*a* patterns across New Zealand aquaculture areas. These satellite datasets capture broad spatial and temporal variability in surface phytoplankton that may be missed by short-term synoptic surveys. Profiling surveys remain important, however, for verifying whether surface changes reflect conditions deeper in the water column, which satellites cannot observe. Overall, published measurements from both small and large New Zealand mussel farms indicate relatively little influence on water column phytoplankton concentrations at typical farming intensities, particularly across the wider area surrounding farms.

Unlike the extensive body of research on mussel-driven phytoplankton depletion, there is a lack of data on how oysters influence the intertidal water column. However, international research suggests that the potential for adverse water quality effects from intertidal oyster farming is low. This conclusion is not surprising given that oyster farms typically operate at much lower stocking densities than mussel farms, that adult oysters have filtration rates comparable to, or lower than, those of mussels, and that intertidal farm sites are fully or substantially flushed during each tidal cycle.

2.2.1.2 Dissolved nutrient and particulate release into the water column

Farmed shellfish release dissolved nutrients (primarily ammonia) and organic particulates (faeces and pseudofaeces) into the water column. This can potentially lead to small-scale nutrient enrichment of the surrounding water which has potential to stimulate phytoplankton and macroalgal growth. There is no evidence in New Zealand of shellfish farming causing or exacerbating toxic microalgal blooms. In fact, the additional filtration pressure from shellfish aquaculture may even help to reduce the size of phytoplankton blooms.

2.2.1.3 Effects from biofouling communities

Farming structures and stock can be colonised by biofouling communities, which are likely to have additional effects on the water column via phytoplankton extraction and organic loading. Common biofouling organisms include seaweeds and filter-feeding invertebrates, such as sea squirts, hydroids, bryozoans and mussels – all of which can increase filtration and nutrient-uptake processes in a farming area. These assemblages also typically have a range of other less mobile animals associated with them, such as worms and small crustaceans. The functional role and impacts of mobile biofoulers is not well understood, and further research is required to determine their contribution to water column effects.

2.2.2 Significance of effects

The ecological effects of shellfish farming on the water column, such as localised phytoplankton depletion, are typically detectable only within, or close to, a farm and are generally short-lived. However, evidence that adult mussels can consume fish eggs suggests that, in theory, the removal of that life stage could have longer-term consequences for affected species. Consequently, it can be important to ensure depletion levels remain within ecologically acceptable limits. The significance of water column effects depends on the carrying capacity of the environment, prevailing currents, and the scale and intensity of farming. These effects are likely to be more pronounced in shallow areas with slow currents than in deeper sites with strong flow and good water exchange.

In New Zealand, most mussel and oyster farms are located in areas that are well flushed, since production is dependent on the natural availability of phytoplankton and overstocking of shellfish can impact the productivity of aquaculture. As such, phytoplankton depletion and nutrient enrichment beyond the farm boundaries is typically small and difficult to detect.

Despite recognised knowledge gaps and limited baseline water quality data in many regions, the fact that substantive water column-related issues have not been documented in relation to shellfish farms in New Zealand suggests that ecological effects on the water column associated with current shellfish farming practices and environments are most likely minor (assuming the farm is appropriately sited, designed and maintained). Furthermore, any local-scale water column effects discussed in this section are reversible upon removal of the farm. However, future climate-driven changes in temperature, nutrient availability and phytoplankton production may alter the underlying processes that currently support mussel farming. While clear warming trends have been recorded, trends in primary production around New Zealand have varied across both time and space, and further analysis is needed to understand their implications. For instance, warming regions may become unsuitable for some aquaculture species in future, or farming at current levels as climate changes occur may lead to additional impacts on the environment.

2.2.3 Management and mitigation options

Effects on the water column can be reduced through careful site selection; that is, well-flushed, deep (in the case of mussel farming) and productive sites. The farm design, orientation and stocking rates should be determined specifically for a site, for example by ensuring that farm structures are configured in a way that has a minimal effect on flushing processes.

There are several design and management factors that will greatly influence potential effects on the water column:

- density of farms – more farms will generally have greater effect (see Section 5);
- stocking density – higher stocking densities on farms will generally have greater effect; and
- orientation to prevailing current direction – this will impact on the amount of hydrodynamic drag on passing water, flushing and settlement of biofouling organisms. Backbone lines should ideally be oriented parallel to the main axis of flow.

Adaptive management and the use of ecological aquaculture and IMTA approaches are also potential mitigation measures (see Section 5).

Models are often a key tool for predicting water column effects at a site, and several different modelling approaches can be used to assess effects of shellfish farming.

Biophysical model simulations in the Firth of Thames

Biophysical model simulations have been used to estimate depletion zones of large-scale mussel farms in the Firth of Thames. These models use field survey data for validation and take into account the growth rates of phytoplankton, zooplankton and fish larvae; water column stratification; seasonal wind direction; tidal currents; and the physiological response of mussels to different food concentrations. The simulated effect in the Firth of Thames predicts an increase in the depletion of suspended particulate matter, phytoplankton and microzooplankton within a farm, but not far beyond a farm's boundary.

Where models indicate that farms may have a significant effect, monitoring of the water column for key plankton (chlorophyll-*a*, phytoplankton abundance, species composition) and nutrient (dissolved carbon, nitrogen, silicate and phosphorus) parameters can be used to validate models and assess the actual effects of farming operations.

Chlorophyll-*a* is commonly used as a proxy for phytoplankton abundance in water column surveys, but it does not capture shifts in phytoplankton community composition. Changes at the community level can be assessed through taxonomic sampling or size-fractioned chlorophyll-*a* measurements, or inferred from biophysical model simulations (see the text box above).

2.3 Benthic effects

Table 2.2: Overview of potential benthic effects of shellfish farming.

Definition	Effects of shellfish aquaculture on the seafloor
Summary of potential effects	• Localised organic enrichment of the seabed beneath the farm • Smothering of benthic organisms by biodeposits • Biofouling drop-off and debris altering the composition of the seabed • Seabed shading by structures which could affect localised algal productivity under the farm
Management and mitigation options	• Careful site selection • Reducing stocking rates, avoiding over-crowding, reducing discard rate of over-settlements • Monitoring physiochemical and biological properties of sediments
Knowledge gaps	• Relative contribution from biofouling vs. shellfish biodeposits to enrichment beneath farms
Key terms defined in glossary	Benthic, biodeposition, biofouling, depositional footprint, effects footprint, intertidal, phytoplankton water column, pseudofaeces

2.3.1 Summary of potential effects

Shellfish farming can increase sedimentation of organic-rich, fine-grained particles (biodeposits of faeces and pseudofaeces), and cause deposition and accumulation of live shellfish, shell litter and other biota onto the seabed. These biodeposits may smother seabed communities and change them by altering the physical composition of the sediments and reducing flow and exchange of water between the sediments and overlying water column.

Information on the benthic effects of shellfish farms relates primarily to changes in soft-sediment habitats, as shellfish farms are almost invariably sited above these habitats to avoid effects to (usually more sensitive) rocky habitats.

The primary benthic effect of concern from shellfish farming is typically organic enrichment of the seabed, which creates only a "minor" effect (organic content increases by ~7.5 percent). Effects on the benthos also manifest as a build-up of shell litter directly beneath the site (from farm biofouling and farmed shellfish drop-off), and, in some instances, increased aggregations of starfish and other mobile benthic species.

Sediment enrichment affects animals living within the sediment (infauna) by generally enhancing productivity through increased food supply, leading to some species becoming more abundant. Increased shell litter may have a positive effect by altering sediment texture and seabed complexity, and in turn increasing benthic diversity by providing habitat for species that would not otherwise inhabit soft-sediment areas (an overview of potentially positive benthic effects is described in Section 7). Changes in surface-dwelling mobile benthic species, such as starfish and sea cucumbers, have been documented, but they are rarely quantified and vary markedly between sites. Some sessile benthic species, such as hydroids, shellfish, brachiopods, sponges and bryozoans, may be smothered by biodeposits. In most instances, the severity of benthic effects has been assessed as low to moderate for soft-sediment habitats where no particularly sensitive, vulnerable or special benthic communities are present.

The environment's capacity to disperse and assimilate fine mussel farm biodeposits is largely controlled by water depth and current speed. Seasonal changes in factors such as water temperature can also influence the system's carrying capacity. Increased flushing not only reduces localised sedimentation and accumulation of organic matter, but it also increases oxygen delivery to the sediments, allowing for more efficient breakdown of organic material. Consequently, deep mussel farm sites (over 30 metres) located in areas of strong water currents will have depositional footprints that are less intense and more widely dispersed than shallow, poorly flushed sites.

Benthic effects from intertidal oyster farms are comparable to those from mussel farms, with the exception that there is increased scope for topographical changes to the seabed due to the positioning of structures within the shallow intertidal zone. The accumulation of live oysters, oyster shell litter, farm debris and biofouling on benthic organisms beneath growing racks can be the most visible effects of oyster farms during low tide.

2.3.2 Significance of effects

While benthic effects are one of the most commonly expected changes from shellfish farming, they are typically of minor ecological consequence beyond the farm boundary. The severity of benthic effects is generally low to moderate in soft-sediment habitats without particularly sensitive, vulnerable or special benthic communities. Localised effects can also have positive ecological impacts (see Section 7).

Benthic effects are most pronounced directly beneath farm sites, reduce rapidly with distance, and are usually difficult to detect beyond 20 to 50 metres (the "effects footprint"). The effects of biodeposition from mussel farms tend to be most evident directly beneath the longline droppers, however, a gradient of seabed enrichment has been measured at some farm sites. In contrast, live mussels, shell material and associated fouling biota settling beneath mussel long-lines are typically confined to within 10 metres of farming structures.

The spatial extent and magnitude of benthic effects of shellfish farms depends on site-specific environmental characteristics (for example, current speeds and directions, existing benthic habitat and communities) and, to a lesser extent, farm management practices, such as stocking densities, line orientation, and harvesting techniques.

When multiple farms are concentrated within a defined geographic area (e.g., a channel or embayment), benthic changes can be seen as a mosaic across the seabed. The cumulative effects of multiple farms can therefore be an important consideration for assessing the significance of effects at a meaningful ecological scale.

2.3.3 Management and mitigation options

Management measures for mitigating benthic effects of shellfish farms are similar to those for mitigating water column effects. Site selection is critical and should include consideration of the dispersive properties of the site and avoid potentially sensitive and valuable habitats (such as conservation areas, biogenic habitats and reefs). Soft, muddy sediments are usually more tolerant of deposition and also tend to be more common or abundant.

Avoiding over-crowding and reducing the discard rate of over-settlements can assist in the management and reduction of biodeposition and smothering of the seabed through drop-off.
Where there is concern about adverse benthic effects, monitoring of physico-chemical and biological properties of sediments at farming sites typically involves a suite of indicators of seabed health, including:

- sediment colour;
- odour;
- reduction–oxidation (redox);
- potential discontinuity layer;

- sulphide concentrations;
- sediment organic content;
- infauna;
- extent of shell and live mussel cover; and
- epifaunal community composition (often qualitative or semi-quantitative).

Recovery rates of seabed communities from deposition-related enrichment effects of mussel and oyster farms occur at a relatively rapid rate for the first few years once farming ceases, but some community changes may persist for longer, depending on how recovery is being measured. Accumulated shell material from drop-off may take several years to more than a decade to break down and is likely to persist in the sediment beyond the point of recovery from typical enrichment type effects. Shell material, sticks and other inorganic debris associated with intertidal oyster farming may persist for years after farming ceases. The introduction of these structural habitat changes may result in fundamental or long-term shifts in seabed community composition, unless the site undergoes targeted remediation. "Recovery" of the seabed from shell drop-off must be put in the context of the potential associated benefits (e.g. increased seabed complexity, biodiversity, structure and stabilisation; see Section 7).

2.4 Marine mammal interactions

Table 2.3: Overview of potential marine mammal interactions with shellfish farming.

Definition	Effects of shellfish aquaculture on marine mammals
Summary of potential effects	• Habitat exclusion or displacement • Entanglement (potentially resulting in injury or drowning) • Vessel / propeller strike • Underwater noise disturbance • Alterations in trophic pathways
Management and mitigation options	• Careful site selection • Regular maintenance of farm structures, including keeping lines secured and anchor warps under tension • Ensure waste material and debris are collected and disposed of correctly • Minimise artificial lighting (navigation, vessels) at night • Monitor and report interactions of marine mammals with farm structures
Knowledge gaps	• Ranges and locations of important habitats of marine mammal species • Design and maintenance features to minimise entanglement risk • Health implications for marine mammals associated with underwater noise exposure
Key terms defined in glossary	Cetacean, conservation status, habitat exclusion, interaction

2.4.1 Summary of potential effects

Documented effects of aquaculture on marine mammals relate mainly to habitat exclusion / displacement issues and entanglement in structures or farm debris. Depending on the size of the farm and nature of operations, other issues such as vessel strike, underwater noise disturbance and possible flow-on effects due to alterations in trophic pathways may also apply.

Marine mammals in New Zealand

There are more than 50 species of cetaceans (whales, dolphins and porpoises) and pinnipeds (seals and sea lions) that are known to live or migrate through New Zealand waters. Species likely to be of most concern for their interaction with aquaculture include:

- those that share the same area and have either high conservation importance, for example, Hector's and Māui dolphins; and
- those most likely to interact with aquaculture gear – for example, fur seals; dusky, bottlenose and common dolphins; and Bryde's, orca, southern right and humpback whales.

Role of DOC

DOC administers the Marine Mammals Protection Act 1978, which provides for the protection, conservation, and management of marine mammals within New Zealand and New Zealand fisheries waters. It is an offence to disturb, harass, injure or kill any marine mammal without a permit issued pursuant to this Act, unless accidentally or incidentally to some other lawful activity. In addition, the Marine Mammals Protection Regulations 1992 stipulate various rules governing the behaviour of people, vessels and aircraft in the vicinity of marine mammals.

Intensive shellfish farming overseas has elicited both reductions and increases in habitat use near or around farms by local dolphin species, depending on whether there is a direct competition for space or indirect effect on the abundance and / or distribution of prey resources. Current research in New Zealand suggests that exclusion or attraction effects depend on the type and scale of the farming method and the marine mammal species impacted. Most whales and particular dolphin species tend to be more sensitive and avoid disturbances, while pinnipeds and other dolphin species (such as common and bottlenose dolphins) may be attracted to the novel habitat. Recent studies, including the use of underwater acoustic recorders to monitor marine mammal presence in shellfish farms, suggest that other factors (e.g. changes in prey distribution, diurnal tendencies, localised climate effects) are likely to affect how and when dolphins, such as dusky or Hector's dolphins, choose to use inshore habitats occupied by marine farms. However, the significance of these changes for local dolphin populations and their overall foraging success remains unclear.

To date, the number of fatal entanglements reported in shellfish farms in New Zealand (five) is much lower than entanglement numbers reported in other countries. Baleen whales (such as humpback and Bryde's whales) are the primary species of concern, with no known records of dolphins or pinnipeds becoming entangled in mussel farms in New Zealand. However, it is not possible to completely eliminate entanglement risk wherever ropes and lines are present in the marine environment. Physical interactions (e.g. nudges, bumps, rubbing) between aquaculture gear and marine mammals can increase the likelihood of fatal entanglement in structures, ropes or non-biological debris associated with farm operations.

The likelihood of vessels striking marine mammals depends on operational factors such as vessel type, speed and location. While shellfish maintenance and harvesting vessels are generally slow moving, they operate day and night, and regularly transit between farms and ports on a daily or weekly basis.

There is also the potential for wider, more indirect ecosystem effects on marine mammals from shellfish farming, including underwater noise. Longer-term, chronic increases in overall underwater noise levels from vessels and harvesting operations may result in more noise-sensitive species (e.g. beaked whales, pilot whales) avoiding affected areas. However, there is currently no documented research focused on the noise associated with ongoing farm activities, or on how localised impacts to habitats or prey resources may lead to flow-on effects for marine mammals in New Zealand.

2.4.2 Significance of effects

Recent global and national reviews of aquaculture and marine mammals acknowledge that there is little empirical data on marine mammal responses to aquaculture or the results of their reactions (if any) to and with the farms, despite the presence of aquaculture in nearshore regions worldwide for more than 40 years. Although interactions between marine mammals and New Zealand marine farms have been relatively minor to date, it is not yet clear whether this reflects genuine low risk or simply low farming density and / or low reporting rates that may be insufficient to detect potentially significant interactions. Based on the evidence to date, the range of natural and anthropogenic factors affecting marine mammals at a given site also needs to be considered alongside any potential effects of aquaculture.

Overseas experience suggests that the potential for adverse effects increases as both marine mammal populations grow and larger-scale, offshore farms develop. The significance of these effects may therefore need to be reconsidered for any future large-scale and / or offshore developments in New Zealand waters, particularly where endangered, threatened or range-restricted species are present. Species of particular concern include Hector's, Māui and bottlenose dolphins, as well as orca, Bryde's, southern right and humpback whales.

2.4.3 Management or mitigation options

Based on the available evidence from marine mammal interactions with shellfish farms, management and mitigation plans are now focused on how to avoid interactions becoming fatal. Farm locations need to be carefully selected to minimise or avoid the likelihood of overlap with important marine mammal migration routes and known habitats, including the home ranges of range-restricted species and critical breeding or foraging habitats. To avoid physical interactions with farm structures, marine mammals need to have safe access around and between farm blocks, with particular attention paid to avoiding dead-end passages through appropriate farm spacing and block layout. The intent is to make animals (especially whales) aware of the structures, while discouraging them from entering farms by placing multiple structures as close to one another as possible, but allowing large passageways between farm blocks that are set parallel to migration paths.

Once sited, farms should develop marine mammal management plans that meet industry best practice and that clearly outline the protocols to be used to minimise interactions with species likely to occur in the area. These plans should also define monitoring and reporting requirements and include a written entanglement response protocol with specified emergency actions. Entanglement risks can be minimised by adopting regular maintenance measures around farm structures, ensuring that debris and waste material do not enter the water, keeping lines well maintained and secured at all times, and ensuring that anchor warps are maintained under sufficient tension. Stiffening lines with rigid or semi-rigid sleeves or replacing them with rigid poles or frames allows them to retain their shape when they are not under tension, so that they do not form loops or pockets that can increase the entanglement risk to marine mammals, particularly whales. Avoiding or minimising spat collection and installation or decommissioning farm structures during critical whale migration periods are additional risk-reduction measures.

To reduce the risk of collision with marine mammals, farm vessels should maintain slower speeds around farms and keep watch for marine wildlife while in transit, in accordance with the farm's marine mammal management plan. Additional protocols and standard operating procedures, such as measures to minimise above-water and underwater noise, prevent rubbish from entering the sea and reduce non-navigational lighting at night, are also necessary and will likely benefit other marine wildlife, including wild fish and seabirds.

Regular and long-term monitoring of marine mammal presence and interactions with farm structures may be undertaken as part of a farm's marine mammal management plan. Marine wildlife monitoring is also incorporated into the Sustainable Management Framework (SMF) for New Zealand mussel

farms developed by Aquaculture New Zealand. The relevant DOC conservancy office should be contacted in the event of marine mammal entanglement.

2.5 Wild fish interactions

Table 2.4: Overview of potential effects on wild fish from shellfish farming.

Definition	Effects of shellfish aquaculture on wild fish populations
Summary of potential effects	• Attraction and aggregation of wild fish around farm structures (artificial habitat creation) • Alteration of existing fish habitats through shell deposition and biodeposition • Changes in local fish distribution, behaviour and productivity associated with farm structures • Influence on recreational fishing patterns and fishing pressure • Incidental removal of fish eggs and larvae by farmed shellfish through filter-feeding (relevant to large-scale operations)
Management and mitigation options	• Careful site selection to avoid critical fish spawning grounds and nursery areas • Minimising accumulation of biodeposits through appropriate farm design, stocking densities and site selection • Monitoring of farm effects to support adaptive management approaches • Alignment of assessments with relevant policy frameworks (e.g. the New Zealand Coastal Policy Statement [NZCPS])
Knowledge gaps	• Effects of shellfish aquaculture on fish larval and early life stages • Uncertainty around cumulative effects of multiple shellfish farms at larger spatial scales • Ecosystem-level and food web interactions arising from shellfish aquaculture • Limited understanding of how site-specific factors (e.g. location, hydrodynamics, farm design) influence the magnitude of effects • The effects of increased recreational pressure around shellfish farms on wild fish populations
Key terms defined in glossary	Biodeposition, UAE test, water column

2.5.1 Summary of potential effects

Shellfish farms influence wild fish primarily by creating artificial habitats that attract species seeking refuge and food, and by altering existing habitats through the accumulation of shell litter and the biodeposition of particulate matter. Off-bottom shellfish aquaculture can increase habitat complexity by adding hard substrate through shell drop-off and farm debris, creating structured benthic environments that support a diverse range of fish and invertebrate species. However, these changes can benefit some species more than others, negatively affect certain communities (e.g. infaunal species), alter trophic dynamics and create “stepping stone” pathways for invasive species. Although such effects are generally localised and spatially limited, their magnitude can vary with farm type, location and environmental conditions.

The attraction of wild fish to aquaculture structures can potentially lead to secondary effects, including shifts in the local distribution and productivity of wild fish populations and the extraction of fish eggs and larvae by farmed shellfish. In some cases, these aggregations may enhance local abundance and foraging opportunities, while in others they may alter natural behaviour or increase vulnerability to fishing pressure.

The presence of marine farms can also shift recreational fishing patterns and pressure, which in turn may influence wild fish populations differently than if these structures were absent. Recreational fishers and boaters frequently report species, such as snapper and kingfish, congregating around mussel farms. These fish appear to be attracted to the food available from the mussel stock (particularly during harvest) and to the structural habitat, and may also prey on other fish aggregating around the farms. The magnitude of these effects are likely to be site-specific, shaped by local species composition and environmental conditions. Little is known about the effects of oyster farms on wild fish populations; however, as oyster farms in New Zealand primarily occupy the shallow intertidal zone, they are likely to have less of an effect on wild fish populations than mussel farms. There is evidence that oyster farms can support fish species typically found on natural oyster habitats, although this is dependent on farming method. Any effects that do occur are expected to be localised and generally of low magnitude.

2.5.2 Significance of effects

In general, any effects of shellfish farms on wild fish populations are likely to be minor compared with their influence on other components of the marine environment. Their impacts are also expected to be smaller than those associated with finfish farms, largely because shellfish farms do not introduce additional feed that can attract fish. However, site-specific factors, including farm density and environmental characteristics, can influence the scale and direction of effects.

Artificial structures such as shellfish farms are recognised as providing novel foraging habitats, detrital food sources, breeding habitats, and refuge from predators for some fish species. Effects are likely to be site and region specific due to the different fish species that may be present, and each species may have unique responses to the type of artificial habitat.

Wild fish abundances around shellfish farms can also be affected by changes in the way the area is subjected to fishing pressure. Sites that have historically been part of a trawl fishery, for example, will no longer be accessible due to the presence of structures. The effect of removing commercial fishing pressure may, however, be somewhat offset by changes in the way the area is used by recreational fishers, but it is not known whether recreational fishing around marine farms has an effect at the population level.

Overall, little is known about the potential effect of farmed mussels filtering zooplankton, including fish eggs and larvae, from the water column. However, it is unlikely that the current level of mussel farming in New Zealand is having significant flow-on effects on the sustainability of wild fish populations. Nonetheless, uncertainty remains around potential cumulative effects at larger spatial scales and under increasing levels of aquaculture development.

2.5.3 Management and mitigation options

An important consideration when determining where to site a farm is to avoid spatial overlap with critical fish spawning grounds and nursery areas. Where possible, farm placement should also consider broader ecosystem interactions, including local fish movement patterns and habitat use[14].

[14] Any new aquaculture activity will require a UAE test to be undertaken by MPI. This will determine whether the proposed aquaculture activity can proceed, based on the extent to which the proposal will affect the commercial, recreational and customary fishing in the area. For more information on the UAE test, see Section 1.

Further research into the effects of shellfish aquaculture on larval stages of wild fish is required to identify whether increased aquaculture developments, including the effects of multiple farms, will impact on wild fish populations. Additional research is also needed to better understand site-specific effects and the role of shellfish farms in influencing wild fish aggregations, behaviour and ecosystem function.

2.6 Effects on seabirds

Table 2.5: Overview of potential effects on seabirds from shellfish farming.

Definition	Effects of shellfish aquaculture on birds
Summary of potential effects	• Habitat exclusion / disturbance • Entanglement (possibly resulting in birds being injured or drowned) • Attraction to farm lighting • Vessel / propeller strike • Provision of roost sites • Attraction / aggregation of prey fish
Management and mitigation options	• Careful site selection – avoid critical breeding and foraging habitats • Design and maintenance features to minimise entanglement risk • Ensure waste material and debris are collected and disposed of correctly • Minimise artificial lighting at night • Monitor and report negative interactions of seabirds with aquaculture structures
Knowledge gaps	• Distribution, abundance and critical habitats of seabird species • Prey and feeding behaviour of key seabird species
Key terms defined in glossary	Benthos, conservation status, habitat exclusion

2.6.1 Summary of potential effects

Despite previous expectations that farm-derived biodeposition and shell litter may smother and reduce the foraging habitat available for some benthic-feeding seabirds, recent tracking research in New Zealand has found the opposite effect. Mussel farm structures (i.e. buoys, lines) were found to provide roost sites closer to foraging areas for king shags, perhaps allowing them to save energy and forage more efficiently. Likewise, the attraction and aggregation of small fish to the farm to feed on organisms growing on ropes and to shelter under the farm structures (e.g. krill, whitebait, other baitfish) can become potential food sources for seabirds such as terns, gulls, shags and penguins (see Section 2.5). Similar results are reported internationally, with some mussel farm areas becoming hotspots of avian biodiversity and / or richness. Whether the physical presence of mussel farm structures may reduce the habitat available for surface-feeding seabirds such as terns, gulls and shearwaters, or alternatively attract them, has yet to be determined in New Zealand and is likely to be dependent on the availability of local habitats.

Intertidal oyster farms can also provide roosting habitat for shorebird species, with overseas studies suggesting that oyster husbandry activities disturb nearby birds only occasionally and temporarily, while attracting others. Overseas studies show that the spatial responses of foraging shorebirds to

intertidal oyster racks vary by species. Multiple lines of racks can interfere behaviourally with species that feed in large, tightly packed flocks (e.g. godwits) or more territorial species, while still attracting individual waders or loose-feeding flocks of other shorebirds.

As with marine mammals, there will always be a low risk of seabird entanglement with shellfish farms, where diving birds become entangled, are injured and / or drown among ropes or lines underwater. However, there have been no reported seabird deaths as a result of entanglement with shellfish farms in New Zealand to date, most likely due to the thicker, highly tensioned and / or weighted ropes currently used in this industry.

Other potential effects include injury or death from ingestion of foreign objects such as marine litter, disturbance of breeding birds by farming activities and vessels, attraction and subsequent collision of seabirds with artificial lighting, and farm vessel / propeller strike.

2.6.2 Significance of effects

The adverse effects of existing aquaculture on seabirds are not presently considered significant. The scale and magnitude of the effect of aquaculture on seabirds depends largely on the bird species impacted, their conservation status, the location of a farm within their range, and the duration of the effect. Of particular concern are negative interactions with species that are threatened, endangered, vulnerable, migrating or range restricted[15].

2.6.3 Management and mitigation options

Effective management can be achieved through careful site selection to avoid the home ranges, critical breeding and foraging habitats, and migration routes of threatened, endangered or protected bird species. Impact prediction methods for shorebirds have been developed overseas to aid the siting of intertidal oyster aquaculture.

Once sited, farms should develop customised seabird management plans. These should clearly describe the protocols to be used to minimise interactions with the species likely to occur in each area, define any monitoring and reporting requirements, and provide a written entanglement response protocol with associated actions. Several protocols and standard operating procedures will likely be applicable to other marine wildlife such as wild fish and marine mammals – for example, those aimed at minimising the potential for rubbish to enter the sea from farms, and those ensuring that minimal non-navigational lighting and downward-pointing, shaded and non-flickering lights are used at night.

Regular reporting of seabird interactions by some farms has helped identify the species most at risk and the mitigation measures that can reduce future interactions. If seabird interactions are identified as a concern, then regular and consistent reporting of any negative interactions of seabirds with aquaculture structures can help lead to species-specific management strategies.

There are significant knowledge gaps concerning almost all seabird species in New Zealand, including detailed information on time-specific distribution, abundance and critical habitats. Also missing is information on key prey species of seabirds, particularly those that may be affected by aquaculture.

[15] The conservation status of New Zealand birds can be found here: New Zealand's threatened birds.

King shags in the Marlborough Sounds

The New Zealand king shag (*Phalacrocorax carunculatus*) is a nationally endangered species found only in the Marlborough Sounds. During the 2020 non-breeding season 815 individuals were identified, indicating a small but slightly larger population than previously estimated. Earlier assessments, including the 2012 New Zealand King Salmon application for new salmon farms in the Marlborough Sounds, concluded that while risks from marine farming were likely to be low, potential impacts on such a small population could be significant. A King Shag Management Plan was therefore recommended to prevent any decline, particularly at key breeding sites such as Duffers Reef in Pelorus Sound / Te Hoiere.

Recent research has improved understanding of interactions with marine farms, including that mussel farms do not exclude king shag from foraging habitat. Instead, many birds use these areas, with 56% of tracked individuals foraging within farm footprints and spending an average of 31% of their foraging time there. Birds from major colonies, including Duffers Reef and Tawhitinui, were regularly observed foraging within farms, suggesting no negative effect on food supply or foraging ability. Mussel farms also appear to provide roosting benefits. King shag were observed roosting on farm buoys between foraging bouts, often preferring them over shoreline sites. These structures may offer safer roosting locations as they are surrounded by water. Overall, current evidence suggests that mussel farms are likely to be neutral in their effects on king shag, while continued monitoring remains important for this nationally endangered species.

2.7 Biosecurity

Table 2.6: Overview of biosecurity risks potentially associated with shellfish farming.

Definition	How shellfish aquaculture may influence risks associated with pests and diseases
Summary of potential effects	• Potential to facilitate establishment and spread of pests and diseases
Management and mitigation options	• Prevention of incursions through effective pathway management, including vessel and equipment maintenance, effective antifouling coatings, and hull inspections and cleaning • Prevention of incursions through appropriate on-farm management, including surveillance of farms and stock during activities, such as harvest, grading or transfer of stock • Farm zoning, placement and fallowing • Effective responses to pests and diseases, including early eradication and appropriate disposal of pests from farm structures, where possible
Knowledge gaps	• The direct and indirect ecological effects of marine pests and diseases in the wider New Zealand environment • Predicting and diagnosing new risk species, including infectious and non-infectious disease, to New Zealand's aquaculture and environment • Environmentally friendly antifoulants and treatments • The natural transmission mechanisms and farm-to-farm dispersal potential of many diseases • Breeding for disease resistance • Rapid assessment tools for diseases like ostreid herpesvirus-1 (OsHV-1)

	• Integrated pest management strategies
Key terms defined in glossary	Biofouling, biosecurity, epidemiological unit, exacerbator, incubator, microscopic pathogens, pathway, pest organisms, reservoir, spat-catching, staged development, zoonoses

2.7.1 Introduction

Biosecurity is defined as "the exclusion, eradication or effective management of risks posed by pests and diseases" (Biosecurity Council 2003). Biosecurity risks are animals, plants and microorganisms capable of causing diseases or otherwise adversely affecting New Zealand's natural, cultural, recreational, amenity or economic values[16].

This section should be read in conjunction with Sections 2.8 and 2.9, as they also contain biosecurity-related themes.

Marine biosecurity risks are most likely to be introduced into New Zealand through vessel biofouling or ballast water. However, all coastal users and activities, including aquaculture, have the potential to introduce or spread marine pests and diseases into regions and farm sites where they do not already occur. Biosecurity risks can also originate from the natural environment. For example, endemic parasitic pea-crabs, *Nepinnotheres novaezelandiae*, contribute to a reduction in green-lipped mussel meat yield with an estimated loss of NZD $2.16 m to aquaculture per annum. These risks can lead to a wide range of ecological effects, from little or no disruption to species or ecosystem processes

2.7.2 Summary of potential effects

Marine farms have the potential to facilitate the establishment and spread of pests and diseases, although they are unlikely to directly introduce risk organisms into New Zealand.

Shellfish farms and other artificial structures provide novel habitat for colonisation by fouling communities (including sea squirts, seaweed, tubeworms, barnacles and blue mussels) and other pests (including predatory flatworms). Once colonised, marine farms may act as a reservoir for the subsequent spread of unwanted pest organisms into the wider environment, to other farm sites or to vessels and equipment capable of transporting them. For example, the spread of the elongate tunicate *Eudistoma elongatum* around Northland harbours was most likely associated with oyster farming operations. Shellfish farms may also alter environmental conditions (such as change in seabed composition or nutrient enrichment) and in doing so can facilitate the establishment or emergence of marine pests and diseases.

Marine farms can also be vulnerable to adverse effects arising from biosecurity incursions. For example, biofouling pest organisms can increase drag on structures and anchoring systems, raising the risk of gear failure and causing shellfish to drop from long-lines. Biofouling can also smother the culture ropes and structures, significantly reducing water flow and thereby limiting the food and oxygen available to farmed species, while potentially increasing the likelihood of disease outbreaks or transmission. In New Zealand, documented examples include negative impacts on mussel farms from infestations of the sea squirts *Didemnum vexillum* and *Styela clava*.

Like pest infestations, diseases can be exacerbated by aquaculture operations and can reduce the growth, condition and health of farmed stocks. For example, during the 2010/11 New Zealand summer, oyster herpes virus (OsHV-1) caused 50 to 80 percent mortality of oyster spat on most North Island Pacific oyster farms. Although the virus appears to have been present in New Zealand waters since at least 1991, when it caused mass mortality of oysters in the Mahurangi Harbour hatchery, it did not manifest in farmed or wild stocks until 2010, possibly triggered by stress related to unusually

[16] See the Aquaculture Readiness Data (ARD) Project – Biosecurity and Aquaculture factsheet for more information on biosecurity risks, preparedness and key findings relevant to the aquaculture sector.

high summer water temperatures. Until then, no serious parasites or pathogens of Pacific oysters had been documented in the 30-year history of oyster farming in New Zealand.

In 2014, the notifiable haplosporidian parasite *Bonamia ostreae* was detected in association with high mortality in flat oysters (*Ostrea chilensis*) in Marlborough Sounds farms. This led to national restrictions on flat oyster movements, and ultimately, the depopulation and closure of all flat oyster farms in 2017.

Over the past decade, several pathogens of aquaculture significance and seafood safety concern have emerged in wild and farmed *Perna canaliculus* populations in New Zealand. The protozoan parasite *Perkinsus olseni*, a notifiable pathogen to the World Organisation for Animal Health and previously thought unable to infect *P. canaliculus*, has now been detected in both the North and South Islands. Hatchery mortalities have been linked to *Vibrio* spp., while commercial grow-out issues include chronic heat stress ("summer mortality syndrome"), which likely predisposes mussels to opportunistic bacterial infections. The pathogen *Vibrio parahaemolyticus* has recently caused outbreaks of foodborne infection linked to commercially grown seafood. Commercial *P. canaliculus* populations have also been found to harbour *Toxoplasma gondii* sporulated oocysts and *Giardia duodenalis*, raising concerns for both human and wildlife health.

2.7.3 Significance of effects

It is important to consider biosecurity risks because of the potential far-reaching and irreversible implications if there is an outbreak or incursion of a pest or disease. The introduction, proliferation and spread of risk organisms in New Zealand can lead to significant effects on marine habitats and their associated values. Once established in marine environments, pests and diseases are typically difficult and costly to manage and the ongoing effects are often permanent. Consequently, considerable effort is placed on preventing incursions of pests and diseases into the New Zealand environment.

To date, there have been few notifiable aquatic diseases detected in New Zealand's shellfish aquaculture industry. The risk of a biosecurity outbreak or incursion, however, is serious given the potential consequences, both in terms of the environment and the operations of the industry.

2.7.4 Management and mitigation options

A Biosecurity Management Plan (BMP) is fundamental to farm operations. The most successful international systems have framed biosecurity as underpinning business resilience and industry growth. Biosecurity supports growth by:

- Protecting production.
- Reducing disease losses.
- Supporting fish welfare.
- Maintaining market access.
- Protecting investor confidence.
- Improving licence security.

Biosecurity management and planning is therefore crucial to limit the introduction of pests and diseases and to be able to respond quickly and effectively to biosecurity risks. Aquaculture requires good biosecurity practice to avoid impacts to its operations and to the environment[17][18].

It is ineffective to manage biosecurity risks from aquaculture without also addressing the wider risk pathways (or sources of risk) in the marine environment – for example, commercial shipping,

[17] 2016 Aquaculture Biosecurity Handbook

[18] Options to Strengthen On-farm Biosecurity Management for Commercial and Non-commercial Aquaculture.

recreational boating, marinas and ports, and tourism activities. Effective biosecurity management ideally requires a collaborative approach involving central, regional and local government, affected industries, iwi and the public (see text box below).

Levels of biosecurity management

Biosecurity management of aquaculture activities currently occurs at multiple levels from national to regional to on-farm practices.

International
New Zealand is a member of the World Organisation for Animal Health (WOAH), whose role is to set the international standards by which member countries agree to abide to ensure that animals and animal products can be safely traded without the international spread of animal diseases or zoonoses.

National
MPI leads New Zealand's biosecurity system. It is responsible for delivering a border risk management system, a surveillance and incursion investigation programme, effective responses to new and emerging biosecurity risks, and facilitating participation and collaboration to achieve improved biosecurity outcomes. The Biosecurity Act 1993 is the primary legislation for providing the powers, duties and obligations needed for effective biosecurity. Biosecurity can also be managed using tools under other legislation such as the Hazardous Substances and New Organisms Act 1996 and the RMA.

MPI works with a broad range of partners to deliver an effective biosecurity system. For marine biosecurity this includes international organisations such as the International Maritime Organisation, other countries, importers, merchant and recreational sailors arriving at the border, regional and local government, iwi and users operating at a national level. Public participation also plays an important role, with mechanisms such as MPI's biosecurity hotline and online reporting tools enabling early detection and reporting of potential pests and diseases.

Regional
Effective biosecurity requires a joint effort involving central government, regional councils, industry, community groups and the public. One example of regional collaboration is the Top of the South marine biosecurity partnership model between central and local government and iwi, of which aquaculture is a key industry participant.

Regional councils have a duty to consider biosecurity issues under the RMA and NZCPS during the plan change and resource consent processes. Farm spacing, zoning, staged development and epidemiological units may be considered on a case-by-case basis to reduce risks of pest and disease transfer between or among farm sites and the coastal environment.

On-farm
Activities undertaken by the marine farm operator to manage biosecurity are termed on-farm biosecurity management and encompass prevention, surveillance and control of pests and diseases. Good on-farm management is often guided by industry codes of practice, such as requirements for farm cleaning and surveillance activities. MPI is continually working with the aquaculture industry to better understand on-farm biosecurity risks and management options.

There are three strands to biosecurity management: prevention, surveillance (detection), and control of populations and outbreaks.

2.7.4.1 Prevention

The prevention of incursions is typically the most effective approach to biosecurity and should focus on the management of high-risk pathways, including from international source regions, pathways that are novel, and domestic source regions known to be infected by recognised high-risk pests.
In New Zealand, international import pathways to the aquaculture industry are controlled by MPI through Import Health Standards. These include requirements that must be undertaken in the exporting country, during transit and on arrival to render the biosecurity risk negligible. For example, current standards include the import of fish food, fish bait and ornamental fish from all countries, and the import of equipment used in association with animals and water.

Domestic aquaculture pathways in New Zealand that pose biosecurity risks involve the movement of reproductive material, stock, equipment and industry vessel movements. These pathways are primarily managed through voluntary measures and industry codes of practice, for example the Greenshell™ Mussel Industry Environmental Code of Practice 2007 and the "New Zealand Mussel Industry National Spat Transfer Programme" (NZMIC 2001). Additional voluntary initiatives include industry-led sustainability programmes such as the A+ standards developed by Aquaculture New Zealand, which apply to mussels, Pacific oysters and salmon.

A biosecurity management plan to support prevention may include:

- filtration of influent and effluent for land-based facilities;
- stock tracking, health certification and quarantine for stock coming onto farm;
- cleaning requirements for equipment being moved onto and between farms;
- a definition of epidemiological units;
- farm cleaning protocols;
- a biosecure waste disposal plan; and
- preventative management of vessels and equipment (such as antifouling coatings, hull inspections, and hull cleaning as necessary).

2.7.4.2 Surveillance (detection)

Surveillance can focus on entry surveillance, routine (passive) surveillance or targeted surveillance of high-risk areas. Entry surveillance includes activities, such as routine screening at airports, ports and mail centres. Routine (active and passive) surveillance undertaken on and around marine farm structures, associated vessels and infrastructure by the farm operator, is crucial and often the first point of detection of pests and diseases.

MPI commissions targeted surveillance of high-risk areas such as ports and harbours around New Zealand, and manages a national Aquatic Animal Health Surveillance Database. It is recommended that, at a minimum, a biosecurity management plan may address:

- regular inspection of vessels and equipment for pests;
- regular inspection of shore infrastructure and any outfalls from such infrastructure;
- record-keeping to detect and report, for example, unusual mortalities, and allow incursions to be traced for source and possible recipient locations; and
- reporting to MPI on the presence or possible presence of pests and diseases (sections 44 and 46 of the Biosecurity Act 1993).

2.7.4.3 Control of populations and outbreaks

Incursions of pests or diseases can be managed for eradication or containment, or to limit spread. Due to the connectivity of the marine environment, such activities are likely to require coordination with,

and support from, all marine stakeholders (whose activities can spread unwanted organisms) and agencies at local, regional and national scales.

Biosecurity management plans may describe:

- the agencies and other users that will need to partner in any response situation;
- criteria for determining when eradication, control or containment should be undertaken;
- generic management actions for pests and diseases, such as appropriate disposal of waste; and
- specific management actions for known pests or diseases – for example, veterinary certification to limit infected stock movements.

The use of eradication treatments is only advised if the risk of re-invasion can be managed and pests can be detected before they become widespread. Treatments may be used to control pest populations, clean aquaculture vessels or equipment before transport to other regions, or contain further spread (for example, to minimise the risk of natural dispersal to other vectors, such as vessels or structures). Eradication treatments include freshwater or acetic acid bath treatments of stock and equipment, manual removal of pests, and wrapping of structures.

In the case of a disease or pathogen, responses may include therapeutant treatments of infected stock, biosecure practices (such as isolation, quarantine or culling of infected stocks) and restricted equipment and vessel movements among infected farms or regions. In New Zealand, management of gear and vessel transfers between geographic zones by voluntary codes of practice developed by industry could be used to minimise risks of inadvertently transferring infected stock, for example, the New Zealand Mussel Industry Seed Transfer Code of Practice (NZMIC 2001).

In addition, the aquaculture industry has developed specific biosecurity management and response plans for high-risk species *Styela clava* and *Didemnum vexillum* (NZOI 2007).

2.8 Escapee and genetic effects

Table 2.7: Overview of potential escapee and genetic effects from shellfish farming.

Definition	• Potential effects of escaped farmed species on the environment • Potential effects of genetic modification and polyploidy on the environment • Potential effects of larval dispersal and connectivity between farmed and wild populations • Potential effects of disease and pathogen transmission associated with stock movement
Summary of potential effects	• Changes to the genetic distinctiveness, fitness, adaptability and diversity of local wild populations • Transmission of pathogens or parasites between regions
Management and mitigation options	• Case-by-case assessment and response • Genetic monitoring of wild and farmed populations • Biosecurity measures to limit pathogen spread • Transgenic and gene-edited organisms are prohibited in New Zealand. The Gene Technology Bill 2024 is currently undergoing Parliamentary process. If passed, it could allow some gene-edited animals to be used for commercial production, although this will still be regulated • Breeding for disease resistance and resilience • Farming of triploids

Knowledge gaps	• Population structure of wild populations • The risks and ecological consequences of transgenic and polyploidy shellfish • Research into sterilisation methods • Research into genotype-by-environment effects
Key terms defined in glossary	Fitness, genetic modification, polyploidy, selective breeding, transgenic organism, triploidy

2.8.1 Summary of potential effects

Shellfish farming can affect the genetic distinctiveness of local wild shellfish populations. Also, mixing farmed and wild populations may result in a change of fitness, adaptability, and diversity or reduced survival of the wild population.

Escapee effects associated with farming mussels and oysters centre on their possible genetic interactions with wild populations of the same species. Mussels and oysters live attached to the structure they are seeded onto so there is little or no active movement. They are broadcast spawners, however, meaning that they release their eggs and sperm into the water for external fertilisation, where they have the potential to interact with wild populations. Recent hydrodynamic and genomic research has shown that larvae from farms can contribute to local recruitment in nearby wild mussel beds. While farms are not the dominant source of larvae, they can act as localised larval sources, and the extent of connectivity varies between regions.

Movement of spat and stock between regions also presents a pathway for the transmission of pathogens or parasites, which can have ecological and genetic consequences for wild populations. In oysters, for example, the dynamics of OsHV-1 are now well studied and spat movement has been identified as a potential vector for pathogen spread. Selective breeding for disease resistance, particularly in response to OsHV-1 in oysters, is increasingly used to reduce disease impacts on farms. While this can improve performance, it may also influence genetic interactions with wild populations if resistance traits spread through larval dispersal or spat movement. The long-term ecological implications of these resistance traits remain an active area of research.

Polyploidy, where individuals have extra sets of chromosomes, has been commercially used in shellfish aquaculture overseas and in New Zealand to stimulate growth and control breeding (such as triploidy in oysters). By contrast, the use of transgenic organisms (genetically modified) is controlled by the Environmental Protection Authority (EPA) and it has not allowed any use of genetic modification in commercial aquaculture.

Selective breeding programmes for green-lipped mussels and Pacific oysters have expanded over the last decade and new hatchery developments are underway. Domestication selection has been documented in traits such as growth, survival and shell characteristics. Hatchery production can reduce effective population size if not carefully managed, and unequal family contributions can increase the risk of genetic drift. These factors may influence wild populations if gene flow occurs.

2.8.2 Significance of effects

The significance of any genetic mixing will depend on the source of stock, the pre-existing level of genetic structuring within that species, and the level of interaction.

Green-lipped mussels are a species native to New Zealand and are found all around the country. The majority of mussels grown on marine farms in New Zealand are sourced from Ninety Mile Beach and the remainder come from Golden Bay and Tasman Bay, resulting in a high pre-existing level of spat transfer between regions. Genomic studies confirm that wild green-lipped mussel populations remain

genetically diverse and highly connected, and that current levels of spat transfer and farm-derived larval dispersal have not significantly altered the genetic structure of wild populations. However, the long-term influence of increased hatchery use remains an area of active research.

Selective breeding programmes for mussels are expanding, and the use of hatchery-reared spat is expected to increase. As hatchery production grows, the potential for changes to the genetic structure of wild populations may also increase. Maintaining high effective population size and monitoring genetic diversity in hatchery lines will be important to minimise these risks.

In the case of Pacific oyster cultivation, ecological effects on wild (naturalised) populations are not as relevant since Pacific oysters are not native to New Zealand. Pacific oyster spat are sourced from outside the region where they are farmed – from both wild and hatchery origins – and the use of selectively bred or triploid lines may influence the genetic composition of naturalised populations. Triploid oysters, which have greatly reduced reproductive output, may help minimise genetic interactions.

Even where genetic effects are minimal, however, oyster farming can still facilitate the establishment or expansion of feral populations through the redistribution of spat and the release of larvae or juveniles. Once established, feral Pacific oysters can alter the structure and functioning of recipient ecosystems, for example by changing habitat complexity, modifying benthic communities, and influencing local nutrient and sediment dynamics.

Climate change may further influence these dynamics by altering larval dispersion patterns, reproductive timing, and the relative fitness of farmed versus wild genotypes.

2.8.3 Management and mitigation options

The risks of escapee and genetic effects are species-specific and should be managed on a case-by-case basis. Important factors to consider include:

- the distance of the farm from viable habitat;
- the distance to natural populations;
- the dispersal range of gametes from the species concerned;
- source of stock; and
- an understanding of the genetic structuring of wild populations.

If the mussel farming industry were to increase its dependence on hatchery-supplied spat, particularly with the advancements in selective breeding, this would present new implications that would need to be carefully considered and could require the development and implementation of genetic management protocols.

Management options include:

- genetic monitoring of hatchery and wild populations to detect changes in diversity or introgression;
- implementing biosecurity measures to limit pathogen spread;
- breeding for disease resistance to reduce pathogen impacts and minimise the likelihood of disease transmission to wild populations;
- preventing genetic modification from contributing to escapee or genetic effects in line with EPA regulations, which prohibit transgenic and gene-edited organisms in New Zealand. Note, however, that the Gene Technology Bill 2024 is currently undergoing Parliamentary process. If passed, it could allow some gene-edited animals to be used for commercial production, although this will still be regulated.

2.9 Effects from additives

Table 2.8: Overview of potential effects of additives (including plastics) from shellfish farming.

Definition	The potential effect of chemicals (including plastics) used in shellfish aquaculture on the environment
Summary of potential effects	• Current shellfish aquaculture does not require the ongoing use of chemicals and antibiotics • Intertidal oyster farming racks constructed from treated timber have potential to leach trace contaminants • Plastics used in aquaculture have the potential to become debris and degrade to release chemical and microplastics
Management and mitigation options	• Adherence to guidelines around the use of treated timber • Retrieve plastic lost accidently and minimise plastic use where possible. Eliminate, innovate and circulate.
Knowledge gaps	• Accumulation and interactions of trace contaminants • Effects of antibiotics on sediments and ecological processes • Release of microplastics from marine farms debris
Key terms defined in glossary	Therapeutant, water column, microplastics

2.9.1 Summary of potential effects

Shellfish farm operations do not require the ongoing use of additives, including chemicals and antibiotics that can introduce contaminants to the marine environment. Wooden oyster farming racks are, however, constructed from timber treated to H6 (marine) standard and use galvanised fasteners, and therefore have the potential to leach trace contaminants such as copper, chromium and arsenic (CCA), as well as zinc. At concentrations above those required for normal metabolism, copper, chromium and zinc can be toxic, especially to the very sensitive development stages of marine invertebrates. Arsenic can also have toxic effects on organisms. CCA and zinc are likely to bind to sediments after their release, reducing the potential for contaminant accumulation in oysters or toxic effects on sediment-dwelling biota. Leaching of contaminants from treated timber is reported to decrease over time.

Plastics are widely used in aquaculture because they meet a variety of functional requirements. However, the different plastic materials used across the industry have distinct properties, which influence how they behave in aquatic environments. Some materials, such as polyethylene (PE) and polypropylene (PP) ropes, gradually abrade over time, generating microplastics that can sink through the water column. Others, such as expanded polystyrene (EPS) flotation structures, tend to fragment, producing floating microplastics. More durable plastics may be less prone to fragmentation but can persist in the marine environment for decades or even generations.

The causes of plastic loss from aquaculture operations are similarly diverse, ranging from equipment wear and tear to storm damage and operational practices. Once released into the environment, aquaculture-related plastics and marine litter can have a range of impacts, including ingestion by wildlife, entrapment and entanglement of animals, and the potential exposure of humans to microplastics through the food chain[19].

[19] Tackling plastic waste in NZ aquaculture Report

2.9.2 Significance of effects

No chemicals, therapeutants or additives are known to be used in the farming of shellfish in New Zealand. These are not, therefore, identified as posing a current risk. The toxicity of treated timber is primarily a result of its potential to leach trace amounts of CCA, although this issue is probably of negligible significance in open systems. When used in moderately well-flushed environments, the water concentrations of contaminants resulting from treated timber will typically remain well below regulatory standards and are far below concentrations which would cause ecological concern.

It is thought the main reason for plastic debris from aquaculture is extreme weather and the catastrophic impact on facilities. In the case of inter or sub-tidal facilities this means entire components e.g. floats, sea-pens, nets and plastic containers being lost directly into the sea. Some major components are likely to be recovered through industry led beach clean-up efforts, whereas smaller items may be permanently lost. There is no evidence of aquaculture contributing significantly to microplastic pollution. The impact of plastic loss from aquaculture likely to be small compared to other anthropogenic inputs.

2.9.3 Management and mitigation options

All species farmed for human consumption from aquaculture must meet strict food safety standards that regulate the acceptable concentrations of metals, chemicals and additives in food products.

If there is concern over sediment contamination, it is relatively straightforward and inexpensive to collect and analyse sediment samples from beneath oyster farm structures, and compare sediment contaminant concentrations to Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018[20]) to ascertain whether this is an issue that warrants more thorough investigation.

Industry actively participates in minimising plastic waste and removing lost plastics from the environment. Industry A+ standards include eliminating farm debris and reducing waste.

2.10 Hydrodynamic alteration of flows

Table 2.9: Overview of potential hydrodynamic alteration of flows from shellfish farming.

Definition	Effects of shellfish aquaculture on the physical attributes of the water, including currents, stratification and waves
Summary of potential effects	• Farm structure altering and reducing current speeds, potentially affecting biological processes, such as phytoplankton production and depletion at locations distant to the farm site • Effects on stratification through vertical mixing and partial blocking of some water layers • Wave dampening may affect shoreline habitat, erosion and sediment transport
Management and mitigation options	• Alternative farm designs or structures, for example, submerged structures • Modelling and monitoring of hydrodynamic effects
Knowledge gaps	• Effect of fouling on hydrodynamics • Effects on currents at small to large scales (metres to kilometres)

[20] Water Quality Guidelines Home

	• The effect of orientation of long-lines to the direction of wave travel • Whether different longline stocking densities and designs significantly alter wave and current attenuation
Key terms defined in glossary	Bay-wide, depositional footprint, intertidal, phytoplankton, staged development, stratification, water column, water residence time, wave attenuation

2.10.1 Summary of potential effects

Hydrodynamics in this section refers to the physical attributes of the water, including currents, stratification, and waves. Mussel and oyster farming both rely on, and influence, hydrodynamic conditions of the environment.

The physical presence of farms can alter and reduce current speeds, which affects water residence times and has implications for associated biological processes, such as phytoplankton production and depletion. Mussel farms can alter currents at local, bay-wide and even regional scales, in some cases. The scale of the effect depends on the size and layout of the farms and their location. Generally, the effect is strongest within the farmed area and decreases with distance, although for large farms in some locations (e.g. near entrances to bays, or estuaries), noticeable changes in currents can still occur in areas distant to the farm structures.

The main effect of suspended farming on vertical stratification is increased vertical mixing due to friction from farm structures on water flow. In the case of oyster farms, the structures may extend to the seabed, but for longline mussel farming, growing-rope structures will not touch the seabed. Effects on vertical mixing will therefore vary with the farming structures used and the magnitude of stratification and currents in the environment in and around the farm.

Some degree of wave dampening will occur for any shellfish structure with surface or near surface structures, due to the wave drag on the suspended crop and farm structures. A wave "shadow" of reduced wave energy may extend beyond the farmed areas, potentially affecting shoreline habitat and sediment transport. The wave dampening effect is likely to be undetectable for small farms or in sheltered areas where wave energy is low.

The intertidal farming of oysters has historically been associated with larger effects on hydrodynamics due to the frame structures occupying the full cross section of the water column and being in contact with the seabed. However, recent developments in floating structures for growing oysters means that these effects may now be reduced when these structures are used.

2.10.2 Significance of effects

International experience shows that when suspended aquaculture covers most of a bay, current speeds can be significantly reduced throughout the bay, including within navigation channels left between farm structures. In New Zealand, aquaculture is less intensive, typically using less than 10 percent of a bay in enclosed waters such as the Marlborough Sounds. Even at this low intensity, modelling indicates that farms can still alter current speeds at locations distant to farm structures. At the farm densities typically used in New Zealand, these hydrodynamic changes are expected to be of little ecological relevance, and evidence suggests that hydrodynamic effects are small. However, if farm densities, or sizes, were to increase substantially in future, there may be a risk of more pronounced effects. Overall, the hydrodynamic impacts of marine farms on their own are generally small compared with other influences on the marine environment (i.e. wind, river or tidal influences).

The physical effects from farm structures on hydrodynamic conditions will persist for as long as the structures and crops remain in place, but recovery can occur almost immediately once they are removed. In contrast, the seabed and associated communities may take longer to recover from cumulative changes resulting from altered currents in combination with other effects.

2.10.3 Management or mitigation options

If changes in hydrodynamics are a key concern, models and monitoring can be employed to estimate the magnitude of change. However, these techniques are unlikely to be required if the effects from the farm (or other cumulative effects) on hydrodynamics are likely to be minor.

The effects of shellfish structures on local and bay-wide currents, circulation, stratification and waves can be predicted using analytical and numerical models. This information can help predict possible hydrodynamic and physical changes (e.g. temperature, salinity) and identify ways to mitigate these effects – for example, using alternative farm designs or submerged structures.

Monitoring of hydrodynamic conditions before and, if necessary, during staged development could be used to ensure that effects are in line with estimated effects. The duration of such monitoring should be sufficient to capture a range of tide, wind and stratification conditions.

3. ECOLOGICAL EFFECTS OF FARMING FISH

3.1 Introduction

This section provides an overview of the potential ecological effects associated with farming finfish at sea in New Zealand, based on the commercially farmed Chinook salmon (*Oncorhynchus tshawytscha*), and two species with potential to be commercially farmed, yellowtail kingfish (*Seriola lalandi*)[21] and snapper (*Pagarus auratus*) (see Figure 3.1).

The marine finfish aquaculture industry in New Zealand is small in comparison with many other countries and based primarily around cage (or "net pen") farming of Chinook (or king) salmon at sites in the Marlborough Sounds, Akaroa Harbour and Big Glory Bay (Stewart Island / Rakiura). There is growing interest in expanding the industry into new areas, particularly sites with greater capacity to disperse farm-derived organic waste, such as deeper, higher-current environments, including more exposed and open ocean[22] locations.

This section summarises information from the *Literature Review of Ecological Effects of Aquaculture*. While the literature review remains a key reference, it has not been reviewed since 2013 and some information may now be outdated. To address this, a new appendix for the literature review has been prepared, comprising a bibliography that summarises the principal additions to the original review, alongside an abbreviated list of references most relevant to those updates. Readers can refer to the literature review for additional background; however, this document provides the most current context on regulatory, policy, technological and research developments relevant to the ecological effects of finfish aquaculture[23].

Aquaculture effects occur within the context of (and potentially interacting with) other natural and human-influenced processes. These interactions and possible cumulative effects are discussed in Section 5.

[21] Yellowtail kingfish are currently being produced at a land-based recirculating aquaculture system located in Ruakākā, operated by Earth Sciences New Zealand.
[22] Open ocean aquaculture generally refers to aquaculture undertaken outside of semi-enclosed bays, harbours or other sheltered coastal environments, typically in more exposed or offshore locations.
[23] The Tasmanian Aquaculture Environment Review Series by the University of Tasmania Institute for Marine and Antarctic Studies also provides a thorough review of the environmental effects of finfish aquaculture in both a Tasmanian and international context.

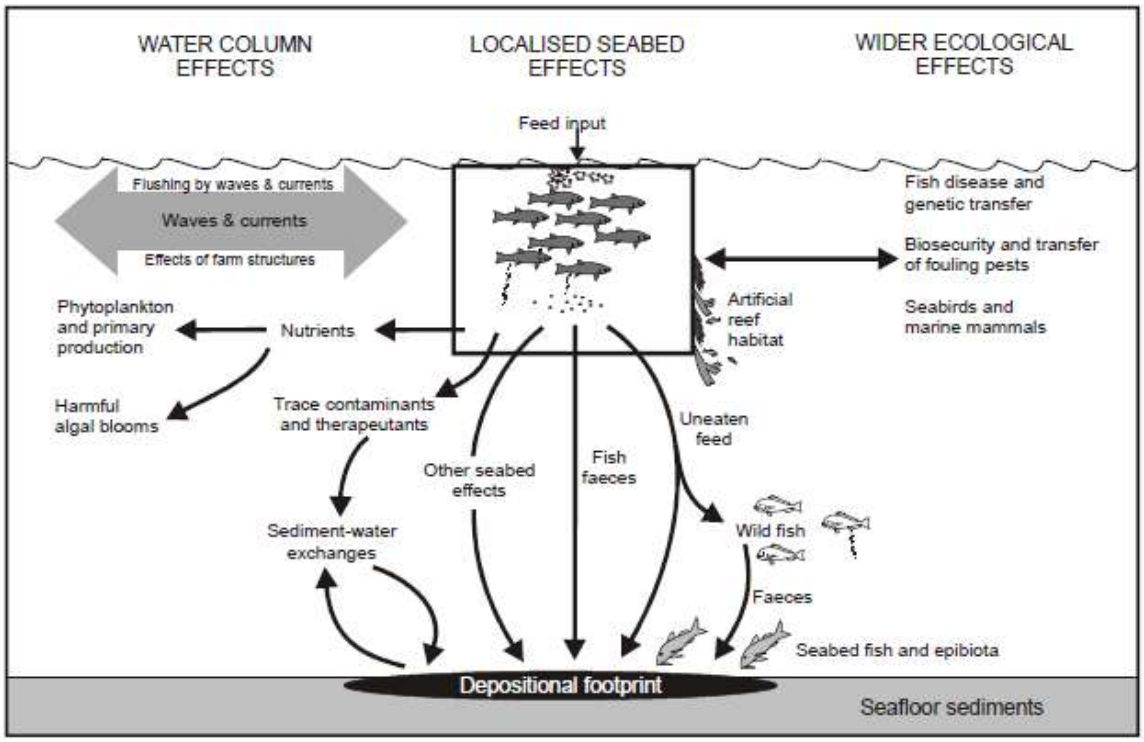


Figure 3.1: Schematic of actual and potential ecological effects from finfish aquaculture. Source: Forrest et al. (2007). Note that this schematic applies primarily to inshore aquaculture; operations located in highly dispersive environments are likely to exert different pressures on the receiving environment.

3.2 Water column effects

Table 3.1: Overview of potential water column effects of finfish farming.

Definition	Effects of finfish aquaculture on the water column at approximately the scale of the farm
Summary of potential effects	• Nutrient enrichment effects • Depletion of dissolved oxygen
Management and mitigation options	• Careful site selection • Optimise farm management practices to control stocking densities and limit feed wastage • Monitoring of water quality and ongoing adaptive management • IMTA / ecological aquaculture
Knowledge gaps	• Baseline water quality in key growing regions • Effectiveness of multi-trophic approaches
Key terms defined in glossary	Adaptive management, bay-wide, benthic, biofouling, biomass, carrying capacity, chlorophyll-a, cumulative effect, eutrophication, farm-scale, feed conversion ratio (FCR), IMTA, nutrient enrichment, phytoplankton, trigger level, water column

3.2.1 Summary of potential effects

This section summarises the potential ecological effects of finfish farming on the water column at the scale of a finfish farm. Broader, bay-wide effects on the water column and wider ecosystem are discussed separately in Section 5.

Farmed finfish require feed inputs from manufactured diets, so most ecological effects associated with their production on the water column are related to their waste products (faeces, uneaten feed and excreted ammonium) entering the ecosystem and changing the concentrations of nutrients (see below). If unmanaged, the input of new nutrients associated with finfish feed can create eutrophication issues – unlike shellfish, which excrete similar waste products but feed on existing nutrients from the environment and remove nutrients from ecosystems when they are harvested. Nutrient changes are primarily associated with ammonium excretion from fish, which may affect phytoplankton biomass or alter phytoplankton species composition. However, in New Zealand no Harmful algal bloom (HAB) events have been directly linked to finfish farming. Harmful algae are of concern to aquaculture due to their potential to impact the safe consumption of seafood, cultured species and other marine life.

Particulate organic wastes expelled into the water column can settle onto the seabed near the farm, so this section should be read in close conjunction with Section 3.3. The subsequent breakdown of any organic wastes from a farm and respiration of cultured fish can also increase the availability of dissolved nutrients and metals from sediments, decrease dissolved oxygen concentrations and increase water acidity (i.e. decrease pH), which are important for wider ecosystem health. In addition to the reduction of dissolved oxygen through organic matter breakdown on the seafloor, fish respiration can decrease dissolved oxygen and increase carbon dioxide concentrations in depths at which they are farmed.

3.2.1.1 Nutrient enrichment effects

The addition of nutrients to the water column through fish wastes and uneaten feed can potentially stimulate phytoplankton growth and cause changes in phytoplankton species composition. In New Zealand's temperate waters, nitrogen (N) is likely to be the nutrient potentially limiting phytoplankton growth under most conditions. Nutrient enrichment beyond natural levels can result in eutrophication: natural or artificial nutrient enrichment in a body of water. In extreme, hypereutrophic scenarios, this can be associated with extensive plankton blooms and the subsequent reduction of dissolved oxygen. Evidence from New Zealand's most intensive salmon farming areas in the Marlborough Sounds suggests that eutrophic conditions are not evident at the present farming locations and levels of aquaculture.

Given historical increases in coastal nutrients from land-based activities in New Zealand, additional nutrients from finfish farming could exacerbate existing water column issues. However, marine finfish farming in New Zealand typically occurs in areas with limited terrestrial inputs and new consents are associated with offshore waters. Relevant to offshore environments is the emerging evidence that some warming surface waters around New Zealand are restricting mixing and upwelling of nutrients into surface waters. Consequently, the role of new nutrients from finfish farming may counteract such climate-induced trends in nutrient reduction.

A concern with water column nutrient enrichment is the potential for an increased occurrence of HABs, including blooms of species that produce biotoxins. Finfish farms are only one source of nutrients in the marine environment, with oceanic upwelling and land-based sources also contributing nutrients to regions where finfish farming occurs. If a HAB event occurs, biotoxins can be directly toxic to fish, and others can accumulate in shellfish and affect consumers, often leading to restrictions in harvesting shellfish.

In New Zealand, no HABs have been directly linked to finfish farming. However phytoplankton blooms, including HABs, have been recorded in the Marlborough Sounds, Akaroa Harbour and Big

Glory Bay, all areas where finfish farming occurs. The occurrence of these species appears to reflect broader regional patterns driven by oceanic or climatic processes rather than salmon farming activities. Nonetheless, the potential for additional nutrient inputs from farms to enhance the abundance of harmful species theoretically remains when nutrient-limited conditions exist (e.g. in summer). To limit potential phytoplankton growth, it is therefore important to site finfish farms in areas with high currents and to manage fish biomass and feed inputs carefully.

Nutrient enrichment may also lead to changes in phytoplankton species composition by changing the ratios of nutrients (for example, an increased nitrogen:silica ratio may favour the growth of dinoflagellates rather than diatoms). This could potentially lead to changes in the occurrence of harmful phytoplankton; however, evidence of such changes is not apparent in data collected in New Zealand.

3.2.1.2 Depletion of dissolved oxygen

Depletion of dissolved oxygen can occur within and around finfish farms due to the respiratory demands of the farmed fish and the microbial degradation of phytoplankton, and waste materials in both the sediments and the water column. Oxygen levels within the fish pens are of direct concern to farmers, as adequate oxygen levels are essential for fish health and performance.

Severe oxygen depletion in the water column has the potential to stress or kill farmed fish and other marine organisms. In the sediments, low-oxygen conditions can result in an increase in porewater acidity (i.e. a pH reduction) and the release of toxic by-products (such as hydrogen sulphide, methane or metals) from the seabed into the overlying water, which can also have adverse effects on farmed fish and other organisms.

Decreases in dissolved oxygen through organic matter breakdown on the seafloor are generally more of a concern for the health of the seabed than fish respiration. This is because finfish are typically farmed near the surface, where diffusion of atmospheric oxygen and mixing by currents can mitigate effects.

3.2.2 Significance of effects

Elevated nutrient concentrations in the water column are most evident during low-flow conditions (e.g. around slack tide) and within the finfish farm. Dissolved nutrient concentrations typically rapidly decrease with increasing distance from the farm due to dilution and uptake processes by phytoplankton and bacteria. The intensity and spatial extent of enrichment is highly site-specific, with deep, high-flow sites producing larger but more diluted footprints. There has been no evidence of HABs being caused by salmon farm-related nutrients in New Zealand. However, HAB events occasionally occur near farming activities, with farm-derived nutrients theoretically able to contribute to the magnitude, or longevity, of such events.

Reduced oxygen levels in the water column in and around finfish farms have been documented internationally, particularly when cages are heavily stocked or located in shallow, weakly flushed sites. In New Zealand, salmon farms are generally sited in areas with sufficient water movement and flushing, and as a result, dissolved oxygen concentrations are typically well maintained.

The significance of the effects of nutrient enrichment, or oxygen depletion, depends on the nature of the receiving environment and the intensity of the farming activity. In shallow areas with slow currents, the localised effects will be more pronounced compared to a deep site with strong flow and good flushing. Water column effects can be controlled through feeding rates and control of farmed biomass, with effects reversible upon removal of the farm.

3.2.3 Management and mitigation options

Effects on the water column can be mitigated by siting farms in deep, well-oxygenated areas with high current flows to widely disperse farm-derived wastes. Additional mitigation is achieved through farm management practices such as controlling stocking densities and minimising feed wastage. There are several other design and management factors that strongly influence the potential effects on the water column:

- Density of farms – a greater number of farms within an area generally increases cumulative effects (see Section 5).
- Stocking density – higher stocking biomass densities typically result in a need for greater feed inputs and higher localised impacts.
- Cage designs, biofouling management and farm layout – these factors influence hydrodynamic drag, water exchange through cages and the settlement of biofouling organisms.
- Oxygen supplementation – can be used to increase dissolved oxygen in sites where fish or ecosystem health may be at risk.

The feed conversion ratio (FCR) reflects the efficiency of converting dry feed into wet fish biomass, with global averages for salmon typically ranging from 1.1 to 1.8, with reported New Zealand farmed Chinook salmon near the higher end of this range. FCR rates generally vary over the growth stages of the fish and environmental conditions, with larger fish in warmer waters associated with higher FCRs. Lower FCRs indicate more efficient feeding and therefore reduced waste production. For example, a reduction in feed wastage at Marlborough Sounds salmon farms was achieved by advances in automated salmon feeders (shut-off signals linked to underwater cameras that detect waste feed), resulting in significantly less waste feed. The use of higher-quality feed and improvements in FCRs can both result in reduced impacts on water quality through reductions in waste nutrients and organic matter. Reducing feed wastage may also mitigate effects on wild fish populations (see Section 3.5).

Monitoring, adaptive management and the use of multi-trophic approaches are also potential mitigation measures for water column effects; for additional information, see Sections 5 and 6.

Monitoring the water column for key parameters of nutrient enrichment will support good management practices to ensure water quality is maintained. A monitoring programme at a regional or bay-wide level, with farm and control sites in alignment with prevailing hydrodynamic regimes, is particularly relevant if there are multiple farms (both finfish and shellfish) and other significant nutrient inputs in the proximity. Typically, wider monitoring of the state of the environment is conducted by regional councils in New Zealand, rather than individual aquaculture consent holders.

Historically, long-term regional monitoring programmes have been limited across much of New Zealand's coastline, constraining the ability to assess changes to the water column associated with the development of aquaculture. However, in recent years several regional councils have implemented regular sampling of coastal nutrients and phytoplankton biomass (through chlorophyll-*a*), providing a valuable dataset for identifying potential trends or changes in these water column properties over time. These data also support the calibration and validation of regional models, improving their accuracy. Biophysical modelling for finfish aquaculture in New Zealand remains limited and inherently complex. Accurately predicting future and cumulative effects requires a large repository of data that captures variability in key environmental and farm-related parameters.

In the absence of long-term environmental monitoring datasets, baseline monitoring prior to the establishment of new finfish farms is important to describe the existing water quality of a region. Baseline monitoring should be undertaken over periods long enough (a minimum of one year) to start to address at least the seasonal, temporal and spatial variations in nutrient concentrations and phytoplankton that naturally occur there. The availability of high-quality, daily satellite data from 2002 onwards can also provide a useful long-term measure of surface chlorophyll-*a* and turbidity for

many areas of New Zealand, although it may not be suitable in areas with narrow waterways (e.g. the Marlborough Sounds) or areas with frequent cloud cover.

Once a farm is operational, monitoring of water quality can be undertaken based on appropriate thresholds and trigger levels. When setting water quality thresholds and trigger levels, it is important that any monitoring results that exceed these levels trigger a more intensive investigation to establish a cause-and-effect relationship, and to inform the need for an appropriate mitigation response.

Baseline and compliance monitoring of the farm-scale water column for water quality parameters typically include:

- phytoplankton (chlorophyll-*a*, phytoplankton abundance, species composition);
- dissolved oxygen;
- nutrient concentrations (dissolved carbon, nitrogen, and phosphorus);
- clarity;
- macroalgal biomass; and
- other indicators of trophic state.

3.3 Benthic effects

Table 3.2: Overview of benthic effects of finfish farming.

Definition	Effects of finfish aquaculture on the seabed
Summary of potential effects	• Localised organic enrichment of the seabed beneath the farm • Smothering of benthic organisms by biodeposits • Biofouling drop-off and debris • Seabed shading by structures • Widespread biodeposition • Sediment contamination (see Section 3.9)
Management and mitigation options	• Careful site selection • Optimise farm management practices to control stocking densities and limit feed wastage • Monitoring of seabed health and ongoing adaptive management
Knowledge gaps	• Manifestation, resilience and recovery of non-soft-sediment habitats to finfish farm biodeposition, including possible effects of low levels of enrichment on biogenic habitats, and the assimilative capacity and recovery dynamics of novel sediment habitats (e.g. coarse sediments) • Sub-lethal responses of key invertebrate taxa to organic enrichment, including the development of indicators and thresholds for detecting physiological and ecological change • Management approaches for non-soft-sediment habitats, including development of appropriate environmental indicators and assessment criteria • Comparative recovery rates at high-flow sites • How much biofouling drop-off contributes to benthic enrichment over and above feed and faeces deposition • Lack of information quantifying the contribution of different farm practices to drop-off
Key terms defined in glossary	Adaptive management, anoxic, azoic, benthic, biodeposition, biofouling, biomass, depositional footprint, EQS

Early research on the ecological effects of finfish farming, internationally and in New Zealand, tended to focus on the most noticeable effects – typically those to the seabed beneath and adjacent to the farm arising from the deposition of organic waste (faeces and uneaten feed) from the farmed fish. The response of the benthos to organic enrichment is well studied for sheltered soft-sediment habitats as these are the habitats over which fish farms have historically been sited. Knowledge of how other habitat types respond to organic enrichment is relatively poor. With the expansion of finfish farming into open ocean areas, where organic deposition is more likely to overlap with structurally complex benthic habitats (e.g. shellfish or bryozoan beds), addressing this information gap is becoming increasingly important.

Preliminary work undertaken through the Environmental Health Measures for Open Ocean Aquaculture (OOA) project examined sub-lethal stress responses in scallops, brachiopods and horse mussels exposed to salmon farm-derived organic enrichment in laboratory and field settings in the Marlborough Sounds. While promising physiological stress indicators and thresholds for stress responses were identified, additional research is needed to refine these indicators and validate their application in other key taxa such as sponges and bryozoans.

Other potential effects to the seabed resulting from accumulated trace contaminants (from nutritional additives, antifoulants and therapeutants) are discussed in Section 3.9.

3.3.1 Summary of potential effects

3.3.1.1 Localised organic enrichment of the seabed

The dominant effect on the seabed arises from the deposition of faeces and uneaten feed falling to the seafloor, which leads to enrichment of the seabed due to the high organic content of the deposited particles. In soft-sediment habitats, organic enrichment (and the increased microbial activity associated with breaking down the organic matter) can dramatically alter the chemistry and ecology of the seafloor beneath the farm. For example, it can change well-aerated and species-rich soft sediments in the vicinity of farm cages into anoxic (oxygen-depleted) zones dominated by only a few sediment-dwelling species tolerant of the degraded conditions, or in extreme cases, can approach azoic conditions (devoid of life). The type of animals living within the sediment (infauna) will also change, with a reduction in diversity and elevated numbers of a few common opportunistic species.

The depositional footprint of a typical "inshore" finfish farm extends tens to hundreds of metres from the cages. In the context of open ocean aquaculture, farm developments generally target areas with increased depth, water currents or wave exposure, which will likely disperse organic wastes further (kilometres) and reduce depositional intensity.

Effects tend to be most evident directly beneath the farm cages and exhibit a strong gradient of decreasing effect with increasing distance. However, recent depositional modelling performed in dynamic coastal and open ocean areas indicates that organic waste may become entrapped and accumulate in some areas (i.e. 'hotspots') – for example, where current patterns and seabed roughness vary spatially. These factors may lead to patchiness in the organic effects footprint.

Smothering of benthic organisms by biodeposition can occur in addition to the organic enrichment effects on the seabed. Smothering effects tend to be more localised than enrichment effects because they are more prevalent at low-flow sites that have smaller, more concentrated depositional footprints.

3.3.1.2 Biofouling drop-off and debris

Drop-off of biofouling organisms to the seabed is most obvious around the perimeter of farm cages. Drop-off can occur naturally (sloughing and natural drop-off) and via net cleaning operations. Biofouling drop-off and debris can potentially contribute substantially to localised organic enrichment and smothering.

Biofouling drop-off and elevated biodeposition can attract aggregations of scavenging and predatory organisms, such as sea cucumbers, sea stars, crabs and sea-lice (isopods). Under highly enriched conditions, these fauna are often displaced from sites directly beneath the cages and instead tend to aggregate around the perimeter of the cages.

3.3.1.3 Seabed shading by structures

The presence of farm structures may decrease the amount of natural light reaching the seabed through shading, potentially reducing algae productivity or affecting organisms on the seafloor that rely on photosynthesis. Such changes are relatively more likely in naturally clear waters. Although shading has been identified as a potential effect, no studies to date have been able to separate its influence from the more dominant effects of benthic enrichment.

3.3.1.4 Widespread biodeposition

Widespread but low-level benthic enrichment can occur beyond the primary depositional footprint, particularly in nearby natural depositional areas (such as blind bays). In most cases, deposition rates in these areas are likely to be low enough to be naturally assimilated, and any resulting effects are expected to be subtle and difficult to detect. However, such effects may become cumulative when multiple farms operate within an area (see Section 5).

3.3.1.5 Seabed contamination

Therapeutants used on farm and biodeposits from uneaten feed and faecal material can lead to the contamination of sediments, which may have toxic effects on seabed communities. These are described further in Section 3.9.

3.3.2 Significance of effects

The primary effect of finfish farming on the seabed is the deposition of organic waste, which leads to the enrichment and subsequent degradation of benthic habitats. This enrichment can cause pronounced, localised effects directly beneath the finfish cages, but environmental conditions typically improve rapidly with increasing distance from farm structures (over tens or hundreds of metres). Patterns of sediment contamination (e.g. metals) arising from uneaten feed and faecal material generally follow a similar gradient to those of organic enrichment.

The magnitude of seabed effects is determined mainly by the flushing characteristics of a site and the intensity of farming activities (including stocking density, feed inputs, feed digestibility and overall biomass). Clear contrasts between high- and low-flow environments are evident in salmon farming within the Marlborough Sounds, as described in the literature review. Effects are substantially less intense at high-flow, dispersive sites than at low-flow sites. For example, organic accumulation tends to be minimal in high-flow areas due to greater resuspension and the export of particles, although infaunal communities may still show noticeable changes. In more dispersive offshore environments targeted for open ocean finfish farming, organic deposition is expected to be more diffuse, resulting in less intense local-scale enrichment but with a greater potential for widespread, low-level enrichment.

Biological benthic effects in soft sediments are generally reversible, although recovery may take many months to years, depending on the site's water flushing characteristics and the degree of impact. At well-managed farms, substantial recovery can occur relatively quickly, often within the first three to 12 months after farming ceases. The seabed is mostly recovered in the medium to long term, typically over several months to years, with low-flow sites in New Zealand estimated to require around five to 10 years for full recovery. Recovery timeframes for other seabed habitat types are poorly understood, but as with soft sediments, they are expected to depend on the degree of impact.

3.3.3 Management and mitigation options

This section focuses on inshore coastal finfish farms. Although in principle it is generally applicable to fish farms in more exposed open ocean areas, MPI has provided specific guidance for open ocean benthic effects monitoring and management elsewhere (Giles et al. 2021).

3.3.3.1 Careful site selection

Seabed effects from finfish farming can be partially mitigated through careful site selection. Farms located in deeper, well-flushed environments experience less intense localised enrichment. In New Zealand, salmon farms are commonly sited over muddy habitats, which helps minimise habitat modification and avoid impacting on the biodiversity of more complex and potentially sensitive seabed habitats.

3.3.3.2 Farm management practices

Farm management practices that control stocking densities, optimise feeding and farm production, and limit feed wastage can also be effective in reducing effects on the seabed (as well as effects on the water column; see Section 3.2.3). At salmon farms in the Marlborough Sounds, the use of higher-quality feed, improved FCRs and advanced automated feeding systems have reduced feed inputs and feed wastage, which can reduce seabed impacts. For salmon farming, the mass of feed used is a primary driver of the level of seabed impact, and adjustments to a farm's annual feed limit are an effective mitigation tool.

For finfish farms in the Marlborough Sounds (see the Environmental Protection Authority webpages for more information), scientists calculated the predicted sustainable feed level (PSFL), taking into account each site's physical characteristics (e.g. depth and water currents), and then set the recommended initial feed level at 75 percent of the PSFL. Adjustments to the feed levels are specified in the consent conditions to ensure ongoing compliance with seabed standards.

Fallowing can be employed, either as an extreme response to excessive (or non-compliant) levels of enrichment effect on the seabed, or as part of a farm rotation schedule (see text box below).

Farm fallowing and rotation

One approach used to mitigate the effects of the farming activity on the immediate environment is to rotate finfish cages between different sites or positions within a lease area over a regular period. This allows the seabed to recover (at least partially) before the farm is re-established, and is known as fallowing. Fallowing is often necessary from an operational perspective, for example to break a disease or parasite infestation cycle, or for single year class farms. To work effectively, fallowing and rotation require multiple sites within a region or a large consented area appropriate for finfish farming.

The benefits of fallowing and cage rotation have been demonstrated (to a limited extent) overseas at sites where seabed recovery can occur within less than six months. Other overseas examples, and experience at salmon farm sites in the Marlborough Sounds, indicate that seabed recovery may take many years, whereas enrichment effects can become well advanced within a matter of a few months from the time a farm is restocked. In this case, the effectiveness of a fallowing strategy is reduced as a large number of alternate sites may be required to make the practice viable, or feed loadings may need to be reduced. It may be preferable to confine seabed effects to a single site rather than spread the effects over a greater area.

The suitability of fallowing and rotation as a farming strategy will therefore be case-specific, dependant on cage design, feed intensity, environmental characteristics and the area available for farming. An example of a rotational farming strategy is that employed in Tasmania, Australia, where polar circle finfish cages are rotated within large (typically 20 to 25 hectares) consented areas. The benthic effects are monitored within and outside the lease areas and managed within approved standards.

3.3.3.3 Monitoring and ongoing adaptive management

Regular monitoring of seabed health, combined with adaptive farm management responses informed by those results, helps manage benthic effects to within acceptable limits, both spatially and in terms of impact level. Acceptable environmental limits are typically defined in resource consent conditions. Although there are often more stringent environmental limits in place, it is international best practice to prohibit seabed conditions becoming anoxic and azoic beneath finfish farms.

Monitoring of seabed health beneath existing or proposed finfish farms involves taking measurements of sediment properties inside and outside the farm site, to predict the level and the spatial extent of enrichment effects. Infaunal communities (animals living in the sediment) are well-recognised indicators of seabed health or enrichment status, and environmental DNA (eDNA) techniques are also being increasingly recognised as reliable biological indicators of seabed health. Sulphide concentrations (μM) and redox potential (Eh_{NHE}, mV) are often used to indicate the oxic status of the sediment. The composition of the sediment also indicates seabed health, using measurements of the proportion of fine mud, sand and shell / gravel, the organic matter content, and the redox depth (an approximation of the depth at which sediment becomes anoxic). These values are compared to the average values for other sediments in the region, including at control sites beyond the influence of the farm.

Depositional modelling can be used to predict the spatial extent and magnitude of depositional effects to the seabed. These models estimate the distance and direction fish farm wastes could travel before reaching the seabed, considering local water current speed, water depth, and the time it takes for particles to settle to the seabed. These models also estimate the amount of deposition that is likely to occur at increasing distances from the farm, and can be used to predict levels of resuspension and redistribution of particles.

Seabed health can be managed using adaptive management, such as the "zones approach" that defines spatial zones of enrichment around a finfish farm and sets environmental quality standards (EQS) for compliance within each zone (see Figure 3.2 and text box below). Zone boundaries can be skewed in the direction of prevailing currents to more accurately reflect the depositional footprint. Another adaptive management approach used in New Zealand, the Limits of Acceptable Change approach, is discussed in more detail in Section 5.

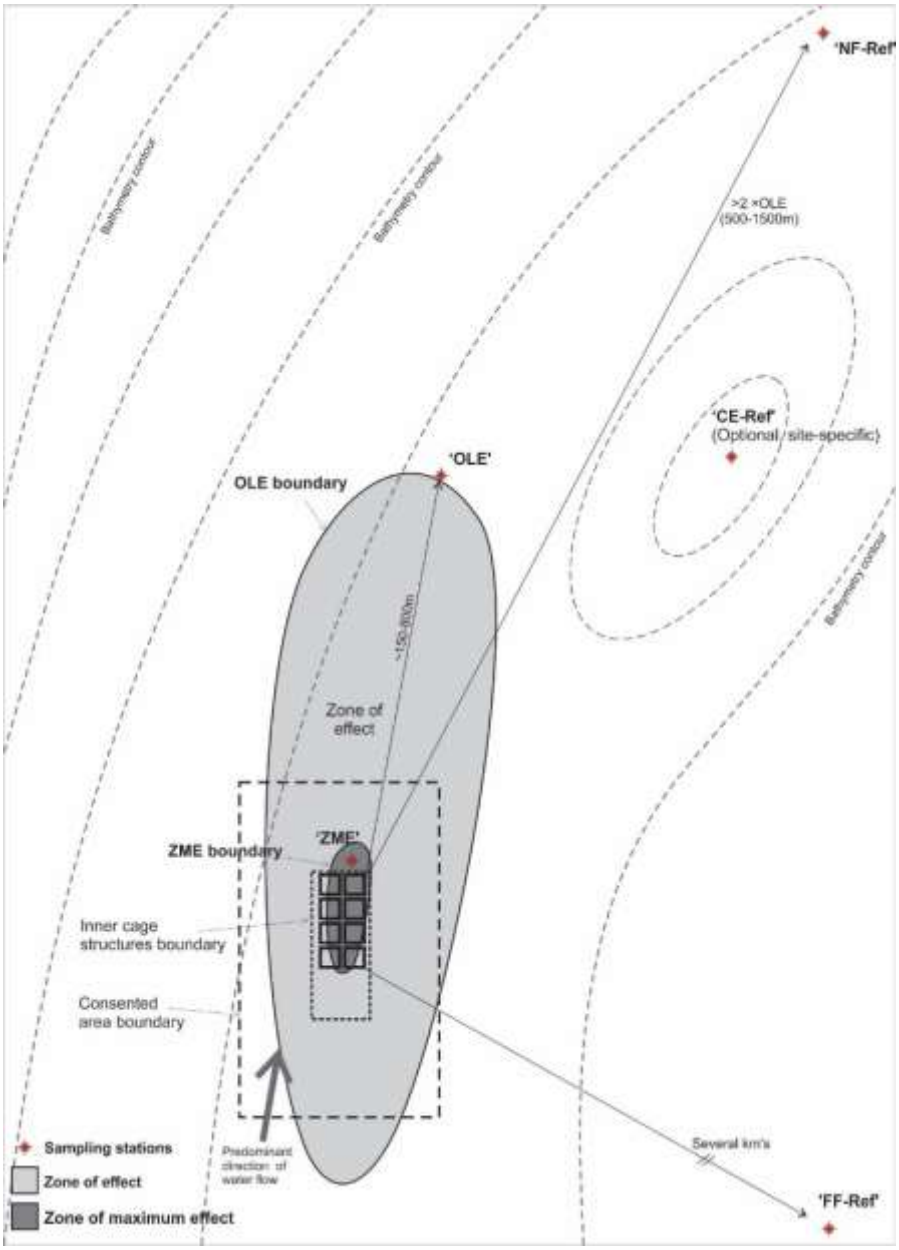


Figure 3.2: Conceptual approach to defining seabed impact zones, adapted to the environmental conditions present at more dispersive sites. Source: Fletcher et al. (2022).

An example of adaptive management – the zones approach and EQS

New Zealand King Salmon have used the zones approach to manage salmon farm sites in the Marlborough Sounds since 2003. It is a complex framework and more detail is in the literature review (McGrath et al. 2026).

EQS are critical to the approach as they provide the quantitative criteria against which effects are assessed. EQS are measurable environmental values that are ecological indicators of certain stages of enrichment (such as sediment characteristics, abundance and diversity of infauna, or the presence of the bacterial mat *Beggiatoa*). They are typically linked to defined zones of impact (see Figure 3.2).

At each zone, the EQS are compared against a pre-defined enrichment gradient (Figure 3.3) with a scale of 1-7 (termed enrichment stage). Enrichment stage 1 is considered "pristine", while enrichment stage 7 is extremely enriched, with no oxygen or infauna in the sediment.

Enrichment stage 5 is the stage of greatly enhanced seabed productivity, showing extreme proliferation of one or a few enrichment-tolerant opportunistic species. Enrichment stage 5 is usually the recommended upper level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds. At enrichment stage 5, the seabed is still considered biologically functional and associated with the greatest biomass and is, therefore, thought to have greatest waste assimilation capacity. Stages beyond enrichment stage 5 are characterised by extremely impacted sediments.

Each of the seven enrichment stages has been validated for the Marlborough Sounds by the Cawthron Institute (and may need some validation prior to use in other regions).

Enrichment stages can be used as EQS trigger points for resource consent conditions that specify tiered responses to non-compliance. For example, a consent condition could specify that enrichment stage 5 is the maximum allowable standard at the zone boundaries, and any breach of this standard could then require a decrease in feed levels or the fallowing of the farm.

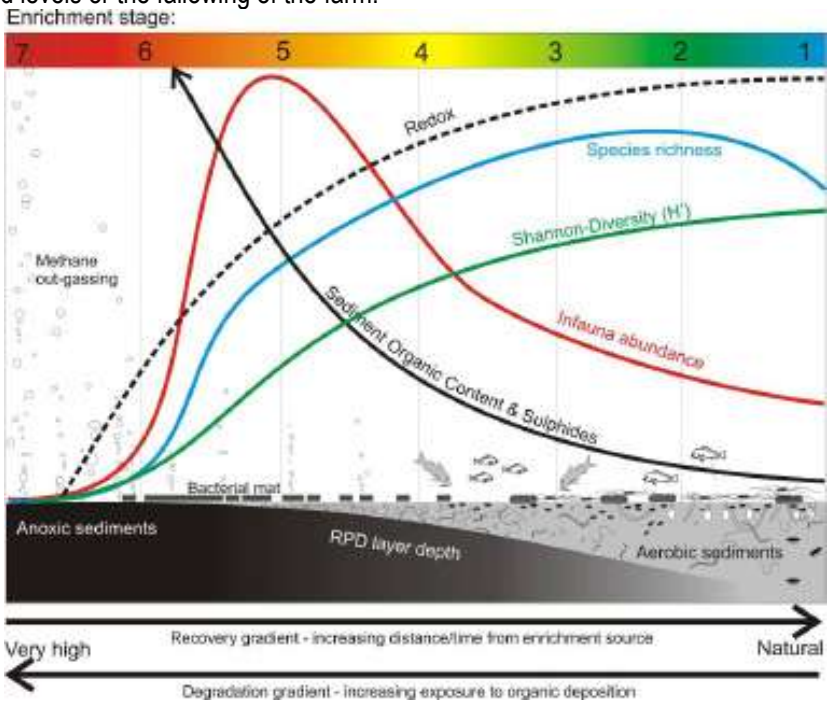


Figure 3.3: Enrichment gradient profile showing enrichment stages 1 through 7 and corresponding expected changes in infauna, sediment organic content and sulphide and redox levels, for a typical low-flow site. Source: Cawthron Institute.

3.4 Marine mammal interactions

Table 3.3: Overview of potential marine mammal interactions with finfish farming.

Definition	Effects of finfish aquaculture on marine mammals
Summary of potential effects	• Habitat exclusion or displacement • Entanglement (potentially resulting in injury or drowning) • Underwater noise disturbance • Vessel / propeller strike • Attraction to artificial lighting • Alterations in trophic pathways
Management and mitigation options	• Careful site selection • Discourage activities that could attract marine mammals to the farm • Minimise predator exclusion nets, or design nets to minimise the likelihood of entrapment, and consider predator-resistant materials • Regular maintenance of farm structures and predator nets, including keeping nets and anchor warps under sufficient tension • Ensure waste material and debris are collected and disposed of correctly • Minimise artificial lighting (husbandry, navigation, vessel) to reduce attracting prey fish and predators • Monitor and report interactions of marine mammals with farm structures
Knowledge gaps	• Ranges and locations of important habitats of marine mammal species • Design and maintenance features to minimise entanglement risk • Health implications for marine mammals that spend most of their time near farms • Health implications of underwater noise exposure for marine mammals
Key terms defined in glossary	Cetacean, conservation status, habitat exclusion, interaction, incident

3.4.1 Summary of potential effects

Documented effects of aquaculture on marine mammals relate mainly to habitat exclusion / displacement issues and entanglement in structures or farm debris. Depending on the size of the farm and nature of operations, other issues such as underwater noise disturbance, vessel strike and possible flow-on effects due to alterations in trophic pathways may also apply.

The presence of marine farm structures and their associated activities can potentially exclude or modify how particular species of marine mammals use critical or sensitive habitats, including foraging or feeding areas, resting or nursery areas, and migration routes. Current research in New Zealand suggests that exclusion or attraction effects depend on the type and scale of the farming method and the marine mammal species impacted. Most whales and particular dolphin species tend to be more sensitive and avoid disturbances, while other dolphin species (such as common and bottlenose dolphins) may be attracted to a novel food source (the farmed fish and any aggregations of wild fish). Pinnipeds, particularly New Zealand fur seals, are attracted to New Zealand salmon farms,

with individuals regularly found resting on structures and / or attempting to feed on fish in the pens. Presently, there has been little overlap between finfish aquaculture and the migratory paths of large whales in New Zealand waters. The development of large offshore finfish farms and the recovery of certain marine mammal populations (notably humpback whales) may result in greater overlap with whale migration routes, as well as increased interactions with larger pods of dolphins (with over 100 animals) and a greater variety of pinnipeds.

A potential adverse effect of attraction is entanglement. Previous New Zealand entanglements, along with overseas entanglement data (particularly from Australia), have helped inform which marine mammal species may be more vulnerable to entanglement risk, as well as which finfish farm configurations or gear may increase or reduce the risk. Pinnipeds (mainly fur seals in New Zealand) are the marine mammals most at risk of entanglement with finfish farms globally. Despite strong attraction, fatal entanglements of New Zealand fur seals are currently considered low and only 10 fatal entanglements of dolphins have been reported since the 1980s. Almost all animals drowned after becoming entangled in predator nets (with teeth, beak or fins caught), or when nets were no longer under tension during construction or maintenance changes (i.e. switching out predator nets) and the animal became trapped in the folds. However, while reporting of mortalities is required by law, regular monitoring and reporting of such interactions has not been required under resource consents for most New Zealand finfish farms. As a result, there are limited available data (less than 10 years of records) from only a few farms that report.

Associated closely with habitat exclusion is habitat degradation in the form of underwater noise disturbance, which is a consistent concern for marine mammals. Longer-term, chronic increases in overall underwater noise levels from vessels and harvesting operations may continue to attract some species, while more noise-sensitive species (e.g. beaked whales, pilot whales) avoid affected areas. However, there is currently no documented research on the noise associated with ongoing farm activities, nor on how such noise may affect local marine mammals.

The likelihood of vessels striking marine mammals depends on operational factors such as vessel type, speed and location. While aquaculture maintenance and harvesting vessels are generally slow moving, they operate day and night, and regularly transit between farms and ports on a daily or weekly basis.

There is also the potential for wider, more indirect ecosystem effects on marine mammals from finfish farming, including submerged lighting (when lighting is used) and possible food web alterations. New Zealand studies have found that submerged artificial lights used on finfish farms are mainly confined to within the cage structures and to mid-water depths. As a result, marine mammals will more likely be attracted to any increase in noise and activity of caged or wild fish in response to the lights, rather than the lights themselves. There is currently no documented research on how the indirect effects of finfish farming on local ecosystems may affect New Zealand marine mammals or their potential prey.

3.4.2 Significance of effects

Recent global and national reviews of aquaculture and marine mammals acknowledge that there is little empirical data on marine mammal responses to aquaculture or the results of their reactions (if any) to and with the farms, despite the presence of aquaculture in nearshore regions worldwide for more than 40 years. While current interactions between marine mammals and finfish farms in New Zealand are considered minor issues, we do not yet know if this is because farms are relatively benign, or because the density of farming, and / or reporting is too low to detect potentially significant interactions. Based on the evidence to date, the number of natural and anthropogenic factors that local marine mammals are subject to at a particular site also needs to be considered alongside any potential effects of aquaculture.

Overseas experience suggests that the potential for adverse effects exists with continued growth in both marine mammal populations and larger-scale, offshore farm developments. The significance of these effects may need to be reconsidered in relation to any future large-scale and / or offshore developments in New Zealand waters, particularly where endangered, threatened or range-restricted species are present. Species of particular concern include Hector's, Māui and bottlenose dolphins, as well as orca, Bryde's, southern right and humpback whales.

3.4.3 Management and mitigation options

Based on the available evidence from marine mammal interactions with finfish farms, management and mitigation plans are now focused on how to avoid interactions becoming fatal. Farm locations need to be carefully selected to minimise or avoid the likelihood of overlap with important marine mammal migration routes and known habitats, including the home ranges of range-restricted species and critical breeding or foraging habitats. To avoid physical interactions with farm structures, marine mammals need to have safe access around and between farm blocks, with particular attention to avoiding dead-end passages through appropriate farm spacing and block layout. The intent is to make animals (especially whales) aware of the structures, while discouraging them from entering farms by placing multiple structures as close to one another as possible, but allowing large passageways between farm blocks that are set parallel to migration paths.

Once sited, farms should develop marine mammal management plans that meet industry best practice and that clearly outline the protocols to be used to minimise interactions with species likely to occur in the area as part of resource consent planning. These plans should also define monitoring and reporting requirements and include a written entanglement response protocol with specified emergency actions. Both national and international records demonstrate that predator nets are the main cause of pinniped and cetacean entanglements in marine finfish farms. Predator nets should be avoided if possible, or if deemed necessary, should be made from predator-resistant materials such as stiffened lines with rigid or semi-rigid cores, or replaced with rigid frames that hold their shape (i.e. have no folds or loose bends) and have a mesh size that minimises the risk of predators penetrating the net with their head or flippers. Entanglement risks can be minimised further by adopting regular maintenance protocols and measures around farm structures, ensuring debris and waste material does not enter the water, keeping lines well maintained and always secured, and ensuring anchor warps are maintained under sufficient tension.

To avoid attracting marine mammals to finfish farms, noise-generating equipment, both above and below water, should be regularly maintained and non-essential lighting at night should be kept to a minimum. To reduce the risk of collision with marine mammals, farm vessels should maintain slower speeds around farms and keep watch for marine wildlife while in transit, in accordance with the farm's marine mammal management plan. Additional protocols and SOPs, such as collecting, appropriately storing and disposing of fish mortalities to reduce attraction, are also necessary and will likely benefit other marine wildlife, including wild fish and seabirds.

In general, farms should undertake regular and long-term monitoring of marine mammal presence and interactions with farm structures as part of their marine mammal management plan. Marine wildlife monitoring is also incorporated into the A+ standards for New Zealand salmon developed by Aquaculture New Zealand. For example, New Zealand King Salmon has a specific pinniped policy in conjunction with DOC, which provides guidelines for recording and reporting, but also includes requirements for handling pinnipeds that enter farms. The relevant DOC conservancy office should be contacted in the event of any marine mammal injury or entanglement.

3.5 Wild fish interactions

Table 3.4: Overview of potential wild fish interactions with finfish farming.

Definition	Effects of finfish aquaculture on wild fish populations
Summary of potential effects	• Effects on existing fish habitats • Attraction and aggregation of wild fish around farm structures (artificial habitat creation) • Alteration of existing fish habitats through biodeposition and feed waste accumulation • Attraction of predators to farm structures (e.g. sharks, seals) • Changes to local fish distribution, behaviour and productivity • Exposure to contaminants • Disease and parasitive interactions between wild and farmed fish • Consumption of waste feed by wild fish, influencing growth and condition • Influence on recreational and commercial fishing patterns and fishing pressure
Management and mitigation options	• Careful site selection to avoid critical fish spawning grounds and nursery areas • Minimise the use of lights above and below the waterline • Optimise feeding practices to minimise waste feed loss • Prompt removal of dead fish and minimisation of fish mortality • Implement predator monitoring and management measures (including for sharks), such as appropriate net design and maintenance, and site-specific management plans • Regular monitoring of wild fish interactions and environmental effects, where practicable • Consider farm spacing, layout and scale to reduce cumulative effects and interactions • Align assessments with relevant policy frameworks (e.g. the New Zealand Coastal Policy Statement [NZCPS])
Knowledge gaps	• The possible effects of farms on neighbouring habitats important to wild fish, such as rocky reefs • The amount of predation by caged fish on wild species attracted by submerged artificial lighting • Whether increased recreational pressure around farms has a negative effect on wild fish populations • Limited understanding of interactions between wild fish (particularly pelagic species) and offshore finfish farms • Lack of reliable methods to estimate feed loss and identify which wild fish species are most affected • Uncertainty around how aggregation affects wild fish behaviour, condition and population dynamics • Limited knowledge of disease and parasite transmission between wild and farmed fish • Uncertainty regarding contaminant uptake in wild fish • Uncertainty around cumulative effects of multiple finfish farms at larger spatial scales • Limited information on predator interactions (including sharks), particularly frequency, drivers and outcomes in New Zealand

Key terms defined in glossary	Benthic, biodeposition, ecological trap, UAE test, pelagic, organohalogenated contaminants

3.5.1 Summary of potential effects

There is limited information on interactions between wild fish and existing salmon farms in New Zealand, and even less is known about how offshore operations may interact with pelagic species and novel habitats. However, a substantial international body of research provides insight into interactions between wild and farmed fish, including studies focused on salmon farms and other finfish aquaculture systems.

3.5.1.1 Effects on existing fish habitats

The placement of a finfish farm directly above or adjacent to benthic habitats that are important to fish (such as spawning areas or rocky reefs) can impact wild fish populations through degradation of their habitat, particularly through biodeposition from fish faeces and waste feed (see Section 3.3). While direct deposition onto the seafloor is most likely to affect benthic species, suspended and resuspended material may also influence pelagic species and organisms in more distant habitats. In New Zealand, there is limited information on how individual species or subpopulations may respond, including the influence of feeding mode, life stage and seasonal variability, and the spatial extent over which these effects may occur.

3.5.1.2 Attraction of wild fish to farm structures

By adding three-dimensional structures to the marine environment, finfish farms create artificial habitats that attract and aggregate wild fish species seeking foraging habitat, food sources and refuge from predators (as well as providing habitat for colonisation by biofouling pests; see Section 3.7). This effect may be more pronounced if operations are large and positioned in shallow water, above rocky substrates and close to coastlines.

The use of submerged artificial lighting, which is frequently used on some finfish farms to control maturation and increase productivity, can also enhance the attraction of wild fish to farm structures. The footprint of submerged artificial lights is mainly confined to within the cage's structures and to mid-water depths. As such, wild fish along the bottom or further than about 10 metres from the cage structures are unlikely to be affected. Routine monitoring surveys of submerged artificial lighting at salmon farms in the Marlborough Sounds have not identified any discernible effects on nocturnal fish feeding activity around illuminated pens[24].

The attraction of wild fish to aquaculture structures can result in the secondary attraction of predators, or enhanced predation by the cultured fish and predatory species (for example, seals and dolphins). Generally, sharks may also be attracted to finfish farms, particularly to the presence of dead fish. As finfish aquaculture expands into offshore or more exposed environments that may be highly productive, interactions with pelagic predators such as sharks may increase. The white shark or great white shark is a protected native species in New Zealand and is classified as Threatened: Nationally Endangered. International observations indicate that white sharks may be attracted to aquaculture operations; for example, interactions have been reported at tuna farms in South Australia, where sharks have occasionally become entangled in nets after damaging netting. There is also potential for indirect attraction where prey species, such as New Zealand fur seals are drawn to farm structures. However, available evidence suggests that white sharks are typically transient around farms and are unlikely to establish long-term residency. The likelihood and nature of shark interactions are also expected to be site-specific, reflecting local species distributions, prey availability and environmental conditions.

[24] Surveys were carried out over 10 one- to two-week periods during the hours of darkness. Data were collected by farm staff over the course of three years when lighting was fully operational.

The attraction of wild fish to aquaculture structures can potentially lead to other related effects, such as changes in the local distribution and productivity of wild fish populations. This may occur where structures aggregate mobile fish species and influence their movement and feeding behaviour, in some instances acting as ecological traps if individuals preferentially remain associated with farms. The presence of finfish farms can also result in changes to fishing patterns and pressure which in turn could affect wild fish populations differently than in the absence of the structures.

If contaminants such as heavy metals (see Section 3.9) or organohalogenated contaminants (OHCs)[25] accumulate in sediments beneath farm structures, concentrations in wild fish tissues may also increase through exposure. However, the use of therapeutants and medications in New Zealand aquaculture is low compared with many international operations, and farmed fish are not currently treated for parasites. While parasite or disease loads in wild fish near fish pens could theoretically increase, international studies suggest that the risk is generally low. Transmission may also occur in the opposite direction, with farmed fish potentially exposed to parasites and pathogens originating from wild fish, although these transmission dynamics remain poorly understood.

3.5.1.3 Consumption of waste feed

Historically, feed loss from finfish farms has been identified as a primary driver of wild fish aggregation around farms overseas; this has been significantly reduced with improved feeding technology. Waste feed pellets may provide an alternative food source for wild fish outside of the cages, while populations of small fish living inside the cages may be supported by smaller feed particles. The shift from a natural diet to one comprising farm-derived waste feed can alter the body condition and reproductive success (potentially both positively and negatively) of wild fish.

3.5.2 Significance of effects

In general, the effects of finfish farms on wild fish populations are likely to be small in comparison with the effects on other aspects of the marine ecosystem.

The attraction of wild fish to waters surrounding finfish farms can have both positive and negative effects on their populations, including through habitat enhancement associated with farm structures and increased food availability from waste feed. Conversely, attraction may alter the local distribution and behaviour of wild fish, potentially increasing their vulnerability to recreational or commercial fishing pressures.

At present, there is limited information on how existing finfish farms in New Zealand affect wild fish populations in their vicinity, although international studies provide evidence of a range of interactions between wild fish and aquaculture operations. The magnitude and direction of these effects are likely to be site-specific and influenced by farm location, the species present and farm operational practices.

3.5.3 Management and mitigation options

While all commercial farms actively record the volume of feed inputs, there are no established methods in New Zealand for reliably estimating volumes of feed waste, identifying which wild fish species may be most affected by farm-derived waste, or monitoring contaminant levels in wild fish associated with aquaculture operations. As a result, site selection remains an important management consideration. In particular, farms should avoid spatial overlap with critical fish spawning grounds and nursery areas[26], and operational practices should seek to minimise the amount of feed waste

[25] Organohalogenated contaminants (OHCs) are pollutants commonly found in marine ecosystems that are known to bioaccumulate in marine fish.

[26] Any new aquaculture activity will require a UAE test to be undertaken by MPI. This will determine whether the proposed aquaculture activity can proceed, based on the extent to which the proposal will affect the commercial, recreational and customary fishing in the area. For more information on the UAE test, see Section 1.

reaching the seafloor. Locating farms in more dispersive environments (e.g. offshore locations) may help to reduce the concentration of farm-derived material reaching the seabed, thereby limiting the potential exposure of wild fish. Farm management practices, such as the prompt removal of dead fish, can minimise the attraction of sharks and other predators.

The evaluation of potential effects should be undertaken in a manner consistent with Policy 11 of the NZCPS, which addresses the protection of indigenous biological diversity.

Marine farmers should aim to minimise the use of non-navigational lights on site, and, where possible, lights should be shielded from all but essential directions. If spotlights must be used, they should be positioned as high above the water as possible so that penetration is maximised and reflection is minimised.

As finfish aquaculture expands into offshore environments, interactions with pelagic predators such as sharks may become more likely. While the following measures focus primarily on sharks for this reason, similar management principles likely apply to other types of wild fish where interactions occur. Avoidance and mitigation measures for shark interactions should be considered for proposed finfish aquaculture operations. These may include using specialised net designs, regularly inspecting and maintaining nets, minimising fish mortality and promptly removing dead stock, increasing monitoring during seasonal periods of elevated shark activity, and developing site-specific shark management plans.

3.6 Effects on seabirds

Table 3.5: Overview of effects on seabirds from finfish farming.

Definition	Effects of finfish aquaculture on birds
Summary of potential effects	• Entanglement (possibly resulting in birds being injured or drowned) • Habitat exclusion / disturbance • Attraction to farm lighting • Vessel / propeller strike • Providing roost sites closer to foraging areas • Attraction / aggregation of prey fish
Management and mitigation options	• Careful site selection – avoid critical breeding and foraging habitats • Dissuade roosting with non-lethal and non-injurious bird deterrents • Good management of farm nets; minimise predator nets below the surface while covering pens (top nets) above the surface • Use predator-resistant material in nets and maintain tautness, and adjust mesh sizes to suit local species (smaller mesh recommended) • Ensure waste material and debris are collected and disposed of correctly • Minimise artificial lighting (husbandry, navigation, vessels) at night • Regularly monitor and report on negative interactions of seabirds with aquaculture structures
Knowledge gaps	• Distribution, abundance and critical habitats of seabird species

	• Research into types of design and maintenance features to minimise entanglement risk • Prey and feeding behaviour of key seabird species
Key terms defined in glossary	Benthic, conservation status, habitat exclusion

3.6.1 Summary of potential effects

There is a potential risk of seabird entanglement with finfish farms, where diving birds, attracted to the fish and fish feed pellets, become entangled and drown in soft, flexible underwater nets used to contain the farmed fish and / or predator nets used above and below the cages. Recent reporting of seabird deaths as a result of entanglement in the Marlborough Sounds finfish farms suggests that a mixture of benthic- and surface-feeding birds, including shags, gulls and penguins, are the most susceptible species.

Potential effects on breeding and feeding seabirds include reduced or altered foraging habitat or displacement from feeding grounds. Recent tracking research on tagged penguins found no evidence of physical exclusion by farm structures or a reduction in feeding ability, with tagged birds feeding near and around farms. Any potential exclusion effects on surface-feeding species have yet to be determined.

Other potential effects include injury or death from ingestion of foreign objects such as marine litter, localised changes in prey supply, disturbance of breeding birds by farming activities and vessels, attraction and subsequent collision of seabirds with artificial lighting and farm vessel / propeller strike.

In contrast, a potential beneficial effect of aquaculture for some seabird species (e.g. shags, gulls and terns) includes the provision of roost sites closer to foraging areas, thus saving the birds energy and enabling more efficient foraging. Likewise, the attraction and aggregation of small fish to farm structures for shelter and to feed on organisms growing there may become potential prey for seabirds such as terns, shags and penguins (see Section 3.5).

3.6.2 Significance of effects

The adverse effects of existing aquaculture on seabirds are not presently considered significant. However, New Zealand's entanglement numbers and the species that have entangled in finfish farms have both increased since farms have begun regular monitoring of seabird interactions.

The scale and magnitude of the effect of aquaculture on seabirds depends largely on the bird species impacted, their conservation status, the location of the farm within their range, and the duration of the effect. Of particular concern are negative interactions with species that are threatened, endangered, vulnerable or range restricted[27].

3.6.3 Management and mitigation options

Effective management can be achieved by careful site selection to avoid the home ranges, critical breeding and foraging habitats, and migration routes of threatened, endangered or protected seabird species.

Once sited, farms should develop customised seabird management plans. These should clearly address the protocols to be used to minimise interactions with the species likely to occur in each area, define

[27] The conservation status of New Zealand birds can be found here: New Zealand's threatened birds.

any monitoring and reporting requirements, and provide a written entanglement response protocol with associated actions.

Adopting a range of non-lethal or non-injurious bird-deterrent measures to dissuade seabirds from roosting on farm structures can help prevent negative interactions. To reduce interactions from becoming entanglements, it is recommended that operational measures be routinely applied; examples include minimising the use of predator exclusion nets, using predator-resistant (rigid) materials in net design and keeping nets taut at all times (including surface nets). Any nets used (above or below cages) should be well maintained and farms should consider diameter and colour of lines and nets to ensure that they are visible to seabirds in flight. Different mesh sizes are likely to have different entanglement risks for different species of seabirds, although smaller sizes (e.g. < 45 millimetres) are considered better. Several protocols and SOPs will most likely be applicable to other marine wildlife such as wild fish and marine mammals – for example, those aimed at minimising the potential for rubbish to enter the sea from farms, and those ensuring that minimal non-navigational lighting and downward-pointing, shaded and non-flickering lights are used at night.

Regular reporting of seabird interactions by some industry farms has helped identify the species most at risk and the mitigation measures that can reduce future interactions. If seabird interactions are identified as a concern, then regular and consistent reporting of any negative interactions of seabirds with aquaculture structures can help lead to species-specific management strategies.

There are significant knowledge gaps concerning almost all seabird species in New Zealand, including detailed information on the time-specific distribution, abundance and critical habitats. Also missing is information on key prey species of seabirds, particularly those that may be affected by aquaculture.

3.7 Biosecurity

Table 3.6: Overview of biosecurity risks potentially associated with finfish farming.

Definition	How finfish aquaculture may influence risks associated with pests and diseases
Summary of potential effects	• Potential to facilitate establishment and spread of pests and diseases
Management and mitigation options	• Prevention of incursions through effective pathway management, including vessel and equipment maintenance, effective antifouling coatings, and hull inspections and cleaning • Prevention of incursions through appropriate on-farm management, including surveillance of farms and stock during activities, such as harvest, grading or transfer of stock • Prevention of infectious diseases through vaccination • Farm zoning, placement and fallowing • Effective responses to pests and diseases, including early eradication and disposal of pests from farm structures, where possible
Knowledge gaps	• The direct and indirect ecological effects of marine pests and diseases in the wider New Zealand environment • Environmentally friendly antifoulants and treatments • The natural transmission mechanisms and farm-to-farm dispersal potential of many diseases

	• Effective and environmentally friendly therapeutants to manage finfish in culture and prevent disease outbreaks • Breeding for disease resistance • Vaccine research and development for priority diseases
Key terms defined in glossary	Biofouling, biosecurity, epidemiological unit, exacerbator, incubator, microscopic pathogens, pathway, pest organisms, reservoir, staged development

3.7.1 Introduction

Biosecurity is defined as "the exclusion, eradication or effective management of risks posed by pests and diseases" (Biosecurity Council 2003). Biosecurity risks are animals, plants and microorganisms that are capable of causing diseases (for example, *Aeromonas salmonicida* bacterium that can affect salmonids), or otherwise adversely affecting New Zealand's natural, cultural, recreational, amenity or economic values (for example, the sea squirt *Styela clava*).

This section should be read in conjunction with Sections 3.8 and 3.9, as they also contain biosecurity-related themes.

Marine biosecurity risks are most likely to be introduced into New Zealand through vessel biofouling or ballast water and trade (e.g. seafood and ornamental fish trade). However, all coastal users and activities, including aquaculture, have the potential to introduce or spread marine pests and diseases into regions and farm sites where they do not already occur. Biosecurity risks largely occur from the movement of stock from one area to another. They can also originate from the natural environment – for example, the ubiquitous bacterium *Tenacibaculum maritimum* is the causative agent of skin disease in numerous marine fishes, including snapper and salmon, while other salmonid production areas experience mortalities from HABs and siphonophore blooms. These risks can lead to a wide range of ecological effects, from little or no disruption to species or ecosystem processes, through to significant impacts on specific species or even entire ecosystem functions.

3.7.2 Summary of potential effects

Marine farms have the potential to facilitate the establishment and spread of pests and diseases, but by virtue of its geographic isolation, New Zealand is in a unique position to develop aquaculture free from notifiable diseases that have emerged in salmonid farming elsewhere. Chinook salmon were introduced to New Zealand as ova, virtually eliminating the risk of introduction of many modern diseases that have emerged in northern hemisphere salmon production.

Open water finfish farms and other artificial structures provide a novel habitat for colonisation by fouling communities (including sea squirts, seaweed, tubeworms, barnacles and mussels), which may serve as suitable intermediate hosts for parasites and / or substrate for biofilm-forming bacteria. Once infected, farms may then act as a reservoir for subsequent spread to the wider environment, to other marine farm sites or to vessels and equipment that can transport them. Finfish farms may also alter environmental conditions (such as change in seabed composition or nutrient enrichment) and facilitate establishment or emergence of marine pests and diseases. These impacts can be substantially reduced in land-based marine fish farming, where a high degree of control can be exerted on effluent (e.g. land-based production of yellowtail kingfish).

Marine farms can also be vulnerable to adverse effects arising from biosecurity incursions. For example, biofouling pest organisms may increase drag on structures and anchoring systems, posing risk of gear failure. Biofouling also has the potential to significantly reduce the flow of water by smothering the nets or structures, reducing the amount of oxygen available to farmed fish and potentially increasing likelihood of the outbreak or transmission of disease.

Farm infrastructure and vessel movements can act as stepping stones for the spread of rodents and other mammalian pests (e.g. stoats and possums). The four rodent species that occur in New Zealand (*Rattus norvegicus*, *Mus musculus*, *R. rattus* and *R. exulans*) can swim distances ranging from 130 m to 2 km, while stoats are capable of swimming several kilometres. This swimming ability enables potential movement between marine farms, vessels and nearby islands.

Like pest infestations, diseases can be exacerbated by aquaculture operations and can reduce growth, condition and health of finfish stocks. For example, mortalities associated with ulcerative skin disease of farmed Chinook salmon have occurred in New Zealand since 2012 and are associated with the key bacterial pathogens *Tenacibaculum* spp. and New Zealand *Rickettsia*-like organisms. In addition to stock losses and costs associated with pest and disease management, pests and disease can lead to restrictions in farming operations and practices, such as stock transfers and international trade.

3.7.3 Significance of effects

It is important to consider biosecurity risks because of the potential far-reaching and irreversible implications if there is an outbreak or incursion of a pest or disease. The introduction, proliferation and spread of risk species in New Zealand can lead to significant effects on marine habitats and their associated values, as well as the subsequent impact on industry, economy and communities. Once established in the marine environment, pests and diseases are typically difficult and costly to manage and the ongoing effects are often permanent. Consequently, considerable effort is placed on preventing incursions of pests, parasites and diseases into the New Zealand environment.

3.7.3.1 Pests

The current risk of inter-regional spread of pest organisms by salmon farming activities in New Zealand is low. A different company operates within each of the main marine salmon farming regions and there are generally no transfers between them. Farming of yellowtail kingfish occurs on a land-based marine facility in Northland, and at the time of writing, no open marine (net pen) kingfish farms were in operation.

With respect to new finfish farming operations, biosecurity risks from fouling pests will be most significant when: (i) pest organisms are dispersed by finfish farm activities into regions or habitats that are optimal for their establishment and where they do not already exist; and (ii) finfish farming activities are the primary mechanism for the spread of the pests.

3.7.3.2 Diseases

Significant disease challenges have been reported in overseas salmon farms, including viral, bacterial and parasitic infections. In New Zealand, finfish farming is largely limited to Chinook salmon, with infectious disease issues to date having been predominantly bacterial in origin. Emerging aquaculture species native to New Zealand are also likely to face disease challenges, as intensive culture conditions increase exposure to endemic parasites and pathogens (see text box below).

Very few notifiable infectious diseases have caused salmon farm production losses in New Zealand, where active surveillance has been undertaken by MPI for decades. Emerging bacterial pathogens present chronic disease challenges for the industry. Notable marine infectious diseases include tenacibaculosis (caused by *Tenacibaculum* spp.) and piscirickettsiosis (caused by *Piscirickettsia salmonis* or New Zealand *Rickettsia*-like organisms). Given Rickettsia-like organism 1 and 2 are not known to occur outside of Marlborough, a Control Area Notice (CAN) was issued in 2016 to identify two contained zones in the Marlborough Sounds. An MPI-led investigation later concluded that these bacteria do not pose an ongoing biosecurity risk to New Zealand and the CAN was no longer required.

In the event of a disease outbreak, interventions such as antibiotics use are regulated under the Agricultural Compounds and Veterinary Medicines Act 1997. However, industry efforts are focused on preventative disease measures, including improved farm management practices and the development of targeted vaccines for endemic bacterial strains.

Indigenous finfish farming and biosecurity risks

Sea-based farming of finfish species indigenous to New Zealand, such as kingfish and snapper, requires case-by-case consideration of biosecurity risks, as neither species has yet been successfully commercially farmed in New Zealand. It is likely that a developing industry will face unexpected issues in relation to biosecurity risks, especially for snapper, for which only limited grow-out trials have been undertaken. Preventative vaccines for key bacterial diseases of kingfish have been developed overseas, and a similar model for vaccine development will be required if the industry grows.

In the case of kingfish, diseases of commercial importance are relatively well understood, whereas for snapper there remains some uncertainty regarding which pathogens or parasites will become commercially significant to culture operations. Wild kingfish and snapper populations that associate with farms are likely to have shared disease risks with their farmed counterparts. However, wild snapper and kingfish wild fish stocks are general considered highly mobile, and this will likely minimise the risk of exposure to disease from infected farm stock. A parasite risk assessment for kingfish farming in Australia identified gill and skin monogeneans, blood flukes (*Aporocotylids*) and myxozoans among the most likely to establish and spread in open net farms. Parasites are typically introduced to land-based operations through infected broodstock and are likely to necessitate periodic therapeutant treatments.

Best practice techniques for addressing uncertainty and helping safeguard against potential unforeseeable biosecurity events, or exacerbation resulting from intensification, would be to develop new aquaculture farms in stages, considering farm spacing, zoning and epidemiological units, within an adaptive management framework that included appropriate monitoring and related research as necessary. Councils and applicants should seek advice on biosecurity management from appropriately qualified experts in either aquatic veterinary or aquatic pest areas when developing a new aquaculture species.

3.7.4 Management and mitigation options

Biosecurity management and planning are crucial to limit the introduction of pests and diseases and to respond quickly and effectively to biosecurity risks. New Zealand aquaculture has been proactive on biosecurity, disease and fish welfare issues, having developed guidelines to aid prevention – in the absence of a major disease event. Appropriate aquaculture biosecurity practice avoids impacts to its operations and to the environment.

It is ineffective to manage biosecurity risks from aquaculture without also addressing the wider risk pathways (or sources of risk) in the marine environment – for example, commercial shipping, recreational boating, marinas and ports, and tourism activities. In some cases, consideration should also be given to terrestrial pest transfer pathways associated with farm infrastructure and vessel movements (e.g. mammalian pests capable of swimming), particularly where operations are located near pest-free or ecologically sensitive islands. Effective biosecurity management ideally requires a collaborative approach involving central, regional and local government, affected industries, iwi and the public (see "Levels of biosecurity management" text box in Section 2.7.4).

There are three strands to biosecurity management: prevention, surveillance (detection), and control of populations and outbreaks; see Section 2.7.4 for more information.

In the case of a disease or pathogen, responses may include therapeutant treatments, biosecure practices (such as isolation, quarantine or culling of infected stocks) and restricted equipment and vessel movements among infected farms or regions. The text box below contains an example of a company-wide biosecurity management plan.

In New Zealand, risks associated with transferring stock, equipment and vessels between geographic regions are managed through national and industry-led biosecurity frameworks, including the Government Industry Agreement for Biosecurity Readiness and Response (GIA), the A+ Sustainable Aquaculture programme, and associated best practice biosecurity measures designed to minimise disease transmission and marine pest spread.

Company-wide biosecurity initiative

An example of a company-wide biosecurity initiative is the New Zealand King Salmon "biosecure approach"; an action plan in the event of a major disease outbreak. Depending on the pathogen or disease, this would involve:

- fallowing the site;
- having fish of only one age class on the farm;
- quarantining one or a "group" of farms; and
- using separate equipment (including service vessels and processing facilities) for a group of farms.

A critical aspect of the biosecure approach is the ability to isolate each of three groups of farms as biosecurity management areas. While the farms within each management area are likely to be connected, at a whole of Marlborough Sounds scale the three farm management areas would have a low epidemiological connection given the large buffer zones between them.

3.8 Escapee and genetic effects

Table 3.7: Overview of potential escapee and genetic effects from finfish farming.

Definition	• Potential environmental effects of escapees (gametes, juveniles and adults) from finfish pens • Potential genetic effects arising from selective breeding, ploidy manipulation (e.g. triploidy) and (where permitted) gene technologies
Summary of potential effects	• Competition for resources with wild fish • Alteration of the genetic structure of wild fish populations • Transmission of pathogens from farmed stocks to wild fish populations
Management and mitigation options	• Good farm management, particularly maintaining net integrity and inventory control • Reporting of escapees • Genetic monitoring of farmed and wild populations for higher-risk species • Use of therapeutants and vaccines to treat and prevent disease • Transgenic or gene-edited stocks (reliant upon approval of the Gene Technology Bill 2024 and requirements therein) • Harvesting before sexual maturity (possible in some species)

	• Production of monosex stocks • Use of lights and triploidy for maturation inhibition (where performance and welfare are acceptable for the species and local environment) • Breeding for disease resistance and other resilience traits • Manage broodstock diversity within breeding programmes • Cryopreservation (gene banking) for broodstock management • Case-by-case assessment and response
Knowledge gaps	• Population structure and effective population size of wild populations (especially indigenous species) • New Zealand-specific quantification of escapee impacts (e.g. kingfish, snapper) and of gamete release from pens • Species-specific sterilisation options (welfare / performance of triploids in New Zealand conditions) • Age / size at sexual maturation under New Zealand farming conditions (indigenous species) • Climate change interaction with escapee and genetic risks (e.g. storm exposure at open ocean sites, heat / oxygen stress, size at maturation, and triploid performance) • Parasites and diseases of indigenous new aquaculture species
Key terms defined in glossary	Genetic modification, polyploidy, triploidy, therapeutant, transgenic organism, gene editing, cryopreservation, single nucleotide polymorphism, genotyping, monosex, single nucleotide polymorphism

3.8.1 Summary of potential effects

The main potential effects of escapees are direct competition for resources with wild fish and related ecosystem effects (such as through predation); and altered genetic structure of wild fish populations (change in fitness, adaptability, diversity or reduced survival) by mixing farmed and wild populations. There is also the potential to transfer pathogens between populations (see Section 3.7). The potential effects of escapees will vary considerably in relation to a number of factors, including the life stage and numbers involved in the escape, the location of the farm in relation to wild populations, whether the species is native or introduced, and the ability of escapees to survive and reproduce in the wild.

For broadcast-spawning species, spawning within pens, resulting in the release of fertilised gametes, is another escape pathway. While survival of early marine life stages is generally low, it is possible. Mitigations include farming monosex stocks, monitoring maturation, using lights to inhibit maturation and, where justified, triploidy (weighing any welfare / performance trade-offs).

The main cause of escapes from finfish farms of juvenile or adult fish is technical and operational failures of farming equipment, primarily through net failure. Net failure can occur in many ways, including biting by predators or caged fish, abrasion, collisions with boats, and handling procedures such as lifting. However, with the implementation of improved net materials, technologies and farm management practices, the incidence of net failure is relatively low. Escapes can also be triggered by extreme oceanic conditions (e.g. storms and high-energy swell), which are increasing in both magnitude and frequency under climate change, particularly at offshore and more exposed sites. In addition, deliberate farm sabotage (the intentional destruction or damage of infrastructure), although less common, is a recognised cause of fish escape. Research indicates that prioritising the prevention of large-scale escape events, typically caused by structural failures, can significantly reduce the overall consequences of escapes.

Overseas experience suggests that escape incidents may heighten the potential for the transfer of diseases and parasites from farmed stock to wild populations. There are known pathogens that affect Chinook salmon in some marine and freshwater environments. Proactive biosecurity and health management, disease surveillance, vaccination, and use of therapeutants and functional diets (see Section 3.9) can reduce the risk of disease transmission to wild populations, as can the breeding of disease-resistant stocks. Risks may change with the farming of indigenous finfish in New Zealand (although the greater likelihood may be of disease transfer to the farmed stock from wild populations of the same species; see Section 3.7).

Genetic effects are species- and location-specific and will vary according to the abundance, distribution and behaviour of wild populations. In the northern hemisphere, farmed fish such as Atlantic salmon can be bred from a small gene pool selected for production traits (for example, fast growth). This can result in genetic divergence from the wild populations.

3.8.1.1 Species context in New Zealand

3.8.1.1.1 Chinook salmon

New Zealand production is mostly based on selectively bred stocks (family-based programmes) and all-female production. Some farms deploy 24-hour lights during parts of the production cycle to inhibit maturation. These practices reduce the probability of successful reproduction by escapees and support on-farm performance, while breeding programmes manage genetic diversity over generations. The species is introduced, and wild salmon numbers are low in many river systems, limiting the risk of interbreeding.

3.8.1.1.2 Yellowtail kingfish

Kingfish is a native species and has recently been commercialised in New Zealand based on rearing in a land-based recirculating aquaculture system. This production is supported by a selective breeding programme that employs genotyping-by-sequencing for diversity management and genomic selection. A marine farm development in the Hauraki Gulf / Tīkapa Moana received consent in 2023, including for kingfish. The consent conditions included genetic, escape management and monitoring plan requirements. Marine farming at this location has not yet commenced. If marine pen production uses selectively bred stocks, genetic divergence from wild populations may increase over time, making monitoring and diversity management essential.

Commercial use of transgenic or gene-edited finfish is not authorised under current New Zealand law. The Gene Technology Bill 2024 would, if enacted, create an enabling but risk-proportionate framework with a dedicated regulator. Any future approvals (if granted) would be tightly regulated and risk management (including facility type / location) would be determined on a case-by-case basis.

The Finfish Aquaculture Environmental Code of Practice also prohibits the use of genetically modified salmon as broodstock.

The main ecological concerns with the use of transgenics upon escape would include:

- altered interactions because of changed fish characteristics;
- potential for genetically modified fish having increased tolerance of physical factors allowing a move to new regions; and
- migratory and territorial behaviour altered resulting in change to fish population dynamics.

3.8.2 Significance of effects

The likelihood of escapee effects in New Zealand is low, based on the current small size of the finfish farming industry, limited overlap of wild and farmed populations (in terms of salmon) and the broad

home range and likelihood of high genetic diversity in these indigenous species (in terms of kingfish and snapper).

For kingfish, significant genetic influences on wild stocks are unlikely. Kingfish are an abundant pelagic species that have a wide geographic range and are likely to be bred initially from wild-sourced broodstock to stock marine sea pens. Genetic risks from other new species will need to be assessed on a case-by-case basis. In this context, an important consideration will be whether management strategies can be implemented to minimise the likelihood of adverse effects, for example, measures to reduce the quantity of escapees and to retain genetic diversity of cultured stock.

If genetic effects occur at scale, they can be difficult to reverse, so precautionary monitoring and preventative management are warranted as industry composition and locations evolve. Establishing baseline genomics and ongoing monitoring based on single nucleotide polymorphism (SNP) (farm versus local wild) can help to quantify and manage this risk over time.

3.8.3 Management and mitigation options

3.8.3.1 Primary prevention

Finfish farms should maintain net integrity and structural resilience (for example, regularly maintain nets and structures) and adopt adaptive management. MPI has developed siting and management guidance for open ocean aquaculture to address exposure to storms / swell. If escape events do occur, all incidents should be reported to councils / regulatory authorities. In addition, fish farm staff should be appropriately trained in escape-critical operations and response techniques. Minimising escapes is recognised by the New Zealand Salmon Farmers Association in its Finfish Aquaculture Environmental Code of Practice, which contains practical advice for minimising escapes from salmon farms. A requirement of the 2023 Hauraki Gulf / Tīkapa Moana kingfish aquaculture resource consent was the implementation of a comprehensive escape management and monitoring plan.

3.8.3.2 Reproduction control (species-specific)

Farms should reduce the risk of escape by fertile fish or viable gamete release by harvesting before sexual maturity, and using all-female / monosex stocks and, where justified and humane, triploidy (recognising welfare / performance constraints seen in salmonids). Photoperiod (such as 24-hour lighting) and temperature regimes can modulate maturation in some salmonids but should be adopted only if permitted and appropriate for the specific species and site.

3.8.3.3 Genetic management

Commercial marine farming of indigenous finfish species in New Zealand will require consideration of the risk for genetic effects on wild stocks. For indigenous species farmed in marine pens, it is important to develop genetic management and mitigation strategies. For example, farms should retain diversity (founder numbers, mating designs), use local broodstock where appropriate, and genetically monitor farm and wild populations using methods such as SNP-based genotyping (diversity, relatedness, introgression). Sperm can also be cryopreserved from genetically diverse wild males to support long-term diversity management.

3.9 Effects from additives

Table 3.8: Overview of potential effects of additives (including plastics) from finfish farming.

Definition	The potential effect of chemicals and plastics used in finfish aquaculture on the environment
Summary of potential effects	• Accumulation of metals from use of antifoulants and additives in fish feed • Use of therapeutants to treat stock • Plastics used in aquaculture have the potential to become debris and degrade to release chemical and microplastics
Management and mitigation options	• Use of mechanical defouling measures • Off-site washing of nets to minimise antifoulant leaching • Fallowing and rotational use of farm sites • Good animal husbandry to reduce need for therapeutants • Monitoring of sediment concentrations of copper and zinc • Retrieve plastic lost accidently and minimise plastic use where possible. Eliminate, innovate and circulate.
Knowledge gaps	• Accumulation and interactions of trace contaminants • Effects of therapeutants on sediments and ecological processes • Release of microplastics from marine farms debris
Key terms defined in glossary	Benthic, biodeposition, biofouling, micronutrient, phytoplankton, trigger level, water column, isoeugenol- / eugenol-based anaesthetic

3.9.1 Summary of potential effects

Chemicals may be used for the maintenance and sustainability of farming activities when required, and can include fish feed additives, metals from antifoulants (such as copper and zinc), therapeutants to condition animals for seasonal stresses and / or bacterial diseases or parasites (such as antibiotics), anaesthetics, and detergents and disinfectants to prevent the spread of diseases. The need to use chemicals in finfish aquaculture varies depending on the species farmed and the scale and intensity of farming.

Copper-containing antifouling coatings have historically been used to control biofouling on finfish farm structures and nets. When used, copper can enter the marine environment, mainly by leaching from antifouling coatings or through the release of coating particles during mechanical cleaning, abrasion or operation of farm structures. The potential for harmful effects depends on factors such as the amount of copper released, hydrodynamic conditions, sediment characteristics and background concentrations. In New Zealand, the use of copper antifouling coatings in finfish aquaculture has declined, with current biofouling management increasingly relying on alternative methods, improved net management practices and operational controls.

Zinc primarily comes from fish feed (uneaten and released in faecal wastes), but also from some antifouling paints. Zinc and copper can accumulate in sediments beneath fish farms and can be toxic at high concentrations.

These metals are naturally present in the environment at trace level concentrations and organisms require these essential elements for physiological processes and growth. The main concern with metals is their toxicity to biota. They can be detrimental to organisms if concentrations significantly exceed those required for normal metabolism.

Therapeutants may be used to treat diseases and parasites in farmed fish stock. Most therapeutants that must gain approval for use in aquaculture have limited environmental risk as they are usually highly water soluble, disperse and break down readily, and do not bind to sediments. However, some therapeutants administered as feed additives may be deposited on the seabed and accumulate locally and / or temporally.

The concentration (and hence toxicity) of chemicals is strongly influenced by the properties of water and the nature of sediments. For example, high-flow sites have higher dilution rates than low-flow sites. Routine monitoring results for salmon farms in the Marlborough Sounds indicate that sediment zinc concentrations beneath farms can exceed guideline values, particularly at heavily impacted low-flow sites where dispersal and recovery processes are reduced.

Plastics are widely used in aquaculture because they meet a variety of functional requirements. However, the different plastic materials used across the industry have distinct properties, which influence how they behave in aquatic environments. Some materials, such as polyethylene (PE) and polypropylene (PP) ropes, gradually abrade over time, generating microplastics that can sink through the water column. Others, such as expanded polystyrene (EPS) flotation structures, tend to fragment, producing floating microplastics. More durable plastics may be less prone to fragmentation but can persist in the marine environment for decades or even generations.

The causes of plastic loss from aquaculture operations are similarly diverse, ranging from equipment wear and tear to storm damage and operational practices. Once released into the environment, aquaculture-related plastics and marine litter can have a range of impacts, including ingestion by wildlife, entrapment and entanglement of animals, and the potential exposure of humans to microplastics through the food chain[28].

3.9.2 Significance of effects

Chemical use in the New Zealand finfish farming industry is currently limited; however, this may increase in future as the sector responds to emerging animal welfare, biosecurity and disease management challenges associated with warming marine environments. The industry has moved away from use of net antifouling coatings, favouring mechanical defouling methods and *ex situ* net cleaning. In addition, there are no antimicrobial or antiparasitic veterinary medicines approved for use in New Zealand aquaculture. The isoeugenol-based anaesthetic AQUI-S is currently the only veterinary medicine registered for aquaculture use. Isoeugenol / eugenol is highly degradable in air, soil and water, including through microbial activity. Therefore, the risk of ecological effects from therapeutants is very low. It is noted, however, that increases in farm scale or densities and the potential culture of indigenous finfish species such as kingfish and snapper may lead to the emergence of diseases that require such treatments (see Section 3.7).

Elevated metal concentrations (above background levels) have been recorded beneath finfish farm sites in New Zealand; however, these concentrations do not necessarily indicate adverse effects as the forms of metals within sediments may not always be highly bioavailable. (e.g. if precipitated as sulphides). However, as conservative contaminants, metals at elevated concentrations may hinder long-term seafloor recovery after fallowing, and their toxicity effects may be masked by those related to elevated benthic enrichment from biodeposition (see Section 3.3). Complete remediation of an impacted farm site can take from several months to several years, depending on the level of impact and recovery conditions.

It is thought the main reason for plastics from aquaculture entering the environment is extreme weather and the catastrophic impact on facilities. In the case of inter or sub-tidal facilities this means entire components e.g. floats, sea-pens, nets and plastic containers being lost directly into the sea.

[28] Tackling plastic waste in NZ aquaculture Report

Some major components are likely to be recovered through industry led beach clean-up efforts, whereas smaller items may be permanently lost. There is no evidence of aquaculture contributing significantly to microplastic pollution. The impact of plastic loss from aquaculture likely to be small compared to other anthropogenic inputs.

3.9.3 Management and mitigation options

All species farmed for human consumption from aquaculture must meet strict food safety standards that regulate the acceptable concentrations of metals, chemicals and additives in food products[29]. There are also industry-backed environmental guidelines developed specifically for and by New Zealand salmon farmers, such as the A+ standards developed by Aquaculture New Zealand.

The New Zealand finfish farming industry and feed supply companies implement various measures to minimise contaminant inputs into the environment. For example, the introduction of forms of zinc (e.g. zinc methionine) in feed have led to proportionately lower zinc inputs overall due to more efficient uptake and, consequently, reduced discharges to the seabed. Alternatives to copper antifouling, such as using in-water net cleaners, have also been introduced.

Where copper coatings are used, management and monitoring focus on minimising inputs and assessing potential effects on the surrounding environment. To minimise potential effects associated with metals in antifouling coatings, their use should be limited to situations where they provide a clear operational benefit and should be managed in accordance with best practice. Where nets or structures with antifouling coatings are cleaned or maintained, practices should minimise the release of coating residues and prevent accumulation of paint particles in the surrounding environment.

The management practices that minimise biodeposition and benthic enrichment on the seabed and allow impacted sediments to improve may also be effective to reduce the effects of metals, such as reducing feed wastage, fallowing and rotational farming strategies (see Section 3.3).

The results of monitoring of zinc and copper concentrations in sediments beneath finfish farms can be compared to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Monitoring can be reduced once it has been demonstrated that sediment metal concentrations beneath farms are maintained below assigned trigger levels. Conversely, further monitoring could be triggered (to establish the extent and magnitude of contamination) if elevated levels of metals in sediments are detected.

The use of therapeutants is regulated by the Agricultural Compounds and Veterinary Medicines Act 1997. Minimising the environmental effects of therapeutants can be achieved by measures to avoid disease introduction, controls on therapeutic use, hygienic measures in fish rearing and vaccination. Other biosecurity and disease management practices, such as spacing farms to prevent the spread of diseases and farming single age classes (see Section 3.7), may also assist in maintaining healthy stock and serve to avoid or reduce the need for therapeutants.

Due to changing technical, operational and environmental parameters, the potential for environmental issues from therapeutant use will need to be assessed on a case-by-case basis. However, to enable effective, timely responses to disease or parasite outbreaks in the future, the aquaculture industry could proactively seek registration for therapeutant use under the Agricultural Compounds and Veterinary Medicines Act 1997, with appropriate conditions (such as veterinary prescription, with due regard to overseas data on safe discharge levels, and food safety requirements).

[29] See the MPI maximum residue levels (MRLs) for agricultural compounds relevant to food production.

3.10 Hydrodynamic alteration of flows

Table 3.9: Overview of the potential hydrodynamic alteration of flows from finfish farming.

Definition	Potential effects of finfish aquaculture on the physical attributes of the water, including currents, stratification and waves
Summary of potential effects	• Finfish cages alter current features and speeds • Effects on stratification through vertical mixing and partial blocking of some water layers • Wave dampening may affect shoreline habitat, erosion and sediment transport
Management and mitigation options	• Modelling and monitoring of hydrodynamic effects • Positioning of cages to promote flushing • Cage design, flexibility or net porosity
Knowledge gaps	• The relationship between drag on cage elements and changes in flow beyond the cage • Effect of fouling on hydrodynamics • The effect of fish stock and fish behaviour on currents and waves • The magnitude and spatial extent of changes to stratification • The interactions between stratified flows and finfish cages
Key terms defined in glossary	Bay-wide, depositional footprint, staged development, stratification, wave attenuation

3.10.1 Summary of potential effects

Hydrodynamics in this section refers to the physical attributes of the water including currents, stratification, and waves. Finfish farming both relies on, and influences, hydrodynamic conditions. The physical presence of farms can alter and reduce current speeds, affecting water residence times, the effects footprint, and have implications for associated biological processes (such as phytoplankton production). The scale of the effect depends on the size and layout of the farms and their location, and, as has been modelled for shellfish farms, effects may manifest away from the farm structures. Generally, the effect is strongest within the farmed area and decreases with distance from the farm.

Finfish cages can create drag that affects currents, causing wakes, turbulence and flow diversion. The presence of fish inside the cage can also alter flow in addition to the flow disruption caused by the nets. Swirl caused by fish schooling may generate an outward flow through the sides of the nets. Finfish cages can alter stratification through the blocking or diversion of some water layers, generation of internal waves, and possible enhancement of vertical mixing from fish-induced swirl. These effects are not yet well understood.

Some degree of wave dampening will occur for any finfish structure due to the wave drag on the finfish cages. A wave "shadow" of reduced wave energy may extend beyond the cages, potentially affecting shoreline habitat and sediment transport. The effect is most likely undetectable for individual cages, small farms or in sheltered areas where wave energy is low.

3.10.2 Significance of effects

In general, the effects of finfish farms on hydrodynamics are likely to be small in comparison with the effects on other aspects of the marine ecosystem.

Local, small-scale changes in currents as a result of the placement of cages are almost certain. Embayment-scale changes in circulation may also occur in small bays or bays with several farms; however, the ecological significance of these changes will depend on the degree and magnitude of modification.

Hydrodynamic changes will persist for the duration that the structures are in place, but recovery will be nearly immediate on removal of all structures. Indirect ecological consequences of modified currents and other cumulative effects on the seabed and associated communities may persist for longer.

3.10.3 Management and mitigation options

If changes in hydrodynamics are a key concern, models and monitoring can be employed; however, these techniques are unlikely to be required if the effects from the farm on hydrodynamics are predicted to be minor.

The effects of farm structures on local and bay-wide currents, stratification and waves can be predicted using existing data or analytical and numerical models. This information can help predict possible hydrodynamic changes and identify ways to mitigate these effects, for example, manipulating cage design, layout, flexibility or net porosity.

Monitoring of hydrodynamic conditions is rare in New Zealand aquaculture consents and is typically only applied to wave monitoring. However, farm structures can affect flows which can be modelled to have a range of ecological effects. If considered necessary, monitoring before and during staged development could be used to ensure hydrodynamic effects are in line with initial modelling.

4. ECOLOGICAL EFFECTS OF FARMING SEAWEEDS AND SEA CUCUMBERS

Table 4.1: Overview of the potential effects of farming seaweeds and sea cucumbers.

Definition	Potential ecological effects of farming seaweeds and sea cucumbers
Summary of potential effects	• Addition of farm structures, leading to localised habitat modification and potential attraction of wild fish, seabirds and other marine species • Uptake of dissolved nutrients and carbon by seaweeds, with potential effects on local nutrient dynamics and phytoplankton availability • Shading, attenuation of water movement and localised changes to hydrodynamics • Release of reproductive material (propagules), with potential for spread and genetic interactions with wild populations • Biosecurity risks, particularly for non-native species (e.g. Undaria), including the spread of pests, pathogens and associated organisms • Potential for localised seabed effects (e.g. organic enrichment from detached biomass or sea cucumber biodeposition), although this is generally much lower than for finfish or shellfish aquaculture • Entanglement risks for marine mammals and seabirds associated with farm structures and lines • Potential positive ecological interactions in IMTA systems, including nutrient uptake (seaweeds) and detritus processing (sea cucumbers)
Management and mitigation options	• Appropriate site selection, including consideration of hydrodynamic conditions, existing habitats and biosecurity • Restricting Undaria farming to areas of established infestation and within approved regulatory frameworks • Implementation of biosecurity measures • Use of locally sourced seaweed strains, where possible, to reduce genetic risks • Monitoring of farms for pests, pathogens and environmental effects • Farm design and operation to minimise entanglement risk (e.g. line tension, layout, visibility) • Adaptive management approaches, including staged development and environmental monitoring to address uncertainty
Knowledge gaps	• Limited New Zealand-specific information due to lack of commercial-scale farming • Uncertainty around genetic interactions between farmed and wild seaweed populations • Limited understanding of pests, pathogens and disease risks, particularly for seaweeds and Undaria • Effects of propagule release on distribution and genetic structure of wild populations • Ecological interactions with wild fish, seabirds and marine mammals

	• Magnitude and spatial extent of nutrient uptake and hydrodynamic effects • Cumulative and large-scale effects of seaweed aquaculture • Environmental effects and disease dynamics associated with sea cucumber aquaculture
Key terms defined in glossary	Epidemiological unit, habitat exclusion, IMTA, phytoplankton, staged development, stratification, subtidal, therapeutant, water column

4.1 Introduction

The Aquaculture Development Plan identifies diversification of aquaculture species as a strategic priority in New Zealand. Seaweed aquaculture is considered a candidate for future growth and is widely regarded as a potentially low-impact addition to the existing aquaculture sector. Current interest includes both native species and the established non-native Asian kelp *Undaria pinnatifida* (*Undaria*) (Figure 4.1).

Other species, such as the sea cucumber *Australostichopus mollis*, have also been identified as having aquaculture potential in New Zealand, but remain at an early stage of development.

This section provides an overview of the potential ecological effects associated with farming seaweed and sea cucumbers in New Zealand.

Both sea cucumbers and seaweeds are being considered for use in IMTA, where they could assist in mitigating ecological effects of other aquaculture activities by assimilating detritus (sea cucumbers) and absorbing excess nutrients in the water column (seaweeds). However, the application of IMTA in New Zealand remains limited.

This section summarises information from the *Literature Review of Ecological Effects of Aquaculture*. While the literature review remains a key reference, it has not been reviewed since 2013 and some information may now be outdated. To address this, a new appendix for the literature review has been prepared, comprising a bibliography that summarises the principal additions to the original review, alongside an abbreviated list of references most relevant to those updates. Readers can refer to the literature review for additional background; however, this document provides the most current context on regulatory, policy, technological and research developments relevant to the ecological effects of seaweed and sea cucumber aquaculture[30].

[30] Additionally, Clark et al. (2021) provide a summary of the ecological effects associated with seaweed farming in New Zealand and biosecurity considerations for *Undaria* cultivation are reviewed by Cunningham et al. (2020).



Figure 4.1: Common seaweeds in New Zealand waters (A) *Lessonia variegata*, (B) juveniles of *Macrocystis pyrifera* and *Durvillaea* sp., (C) *Ecklonia radiata*, (D) reproductive blades at the base of an adult *Macrocystis pyrifera*, (E) assemblage of seaweeds including *Caulerpa* sp. and fucoids, (F) *Asparagopsis armata* gametophytes, (G) *Ulva* sp., (H) *Pyropia plicata*, (I) Sea cucumber *Australostichopus mollis*, (J) *Undaria pinnatifida*. Source: A–H, Biancacci et al. (2026); I, Leo Zamora; J, *Overview of Ecological Aquaculture* (2013).

4.1.1 Seaweed aquaculture

There has been considerable and growing interest in native seaweed aquaculture development in New Zealand over the last decade. Species of interest include kelps (*Macrocystis pyrifera*, *Ecklonia radiata* and *Lessonia variegata*), sea moss (*Gracilaria* spp.), fucoids (*Hormosira banksia*, *Cystophora retroflexa*, *Cystophora scalaris*, *Landsburgia quercifolia*, *Carpophyllum maschalocarpum*, *Xiphophora chondrophylla*), red seaweeds (*Asparagopsis armata*, *Pterocladiella capillacea*, karengo [*Pyropia* spp., *Porphyra* spp.]) and green seaweeds (*Ulva* cf. *lactuca, Codium fragile*).

Undaria is an introduced species classified as an "unwanted organism" under the Biosecurity Act 1993 and a "pest" in some regional pest management plans (e.g. the Southland Regional Pest

Management Plan 2019–2029). In 2012, MPI introduced a policy that allows for commercial harvesting of *Undaria* from artificial surfaces such as mussel farm backbones, droppers and anchor warps, and farming of *Undaria* in selected coastal areas already heavily infested with the species, subject to approval.

Seaweed cultivation methods have not yet been developed at commercial scale in New Zealand and remain largely at the trial stage. Production may occur in land-based systems or marine environments. For marine operations, floating subtidal cultivation systems are likely to be most common, with intertidal approaches also possible – for example, where existing oyster farm infrastructure could be adapted for seaweed cultivation.

4.1.2 Sea cucumber aquaculture

Sea cucumbers are deposit-feeding echinoderms (in the same family as sea urchins) that live on the seabed and feed on detritus and organic matter. They are often attracted to farm-derived organic waste deposited beneath mussel farms. There is a wild fishery in New Zealand for sea cucumber for the Asian food and medicine market, and the concept of sea-ranching of this species has been considered as a potential development pathway. However, stock ownership restrictions under the Fisheries Act present challenges for the implantation of sea-ranching approaches. Marine-based farming of sea cucumbers could take a variety of forms including on the seabed in pens or cages, uncontained on the seabed (sea- or open-ranching), or grown in suspended cages with or without the addition of feed.

4.2 Summary of potential effects and significance

Understanding of the ecological effects associated with farming of native seaweeds, *Undaria* and sea cucumbers in New Zealand remains limited, as these species are not currently farmed here at a commercial scale. This review therefore draws on the international knowledge base for these sectors.

Further policy development and environmental guidance may be required as the sector develops. For emerging or experimental aquaculture species such as seaweeds and sea cucumbers, we can make only general comments on the potential broader ecological issues, because the culture methods and environments are yet to be defined, and many issues are highly species-specific or poorly understood (such as disease issues and genetic interactions with wild stocks). We can roughly predict ecological effects by the species grouping: its diet and feeding mechanism, waste production and farming method. In most cases, the ecological effects of farming seaweeds and sea cucumber are likely to be less pronounced than those from shellfish or finfish aquaculture.

4.2.1 Seaweeds

The cultivation of seaweeds is generally expected to have minor ecological effects on the seabed and water column, as seaweeds occupy a lower trophic level and obtain nutrients primarily from dissolved organic nitrogen in the water column. Nevertheless, a range of environmental interactions may occur. These include shading, uptake of dissolved nutrients and carbon, attenuation of water movement, and the release of reproductive material from cultivated seaweeds. Nutrient uptake may also reduce the availability of dissolved nutrients for natural phytoplankton populations, although the magnitude of such effects is likely to depend on species, scale and location.

In many respects, the effects of seaweed aquaculture are likely to be broadly comparable to those associated with other suspended aquaculture activities, such as mussel longline farming. The magnitude of effects will depend on the farm placement, scale of operations, species cultivated, structures used and frequency of harvest. However, seaweed biomass is typically concentrated near the surface and cultivation lines are generally shallower than those used for mussels, with seasonal variation in crop biomass likely to be greater than in mussel farming. Seaweed aquaculture may also generate particulate organic and inorganic material that could contribute to localised enrichment,

although effects are expected to be less intense than in shellfish aquaculture because seaweeds do not produce biodeposits and detached biomass is likely to disperse beyond the farm area; however, research on these processes remains limited.

The potential for genetic interactions between cultivated seaweeds and wild populations is not well understood but may represent a significant environmental risk, particularly where native populations are reduced or otherwise under stress. Many seaweed species in New Zealand have restricted natural distributions, meaning that aquaculture could potentially alter the genetic structure or fitness of wild populations if farm-derived propagules establish or interbreed with them. Use of locally sourced strains may reduce this risk, although further research on population structure and genetics of New Zealand seaweeds is required.

Seaweed aquaculture may present a higher marine mammal entanglement risk than some other culture methods, such as mussel farming. This risk is primarily associated with the use of loose, thin moorings and crop lines that operate under relatively low tension, the potential for overlapping or crossing lines, reduced visibility of farm structures in the water column, the potentially large spatial footprint of farms, and mooring components that may be unable to withstand the forces generated during encounters with large marine mammals such as whales.

Similarly, the effects of farming seaweed species on wild fish populations and seabirds have not been well documented. Whether potential effects are more or less pronounced than those associated with shellfish or finfish farming will depend on the size and layout of the farm and its components. Potential effects will most likely stem from the addition of farm structures that may change the fishing pressure on local wild fish populations due to increased aggregation of prey fish. For seabirds, farm structures may increase entanglement risk, potentially exclude habitat (the significance of which would depend on the scale of the farm relative to available habitat), or increase aggregations of prey fish and the provision of roosting sites, and farm activities may lead to disturbance. Lost or discarded synthetic materials also represent a choking and entanglement hazard for wild fish and seabirds.

4.2.1.1 Native seaweeds

A key consideration of native seaweed aquaculture expansion is the sustainability of wild harvest. At present, the domestic seaweed industry remains limited and is largely reliant on wild harvest from natural beds and shorelines or artificial structures. Commercial hatchery and nursery infrastructure is minimal, and sea-based cultivation remains constrained by reliance on wild recruitment. Only bladder kelp (*Macrocystis pyrifera*) and beach-cast seaweed for spat are currently managed within the Quota Management System, while harvest and cultivation of other species may be subject to a combination of fisheries regulations, marine farming consents and regional coastal plan provisions. As interest in these species grows, further development of policy settings, hatchery capability and environmental guidance is likely to be required to support sustainable industry expansion.

4.2.1.2 Undaria

Undaria is a non-native seaweed regarded as both a fouling nuisance on marine farms and as a potential threat to the ecology of high-value coastal areas of New Zealand (see Sections 2.7 and 3.7). Biosecurity risks associated with commercial cultivation may be reduced to some extent by restricting farming to areas where *Undaria* is well established.

If *Undaria* farming occurs, consideration may need to be given to whether additional biosecurity risk pathways arise beyond those already associated with aquaculture operations generally, and whether these may be regionally or nationally significant. Ecological effects arising from pest species associated with *Undaria* farming are likely to be broadly comparable to those associated with subtidal shellfish aquaculture, as the pathways, biofouling assemblages and operational processes involved are similar. There is currently limited New Zealand-specific experience and research on pests, pathogens and parasites associated with *Undaria*, increasing the likelihood that some potential effects will be difficult to quantify. Such organisms may represent biosecurity risks both to native seaweed

communities and to the commercial cultivation of *Undaria*. Movement of stock, equipment, vessels and water between facilities represents a primary pathway for the spread of vegetative material, propagules and associated organisms. In addition, the release of large quantities of propagules from farms may increase propagule pressure and potentially influence the distribution or genetic structure of feral populations, particularly where cultivation occurs outside areas of existing infestation or beyond established haplotype ranges.

4.2.2 Sea cucumbers

The ecological effects associated with culturing sea cucumbers in New Zealand are not well understood due to the limited number of studies assessing its environmental impacts. Existing international research instead tends to focus on the capacity of sea cucumbers, as deposit feeders, to mitigate the depositional impacts of farming other species. These organisms can contribute to a reduction in organic loading through consumption and processing of organic matter, enhance remineralisation processes and promote oxygenation of surface sediments. Additional ecosystem functions may include the consumption of HAB cysts and facilitation of bentho-pelagic coupling. Together, these functions suggest that sea cucumbers may help to reduce the overall environmental footprint of farming activities. For this reason, sea cucumbers are considered to have significant potential as a valuable secondary crop in the context of multispecies farming approaches (e.g. IMTA).

There is potential for minor, localised seabed enrichment from the biodeposition of sea cucumber faeces; however, overall organic loading is typically reduced through sediment processing and is likely to be substantially lower than that associated with finfish and shellfish aquaculture.

The effect of sea cucumber farming on the hydrodynamics of a region will depend largely on whether any structure or enclosure is used to contain the crop. The effects of structures on current flow are expected to be greatest in shallow sites. Alterations to current flows are likely to be most pronounced for suspended structures, followed by bottom-mounted structures. Structures on the seabed are likely to reduce current velocities near the bed, with the potential for localised scouring around cages or piles, as well as increased near-bottom turbulence. Any localised hydrodynamic changes resulting from sea cucumber culture are expected to be reversible following the removal of all structures.

Very little has been documented for sea cucumber aquaculture on the possible adverse interactions of marine mammals with farms. The physical presence of farm structures will have similar risks to other types of aquaculture structures (e.g. potential exclusion, habitat modification, litter, and entanglement risks) and will depend on the size and layout of the farm and its components.

Ecological effects from pests, parasites and diseases associated with sea cucumber aquaculture in New Zealand are unknown as the industry is currently undeveloped. Based on overseas experience, however, it is possible that the intensive cultivation of sea cucumbers (e.g. high-density monoculture intertidal pond farming) will require careful management depending on the causative agent, when known.

4.2.3 Management and mitigation options

Appropriate site selection is critical to avoid adverse ecological effects, where possible, for both subtidal and intertidal operations. Where species are cultured in an IMTA context to mitigate the effects of farming finfish or shellfish, site selection will depend on the location of existing aquaculture activities.

As with other forms of aquaculture, the key factor in limiting adverse effects on marine mammals and seabirds in New Zealand is to avoid overlapping with critical habitats, breeding and feeding sites (of species with restricted habitat requirements), and traditional migration routes.

In the case of *Undaria*, farming is legally restricted to selected locations where the seaweed is already well established. To harvest and farm *Undaria*, permissions under the Biosecurity Act 1993 are required. Management options for *Undaria* farming may include a range of generic conditions – for example, details on the source of stock, vessel and equipment treatments, and how *Undaria* is harvested, transferred and processed to prevent the inadvertent spread of the seaweed and reduce the biosecurity risk of the activity. MPI has developed a standardised risk management plan template (within the application form) to assist applicants with identifying potential biosecurity risks associated with their *Undaria* farming operation and how these risks might be mitigated.

Given the uncertainties surrounding *Undaria* aquaculture development, and the substantial information gaps on the details of *Undaria* culture methods and suitable farming environments, a precautionary and adaptive management approach is warranted. Established biosecurity pathway management, surveillance and contingency planning frameworks used in the shellfish and finfish sectors are likely to be broadly transferable to seaweed cultivation, supplemented by *Undaria*-specific measures and supported by monitoring to improve understanding as operational experience develops.

Potential ecological issues such as genetic risks, biosecurity pests and diseases, and interactions with wild fish populations are likely to require case-by-case assessment, as risks will depend on the species cultivated, farm location and stocking density. Management considerations such as farm spacing, staged development and epidemiological units should be considered if necessary.

5. CUMULATIVE EFFECTS ASSOCIATED WITH AQUACULTURE

Table 5.1: Overview of potential cumulative effects associated with aquaculture.

Definition	The cumulative effects of aquaculture at scales greater than the farm
Summary of potential effects	• A key concern is that nutrient release from aquaculture will exceed the environment's capability to process these nutrients without adverse effects (the carrying capacity) • A broad range of other effects is possible but prediction is difficult, due to a changing environment and the interaction of factors • Changing environments driven by climate change and land-based activities may mitigate or add cumulatively to aquaculture – consideration of the type of aquaculture and its location is important
Management and mitigation options	• Careful site selection and regional spatial planning • Adaptive management within precautionary limits nested within good state of the environment monitoring (to detect anthropogenic versus natural change)
Knowledge gaps	• Good long-term state of the environment monitoring for understanding baseline conditions • Good co-design of aquaculture monitoring and state of the environment monitoring • Determination of carrying capacity and limit setting of growing waters in estuaries, harbours, embayments, coastal and offshore regions
Key terms defined in glossary	Adaptive management, anthropogenic, bay-wide, benthic, carrying capacity, cumulative effect, EQS, eutrophication, farm-scale, food web, IMTA / ecological aquaculture, nutrient enrichment, oligotrophication, phytoplankton, staged development, stressor, water column

5.1 Introduction

The farm-scale effects from aquaculture have been covered in previous sections; however, potential widescale effects (for example, effects on the water column away from the farm and effects on wider ecosystem processes), although acknowledged, are far less understood.

Many human activities, including aquaculture, potentially affect the marine environment in complex ways (see Figure 5.1). These effects can occur cumulatively over different spatial and temporal scales. In addition, the response of the marine environment is likely to depend on ambient water conditions and several factors including topography, weather and climate-related processes.

A cumulative effect is referred to in section 3 of the RMA as an effect which arises over time or in combination with other effects. This should include both positive and adverse effects, temporary and permanent effects, as well as past, present and future effects. For aquaculture development in the marine environment, cumulative effects are defined as: ecological effects in the marine environment that result from the incremental, accumulating and interacting effects of an aquaculture development when added to other stressors from anthropogenic activities affecting the marine environment (past, present and future activities) and foreseeable changes in ocean conditions (such as in response to

climate change). In addition, cumulative effects also refer to the combined ecological changes arising from multiple aquaculture operations within a defined geographic area, which may manifest as a mosaic of impacts (e.g. benthic changes) across the seabed and are important to consider when assessing effects at an ecologically relevant scale. This is particularly important as aquaculture extends into open ocean and dispersive sites at a larger scale. The remainder of this section focuses on the interpretation and application of the RMA definition of cumulative effects.

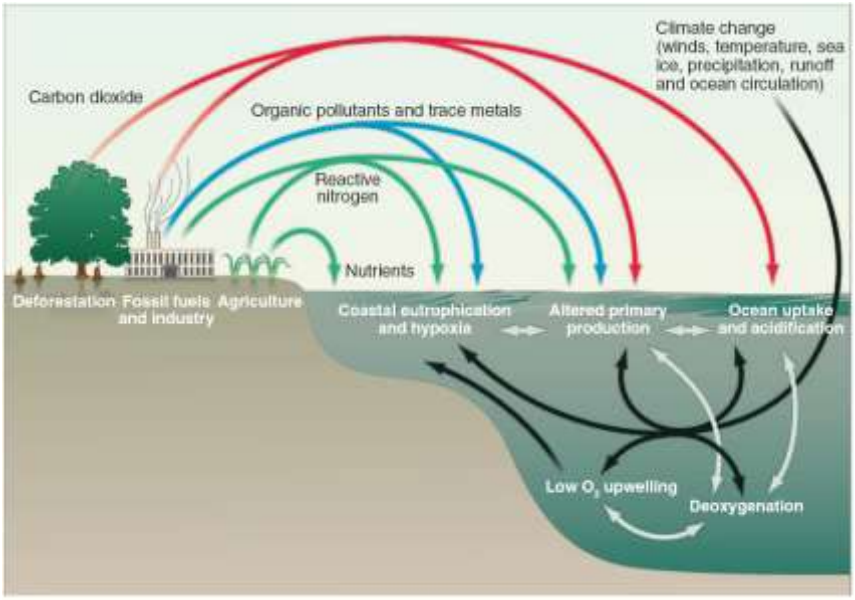


Figure 5.1: Conceptual diagram of cumulative anthropogenic effects in marine ecosystems, including inputs of materials into the system (coloured arrows), indirect effects of climate change and altered ocean circulation (black arrows), and interconnectivity of ocean biogeochemical processes (white arrows). Source: Doney (2010).

5.2 Summary of potential effects and significance

There is a broad range of potential cumulative effects of aquaculture, including additive spatial effects of multiple farms on other components of the ecosystem (such as the incremental increases in habitat loss or habitat creation for marine mammals, seabirds or wild fish populations), and subtle flow-on effects to wider ecosystem processes (for example, shifts in the food web following changes in phytoplankton community composition or nutrient ratios). Alternatively, they could be potentially large scale, such as the effects of nutrient enrichment of the water column at bay-wide scales when combined with other marine farms and inputs from the land. There is also potential for cumulative interactions between different stressors associated with aquaculture (such as the effects of organic enrichment and metal contamination on soft-sediment communities).

A key area when assessing cumulative environmental change is how aquaculture contributes to cumulative changes in nutrient conditions and primary production, and the flow-on effects on the wider ecosystem. This may include:

- finfish aquaculture adding nutrients to the water column and seabed;
- shellfish aquaculture adding nutrients to the water column and seabed and extracting plankton; and
- seaweed aquaculture extracting nutrients from the water column.

In many cases, the potential contribution of different types of aquaculture will need to be considered together, since different forms of aquaculture often co-occur within the same waterbodies and therefore contribute collectively to wider ecosystem conditions.

Cumulative effects could range from bay-wide to regional scales and could occur for the duration of farm operations or extend beyond, depending on levels of change in the surrounding ecosystem. If aquaculture activities were to cease, recovery of water column conditions from nutrient enrichment or extraction is likely to be over the scale of days to weeks. Recovery of benthic structure and function is likely to take longer (~1–10 years) depending on the level of modification of the seabed. With the emergence of offshore aquaculture sites, increasingly better information on trends and stressors associated with climate changes at these remote sites will be required.

5.3 Effects of shellfish and seaweed aquaculture

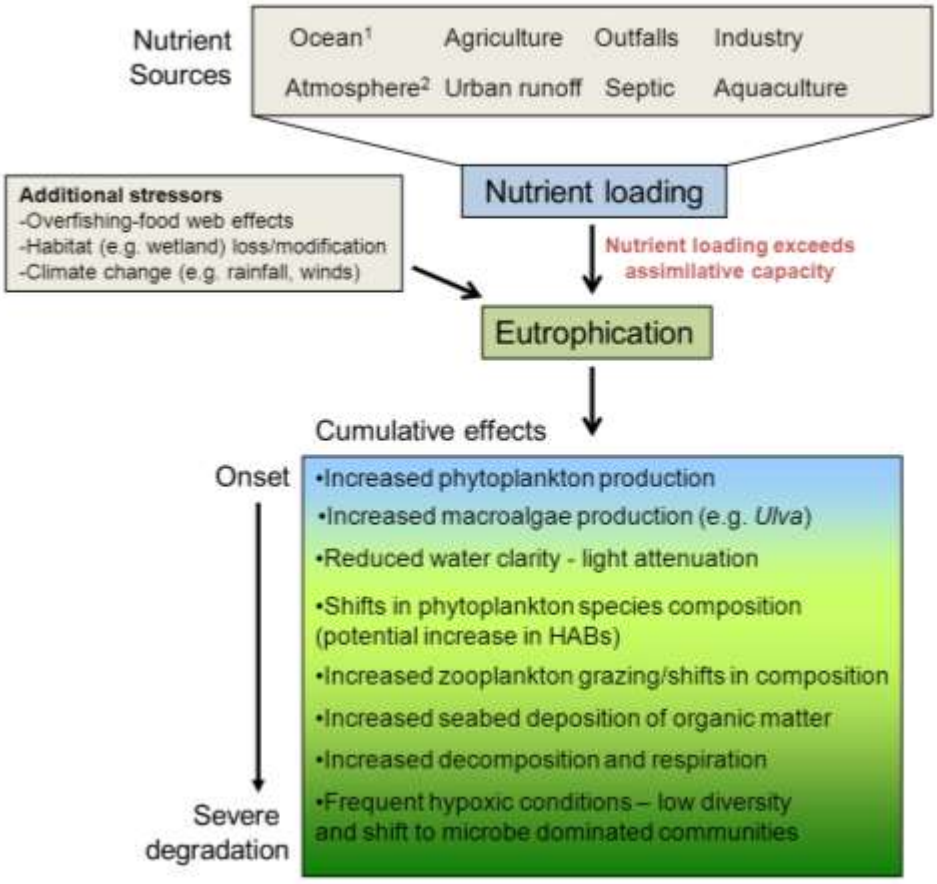
Multiple shellfish farms extracting plankton could potentially lead to widescale changes in plankton abundance and plankton community composition, and in turn, to flow-on effects on the food web. Long-term monitoring has detected low levels of pigment concentration changes associated with phytoplankton (chlorophyll-*a*) at shellfish sites in New Zealand. However, long-term monitoring in New Zealand mussel farming regions to date has not detected such changes in plankton community structure (see Section 2.2).

Farming of seaweed could further deplete levels of phytoplankton by removing dissolved nutrients from the water column. The nature and extent of effects could vary in time and space depending on a number of factors, such as season, site characteristics, and surrounding developments. Given limited development of seaweed farms in New Zealand, no measurements of nutrient and phytoplankton effects have not been undertaken locally; however, overseas measurements and models suggest effects can be modest, if culture density is managed appropriately.

5.4 Effects of finfish aquaculture

The contribution of the effects of finfish aquaculture towards wider cumulative environmental change may occur from nutrient and organic matter additions and will most likely vary considerably depending in the level of finfish aquaculture (combined with other nutrient inputs) relative to the region's carrying capacity. Effects may include subtle increases in phytoplankton production and benthic organic enrichment, or more advanced symptoms of eutrophication, such as large changes in phytoplankton biomass and bay-wide organic accumulation on the seabed, coupled with increased decomposition and low oxygen levels in extreme cases.

Potential effects from increased nutrient additions on the wider ecosystem are shown in Figure 5.2. Factors such as changes in upstream land use, habitat loss and modification along rivers and coastal margins, fishing and climate change may also contribute in cumulative ways to the eutrophication effects in coastal waters.



Notes
1) Ocean sources to coastal waters include dissolved nutrients through breakdown of organic matter, nitrification, and downwelling / upwelling of nutrient-rich deeper waters.
2) Atmospheric deposition of nutrients from fossil fuel combustion, agricultural fertilisers and livestock operations can also significantly contribute to nutrients in coastal waters.

Figure 5.2: Diagram of the eutrophication process. Source: Díaz et al. (2012).

5.5 Management and mitigation options

The cumulative ecological effects of aquaculture could potentially be significant, particularly if an ecosystem is already in a stressed state or approaching carrying capacity limits (from other anthropogenic influences, natural changes or a highly sensitive system). It is therefore important to understand the main drivers of ecosystem change in a region. But it is challenging to firstly detect and quantify ecosystem changes, and secondly to establish any causal relationships to changes that are detected.

Efforts to address cumulative effects associated with multiple activities tend to lie outside the scope of individual marine farms; however, as outlined in the previous sections, there are ways to manage and mitigate effects at the farm scale, which in turn may contribute to minimising cumulative effects in the wider ecosystem. This is more the case for nutrient enrichment from finfish aquaculture, which may be reduced or mitigated through good farm practices, (described in Section 3), such as:

- reducing feed wastage and increasing feeding efficiencies;
- reducing stocking densities;
- in theory, through an integrated multi-trophic aquaculture (IMTA) approach; or
- siting near restorative aquaculture sites.

IMTA can theoretically mitigate some effects by farming organisms capable of using wastes from other types of aquaculture located nearby. For example, phytoplankton stimulated by excess finfish farm-derived nutrients can be consumed by mussels, dissolved nutrients from fish and mussels can be assimilated by adjacent seaweeds at the farm, and sea cucumbers can process excess organic enrichment beneath farm pens. In addition, co-cultured species could be harvested to improve the economic performance of the farm. Concepts such as restorative aquaculture are similar to IMTA but can consider wider restorative benefits that aquaculture effects can have to remediate historical and ongoing impacts to aquatic environments and wild organisms (see Section 7). Current literature suggests that restorative aquaculture is primarily focused on low-trophic species, such as shellfish and seaweeds, due to their capacity to help restore degraded ecosystem characteristics (e.g. reduce elevated nutrient concentrations and restore mid-water seaweed reef habitats).

Mitigation of cumulative effects ultimately requires a wider ecosystem-based approach to planning and managing marine resources, and consideration of the effects of aquaculture within the context of other human activities that impact on the marine environment. Informed spatial planning and site selection can help minimise the extent to which aquaculture contributes to wider cumulative effects. As knowledge of potential cumulative effects is poor, setting of conservative limits for development based on knowledge (including modelled predictions) of likely carrying capacity of ambient growing waters is recommended. In multiple farm situations, modelling can assist in understanding not just the carrying capacity, but also the spatial distribution of effects under various development scenarios.

Knowledge of baseline environmental conditions and how they vary over space and time is essential to enable any changes above baseline to be detected, and to predict any future contributions of aquaculture to cumulative effects from other sources. Regional state of the environment monitoring programmes, as well as available data from consent-related monitoring, can contribute to long-term datasets for assessing cumulative environmental change. The establishment of permanent observation platforms can be an effective means of obtaining time-series data for describing trends in water quality conditions (see Section 6).

Information on baseline environmental conditions contributes to understanding the carrying capacity of the region for aquaculture development. The carrying capacity for coastal environments remains unknown in most regions. To better address this issue and assist predictions of carrying capacity of a region, appropriate indicators and trigger points may be selected. Indicators and triggers may be linked to measures of water quality and primary production in the wider environment, such as levels of nutrients, chlorophyll-*a*, and oxygen and perhaps the frequency and abundance of nuisance algal blooms occurring throughout the region.

Staged development in the presence of long-term regional monitoring of background conditions and environmental change can allow for adaptive management of cumulative effects. Adaptive management means that development is staged and if environmental change goes beyond accepted limits, development can then be stopped, reduced or removed. This can also include having tiered monitoring, whereby the monitoring effort increases as sites approach, or exceed, EQS. Targeted monitoring and research associated with adaptive management can also aid in improving the accuracy of models and clarifying the role of aquaculture in driving cumulative effects.

An example of a New Zealand adaptive management approach is given below.

Blue Endeavour – offshore aquaculture development

The Blue Endeavour salmon farm is large-scale offshore aquaculture development that, once stocked, will employ a staged, adaptive management approach. The project is designed to enable progressive expansion based on environmental performance, with monitoring data informing each stage of development. This approach will allow uncertainty to be reduced over time as empirical data are collected from an open ocean environment with high dispersive capacity.

A suite of environmental indicators will be monitored to assess effects and inform management decisions, with thresholds established to guide operational responses and progression between stages. If monitoring indicates that effects approach or exceed agreed limits, adaptive management responses will be triggered, which may include modifications to farming practices, adjustments to stocking levels or reassessment of the development pathway. The staged approach is intended to ensure that environmental effects remain within acceptable bounds while supporting the incremental growth of offshore aquaculture.

5.6 Knowledge gaps

Baseline conditions and current levels of cumulative effects from past and existing developments and activities (including land-based) are not well known in the coastal environment. This is in part due to a lack of long-term data describing trends in wider environmental conditions such as water quality, which are required for establishing environmental baselines and assessing changes that may be occurring beyond natural levels of variability (see Section 6.3).

Typical gaps in knowledge relating to cumulative effects include good estimates of natural and anthropogenic nutrient inputs, an understanding of the far-field effects of farm wastes from multiple farms, and the effects that may arise from aquaculture activities combined with other stressors present in coastal waters (such as land-based pollution and fishing). Also needed is a better understanding of the functional role of aquaculture as a component of the wider marine ecosystem. For example, in the case of shellfish, it may be that farmed shellfish actually restore some of the historical ecosystem functions of past shellfish beds that are no longer dominant in areas such as the Firth of Thames and Tasman Bay. These aspects are discussed more fully in Section 7.

Models have an important role to play in understanding and estimating effects from aquaculture in the context of cumulative effects; however, uncertainly remains high in many models due to limited field data for model calibration and validation.

6. MONITORING THE EFFECTS OF AQUACULTURE

6.1 Introduction

Appropriate monitoring of the ecological effects of aquaculture is crucial to ensure that aquaculture can operate sustainably, to ensure environmental outcomes are being met, and, if relevant, to support the adaptive management of the farm. This is especially so in areas where there has previously been little or no monitoring, where a new species or farming method is being introduced, or where a relatively large-scale new farm is being proposed.

Monitoring is required under the RMA, both at an individual consent level and a wider state of the environment (SoE) level. Ideally, monitoring should be undertaken in an integrated manner – monitoring of individual farms for specific localised effects in conjunction with SoE monitoring for cumulative effects. This enables a baseline of data to be established on which future decisions can then be made.

Aquaculture monitoring needs to be well thought through, providing useful information for the industry and for decision-making, both in terms of specific consents and for future plan development. Monitoring should be targeted to areas of key concern and build on existing knowledge.

6.2 Individual consent monitoring

When a resource consent for aquaculture is granted, it will include specific conditions requiring monitoring to be undertaken by the consent holder. Monitoring conditions can be included under section 108 of the RMA.

Monitoring plays an important role in identifying and assessing an aquaculture activity's ecological effects. Monitoring also helps determine whether consent conditions are effective and, if necessary, can assist in identifying ways to improve performance. Monitoring is also a crucial aspect of adaptive management if this technique is being used.

Regional coastal plans could include information on what type of monitoring is required for aquaculture activities. This provides a foundation on which the monitoring conditions for specific consents can be established. These monitoring requirements should be species-type specific where possible, while also allowing for flexibility to ensure that the most appropriate aspects of each activity is being monitored. Flexibility will ensure that monitoring requirements can be changed over time to reflect new information, methods or techniques.

Whilst standard monitoring conditions may be used, conditions could be tailored for each consent with advice from relevant scientific experts. They should be based on existing data or in the absence of existing data, information provided as part of baseline monitoring. Baseline data are important to determine the actual effects of a farm and to monitor trends over time (see Section 6.3). Conditions should focus on the key areas of concern for the farm, and should be appropriate to the nature and scale of the proposed farm. For more complex applications, such as new technology or species, or sensitive environments or habitats, more specific monitoring conditions will most likely be required.

In areas where the farm-scale effects of aquaculture are largely well known (for example, conventional longline mussel farming in coastal bays), the need for monitoring may be reduced. In these situations, monitoring conditions may largely focus on those aspects of the activity which may, in conjunction with other activities including other marine farms, give rise to cumulative effects.

Consent conditions need to be clear and certain. They should establish the frequency and location of the monitoring, any specific methods that should be used, and when and how reporting to the regional council should occur.

Monitoring is usually the responsibility of the applicant, but conditions should specify that it be undertaken by appropriately qualified people.

When writing review conditions for aquaculture consents within a specific geographic area, regional councils should consider whether it is possible to synchronise the review periods for all of the consents. This enables the conditions for all of the consents to be reviewed at the same time, assisting with the monitoring of the cumulative effects in that location.

Guidance for open ocean aquaculture

Siting and Management Guidelines for Open Ocean Aquaculture
The Siting and Management Guidelines for Open Ocean Aquaculture focus on identifying suitable locations and operational practices to minimise environmental effects and support sustainable offshore aquaculture development. The guidelines outline key considerations for site selection, and address farm design, biosecurity and risk management, with an emphasis on avoiding sensitive habitats and reducing cumulative effects. Together, these considerations support a risk-based, effects-driven approach to offshore aquaculture, recognising the importance of site-specific assessment and adaptive management in novel environments.

Best Practice Guidelines for Benthic and Water Quality Monitoring of Open Ocean Finfish Culture in New Zealand (Giles et al. 2021)
The Open Ocean Aquaculture Guidelines provide a framework to support the planning, consenting and management of aquaculture in exposed offshore environments. The guidance emphasises the importance of baseline data collection and fit-for-purpose environmental monitoring programmes that reflect the dynamic and highly dispersive nature of open ocean settings. A precautionary, adaptive management approach is promoted, whereby monitoring results inform staged development and trigger management responses, where required. The document also highlights the need to integrate monitoring with site selection, farm design and operational practices, while allowing for refinement of approaches as knowledge and experience develop.

6.3 Baseline monitoring

Where uncertainty over the effects of a new aquaculture activity exists, particularly when existing information on the coastal environment is absent or outdated, baseline monitoring prior to the establishment of the new aquaculture activity is prudent.

In many locations in New Zealand, existing information is scarce, and in the case of proposed open ocean operations, the basic physiological functioning of species in novel habitats is poorly understood. As a result, consents for new aquaculture involving new species or significant scale may require baseline monitoring. This position has been reinforced through more recent offshore aquaculture consenting processes, such as those associated with the Blue Endeavour development.

The purpose of baseline monitoring is to provide an understanding of the existing environment into which the aquaculture activity is to be located. It creates a starting point from which more specific ongoing monitoring conditions can be established.

Information to be included as part of baseline monitoring should be determined on a case-by-case basis, but may include the following aspects:

- the benthic area both beneath and in the vicinity of the farm, including habitats and communities;
- water quality, as well as targeted sampling, which may also include relevant satellite data to determine surface properties such as temperature, turbidity and chlorophyll-*a*;
- local marine wildlife, and
- hydrodynamic conditions.

Best Management Practice Guidelines for Salmon Farms in the Marlborough Sounds (Fletcher et al. 2022)

The BMP guidelines represent an adaptive, "living" framework for environmental monitoring and management of salmon aquaculture in New Zealand. Originally developed in 2015 and subsequently revised in 2019 and 2022, the guidelines are periodically reviewed by a multi-stakeholder technical working group comprising scientists, regulators, industry and regional representatives to ensure that monitoring approaches remain aligned with current scientific understanding and operational practice. This iterative process allows for the incorporation of emerging technologies and methods, including recent advances such as environmental DNA (eDNA) for improved detection and monitoring of ecological effects. As a result, the guidelines provide a consistent but flexible framework that can evolve over time, supporting robust, science-based management of salmon farming in the Marlborough Sounds.

6.4 State of the environment and regional monitoring

Regional councils carry out SoE monitoring under section 35(2)(a) of the RMA. State of the environment monitoring could involve monitoring of the entire coastal management area of a region or part of it. Currently, SoE monitoring is generally focused on water column attributes, such as water quality, nutrients and phytoplankton dynamics. While this provides useful information on broad-scale environmental trends and pressures, monitoring of benthic environments is typically more limited and often targeted or site-specific. As a result, SoE programmes may not fully capture all ecological effects associated with aquaculture, particularly those occurring at the seabed, and are commonly supplemented by consent-based monitoring requirements.

The results of SoE monitoring are crucial to both examining the cumulative effects of existing aquaculture and other activities and providing a baseline of the existing environmental health to aid in assessing the potential effects of future aquaculture activities. It can also help with future coastal plan development, such as identifying appropriate locations for new aquaculture space.

It is important that sufficient quality data are gathered at regular intervals in order to show trends over time. Regional councils should make the most of the monitoring information that is currently available (for example, from individual consents, water quality monitoring), however, this will often form an incomplete picture of what is actually happening. To assist regional councils, it is important that the underlying data sets gathered by marine farmers and research providers are made publicly available in accessible formats.

If possible, councils should consider whether the installation of permanent monitoring instrumentation is feasible. Costs associated with this could be sourced from the council directly, industry contributions, and external funding sources. As well, councils and marine farmers should consider developing joint monitoring programmes between consent holders and councils (for example a bay- or

even region-wide monitoring programme, a “consortium” approach) instead of or in addition to individual consent monitoring.

6.5 Monitoring cumulative effects – additional considerations

Currently, it is difficult to determine the cumulative effects (see Section 5) of aquaculture using just the available regional monitoring. Crucial to regional assessments of cumulative effects in the marine environment is accessibility and coordination of datasets, including those derived from consent monitoring at individual farms, and long-term SoE monitoring programmes. Standardised monitoring requirements for aquaculture are an important step to ensuring usefulness of consent monitoring datasets within broader-scale assessments. The Tasmanian Benthic Effects Monitoring Programme (BEMP) provides an example of a standardised monitoring framework designed to support consistent data collection and regional-scale assessment of aquaculture effects.

7. RESTORATIVE AQUACULTURE

Table 7.1: Overview of potential restorative effects associated with aquaculture.

Definition of restorative aquaculture	Direct ecological benefits to the environment provided by commercial or subsistence aquaculture, with the potential to generate net positive environmental outcomes
Summary of potential restorative effects / benefits	• Farm structures create habitats exploited by a range of species, leading to localised enhancement of biodiversity • Farm structures can attenuate wave energy and assist with sediment and shoreline stabilisation • Farmed stock, especially bivalves and seaweeds, can help improve local water quality through filter-feeding and / or growth
Management options	• Careful site selection and regional consideration of potential restorative effects of farm siting • Species selection and cultivation based on the remedial needs of the environment and interactions with existing aquaculture operations • Management timing (including monitoring) and practices to capture restorative effects • Gear and equipment design to support restorative benefits • Matching farm scale and intensity to ecosystem capacity
Knowledge gaps	• Quantification of restorative outcomes (including carbon sequestration) across spatial and temporal scales • Monitoring approaches for detecting and validating positive ecological outcomes • Whether farm stock can enhance larval supply and connectivity for wild populations • The interaction of aquaculture and climate-related stressors, including carbon-capture dynamics, increased sedimentation and nutrient loading from increased storm frequency in New Zealand
Key terms defined in glossary	Restorative aquaculture, ecological aquaculture, ecosystem services, ecosystem functions

7.1 Introduction

When planned and designed well, aquaculture can generate a wide range of positive ecological effects by supporting and enhancing ecosystem function at farm, bay and regional scales. *Restorative aquaculture* refers to farming practices that deliver direct, measurable improvements to ecosystem health, such as habitat creation, enhanced water quality and climate resilience (Figure 7.1). It aligns with the principles of *ecological aquaculture*, which emphasises designing farm systems to function in harmony with surrounding ecosystems. The distinction lies in the explicit requirement for restorative aquaculture to demonstrate environmental gains, a key consideration in regions where ecological functions have been lost or diminished.

Globally, interest in the environmental role of aquaculture is growing, accelerating efforts to understand and quantify the ecosystem functions and services farm systems provide. Environmental benefits arise through different mechanisms and over varying time scales. Some are immediate, such as increased water filtration by cultured shellfish, which remove particulates and organic matter from the water column, improving water clarity and influencing local nutrient dynamics. Other benefits

accrue gradually, including longer-term nitrogen removal through harvest or denitrification associated with mussel crop matrices and sediments, as well as incremental improvements in habitat structure as suspended and benthic communities develop beneath farms. Together, these immediate and longer-term functions underpin the potential for aquaculture to generate meaningful nature-positive outcomes.

In a global spatial analysis of over 200 marine ecoregions, New Zealand's coastal regions were ranked among the top zones for restorative aquaculture opportunity, reflecting a favourable combination of environmental characteristics, robust regulatory and management systems, and strong social and human-health indicators. In New Zealand, aquaculture development has generally taken place in areas with a history of environmental degradation, such as seafloor habitat loss. As these regions overlap with key aquaculture areas (e.g. Coromandel, Marlborough, Golden and Tasman Bays), any positive ecological effects from existing farms may be viewed within a restorative context.

This section provides an overview of the potential restorative effects associated with aquaculture in New Zealand, drawing on both international examples and relevant local case studies and research. Among New Zealand's key aquaculture species, shellfish (particularly cultured green-lipped mussels) are considered strong candidates for restorative aquaculture. This reflects both the scale of the existing industry, and the ecological roles mussels can provide in the wild, including water filtration, nutrient cycling and the creation of biogenic habitat that supports other marine species.

At present, the restorative effects of finfish aquaculture have not been formally assessed in New Zealand, and international evidence is limited. The domestic seaweed industry is still in early development, with limited monitoring despite strong international evidence of ecological benefits. Given these gaps, this section focuses primarily on the restorative potential of shellfish aquaculture, while providing brief overviews of emerging restorative opportunities associated with seaweed and finfish farming based on international examples.

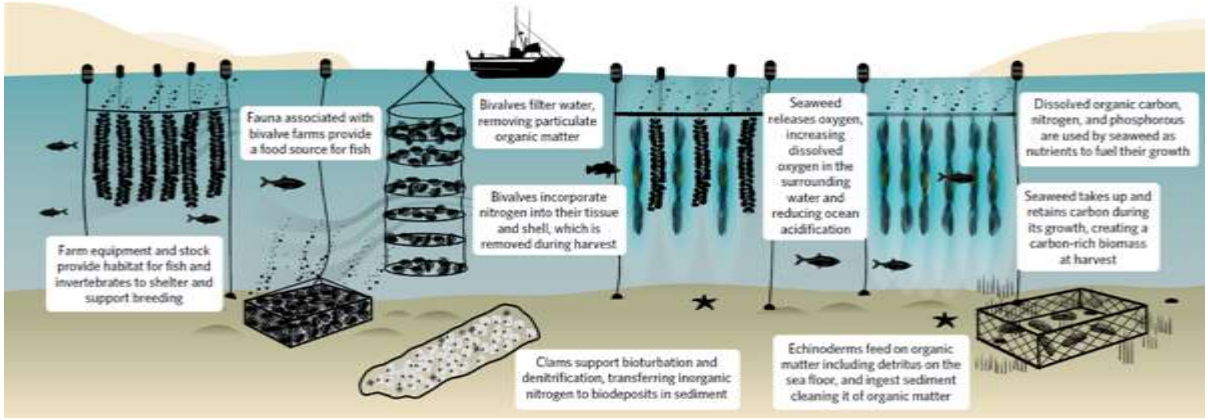


Figure 7.1. Ecological services associated with bivalve, seaweed and echinoderm aquaculture using different farming techniques (e.g. subtidal lines, cages on the seabed and hanging baskets). Source: A global monitoring, evaluation and learning framework for regenerative and restorative aquaculture: Helping nature thrive through aquaculture (The Nature Conservancy 2024).

7.2 Summary of potential effects and significance

For aquaculture to deliver positive environmental outcomes alongside economic and cultural benefits, operations must be designed and managed in ways that enhance ecosystem function while minimising adverse effects. The Nature Conservancy has provided guidance on how to practice restorative aquaculture and monitor for the restorative effects of aquaculture grouping potential benefits under four main categories: habitat and biodiversity, water quality, climate change, and sustainable food, resources and livelihoods (not discussed herein).

7.2.1 Restorative effects of shellfish and seaweed aquaculture

Research shows that non-fed species such as bivalves and seaweeds can deliver measurable ecological benefits by physically and biologically modifying their environment. Although further work is needed to quantify these services across diverse aquaculture settings, a substantial evidence base for New Zealand has emerged and is growing.

7.2.1.1 Habitat and biodiversity

Mussel and oyster farm structures create complex, three-dimensional habitats that provide refuge, feeding opportunities and settlement surfaces for a wide range of marine species. These structures support both sessile and mobile organisms, enhancing local biodiversity by offering hard surfaces for attachment in water column zones ideal for filter-feeders. Farmed stock and associated biofouling can also supply a high-quality food source for ecological communities. New Zealand studies have documented diverse ecological assemblages on farms, including encrusting biota, invertebrates and fish communities that use farms as shelter, feeding grounds and nursery habitat. Beneath farms, the accumulation of shell material, biodeposits and dropped mussels can form patchy, shell-based habitat that alters sediment structure. This habitat can support more functionally diverse infaunal and epifaunal communities than are typically found in degraded soft-sediment environments, sometimes contributing to mild forms of seabed recovery during farm operation. However, increases in diversity may also reflect low-level organic enrichment, so ecological benefits can be context dependent. Emerging research is also examining the extent to which seabirds and other mobile fauna use farm structures and cultivated species, contributing to a more comprehensive understanding of how mussel farms influence wider ecosystems.

7.2.1.2 Water quality

Bivalve and seaweed aquaculture can jointly improve coastal water quality through complementary pathways. As filter-feeders, mussels and oysters remove suspended particles from the water column, increasing water clarity, enhancing light penetration and, in some settings, supporting primary production. They also assimilate nitrogen and phosphorus into their tissues and shells, exporting nutrients from the system upon harvest. In parallel, microbial activity on farm structures, together with those associated with bivalve biodeposits on the seafloor, can stimulate denitrification. Similarly, cultured seaweeds take up dissolved inorganic nitrogen and phosphorus into their biomass and can locally increase dissolved oxygen and pH. This may help buffer against ocean acidification; however, the magnitude and persistence of this effect remains uncertain and is likely to be highly site-specific.

7.2.1.3 Climate change

Seaweed and shellfish aquaculture can contribute to climate-related resilience through several complementary mechanisms. Dense canopies of farmed seaweed and the physical structure of suspended aquaculture gear can attenuate wave energy, providing a natural buffer against storm surges and reducing local erosion risk, an effect demonstrated in modelling studies showing significant wave dissipation around suspended farms. Farmed seaweeds also play a direct role in carbon cycling by removing carbon dioxide from the water during growth and storing it in their biomass. Where seaweed biomass is harvested, carbon is removed from the marine environment; however, the extent to which this contributes to long-term carbon sequestration depends on the fate of the harvested material (e.g. animal feed, fertiliser, biofuel or more durable products). Some farmed

seaweed biomass may also be naturally dislodged or eroded, with the potential for local burial in seabed sediments, or transported to deeper waters, where it may contribute to other longer-term carbon sequestration pathways, although this remains an area of active research. Bivalves also influence carbon cycling through shell formation; however, calcification releases carbon dioxide and is unlikely to yield net sequestration at climate-relevant timescales. As such, shell production should be framed as participation in the carbon cycle rather than a carbon sink. The climate value of shells depends on their fate: durable reuse (e.g. reef restoration, shell recycling for habitat or construction) can store carbonate material for long periods, whereas dissolution or inappropriate disposal can negate benefits and may even contribute to carbon dioxide released from the ocean to the atmosphere. Accordingly, shells are best considered a long-lived material for restoration or circular-economy uses – not a basis for claiming net carbon removal.

7.2.2 Restorative effects of finfish aquaculture

Marine finfish farming, especially salmon farming, carries well-known environmental risks, although these are increasingly managed through regulation, mitigation and monitoring (see Section 3). Finfish farms are likely to provide only modest restorative benefits, mainly by attracting organisms to farm structures and provision of incidental refuge from fishing pressures, particularly trawling. However, to achieve any net ecological gain will require strong risk mitigation and management. Furthermore, the role of finfish farms in conservation (e.g. acting as other effective area-based conservation measures, or OECMs) remains uncertain. Unlike shellfish and seaweed, finfish farming is unlikely to improve water quality or support climate adaptation unless integrated with co-culture such as IMTA, or if supplemented with additional artificial habitats. In New Zealand, the salmon aquaculture sector takes part in voluntary sustainability programmes, and the sector has comparatively moderate carbon footprints (compared to beef and lamb) while supporting regional employment.

7.2.3 Management options

The Nature Conservancy has created six global principles of restorative aquaculture to provide a framework for achieving restorative outcomes that can be applied to existing and future farms. These principles assume that negative effects are already being minimised and mitigated (Figure 7.2), and can be used to provide guidance for industry, iwi / Māori and government agencies. Understanding whether these principles currently apply to farming systems in New Zealand or should be implemented during the development of new farms will potentially strengthen the delivery of environmental benefits, aligning aquaculture operations with broader goals for ecosystem health, community well-being and kaitiakitanga.

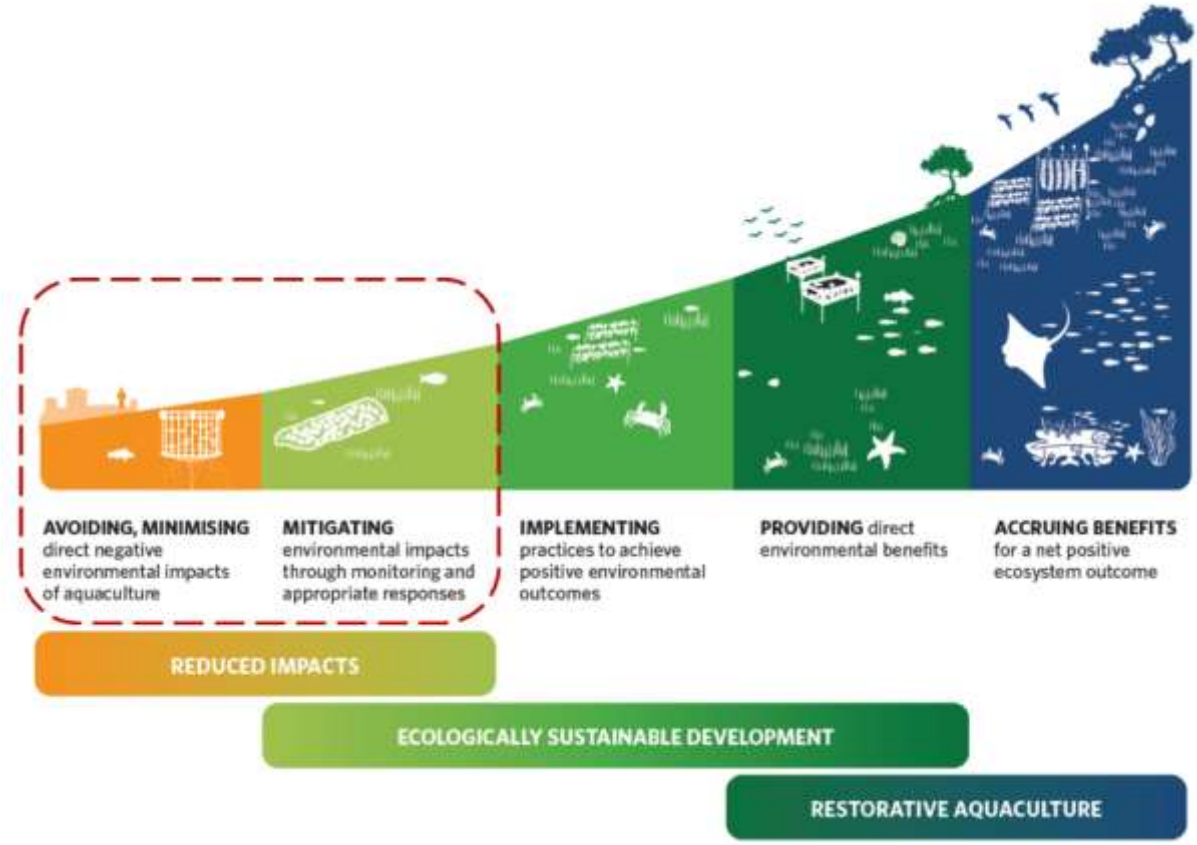


Figure 7.2. Illustration of the conceptual pathway towards restorative aquaculture and associated net-positive ecosystem outcomes, with the red-dashed box indicating New Zealand's current position along this trajectory. Source: Adapted from The Nature Conservancy (2021).

Although restorative aquaculture can offer significant environmental benefits, poorly managed operations can still cause ecological harm. Net positive outcomes cannot be achieved if gains are undermined by damage to habitats, species, ecosystem functions, or the cultural and economic values they support. Risks also include inappropriate farm siting and the use of non-native or invasive species that pose biosecurity or genetic threats.

Through planning regulations and careful development, portions of New Zealand's shellfish aquaculture sector already reflect some restorative principles.

An example of restorative aquaculture principles from The Nature Conservancy (note that Principle 6 has been left out as it relates to the social, cultural and economic value of environmental benefits and remains beyond the scope of this document).

Principle 1: *Site farms where environmental benefits can be generated.* Farm placement strongly influences ecological outcomes. Locating farms in areas that are already degraded or characterised by low structural habitat complexity (e.g. soft sediment areas) allows farm structures to provide shelter or habitat that would otherwise be absent, potentially enhancing local biodiversity. In New Zealand, most shellfish farms are situated over soft, muddy sediments that are common and widespread. Continuing to prioritise farm siting in the consent process in degraded areas where ecological gains are possible could provide opportunities to enhance the biodiversity or health of nearby degraded shellfish beds.

Principle 2: *Culture species that can provide environmental benefits.* Cultivating native species typically maximises ecological gains, although naturalised species in New Zealand such as Pacific oysters (*Magallana gigas*) can also provide comparable functions. Continuing to prioritise the culture of native species, particularly green-lipped mussels, while ensuring responsible genetic management of non-indigenous (naturalised) species (e.g. using triploid, sterile Pacific oyster lines), will help balance ecological benefits with biosecurity and sustainability considerations. Furthermore, emerging aquaculture species should also be assessed to understand how they may provide similar or complementary restorative benefits.

Principle 3: *Prioritise farming equipment that enhances the delivery of environmental benefits.* Farm gear and infrastructure can actively support environmental benefits by creating habitat complexity, providing refuge for juvenile species, and promoting the settlement of wild bivalves and other organisms. Across New Zealand, mussel farms (including spat-collecting farms) already use culture systems that deliver both mussel production and habitat-forming benefits. Building on this foundation, future farm designs and gear trials could intentionally balance enhanced biodiversity and ecosystem services with production efficiency, for example by reducing mussel loss associated with increased biofouling or predation while supporting habitat complexity.

Principle 4: *Adopt farm management practices that support environmental enhancement.* Effective management throughout the installation, operation, maintenance, and end-of-life decommissioning of marine farm structures is essential to ensure that farms deliver long-lasting ecological benefits. Each of these activities can influence the scale and quality of environmental outcomes. Operational schedules such as deployment and harvest could align with ecological windows to avoid disruption and maximise positive outcomes. In New Zealand, the timing of shellfish seeding and harvest is largely guided by local environmental conditions, such as food availability and water temperature, which drive shellfish growth and development.

Principle 5: *Farm at an intensity and scale that enhances the ecosystem.* Farming must operate at levels that enhance, rather than stress, local ecosystems. Appropriate scale and stock density help avoid pressures such as benthic enrichment, nutrient depletion and excessive particulate loading, ensuring that farming supports the recovery of natural functions and habitats. In New Zealand, consent monitoring is intended to provide an oversight of farming intensity and its environmental effects. However, although farming intensity and scale are key considerations in consent decisions, particularly for the finfish sector, there remains a need to review whether this monitoring is effective for capturing enhancement effects. Currently, these measures are designed to monitor and prevent adverse impacts rather than deliver data on net environmental benefits. Developing frameworks to measure enhancement would require a stronger evidence base, including the identification of ecological thresholds and the conditions under which both positive and negative outcomes can be consistently assessed.

7.2.4 Knowledge gaps

7.2.4.1 Quantification and monitoring

One of the major knowledge gaps lies in the limited quantification and monitoring of potential restorative effects. Many benefits are spatially and temporally variable, and current evidence is drawn largely from site-specific case studies, offering only a partial understanding of broader restorative outcomes. Existing consent monitoring approaches are also designed to detect adverse effects required by legislation (Section 6), rather than to measure net ecological gains or ecosystem services. Addressing this gap will require assessment of long-term or historical datasets to develop standardised indicators and robust methods capable of detecting restorative outcomes. New Zealand will need to develop such approaches to local species, habitats and management settings.

7.2.4.2 Conservation measures

Improving understanding of how farm structures contribute to habitat creation and other ecological benefits is important for realising farms as OECMs. In New Zealand, farms are often developed over soft, homogenous sediments to avoid ecologically sensitive habitats. As a result, New Zealand farms may function as OECMs for the patchy seafloor habitat that develops beneath them as their presence excludes disruptive bottom-towed fishing gear, thereby reducing physical disturbance and potentially improving benthic habitat complexity over time. However, while these structures support biodiversity and align with sustainable aquaculture frameworks and the principles of restorative aquaculture, critical knowledge gaps remain. In particular, these include how farms influence commercially valuable species and how they interact with recreational fisheries at local and regional scales. Emerging evidence shows that aquaculture can also support broader conservation and restoration outcomes by enhancing larval supply and connectivity with wild populations. Well-sited farms may contribute recruits to nearby wild stocks, indicating potential benefits for population and ecosystem function, although these effects are context dependent and subject to risks such as genetic interactions and escapees (see Section 3.8).

7.2.4.3 Climate change

While restorative aquaculture offers considerable potential to support ecological enhancement, there is limited understanding of how these benefits may evolve under the added pressure of climate change. Rising sea temperatures, shifts in storm intensity, altered nutrient and sediment inputs, and changes in coastal processes all have the capacity to reshape the ecological functions provided by aquaculture systems. For example, shellfish may experience reduced filtration performance under thermal stress, seaweed growth may respond differently to increased carbon dioxide availability, and farm structures may interact with changing hydrodynamics in ways that either strengthen or diminish habitat value. Consequently, the extent to which aquaculture systems can deliver restorative outcomes is likely to change over time, meaning that restorative benefits may vary under future conditions. Understanding these dynamics will require new research that integrates climate projections, ecosystem modelling and targeted field observations over spatial and temporal scales relevant to management.

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9. REFERENCES

Biancacci, C.; Crossett, D.; Scott, N.; South, P.M. (2026). Starting from scratch: Evaluating research investment to underpin seaweed aquaculture in Aotearoa New Zealand (A-NZ). In: A.T. Critchley, A.Q. Hurtado, I.C. Neish and L. Pereira (eds.) Advances in temperate phyconomy: Algal harvest and cultivation in globally distributed temperate waters. *Developments in Applied Phycology, Vol. 15.* Cham: Springer

Biosecurity Council. (2003). Tiakina Aotearoa Protect New Zealand: The Biosecurity Strategy for New Zealand. Biosecurity Council, Wellington, New Zealand. www.biosecurity.govt.nz/files/biosec/sys/strategy/biosecurity-strategy.pdf.

Clark, D.E.; Newcombe, E.; Clement, D.; Magnusson, M.; Lawton, R.J.; Glasson, C.R.K.; Major, R.; Adams, S. (2021). Stocktake and characterisation of Aotearoa New Zealand's seaweed sector: Environmental effects of seaweed wild-harvest and aquaculture (Part 3) (Sustainable Seas National Science Challenge). https://backend.sustainableseaschallenge.co.nz/assets/dms/Reports/Seaweed-sector-review-part-3-Environmental-effects-seaweed-aq/Environmental-effects-of-seaweed-wild-harvest-and-aquaculture.pdf

Cunningham, S.; South, P.; Cahill, P. (2020). Biosecurity Considerations for Farming Non-Native Seaweeds: A Case Study of Undaria pinnatifida in New Zealand. Cawthron Report No. 3395. Prepared for the Ministry of Business, Innovation and Employment: Shellfish Aquaculture Research Platform.

Díaz, R.; Rabalais, N.N.; Breitburg, D.L. (2012). Agriculture's impact on aquaculture: Hypoxia and eutrophication in marine waters. Report under Directorate for Trade and Agriculture for the OECD (Organisation for Economic Co-operation and Development).

Doney, S.C. (2010). The growing human footprint on coastal and open-ocean biogeochemistry. Science 328(5985): 1512–1516.

Fletcher, L.; Bennett, H.; Elvines, D.; Preece, M.; Broekhuizen, N.; Ford, R.; Heath, P.; Murray, C.; Jorgensen, E.; Wade, O.; Ferguson, G. (2022). Best management practice guidelines for salmon farms in the Marlborough Sounds: Part 1: Benthic environmental quality standards and monitoring protocol (Version 1.2 August 2022). New Zealand Aquatic Environment and Biodiversity Report No. 294.

Forrest, B.M.; Elmetri, I.; Clark, K. (2007). Ecological effects of intertidal oyster aquaculture. Nelson: Cawthron Institute. Cawthron Report No. 1275. Prepared for Northland Regional Council.

Giles, H.; Baxter, A.; Taylor, D.; Elvines, D.; Neale, D.; Jorgensen, E.; James, M.; Bunce, M.; Broekhuizen, N.; Wade, O.; Ford, R.; Cumming, S.; O'Connell-Milne, S.; Hart, S.-R.; Hampton, B. (2021). Best practice guidelines for benthic and water quality monitoring of open ocean finfish culture in New Zealand. *New Zealand Aquatic Environment and Biodiversity Report No. 278*. 96 p.

Keeley, N.; Forrest, B.; Hopkins, G.; Gillespie, P.; Clement, D.; Webb, S.; Knight, B; Gardner, J. (2009). Sustainable aquaculture in New Zealand: Review of the ecological effects of farming shellfish and other non-finfish species. Nelson: Cawthron Institute. Cawthron Report No. 1476. Prepared for the Ministry of Fisheries.

McGrath, E.; Knight, B.; Elvines, D.; Clement, D.; Bull, L.; Sneddon, R.; Atalah, J.; Hutson, K.; Symonds, J.; Costilla, R.; Scholtens, M.; Millar, R.; Alder, A. (2026). Recent literature on the ecosystem effects of aquaculture (2013 to 2024). *New Zealand Aquatic Environment and Biodiversity Report No. 376*. 35 p.

McMullin, R.M.; McGrath, E.C.; Atalah J. (2025). Environmental health measures for open ocean salmon aquaculture – identifying thresholds for sub-lethal responses in the context of wider ecosystem change. *New Zealand Aquatic Environment and Biodiversity Report No. 364*.

McMullin, R.; McGrath, E.; Bennett, H.; Copedo, J.; Ericson, J.; Delorme, N.; Miller, M.; Biessy. L.; Pearman, J. (2025). Environmental health measures for open ocean aquaculture – physiological responses of epifauna to enrichment under laboratory and field studies. *New Zealand Aquatic Environment and Biodiversity Report No. 353*.

Morrisey, D.J.; Stenton-Dozey, J.; Hadfield, M.; Plew, D.; Govier, D.; Gibbs, M.; Senior, A. (2006). Fisheries resource impact assessment (Golden Bay, Tasman Bay Interim AMAs). Nelson:

NIWA. NIWA Client Report No: NEL2006-014. Prepared for Ministry of Fisheries (Project: IPA2005-07).
NZMIC (New Zealand Mussel Industry Council). (2001). Code of practice for transfer of mussel seed. Aquaculture New Zealand.
NZOI (New Zealand Oyster Industry). (2007). New Zealand oyster industry code of practice. Aquaculture New Zealand.
The Nature Conservancy. (2021). Global principles of restorative aquaculture. Arlington (VA): The Nature Conservancy.
The Nature Conservancy. (2024). A global monitoring, evaluation and learning framework for regenerative and restorative aquaculture: Helping nature thrive through aquaculture. Arlington (VA): The Nature Conservancy

10. GLOSSARY

Adaptive management: An experimental approach to management, or "structured learning by doing". It is based on developing dynamic models that attempt to make predictions or hypotheses about the impacts of alternative management policies. Management learning then proceeds by systematic testing of these models, rather than by random trial and error. Adaptive management is most useful when large complex ecological systems are being managed and management decisions cannot wait for final research results.

Anoxic: Devoid of oxygen.

Anthropogenic: Caused or influenced by humans.

Assessment of environmental effects (AEE): A report that must be given to the council with the resource consent application. It outlines the effects that the proposed activity might have on the environment.

Azoic: Having no trace of life.

Bay-wide: For the purpose of this document, a spatial scale indicating that the extent of an effect is from 100 m to 1 km from the farm structure.

Benthic: Of, or relating to, or happening on the seafloor.

Benthos: Organisms that live on or in the sediment in aquatic environments.

Biodeposition: The excretion of faeces and pseudofaeces onto the sediment below.

Biofouling: The attachment of organisms to a surface in contact with water.

Biomass: The total mass of all living material in a defined area, habitat, or region.

Biosecurity: The exclusion, eradication or effective management of risks posed by introduced pests and diseases.

Carrying capacity: The amount of a given activity that can be accommodated within the environmental capacity of a defined area. In aquaculture: usually considered to be the maximum quantity of a farmed species that any particular body of water can support over a long period without negative effects to the fish or to the environment.

Cetacean: Aquatic mammals including whales, dolphins and porpoises.

Chlorophyll-*a*: The green pigment found in the chloroplasts of plants.

Conservation status: Measure of the risk of extinction for species such as marine mammals or seabirds.

Cumulative effect: Ecological effects in the marine environment that result from the incremental, accumulating and interacting effects of an aquaculture development when added to other stressors from anthropogenic activities affecting the marine environment (past, present and future activities) and foreseeable changes in ocean conditions (such as in response to climate change).

Depletion footprint: Area surrounding a marine farm where it is predicted that there will be appreciable phytoplankton depletion.

Depositional footprint: Area that is predicted to be directly exposed to farm-derived organic deposits.

Ecological aquaculture: A model of aquaculture development that uses ecological principles and practices to re-create, design or facilitate farming ecosystems that mimic the function of natural ecosystems.

Ecological trap: A low-quality habitat that animals mistakenly prefer over other available habitats of higher quality.

Ecosystem functions: Ecological processes occurring within an environment.

Ecosystem services: The benefits humans derive from ecosystem functions.

Effects footprint: The area over which the proposed activity would have a noticeable effect on the existing environment.

Environmental quality standards (EQS): Standards that relate to the magnitude and spatial extent of effects. EQS provide quantitative criteria which can be used to inform adaptive management approaches.

Epidemiological unit: A group of animals that share approximately the same risk of exposure to a pathogenic agent with a defined location. This may be because they share a common aquatic environment (for example, mussels in suspension at a farm, caged fish), or because management practices make it likely that a pathogenic agent in one group of animals would quickly spread to other animals (for example, all the oyster racks on a farm, all the oyster farms in a harbour system).

Eutrophication: Natural or artificial nutrient enrichment in a body of water, associated with extensive plankton blooms and subsequent reduction of dissolved oxygen.

Exacerbator: Exacerbators create incubators or stepping stones for otherwise benign or low-impact pests, pathogens or parasites (both native and exotic species).

Farm-scale: For the purpose of this document, a spatial scale indicating that the extent of an effect is up to 100 m from the farm structure.

Feed-added species: Species that are farmed with the addition of feed; for example, finfish, including salmon.

Feed conversion ratio (FCR): Ratio between the dry weight of feed fed and the weight of yield gain. Measure of the efficiency of conversion of feed to fish (for example, FCR = 2.8 means that 2.8 kg of feed is needed to produce one kilogram of fish live weight).

Filter-feeder: An organism that strains water through passive feeding organs that trap particulates, including plankton. Includes shellfish species such as mussels and oysters.

Finfish: For the purpose of this document, finfish refers primarily to salmon, kingfish and snapper. The general definition of finfish is “true” fish so as to be distinguished from shellfish.

Fitness: An organism’s ability to survive and reproduce in a particular environment.

Food web: A community of organisms where there are several interrelated food chains.

Genetic modification: An organism in which the genetic material has been altered by means of gene or cell technologies.

Habitat exclusion: The exclusion of one or more species of animals from an existing habitat due to the introduction of a new activity (for example, a new marine farm).

Incident: An interaction that leads to injury (e.g. rope cut, abrasion), entrapment or entanglement (live or fatal) of seabirds or marine mammals with farm structures.

Incubator (biosecurity): An activity that can unintentionally harbour a pest or disease.

Integrated Multi-Trophic Aquaculture (IMTA): IMTA combines, in the appropriate proportions, the cultivation of fed aquaculture species (for example, finfish) with organic extractive aquaculture species (for example, shellfish) and inorganic extractive aquaculture species (for example, seaweed) for a balanced ecosystem management approach that takes into consideration site specificity, operational limits, and food safety guidelines and regulations.

Interaction: An event when a seabird or marine mammal makes physical contact with the farm structure, which may lead to an incident (see "Incident").

Intertidal: The area between high- and low-water marks.

Isoeugenol / eugenol-based anaesthetic: A type of anaesthetic commonly used in finfish aquaculture.

Lower trophic: For the purposes of this document, lower trophic refers primarily to species occupying lower levels of the food web, including sea cucumbers, seaweeds, and filter-feeders such as mussels and oysters.

Meroplankton: Any of various organisms that spend part of their life cycle, usually the larval or egg stages, as plankton.

Micronutrient: A chemical element or substance required in trace amounts for the normal growth and development of organisms.

Microplastics: Any fragment of plastic that is between 1 nanometer and 5 millimetres wide.

Microscopic pathogens: An agent of disease, such as a bacterium or virus.

Monosex: The aquaculture practice of culturing populations consisting of only one gender.

Nutrient enrichment: See "Eutrophication".

Oligotrophication: The natural or artificial extraction of nutrients from a body of water to the point where the productivity of plants (including algae) diminishes.

Organohalogenated contaminants (OHCs): A broad group of persistent environmental pollutants that can bioaccumulate in living tissues.

Other Effective area-based Conservation Measures (OECMs): Areas that are managed with the aim of achieving positive, long-term conservation outcomes (i.e. biodiversity, ecosystem functions and services) and are distinct from traditional protected areas.

Pathway: The way in which a risk organism may be transported into the country and within New Zealand. Pathways include goods, the material in which goods are packaged, containers, luggage, aircraft and vessels, and natural pathways such as wind and the sea.

Pelagic: Relating to, living in or occurring in the water column of open water areas of lakes or oceans.

Pest organisms: Include animals, plants and microorganisms capable of causing diseases (for example, the OsHV-1 in Pacific oysters) or otherwise adversely affecting New Zealand's natural, traditional or economic values (for example, the sea squirt *Styela clava*, and the red seaweed *Grataloupia turuturu*). These organisms may include not only non-indigenous species, but also indigenous species already present in the environment that are magnified as a result of culture operations.

Phytoplankton: Microscopic, plant-like organisms that drift in the sunlit upper layers of waterbodies and form the base of many aquatic food webs. They are an important food source for filter-feeders and other marine organisms.

Polyploidy: Refers to individuals with induced extra sets of chromosomes through the manipulation of embryos.

Pseudofaeces: The particles filtered from the water column by bivalve molluscs that are not incorporated into the digestive system; larger particles are wrapped in mucous prior to expulsion.

Reservoir: Reservoirs host risk organisms that can then spread by either natural or human-mediated mechanisms.

Restorative aquaculture: Commercial or subsistence aquaculture that provides direct ecological benefits, with the potential to generate net positive environmental outcomes.

Selective breeding: The selection of individuals with desirable traits for use in breeding. Over many generations, the practice leads to the development of strains with the desired characteristics.

Shellfish: For the purpose of this document, shellfish refers primarily to oysters and mussels, however, can extend to all filter-feeding bivalves.

Single Nucleotide Polymorphism (SNP): A high-resolution molecular marker representing a variation at a single nucleotide position (A, T, C or G) in the genome that differs among individuals of a species or between populations. SNP monitoring can be useful in identifying finfish escapees in a population.

Spat-catching: The process of obtaining juvenile mussels and oysters (spat) by placing specialised structures (sticks and ropes) in areas where there are large numbers of spat in the water. The spat attaches itself to the structures and is then transferred onto growing structures. Note that this definition does not include the harvest of green-lipped mussel spat from seaweed washed ashore at Ninety Mile Beach.

Staged development: A form of adaptive management whereby the development of the farm is divided into a series of stages.

Stratification: The layering of water caused by differences in temperature and salinity.

Stressor: Any environmental or biotic factor that exceeds natural levels of variation.

Subtidal: The shallow marine or tidal flat environment that is below the mean low-water level of spring tides.

Therapeutant: Chemical substances used on fish farms or aquaculture operations, when necessary, to keep aquatic animals (such as finfish or shellfish) healthy while they are being raised. Therapeutants could be vaccines, antibiotics or pesticides.

Transgenic organism: Organisms that have had foreign DNA inserted into their own genomes; that is, organisms that have been genetically modified.

Trigger level: Used in adaptive management, trigger points define levels of particular (monitored) environmental variables that indicate a potential adverse environmental effect may occur, and if exceeded, trigger a management response.

Triploidy: The induction of a third set of chromosomes in fish and shellfish resulting in sterile individuals.

UAE test: MPI assesses the effects of proposed marine farms on fishing through the Undue Adverse Effects test (UAE test). A proposed marine farm cannot proceed if it would have "undue" adverse effects on recreational or customary fishing, or commercial fishing for non-quota management system (QMS) stocks. And, unless an aquaculture agreement or compensation declaration is reached, a proposed marine farm cannot proceed if it would have undue adverse effects on commercial fishing for QMS stocks.

Water column: A vertical expanse of seawater stretching from the ocean surface to just above the ocean floor.

Water residence time: The length of time that water spends in a particular body of water (for example, an embayment) before flowing out of it again.

Wave attenuation: The weakening of wave force or intensity.

Zoonosis (pl. zoonoses): An infectious disease that has naturally spread from vertebrate animals to humans.

Acronyms

AEE: Assessment of Environmental Effects

ANZECC: Australian and New Zealand Environment and Conservation Council

CCA: Copper, Chromium and Arsenic

DOC: Department of Conservation

EPA: Environmental Protection Authority

EQS: Environmental Quality Standards

FAO: United Nations Food and Agriculture Organization

FCR: Feed Conversion Ratio

GIA: Government Industry Agreement for Biosecurity Readiness and Response

HAB: Harmful Algal Bloom

IMTA: Integrated Multi-Trophic Aquaculture

MPI: Ministry for Primary Industries

NZCPS: New Zealand Coastal Policy Statement 2010

OsHV-1: Ostreid herpesvirus-1

PSFL: Predicted Sustainable Feed Level

Redox: Reduction–oxidation

RMA: Resource Management Act 1991

SNP: Single Nucleotide Polymorphism

SoE: State of the Environment monitoring

UAE: Undue Adverse Effects on fishing test