Ministry for Primary Industries
Manatū Ahu Matua

OVERVIEW OF ECOLOGICAL EFFECTS OF AQUACULTURE

Growing and Protecting New Zealand

Acknowledgements

Underpinning the **Aquaculture Ecological Guidance Package** is the *Literature Review of Ecological Effects of Aquaculture.* The review was compiled by two of New Zealand's main science providers in aquaculture – the National Institute of Water and Atmospheric Research and the Cawthron Institute. MPI would like to acknowledge their important contributions to the *Literature Review* and their helpful input into the guidance package as a whole.

MPI would also like to acknowledge the following organisations for their contributions in developing this resource (in alphabetical order):

- Aquaculture New Zealand
- Bay of Plenty Regional Council
- Department of Conservation
- The New Zealand King Salmon Company Ltd
- The University of Auckland
- Waikato Regional Council

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FOREWORD

To build our understanding of the environmental effects of marine-based aquaculture, the Ministry for Primary Industries (MPI) has worked with two of New Zealand's main science providers in aquaculture – the Cawthron Institute (Cawthron) and the National Institute of Water and Atmospheric Research (NIWA) – along with the Department of Conservation, regional councils, the aquaculture industry, and others to develop the **Aquaculture Ecological Guidance Package**. This web-based package provides information and advice on the ecological effects of marine-based aquaculture to assist in planning and managing aquaculture development.

The **guidance** includes a *Literature Review of Ecological Effects of Aquaculture* and an *Overview of Ecological Effects of Aquaculture.* Later this year, an *Aquaculture Risk Screening Tool* and *Decision-makers' Dashboard* will be released to help decision-makers, planners, marine farmers and others with an interest in the coastal environment to identify potential ecological risks of specific aquaculture development.

Underpinning the **Aquaculture Ecological Guidance Package** is the *Literature Review of Ecological Effects of Aquaculture*. Published in 2013, the review brings together existing scientific knowledge on the main potential ecological effects of aquaculture in New Zealand. The review was compiled by NIWA and Cawthron with input from other scientists and technical specialists.

The *Literature Review* and *Overview* focus on the potential ecological effects of existing commercial aquaculture species in New Zealand, and those species that are likely to be developed over the next five years. Beyond assisting with current planning and management decisions, the *Literature Review* also identifies knowledge gaps and will aid in prioritising future research.

New Zealand has some distinct advantages to increase our market share in higher-value markets, including our reputation for high environmental performance and a legislative framework that ensures this is maintained. Our good water quality in aquaculture growing areas, food safety standards, and our relative geographic isolation and biosecurity measures mean we are relatively free from diseases and pests commonly affecting aquaculture production elsewhere in the world. The **Aquaculture Ecological Guidance Package** has been developed to assist in maintaining and strengthening this environmental advantage – so that aquaculture growth can be good for our environment and good for our economy.

Sincerely

Dr Richard Ford
Chair
Aquatic Environment Working Group
(Habitats and Ecosystems strand)

CHAPTER 1: INTRODUCTION

1.1 AQUACULTURE ECOLOGICAL GUIDANCE PACKAGE

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. Some previous development has been hampered by a lack of information or, in some cases, misinformation on the effects of aquaculture in New Zealand and inconsistent information requirements.

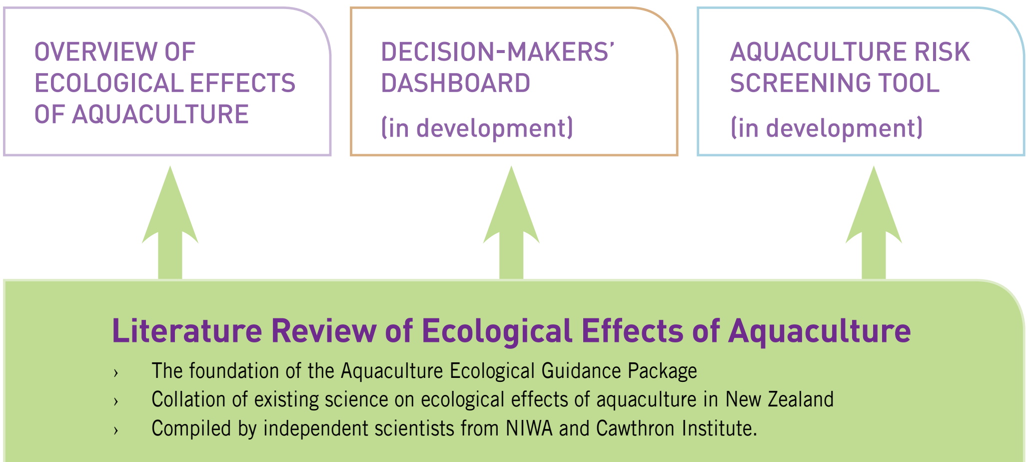
The **Aquaculture Ecological Guidance Package** (Figure 1.1) has been developed by the Ministry for Primary Industries (MPI) to provide current and science-based information and advice on ecological effects of marine-based aquaculture at a national level to assist local authorities, the aquaculture industry, and other stakeholders with their planning for and management of aquaculture. The package includes:

- *Literature Review of Ecological Effects of Aquaculture* – a comprehensive scientific review of ecological effects of marine-based aquaculture in New Zealand;
- *Overview of Ecological Effects of Aquaculture* – summarises the key messages and content from the *Literature Review*;
- *Decision-makers' Dashboard* (in development) – a brief rundown on management and mitigation options to avoid or minimise the negative ecological effects of aquaculture; and
- *Aquaculture Risk Screening Tool* (in development) – a risk-assessment tool for identifying and prioritising initial ecological risks is currently being developed.

The **Aquaculture Ecological Guidance Package** will be useful for 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; and
- for research providers as a resource of information.

Figure 1.1: Aquaculture Ecological Guidance Package



Our scientific understanding of the ecological effects of aquaculture continues to grow. For this reason, the **Aquaculture Ecological Guidance Package** is web-based and is able to be updated to reflect current thinking and research.

1.1.1 *Literature Review* of Ecological Effects of Aquaculture

The foundation of the **Aquaculture Ecological Guidance Package** is the *Literature Review of Ecological Effects of Aquaculture*, a review which brings together existing scientific knowledge on the main potential ecological effects of aquaculture in New Zealand and identifies uncertainties and knowledge gaps. The *Literature Review* was compiled in 2012 by two of New Zealand's main science providers in aquaculture – the National Institute of Water and Atmospheric Research (NIWA) and the Cawthron Institute (Cawthron). The review focuses on the potential ecological effects of existing commercial aquaculture species in New Zealand, and those species that are likely to be developed over the next five years (those species with short-term potential, see Table 1.1). Species discussed include:

- shellfish – green-lipped mussels[1] and oysters (referred to as filter-feeder in the *Literature Review*);
- finfish – Chinook salmon, hāpuku and kingfish (referred to as *feed-added* in the *Literature Review*); and
- sea cucumbers and seaweeds (primarily *Undaria pinnatifida*) (referred to as *lower trophic* in the *Literature Review*).

Information contained in the *Literature Review* can underpin the development of guidelines and approved methodologies to assess the ecological effects of aquaculture in New Zealand. This information should be particularly useful for prioritising future research and informing the planning of aquaculture zones and the consenting process for existing farms and proposed new aquaculture sites.

1.1.2 *Overview of Ecological Effects of Aquaculture*

The *Overview of Ecological Effects of Aquaculture* summarises the key potential ecological effects of aquaculture in New Zealand, gives comment on their likely significance, and suggests management and mitigation options. The purpose of the overview is to communicate, in an easy-to-understand manner, the key technical details of the *Literature Review*. The overview is not intended to replace the scientific content of the *Literature Review* and readers should refer to the *Literature Review* for more in-depth information.

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

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

Species	Farming status	Trophic Level
Green-lipped mussels *(Perna canaliculus)*	Current	Filter feeders
Pacific oysters *(Crassostrea gigas)*	Current	Filter feeders
Chinook salmon *(Oncorhynchus tshawytscha)*	Current	Feed-added species
Yellowtail kingfish *(Seriola lalandi)*	Short-term potential	Feed-added species
Hāpuku *(Polyprion oxygeneios)*	Short-term potential	Feed-added species
Sea cucumber *(Australostichopus mollis)*	Short-term potential	Lower trophic levels
Undaria (Undaria pinnatifida)	Short-term potential	Lower trophic levels

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 chapters:

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

This separate grouping of shellfish and finfish (Chapters 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 Chapters 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;
- wild fish interactions;
- effects on seabirds;
- biosecurity;
- escapee and genetic effects;
- effects from additives; and
- alteration of hydrodynamic flows.

Because the *Overview of Ecological Effects of Aquaculture* chapters may be viewed seperately, there is some necessary repetition between the chapters. For example, the shellfish and finfish chapters 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.

1.1.3 Aquaculture Risk Screening Tool and Decision-makers' Dashboard (in development)

The *Aquaculture Risk Screening Tool* will provide a method of initially screening an aquaculture proposal to help identify, prioritise and then manage ecological risks and uncertainty associated with the proposal. The methodology has been tested using case studies and refined following a workshop with key technical and management stakeholders. The tool will be primarily intended for use during the site selection phase of aquaculture development (whether by an applicant at consenting level or a council at a plan level) as a coarse filter to flag potential ecological risks so they can then be addressed appropriately.

The *Aquaculture Risk Screening Tool* is currently in development. A prototype of the tool is expected to be available on the MPI website later this year.

The *Decision-makers' Dashboard* will complement the *Aquaculture Risk Screening Tool* and will provide guidance to decision-makers on the types of things they should be looking for when reviewing planning and resource consent documents.

1.2 AQUACULTURE IN NEW ZEALAND

1.2.1 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 in New Zealand and is committed to enabling this industry to achieve its goal of NZD1 billion in annual sales by 2025[2]. An essential part of this commitment is to ensure expansion of aquaculture takes place within acceptable environmental limits and respects other uses and values of our waterways and marine environment. Planning for sustainable aquaculture needs to be supported by science-based information on ecological effects.

Aquaculture production in New Zealand is dominated by three species: green-lipped mussels, Chinook salmon and Pacific oysters. The majority of aquaculture activities are located in the coastal marine environment, and the main aquaculture locations are shown in Figure 1.2.

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

Aquaculture planning and consenting processes in New Zealand are managed by regional councils and unitary authorities under the Resource Management Act 1991 (RMA). The RMA is the key piece of legislation responsible for the sustainable management of natural and physical resources of our environment in New Zealand. Sustainable management includes the requirement to avoid, remedy or mitigate any adverse effects of aquaculture on the environment[3].

Under the RMA, New Zealand's regional councils and unitary authorities are responsible for managing aquaculture within their coastal marine area – the zone between the mean high water springs and the 12 nautical mile limit.

In addition to their other responsibilities in the coastal marine area, regional councils and unitary authorities can perform their functions in relation to the coastal marine area, as specified in section 30(3) of the RMA: *"to control aquaculture activities for the purpose of avoiding, remedying, or mitigating the effects of aquaculture activities on fishing and fisheries resources".*

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

Any person wishing to establish a marine farm must obtain a resource consent from the appropriate regional council. 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 looks at the effects of the proposed activity and considers those effects against the purpose of the RMA to promote the sustainable management of natural and physical resources. A regional coastal plan may specify additional information requirements.

2 View the **Government's Aquaculture Strategy and Five-year Action Plan**.

3 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;

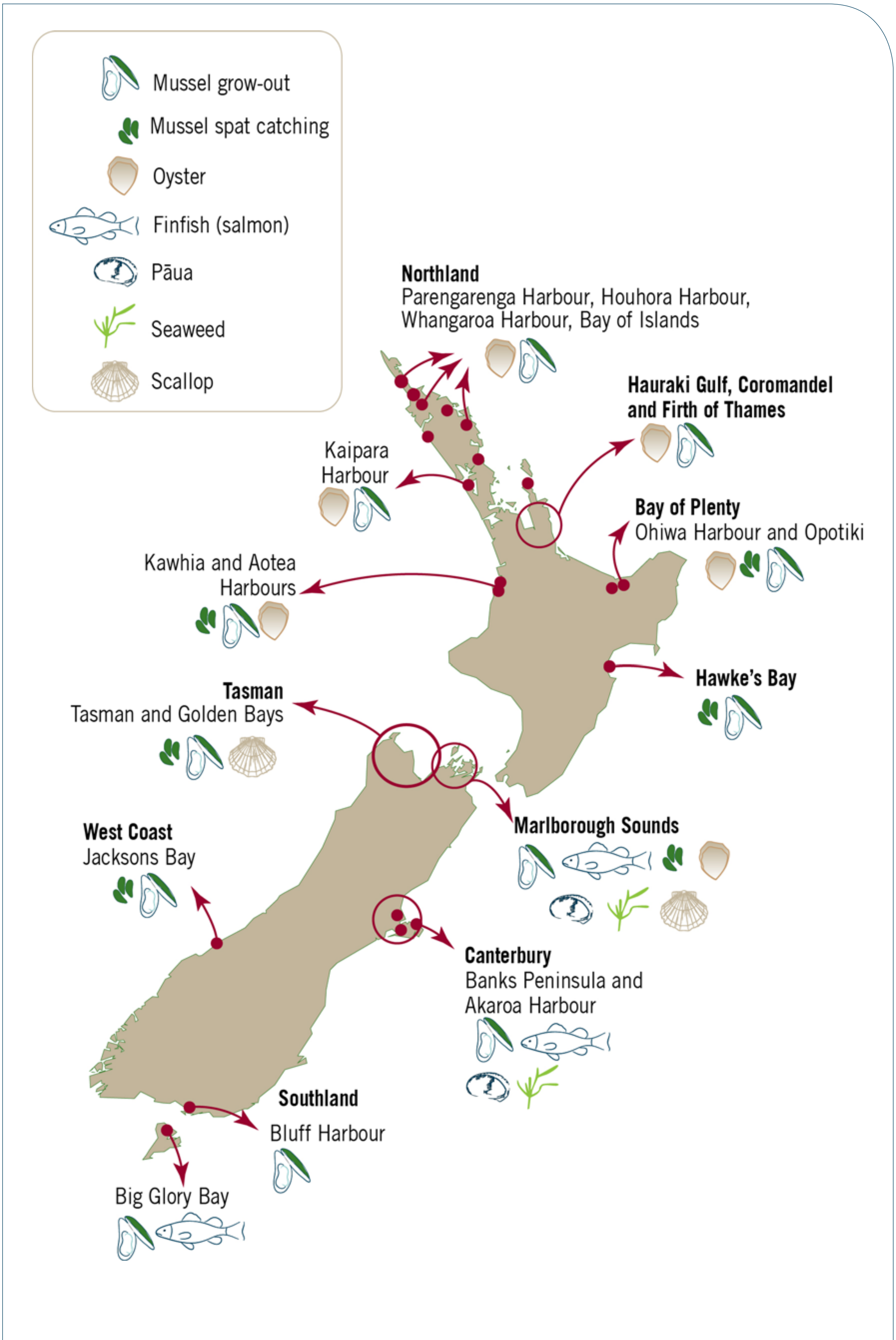
(b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and

(c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Figure 1.2: Geographic locations of main aquaculture activities in New Zealand

Source: Based on Keeley et al., 2009.

Note: Not all species shown here are considered in this document.



The regional council can grant consent for a maximum duration of 35 years (and in most cases, the duration must be a minimum duration of 20 years[4]). The regional council will set consent conditions to ensure the aquaculture activity is carried out in a manner which avoids remedies or mitigates any adverse effects on the environment. The regional council should also monitor the aquaculture activity to ensure the consent conditions are being complied with.

In the RMA consenting process, other matters, such as cultural effects and effects on other users, natural character and navigation must also be taken into consideration in decision-making. All these matters will need to be considered when preparing a consent application[5].

Other roles and responsibilities

MPI is responsible for determining whether aquaculture activities will have adverse effects on fishing under the Fisheries Act 1996. This assessment, known as the undue adverse effects (UAE) test, assesses the effects of an aquaculture activity on commercial, recreational and customary fishing. It is undertaken once a regional council has granted the resource consent. A proposed marine farm cannot proceed if it would have undue adverse effects on recreational or customary fishing. Where a marine farm is found to have an undue adverse effect on commercial fishing, an aquaculture agreement is required 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 and works with a broad range of partners (under the Biosecurity Act 1993, the RMA, and the Hazardous Substances and New Organisms Act 1996) to deliver an effective biosecurity system. At the regional level, regional councils have a duty to consider biosecurity issues under the RMA and New Zealand Coastal Policy Statement 2010 (NZCPS) during the plan change and resource consent processes. At the marine farm level, on-farm biosecurity management should be in place that encompasses 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.

The Department of Conservation (DOC) has functions under the Conservation Act 1987 and a number of other Acts, 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's functions include managing land, fresh and coastal waters and historical sites that have been protected for conservation purposes. Many of these areas are coastal and are valued for their biodiversity, naturalness and recreational amenity. The direction for the management of these areas is set by statutory policies and plans that support the legislation.

DOC also supports the Minister of Conservation's RMA coastal role including the preparation of the NZCPS, and the approval of regional coastal plans.

The **NZCPS 2010** states policies for the sustainable management of the coastal environment and promotes better planning and zoning for coastal activities, including aquaculture. The NZCPS 2010 also recognises the need for high water quality for aquaculture activities, and that aquaculture can make a significant potential contribution to the economic and cultural well-being of people and communities (policy 8).

4 See section 123A of the RMA for more information.

5 View information on **applying for a resource consent**.

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.

LOCATION, LOCATION, LOCATION

Appropriate siting of an 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. Siting considerations should include:

- Avoid sensitive, rare or endangered habitats, species and communities.
- Dilute and diffuse: 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.
- Soft, muddy sediments without any significant benthic community 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.
- Research your site first. Know what is in the “effects footprint” of your activity and if there is the potential for cumulative effects.

TALK TO YOUR REGIONAL COUNCIL

Regional councils have specific policies on marine farming stated in regional coastal plans. We suggest you contact your regional council as early as possible to discuss how you can best prepare your resource consent application.

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. 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. Some regional councils have planning tools available or under development.

DO YOUR HOMEWORK

Every aquaculture resource consent application 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.

AQUACULTURE SCIENCE REVIEW

MPI convenes the Aquatic Environment Working Group (AEWG) to provide scientific feedback and review of research, including aquaculture. Regional councils and private applicants can request their projects are reviewed by AEWG. Although not a statutory requirement, a science review could be worthwhile particularly for large, novel or potentially contentious aquaculture proposals or research. Learn how to get involved in the **working group.**

THINK EFFECTS, NOT SPECIES

When applying for or issuing resource consent 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.

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 maintains environmental codes of practice for the oyster, mussel and finfish farming industries.

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 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 experimental aquaculture.

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 water body. As such, it is important regional councils encourage applicants to consult with relevant groups during the preparation of the AEE.

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’s important to look at what monitoring already exists to see whether that can be used.

CHAPTER 2: ECOLOGICAL EFFECTS OF FARMING SHELLFISH

2.1 INTRODUCTION

This chapter 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 (*Crassostrea gigas*) grown on intertidal racks or in baskets (see Figure 2.1 and Figure 2.2). This chapter also generally applies to other shellfish species farmed using suspended culture methods.

This chapter summarises information in the *Literature Review of Ecological Effects of Aquaculture*. Readers should refer to this *Literature Review* for additional information. Other recent relevant documents are the **Review of the ecological effects of non-finfish aquaculture** (Keeley et al., 2009) and the **Review of intertidal oyster culture in New Zealand** (Forrest et al., 2009).

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 Chapter 5 of this document.

Effects of spat-catching

Spat-catching is the process of obtaining juvenile mussels and oysters (spat) by placing specialised structures (such as ropes or sticks) in areas where there are naturally large numbers of spat in the water. The spat settles on the structures and is subsequently transferred onto growing structures. Note this definition does not include the harvest of green-lipped mussel spat from seaweed washed ashore at Ninety Mile Beach. The alternative to wild-caught spat is spat produced in a hatchery; this overview does not consider the potential ecological effects specific to hatchery (land-based) operations.

From the available information on spat-catching effects in New Zealand, it appears that the effects are similar or lesser than for the cultivation stage, with no issues that are likely to be of more significance than for the cultivation phase. An exception may be an increase in the potential for entanglement of medium- to large-sized whales. Spat-catching lines are comparatively light weight and could pose a greater entanglement risk, especially when initially set, than cultivation ropes that are under load from product.

Figure 2.1: Diagram illustrating the actual and potential ecological effects from long-line mussel farming

Source: Based on Keeley et al., 2009.

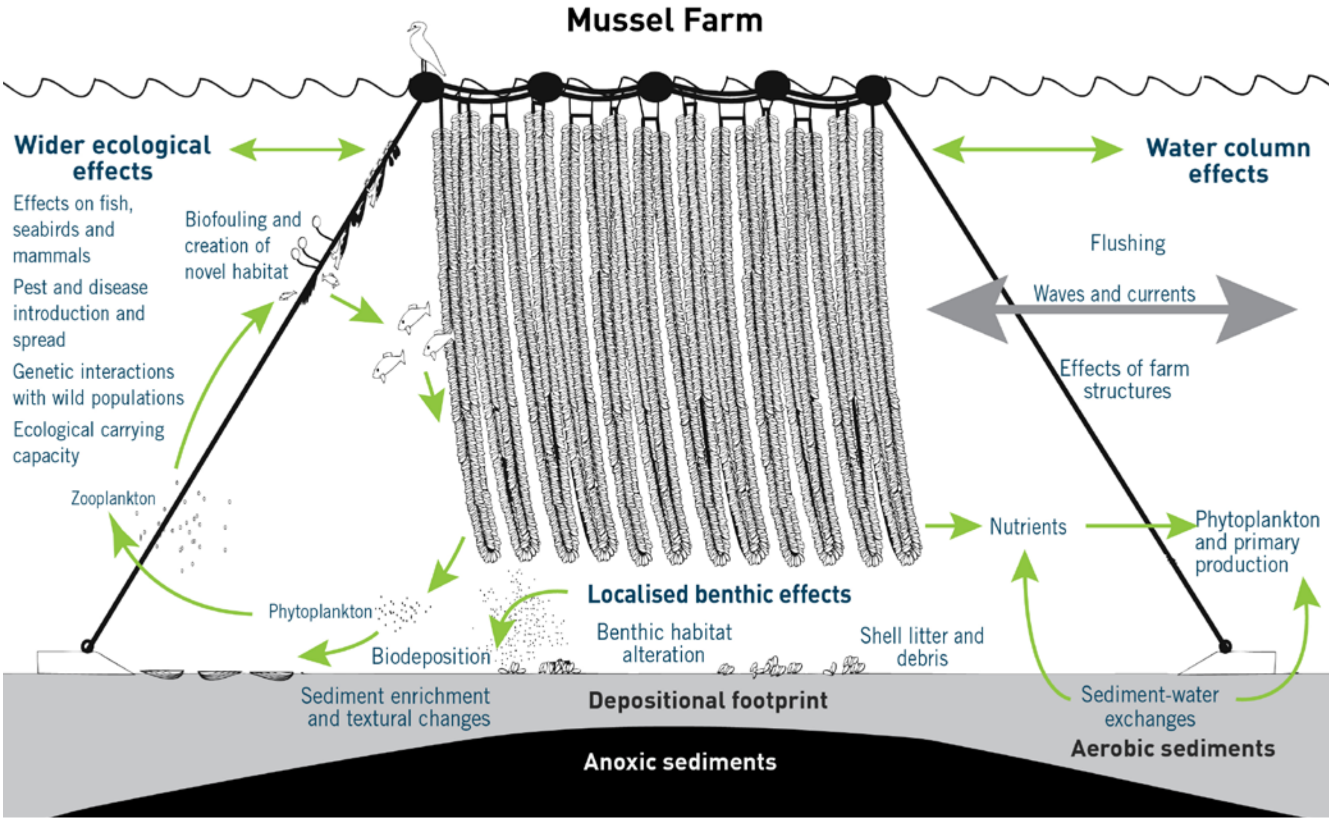
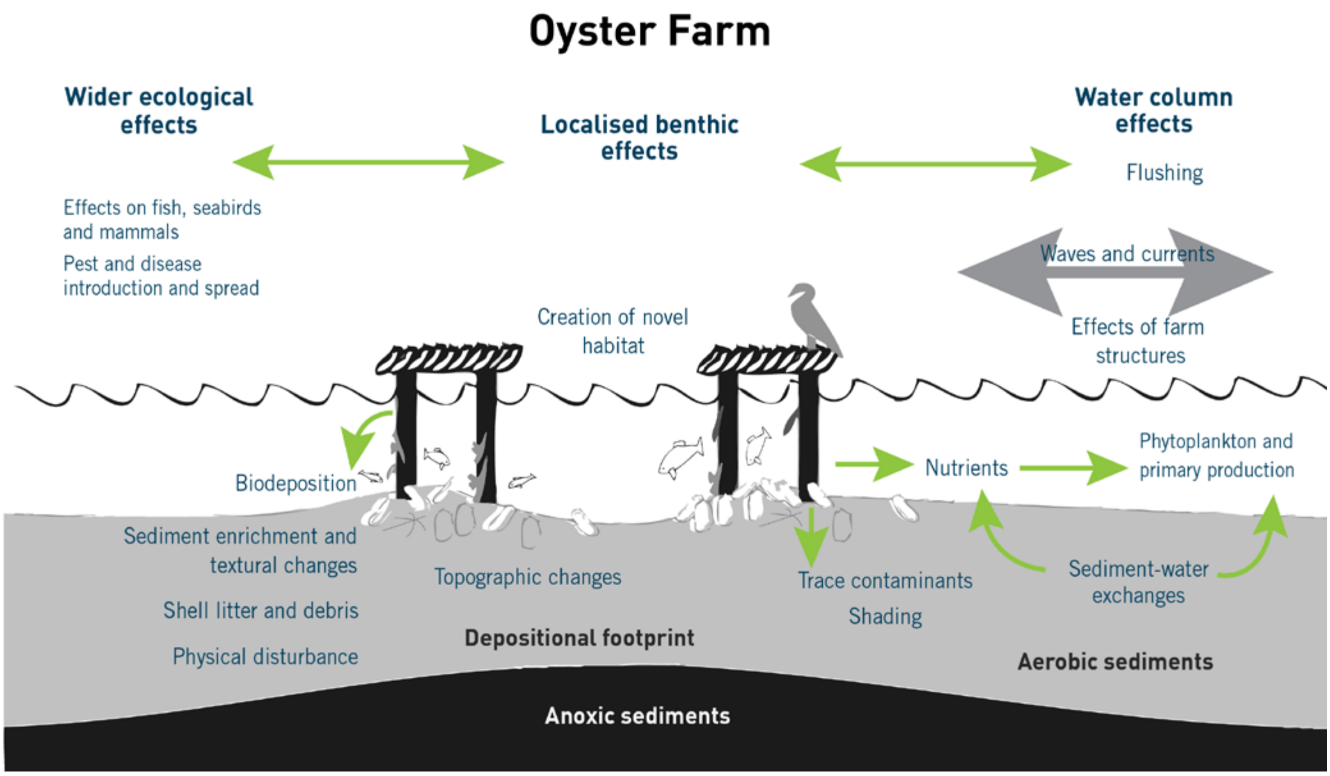


Figure 2.2: Diagram illustrating the actual and potential effects from elevated intertidal oyster cultivation

Source: Based on Forrest et al., 2009



2.2 WATER COLUMN EFFECTS

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

Definition	Effects of 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 • Determination of carrying capacity of estuaries, harbours, embayments and coastal regions for shellfish farming • Effectiveness of integrated multi-trophic aquaculture
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 Chapter 5.

Phytoplankton depletion

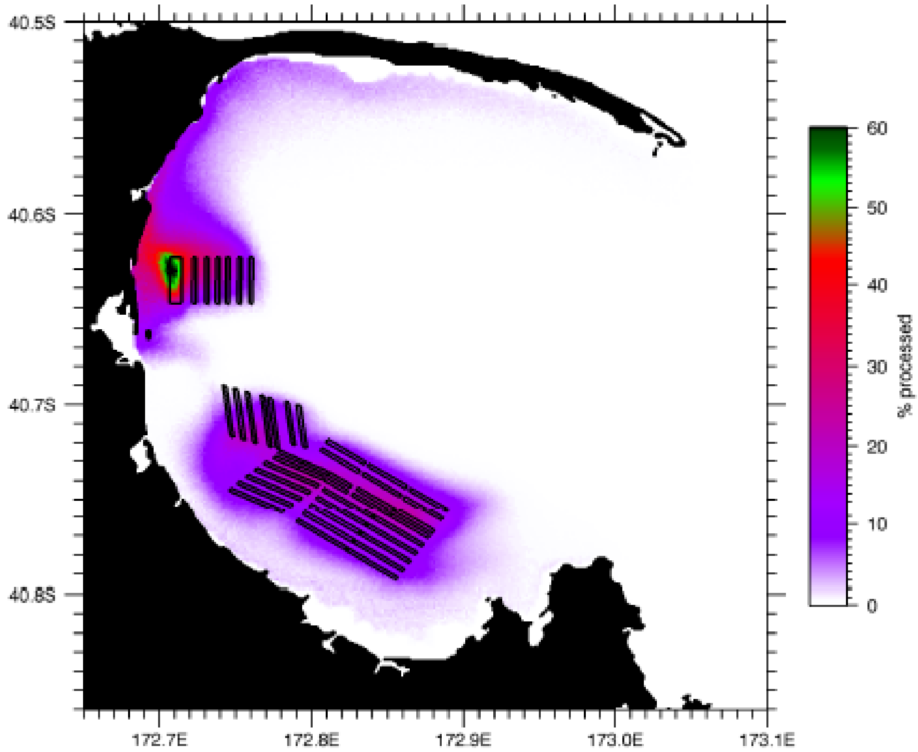
The main effect on the water column from the farming of shellfish is the extraction of phytoplankton and organic particulates by the farmed shellfish. Depletion can be extensive, particularly in sheltered bays, and has been speculated to potentially alter the composition of the phytoplankton, zooplankton, and meroplankton communities. Long-term monitoring of the water column (for example, over an eight-year period around mussel farms in the Firth of Thames) has shown, however, no changes to the long-term composition of these communities. For this reason, the degree to which this occurs and its ecological consequences are poorly understood.

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

Water column surveys gather temporal snapshots of phytoplankton abundance (as indicated by chlorophyll *a*) and provide some evidence of phytoplankton depletion. There is, however, a high degree of temporal and spatial variability in patterns of phytoplankton depletion in and around existing mussel farms in New Zealand. Typically, small New Zealand mussel farms have relatively little influence on the overall concentration of phytoplankton in the water column, particularly within the context of the wider spatial area surrounding the farms.

Unlike the extensive research on phytoplankton depletion by mussels, there is little data on the effects of oysters on the intertidal water column environment. International research suggests that the potential for adverse water quality-related effects as a result of intertidal oyster farming is low. This conclusion is not surprising given the significantly lower stocking densities than mussel farms and that intertidal farm sites are substantially or completely flushed with every tidal cycle.

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.



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.

Effects from biofouling communities

Farming structures and stock can be settled with 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. These assemblages typically have a range of other less mobile animals associated with them, such as worms and small crustaceans. The functional role of these biofoulers is not well understood, and further research is required to determine the contribution of biofouling communities to water column effects.

2.2.2 Significance of effects

Typically, the ecological effects on the water column from farming shellfish are generally only detectable within the farm and its phytoplankton depletion footprint, and are of short duration. The significance of these effects depends on the carrying capacity of the environment and the prevailing water currents. Effects on the water column will be more pronounced if farms are located in shallow areas with slow currents, compared to deep sites with strong flow and good flushing.

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. As such, nutrient enrichment beyond the farm boundaries is difficult to detect.

Despite recognised knowledge gaps and a lack of baseline water quality data in many regions, the fact that no significant water column-related issues have been documented in relation to shellfish farms in New Zealand suggests that ecological effects on the water column associated with current shellfish farming practices 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.

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 then 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 a number of 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 Chapter 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.

Models are often an important component in predicting water column effects at a site and a number of potential types of models are identified in the *Literature Review*.

Adaptive management and the use of IMTA are also potential mitigation measures (see Chapter 5).

Compliance monitoring of the immediate water column for key plankton (chlorophyll *a*, phytoplankton abundance, species composition) and nutrient parameters (dissolved carbon, nitrogen, and phosphorous) can also be useful to validate models and assess effects of existing farming operations. Chlorophyll *a* is typically used as a proxy for phytoplankton abundance in water column surveys, but it doesn't describe changes that may be occurring in phytoplankton community composition. Likely changes at a phytoplankton community level can be estimated using biophysical model simulations (see the text box below).

Biophysical model simulations in the Firth of Thames

Biophysical model simulations have been used to identify 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.

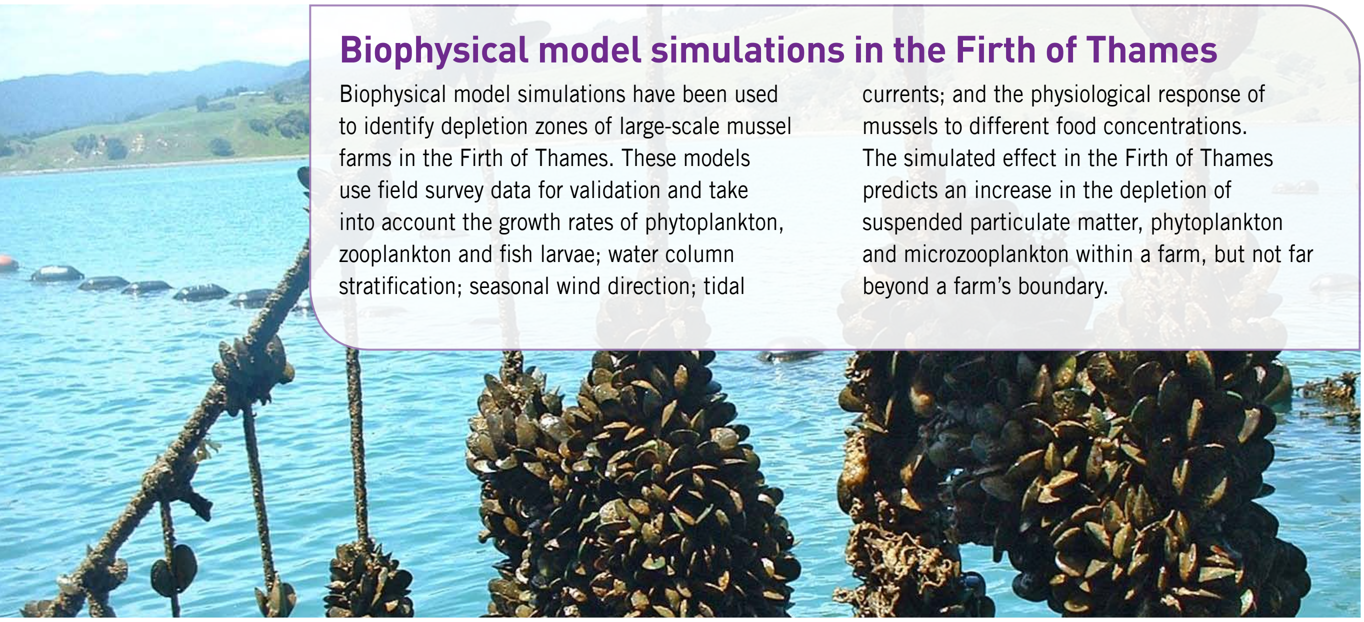


Photo: Graeme Silver.

2.3 BENTHIC EFFECTS

Table 2.2: Overview of potential benthic effects of shellfish farming

Definition	Effects of 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 of biofouling (compared with shellfish biodeposits) to enrichment beneath farms • Breakdown time of mussel and oyster shells in sediments
Key terms defined in glossary	Benthic, biodeposition, biofouling, depositional footprint, effects footprint, intertidal, phytoplankton water column

2.3.1 Summary of potential effects

The benthic effects from the farming of shellfish result from the sedimentation of organic-rich, fine-grained particles (biodeposits of faeces and pseudofaeces), and the deposition and accumulation of live shellfish, shell litter and other biota onto the seabed. These may smother seabed communities and change these communities 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 from shellfish farming is typically enrichment of the seabed due to the high organic content of the deposited particles. The effects exhibit as minor enrichment of the seabed sediments (organic content increases by ~7.5 percent), increased build-up of shell litter directly beneath the site, and, in some instances, increased aggregations of starfish and other benthic species.

Sediment enrichment affects sediment-dwelling species (infauna) by generally enhancing their productivity, leading to some smaller species becoming more prolific. Increased shell litter may have a positive effect through increasing benthic diversity by providing habitat for species that cannot otherwise inhabit soft-sediment areas. Changes to the surface dwelling mobile species, such as starfish and sea cucumbers, have been documented but have rarely been quantified and vary significantly between sites. Some benthic species, such as hydroids, shellfish, brachiopods, sponges and bryzoans 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 there are no particularly sensitive, vulnerable or special benthic communities.

The capacity of the environment to disperse and assimilate finer mussel farm biodeposits is largely determined by water depth and current speeds, although the carrying capacity of the environment may also vary seasonally in relation to the factors, such as water temperature. Increased flushing not only reduces localised sedimentation and accumulation of organic matter, 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 and farm debris, and biofouling or 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 as a result of shellfish farming, they are typically of minor ecological consequence beyond the boundary of a farm. The severity of benthic effects is typically low to moderate for soft-sediment habitats where there are no particularly sensitive, vulnerable or special benthic communities.

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

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 benthic effects, monitoring of physicochemical and biological properties of sediments at farming sites typically involves a suite of indicators of seabed health, including:

- observations of sediment colour;
- odour;
- reduction-oxidation (redox);
- potential discontinuity layer;
- sulphide concentrations;
- sediment organic content;
- infauna; and
- extent of shell and live mussel cover.

Recovery rates of seabed communities from deposition-related enrichment effects of mussel and oyster farms have not been widely researched, but are assumed to be site specific and relatively rapid once farming ceases. Accumulated shell material from drop-off may take several years 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 novel habitats may result in fundamental or long-term shifts in seabed community composition, unless the site undergoes targeted remediation.

2.4 MARINE MAMMAL INTERACTIONS

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

Definition	Effects of aquaculture on marine mammals
Summary of potential effects	• Habitat exclusion or modification leading to less use or less productive use • Potential for entanglement • Underwater noise disturbance
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 is collected and disposed of correctly • Monitoring of presence of marine mammal species in vicinity of farm
Knowledge gaps	• Ranges and locations of important habitats of marine mammal species • Types of 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

2.4.1 Summary of potential effects

Interactions between marine mammals and aquaculture result from an overlap between the spatial location of the farm structures and the habitats and migration routes of the species. Such interactions have been relatively minor issues with New Zealand marine farms given the small scale and location of the current aquaculture activities here. Overseas experience with these issues suggests the potential for adverse effects exists with continued growth in both marine mammal populations and larger scale, offshore farm developments.

Habitat modification or exclusion

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 has highlighted that the nature of the exclusion greatly depends on the type and scale of the farming method and the particular marine mammal species affected. Whales and particular dolphin species (for example, dusky dolphins) tend to be more sensitive and avoid such disturbances, while seals and other dolphin species (such as common and bottlenose dolphins) may actually be attracted to the novel habitat.

Studies in New Zealand have so far only addressed interactions between mussel farms and Hector's and dusky dolphins. Collectively, these studies suggest that while some marine mammal species are not displaced from regions as a whole, they do not appear to be using habitats occupied by shellfish farms in the same manner as prior to the establishment of the farms.

To date, there has been little overlap between aquaculture and the migratory paths of large whales in New Zealand waters. Further development of large offshore marine farms and the recovery of certain populations (notable humpback whales) may result in greater overlap with whale migration routes.

Entanglement

Physical interactions between aquaculture and marine mammals can lead to an increased risk of entanglement in structures, ropes or non-biological wastes from farm production. The risk of

Marine mammals in New Zealand

There are more than 50 species of cetaceans (whales, dolphins and porpoises), 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 Maui's dolphins; and
- those most likely to interact with manmade structures or fishing gear, for example, dusky, bottlenose and common dolphins; Bryde's, orca, southern right and humpback whales; and fur seals.

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.

Photos: Department of Conservation.

entanglement also increases as marine mammals tend to be attracted to the associated aggregations of wild fish (see Section 2.5).

The risk of entanglement will vary between species depending on several factors including[6]:

- behaviour – inquisitive or playful animals will be more at risk;
- propensity to roll – for example, humpback whales tend to roll when they become entangled in ropes;
- echolocation – dolphins and other toothed whales are able to echolocate and perceive obstacles with their sonar, whereas baleen whales cannot echolocate;
- morphology and size – whales with large pectoral fins and tail flukes (for example, humpback whales) or large gaping mouths (most baleen whales) could be more at risk; and
- agility – dolphins and smaller whales are more agile and therefore at less risk.

Underwater noise

Underwater noise associated with regular, ongoing farm activities, including vessels, may either exclude or attract marine mammals. Whales and particular dolphin species tend to be sensitive to such disturbances. Seals and other dolphin species, such as common and bottlenose dolphins, may actually be attracted to the novel noise source.

2.4.2 Significance of effects

The adverse effects of existing aquaculture on marine mammals are not presently considered significant issues (with the exception of a specific case regarding dusky dolphins in Admiralty Bay, Marlborough Sounds). While there is some current overlap with marine mammal habitats, very little of this occurs in what may be described as critical habitat (such as breeding and foraging grounds for cetaceans, and haul out sites and colonies for seals). In addition, the consequences of a physical interaction are considered minor in most cases, as the outcomes are generally expected to affect individuals or result in only small-scale avoidance or attraction.

The scale and magnitude of the effect of aquaculture on marine mammals depends largely on the species and its population range, particularly if it is an endangered, threatened, or range-restricted species. Critical species in this regard include Hector's, Maui's and bottlenose dolphins; along with orca, Bryde's, southern right and humpback whales[7].

The significance of these effects may need to be reconsidered in relation to any larger-scale and offshore developments in New Zealand waters.

2.4.3 Management or mitigation options

Farm locations need to be carefully selected to minimise the likelihood of overlap with important marine mammal migration routes and known habitats (species' home ranges, critical breeding and foraging habitats).

The large variation in the potential significance of aquaculture effects on New Zealand marine mammals (depending on the affected populations) makes developing and implementing one set of effective management guidelines or standards extremely difficult.

The risks associated with physical interactions can be further minimised by adopting appropriate maintenance and operational guidelines and standards for farm structures, as well as any noise-generating equipment. In addition, seals and dolphins may be attracted to the structures and wild fish aggregations that are often associated with the farms. Any resulting entanglement risks can be minimised by adopting regular maintenance measures around farm structures,

6 Personal communication Andrew Baxter, Technical Advisor, Department of Conservation.

7 Ibid.

ensuring debris and waste material does not enter the water, keeping lines well maintained and secured at all times, and ensuring anchor warps are maintained under sufficient tension (see Section 2.5).

Detailed information on abundance, distribution and critical habitats is available for only a handful of New Zealand's marine mammals. Where there are distinct concerns about a specific species, a management plan, developed in conjunction with DOC, could be developed. The purpose of a management plan would be to help ensure that the adverse effects on marine mammals as a result of the operation of the marine farm are minimised.

In general, monitoring records of the presence of marine mammal species in the vicinity of the farm site along with any detailed observations of their time spent around farm structures should be documented by the marine farmer. The relevant DOC conservancy office should be contacted in the event of marine mammal entanglement.

2.5 EFFECTS ON WILD FISH

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

Definition	Effects of aquaculture on wild fish populations
Summary of potential effects	• Attraction of wild fish to aquaculture structures (creation of artificial habitats) • Alteration of existing fish habitats
Management and mitigation options	• Careful site selection – avoid critical fish spawning grounds and nursery areas
Knowledge gaps	• Effects of shellfish aquaculture on larval stages of wild fish • 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

The primary ways in which shellfish farms affect wild fish are through the creation of artificial habitats that attract wild fish species seeking refuge and food sources, and the alteration of existing fish habitats through the deposition of shell litter and biodeposition of particulate matter.

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, changes in recreational fishing patterns, and extraction of fish eggs and larvae by farmed shellfish.

The presence of marine farms can result in changes in recreational fishing patterns and pressure which in turn could affect wild fish populations differently than in the absence of the structures. Recreational fishers and boaters have observed certain fish species, such as snapper and kingfish, congregating around mussel farms. They appear to be attracted to the food supply provided by the mussel stock (particularly during harvest), and possibly prey on other fish species aggregating around the farms.

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.

2.5.2 Significance of effects

In general, any effects of shellfish farms on wild fish populations are likely to be minor in comparison with the effects on other aspects of the marine ecosystem. The effects of shellfish farms on wild fish are likely to be less than finfish farms due to the lack of fish feed as an additional attractant.

Shellfish farms can have a positive effect of enhancing wild fish abundances by creating a habitat for fish to aggregate (providing food sources and refuge from predators). Conversely, the effects could potentially be negative if they result in regional fish populations becoming displaced from other habitats or more vulnerable to recreational fishing pressure.

There is little known about the potential effect of farmed mussels filtering zooplankton, including fish eggs and larvae, from the water column. However, based on the information available from regional scientific studies on plankton uptake and nutrient input, it is unlikely the current level of mussel farming in New Zealand is having significant flow-on effects on the sustainability of wild fish populations.

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.

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.

UAE test

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 Chapter 1.

2.6 EFFECTS ON SEABIRDS

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

Definition	Effects of aquaculture on birds
Summary of potential effects	• Entanglement (resulting in birds drowning) • Habitat exclusion • Providing roost sites closer to foraging areas • Aggregation of prey fish
Management and mitigation options	• Careful site selection – avoid critical breeding and foraging habitats • Ensure waste material and debris are collected and disposed of correctly • Minimise lighting at night • Monitoring and reporting of 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 • Food and feeding behaviour of key seabird species
Key terms defined in glossary	Benthos, conservation status, habitat exclusion

2.6.1 Summary of potential effects

There is a potential risk of seabird entanglement with shellfish farms, where diving birds can drown as a result of becoming entangled in underwater ropes. There have been very few reports of seabird deaths as a result of entanglement, however, in aquaculture facilities in New Zealand.

The potential effect to breeding and feeding seabirds also includes reduced habitat for feeding and from the smothering of the seabed by farm-derived biodeposition and shell litter. The physical presence of farm structures can reduce the habitat available for surface-feeding seabirds, such as gulls, terns and shearwaters.

Other potential effects include injury or death from ingestion of foreign objects, such as marine litter, collision with farm structures, and the attraction of seabirds to artificial lighting.

In contrast, a potential beneficial effect to seabirds of aquaculture includes the provision of roost sites closer to foraging areas, thus saving energy and enabling more efficient foraging. This is most likely to benefit shags, gulls and terns. 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 may become potential prey of birds, such as terns, shags and penguins (see Section 2.5).

2.6.2 Significance of effects

The adverse effects of existing aquaculture on seabirds are not presently considered significant.

As with marine mammals (see Section 2.4), loose and thin lines tend to pose the greatest threat to diving seabirds. Hence, entanglement risk appears low in the New Zealand mussel industry where long-lines are placed under considerable tension.

The scale and magnitude of the effect of aquaculture on seabirds depends largely on the location of a farm within the range of seabirds, the bird species, its conservation status, and the duration of the effect. Of particular concern are negative interactions with species that are threatened, endangered, vulnerable or range restricted. Learn more on the **conservation status** of New Zealand birds.

2.6.3 Management and mitigation options

Effective management can be achieved by careful site selection to avoid threatened, endangered or protected bird species' home ranges, critical breeding and foraging habitats and migration routes. Minimising the potential for rubbish to get into the sea and ensuring that minimal non-navigational lighting occurs at night and using downward-pointing and shaded lights are easily managed on a farm-by-farm basis.

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

If seabird interactions are identified as a concern, then reporting of any negative interactions of seabirds with aquaculture structures could be undertaken. Such information can then lead into species-specific management strategies.

2.7 BIOSECURITY

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

Definition	How 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 and placement • 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 new risk species to New Zealand's aquaculture and environment • Environmentally friendly antifoulants • 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)
Key terms defined in glossary	Biofouling, biosecurity, epidemiological unit, exacerbator, incubator, microscopic pathogens, pathway, pest organisms, reservoir, spat-catching, staged development

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 can be triggered by animals, plants and microorganisms capable of causing diseases or otherwise adversely affecting New Zealand's natural, cultural, recreational, amenity or economic values.

This section should be read in conjunction with the Escapee and genetic effects (Section 2.8) and Effects from additives (Section 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. This can result in the full spectrum of ecological effects: from little or no disruption to species or ecosystem processes, through to disruptions to specific species or entire 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). Once they are colonised, marine farms may act as a reservoir for subsequent spread of unwanted pest organisms to the wider environment, or to other marine farm sites or to vessels and equipment that can transport them. Shellfish 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. For example, the spread of the elongate tunicate *Eudistoma elongatum* around Northland harbours was likely associated with oyster farming operations.

Marine farms can also be vulnerable to adverse effects as a result of biosecurity incursions. For example, biofouling pest organisms may then increase drag on structures and anchoring systems, posing risk of gear failure and shellfish dropping off their long-lines. Biofouling also has the potential to significantly reduce the flow of water by smothering the culture ropes or structures, reducing the amount of food and oxygen available to farmed species and potentially increasing likelihood of the outbreak or transmission of disease. Examples of biofouling pest organisms on marine farms in New Zealand include documented negative effects from infestation and smothering of mussel farms with the sea squirts *Didemnum vexillum* and *Styela clava.*

Like pest infestations, diseases can be exacerbated by aquaculture operations and can reduce growth, condition and health of aquaculture stocks. For example, in the New Zealand summer of 2010/11 an OsHV-1 strain was identified as a cause of 50 to 80 percent die-off of oyster spat in most North Island Pacific oyster farms. It appears this virus may have been present in New Zealand waters since at least 1991, where it caused mass mortality of oysters in a hatchery in the Mahurangi Harbour, but did not manifest in farmed or wild stocks until 2010, possibly triggered by stress related to unusually high summer water temperatures. Until that time there were no documented serious parasites or pathogens of Pacific oysters from the 30-year history of farming this species in New Zealand.

Based on the absence of any significant disease outbreaks since being cultivated in New Zealand, green-lipped mussels are not considered highly prone to infection. For this reason, risks associated with disease transmission from farmed to wild mussels, or vice versa, remain unknown.

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.

The prevalence of pests and diseases occurring in New Zealand's aquaculture industry is low compared to other countries. The risk of a biosecurity outbreak or incursion, however, is generally considered serious to the aquaculture industry given the potential consequences, both in terms of the environment and the operations of the industry.

2.7.4 Management and mitigation options

Biosecurity management and planning is crucial to limit the introduction of pests and diseases and to be able to respond quickly and effectively to biosecurity risks. Aquaculture has to have good biosecurity practice to avoid impacts to its operations as much as avoiding impacting the environment.

It is ineffective to manage biosecurity risks from aquaculture in the absence of managing the other risk pathways (or sources of risk) in the marine environment, for example, commercial shipping, recreational boating, marinas and ports, and tourism activities. Biosecurity management should ideally be a collaborative approach between central, regional and local government, affected industries, iwi and the public (see text box on next page).

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

Levels of biosecurity management

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

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.

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 amongst 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.

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 and fish bait 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 2002).

A biosecurity management plan or consent conditions to support prevention should include:

- cleaning requirements for equipment being moved 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).

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 (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 also commissions targeted surveillance of high-risk areas, such as ports and harbours around New Zealand.

It is recommended that at a minimum, a biosecurity management plan or consent conditions should 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, anomalous mortalities, and allow incursions to be traced for source and possible recipient locations; and
- duties to report to MPI the presence or possible presence of pests and diseases (sections 44 and 46 of the Biosecurity Act 1993).

Control of populations and outbreaks

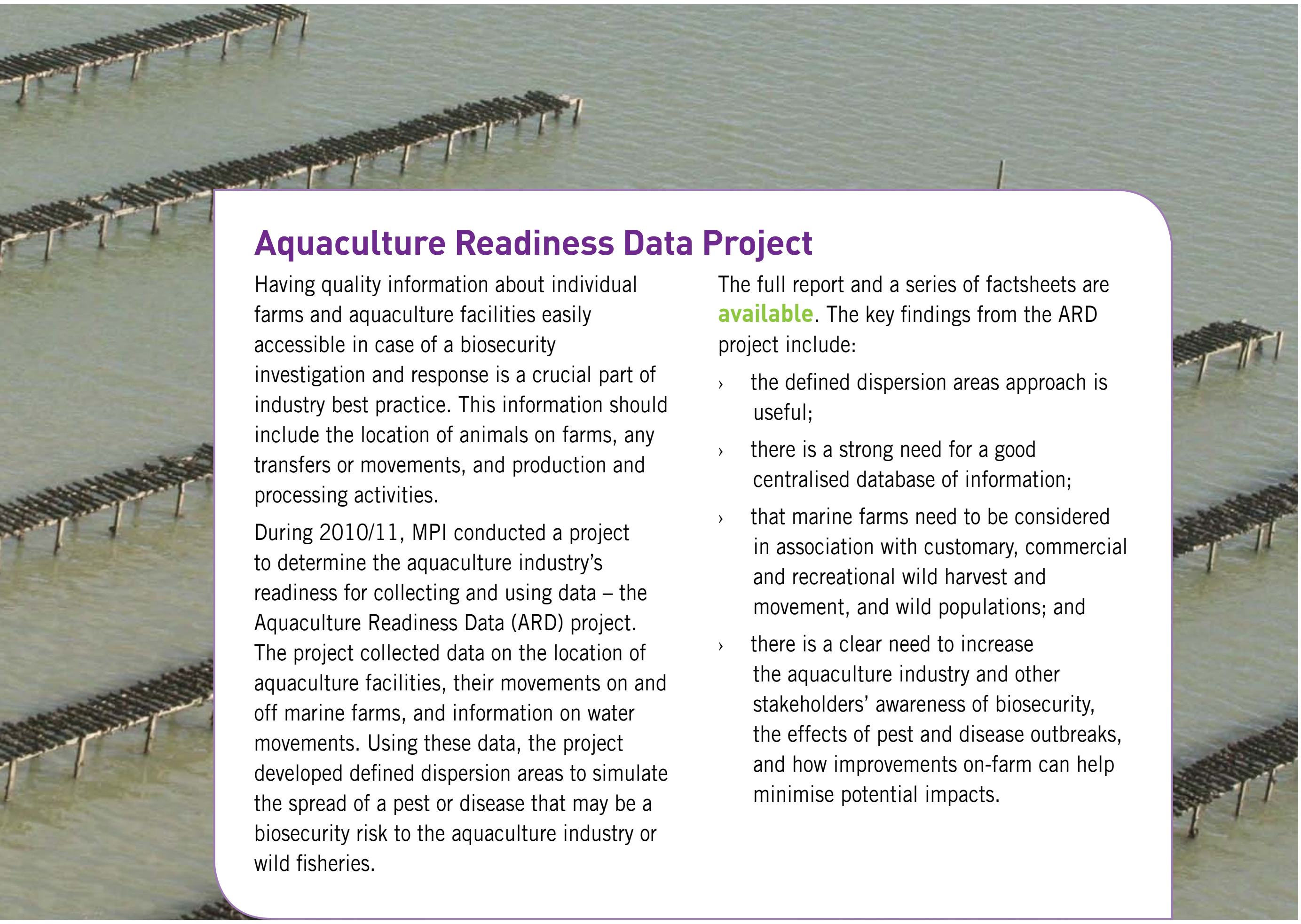
Incursions of pests or diseases can be managed for eradication, containment or spread limitation. Due to the connectivity of the marine environment, such activities are likely to require coordination with, and support from, all marine stakeholders (whose activities can spread unwanted organisms) and agencies at local, regional and national scales.

Biosecurity management plans or consent conditions should describe:

- the agencies and other users that will need to partner in any response situation;
- citeria for determining when eradication, control or containment should be undertaken;
- generic management actions for pests and diseases, such as appropriate disposal of wastes; and
- specific management actions for known pests or diseases, for example, testing protocols for OsHV-1 to ensure no 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*.



Aquaculture Readiness Data Project

Having quality information about individual farms and aquaculture facilities easily accessible in case of a biosecurity investigation and response is a crucial part of industry best practice. This information should include the location of animals on farms, any transfers or movements, and production and processing activities.

During 2010/11, MPI conducted a project to determine the aquaculture industry's readiness for collecting and using data – the Aquaculture Readiness Data (ARD) project. The project collected data on the location of aquaculture facilities, their movements on and off marine farms, and information on water movements. Using these data, the project developed defined dispersion areas to simulate the spread of a pest or disease that may be a biosecurity risk to the aquaculture industry or wild fisheries.

The full report and a series of factsheets are **available**. The key findings from the ARD project include:

› the defined dispersion areas approach is useful;

› there is a strong need for a good centralised database of information;

› that marine farms need to be considered in association with customary, commercial and recreational wild harvest and movement, and wild populations; and

› there is a clear need to increase the aquaculture industry and other stakeholders' awareness of biosecurity, the effects of pest and disease outbreaks, and how improvements on-farm can help minimise potential impacts.

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, genetic modification and polyploidy on the environment
Summary of potential effects	• Changes to the genetic distinctiveness, fitness, adaptability and diversity of local wild populations
Management and mitigation options	• Case-by-case assessment and response
Knowledge gaps	• 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

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 they release their eggs and sperm into the water for external fertilisation, where they have potential to interact with wild populations.

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.

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. Studies have consistently demonstrated high levels of genetic variation within the species and a high degree of connectivity (gene flow due to larval dispersion). 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. Research on the genetic profile of mussels in New Zealand suggests that the continued transfer of wild green-lipped mussel spat within and between mussel farming areas in New Zealand does not significantly alter the genetic profile of wild mussel populations.

Currently there is considerable research into domesticating mussels through selective breeding programmes in New Zealand. As these programmes develop and the use of hatchery-reared mussel spat increases, the risks of alterations to the genetic structure of wild populations may change.

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 often sourced from outside the region where they are farmed – often from the wild, but sometimes also from hatcheries with selective breeding programmes. Factors specific to risks associated with the transfer of hatchery-reared stock to wild populations mostly concern the potential for creating a bottleneck in the gene pool. Recent advances in breeding and the future production of triploid oyster spat that are sterile, however, will likely eliminate effects associated with genetic interactions between naturalised, farmed and hatchery populations.

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.

2.9 EFFECTS FROM ADDITIVES

Table 2.8: Overview of potential effects of additives from shellfish farming

Definition	The effect of chemicals used in 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
Management and mitigation options	• Adherence to guidelines around the use of treated timber
Knowledge gaps	• Accumulation and interactions of trace contaminants • Effects of antibiotics on sediments and ecological processes
Key terms defined in glossary	Therapeutant, water column

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 treated timber and therefore have the potential to leach trace contaminants, such as copper, chromium and arsenic (CCA). At concentrations slightly above those required for normal metabolism, copper and chromium can be toxic, especially to the very sensitive development stages of marine invertebrates. Arsenic can also have toxic effects on organisms. CCA 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.

2.9.2 Significance of effects

No chemicals, therapeutants or additives are known to be used in the farming of shellfish in New Zealand, and therefore do not pose a 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. When used in moderately well-flushed environments, the levels of contaminants resulting from treated timber are normally well below regulatory standards and are far below concentrations which would cause ecological concern.

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 (ANZECC guidelines) to ascertain whether this is an issue that warrants more thorough investigation.

2.10 HYDRODYNAMIC ALTERATION OF FLOWS

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

Definition	Effects of 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 • Effects on stratification through vertical mixing and partial blocking of some water layers • Wave dampening may affect shoreline habitat 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 a small to medium (metres to hundreds of metres) scale • The effect of orientation of long-lines to the direction of wave travel • Whether different long-line stocking densities and designs significantly alter wave 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 have been shown to affect currents on local, bay-wide and 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 from the farm.

The main effects of suspended farming on stratification are vertical mixing and potential partial blocking of some water layers. These effects are not yet well understood.

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 effect is likely undetectable for small farms or in sheltered areas.

The intertidal farming of oysters is thought to have larger effects on hydrodynamics due to the structures occupying the full cross section of the water column and being in contact with the seabed.

2.10.2 Significance of effects

Overseas experience shows that if suspended aquaculture covers the majority of a bay, currents are significantly reduced throughout the bay, including within navigation channels left between crops. Aquaculture in New Zealand is less intensive, typically occupying up to 10 percent of a bay in enclosed waters such as the Marlborough Sounds. Modelling of tidal currents shows that this less intensive approach to farming still has effects on current speeds that can extend over the whole bay, or beyond. At the typical densities of farms in New Zealand currently they are of little ecological relevance; however, there is risk of significant effects if densities become too high. In general, the effects of marine farms on hydrodynamics are likely to be small in comparison with the effects on other aspects of the marine ecosystem.

The physical effects on hydrodynamic conditions will persist for the duration that the structures and crop are in place, but recovery will be nearly immediate on removal of all structures. Indirect ecological consequences of modified currents on the seabed and associated communities may persist for longer.

2.10.3 Management or 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 shellfish structures on local and bay-wide currents, stratification and waves can be predicted using analytical and numerical models. This information can help predict possible hydrodynamic changes 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 effects are in line with initial modelling. The duration of monitoring should be sufficient to capture a range of tide, wind and stratification conditions.

CHAPTER 3: ECOLOGICAL EFFECTS OF FARMING FINFISH

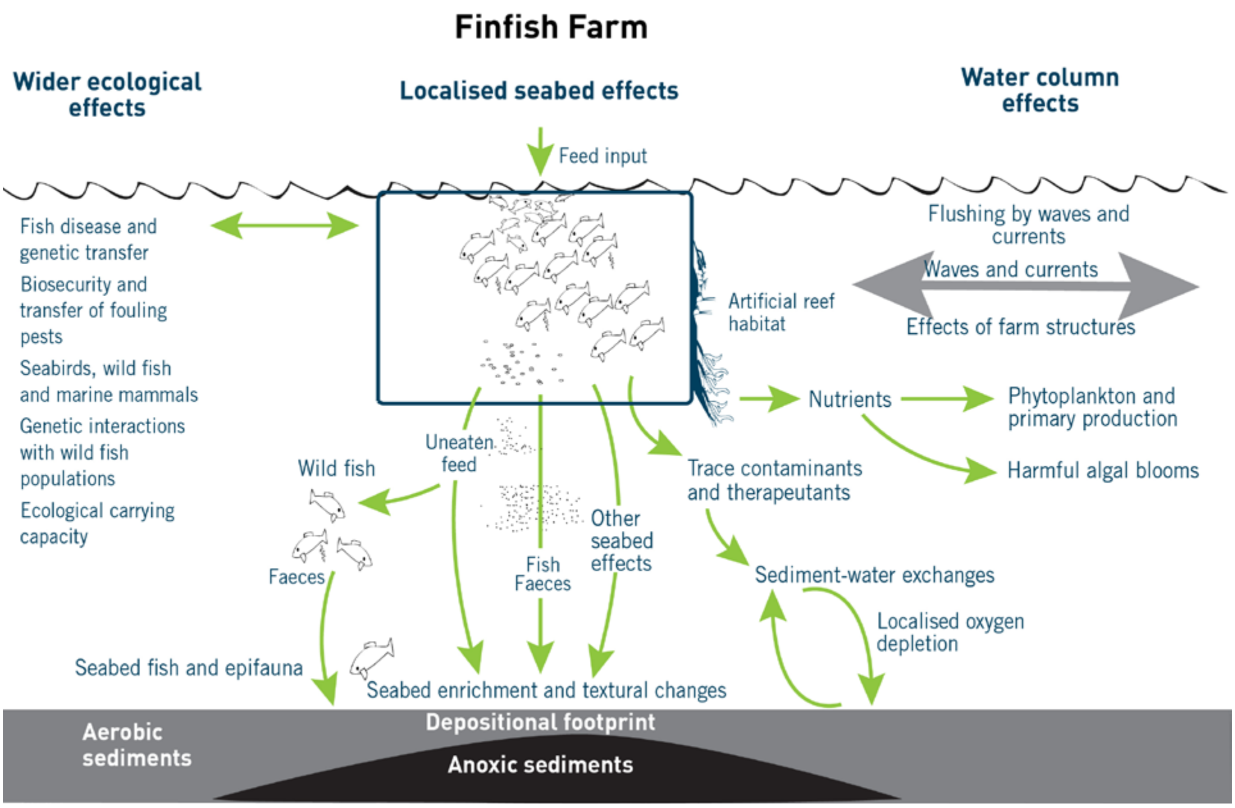
3.1 INTRODUCTION

This chapter provides an overview of the potential ecological effects associated with farming finfish 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*) and hāpuku (*Polyprion oxygeneios*) (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). There has been recent interest in expansion of the finfish industry to new areas and new species, such as yellowtail kingfish and hāpuku (groper).

This chapter summarises information contained in the ***Literature Review of Ecological Effects of Aquaculture***. Readers are referred to the *Literature Review* for additional information and source references. The other most relevant document is the **Review of Ecological Effects of Marine Finfish Aquaculture** by Forrest et al. (2007).

Figure 3.1: Schematic of actual and potential ecological effects from finfish aquaculture
Source: Based on Forrest et al., 2007.



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 Chapter 5.

3.2 WATER COLUMN EFFECTS

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

Definition	Effects of 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
Knowledge gaps	• Baseline water quality in key growing regions • Effectiveness of IMTA
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 in the water column at approximately the scale of the finfish farm. Bay-wide effects on the water column and wider ecosystem are discussed separately in Chapter 5.

Farmed finfish require the addition of artificial diets – so most ecological effects on the water column are related to their waste products (faeces, uneaten feed and excreted ammonia) entering the system and changing the concentrations of nutrients (see below). Particulate wastes expelled into the water column will also settle onto the seabed near the farm, so this section should be read in close conjunction with the Benthic Effects section (see Section 3.3).

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. Nutrient enrichment beyond natural levels can result in eutrophication: natural or artificial nutrient enrichment in a body of water, associated with extensive plankton blooms and subsequent reduction of dissolved oxygen.

A concern with water column nutrient enrichment is the potential for an increased occurrence of harmful algal blooms (HABs), including blooms of species that produce biotoxins. Some 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, there have been no known HABs directly attributable to finfish farming. Phytoplankton blooms have been recorded and harmful species detected throughout the Marlborough Sounds; however, these appear to be regional phenomena driven by oceanic processes not salmon farming activities.

Nutrient enrichment may also lead to changes in phytoplankton species composition by changing the ratios of nutrients (for example, an increased nitrogen:silica ratio favours the growth of dinoflagellates rather than diatoms). This could potentially lead to changes to the food web.

Photo: Richard Fraser.

Nutrients and finfish farms in the marine environment – a chemistry lesson

Finfish farms contribute both particulate (solid) and dissolved nutrients to the environment. Particulate organic (containing carbon-hydrogen bonds) nitrogen and phosphorus are primarily deposited onto the seabed as fish faeces, but also as waste feed pellets and particles. As this organic material is broken down, dissolved forms of nutrients may be released back into the water column and oxygen is removed from the water. The farmed fish also excrete dissolved inorganic nutrients such as ammonium (NH_4).

The dissolved inorganic nutrients from finfish farms, combined with nutrient inputs from other sources (such as oceanic and terrestrial inputs), stimulate growth of phytoplankton and seaweeds. In New Zealand's temperate waters, nitrogen (N) is likely to be the nutrient potentially limiting phytoplankton growth under most conditions. Therefore, the amount of N released during fish production is important, especially dissolved inorganic N (as this is the most biologically available form of N). Complicating matters is the fact that finfish farms are only one source of nutrients in the marine environment, and, like other sources, their inputs vary over time.

Depletion of dissolved oxygen

Depletion of dissolved oxygen can occur within and around finfish farms due to the respiratory activities of the farmed fish and microbial degradation of phytoplankton or waste materials in sediments and in the water column. This effect is of concern to the farmers themselves, as oxygen is critical for the survival and good performance of farmed fish.

Excessive oxygen depletion in the water column could potentially stress or kill the fish and other animals. Depletion of oxygen in sediments can result in the release of toxic by-products (such as hydrogen sulphide and methane) from the seabed into the water (out-gassing), which can also have adverse effects on the farmed fish and other organisms.

3.2.2 Significance of effects

Elevated nutrient concentrations in the water column are most evident within the finfish farm and rapidly decrease with increasing distance from the farm. The intensity and spatial extent of enrichment is highly site specific, with high flow, deep sites producing larger but more diluted footprints. There has been no evidence of HABs caused by salmon farm-related nutrients in New Zealand.

Reduced oxygen levels in the immediate water column in and around finfish farms have been observed in international studies when cages are heavily stocked or where they are located in shallow sites with weak flushing. In New Zealand, salmon farms are generally sited in areas with sufficient water flushing, so 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. 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 are 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 (approximately >25 metres) well-oxygenated areas that have sufficient flushing to widely disperse farm wastes.

Effects can be further reduced through farm management practices, for example, to control stocking densities and limit feed wastage. There are a number of other 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 Chapter 5).
- Stocking density – higher stocking densities will generally have greater effect.
- Cage designs and orientation to prevailing current direction – this will impact on the amount of hydrodynamic drag on passing water, flushing of cages and settlement of biofouling organisms.
- FCR is a measure of the efficiency of growth relative to feed used, the global range is 1.1 to 1.7 on average. The lower the FCR, the less waste will be produced.

For example, a reduction in feed wastage at Marlborough Sounds salmon farms that resulted in improved seabed and water column conditions 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; and the use of higher-quality feed and improvement in FCRs, meaning that less food is needed to grow the same amount of fish.

These types of strategies may also mitigate effects on wild fish populations by reducing the amount of waste feed available for consumption (see Section 3.5).

Monitoring, adaptive management, and the use of IMTA are also potential mitigation measures for water column effects and additional information on monitoring, adaptive management, and IMTA can be found in Chapters 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.

There is a significant lack of long-term regional monitoring programmes around much of New Zealand's coastline, limiting any assessments of changes to the water column with the introduction of aquaculture. Data generated from these programmes would also assist to calibrate and validate regional models, improving their accuracy. Current inaccuracies of modelling can include a tendency to underestimate non-marine farm dissolved inorganic nitrogen, which will lead to a tendency to over-estimate the relative effects of marine farms.

In the absence of long-term environmental monitoring datasets, baseline monitoring prior to 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.

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 phosphorous);

- 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 aquaculture on the seabed
Summary of potential effects	• Localised organic enrichment of the seabed beneath the farm • Biofouling drop-off and debris • Seabed shading by structures • Widespread biodeposition
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	• 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 ecological effects of finfish farming, internationally and in New Zealand, often 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.

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

3.3.1 Summary of potential effects

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 over-enrichment of the seabed due to the high organic content of the deposited particles. 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 finfish farm extends tens to hundreds of metres from the cages. Effects tend to be most evident directly beneath the farm cages, and exhibit a strong gradient of decreasing effect with increasing distance, which is consistent with other organic enrichment gradients.

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.

Biofouling drop-off and debris

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

Biofouling drop-off and elevated biodeposition can lead to aggregations of scavenging or predatory organisms, such as sea cucumbers, sea stars, crabs and sea-lice (isopods). These fauna tend to be displaced under highly enriched conditions and instead they often aggregate around the perimeter of the farm.

Seabed shading by structures

The presence of farm structures or reduced water clarity could potentially reduce the amount of natural light reaching the seabed, thereby reducing algae productivity. Changes would be most evident when situated in naturally clear waters. Although identified as a potential effect, no studies exist which separate the effects of shading from the (more dominant) benthic enrichment effect.

Widespread biodeposition

Widespread but very diffuse benthic enrichment is possible outside of the primary footprint in nearby natural depositional areas (such as blind bays). In most cases, the rate of deposition is likely to be low enough to be naturally assimilated. Any effects are likely to be subtle and difficult to detect. Such effects could be cumulative across multiple farms in an area (see Chapter 5).

3.3.2 Significance of effects

The deposition of organic waste resulting in seabed enrichment and degradation is the main effect on the seabed from finfish farming. This enrichment can have pronounced, localised effects directly beneath the finfish cages, but there is typically a rapid improvement in environmental conditions with increasing distance from farm structures (over tens or hundreds of metres).

How great these effects are depends mainly on the flushing characteristics of the site and the farming intensity (that is, fish stocking density, feed level, feed digestibility and biomass). Contrasts in seabed effects between high- and low-flow environments are evident in the case of salmon farming in the Marlborough Sounds, and are fully described in the *Literature Review*. The effects are substantially less intense with high-flow (dispersive) sites in comparison with low-flow sites. For example, organic accumulation tends to be minimal at high-flow sites due to the increased levels of resuspension and the export of particles elsewhere (although infaunal communities will still noticeably change).

Benthic effects are largely reversible, although recovery is likely to take many months or years, depending on water flushing characteristics. Significant recovery is rapid, occurring within the first few months (three to 12 months) of the farm's removal. The seabed is mostly recovered in the medium- to long-term, within the timeframe of months to years (estimated five to 10 years for low-flow sites in New Zealand).

3.3.3 Management and mitigation options

Careful site selection

Effects on the seabed from finfish farming can be partially mitigated through careful site selection, as farms in deeper, well-flushed environments have less intense localised enrichment of the seabed. In New Zealand, it is also usual to site salmon farms over muddy habitats. This minimises habitat modification and protects biodiversity of more sensitive habitats.

Farm management practices

Farm management practices that control stocking densities, optimise feeding and farm production, and limit feed wastage are also effective in reducing effects to the seabed (as well as effects on the water column, see Section 3.2.3). For example, use of higher quality feed, an increase in FCR and advanced automated feeders improved seabed quality at Marlborough Sounds salmon farms. For salmon farming, a primary driver of the level of seabed impact is the mass of feed used; adjustments to the annual feed limit at a farm are effective at mitigating seabed effects. For example, increases or decreases of salmon feed, in the order of 20 to 30 percent, are usually measurable in terms of the effects on the seabed in the following year's monitoring results.

In the case of New Zealand King Salmon proposed new farms (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 such as 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 proposed 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).

Monitoring and ongoing adaptive management

Regular monitoring of seabed health, combined with adaptive farm management responses based on the monitoring results, ensure benthic effects are minimised and spatially contained. Acceptable limits are generally specified in resource consent conditions. It is international best practice to prohibit seabed conditions becoming anoxic and azoic beneath finfish farms.

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.

Photo: Phil Kirk.

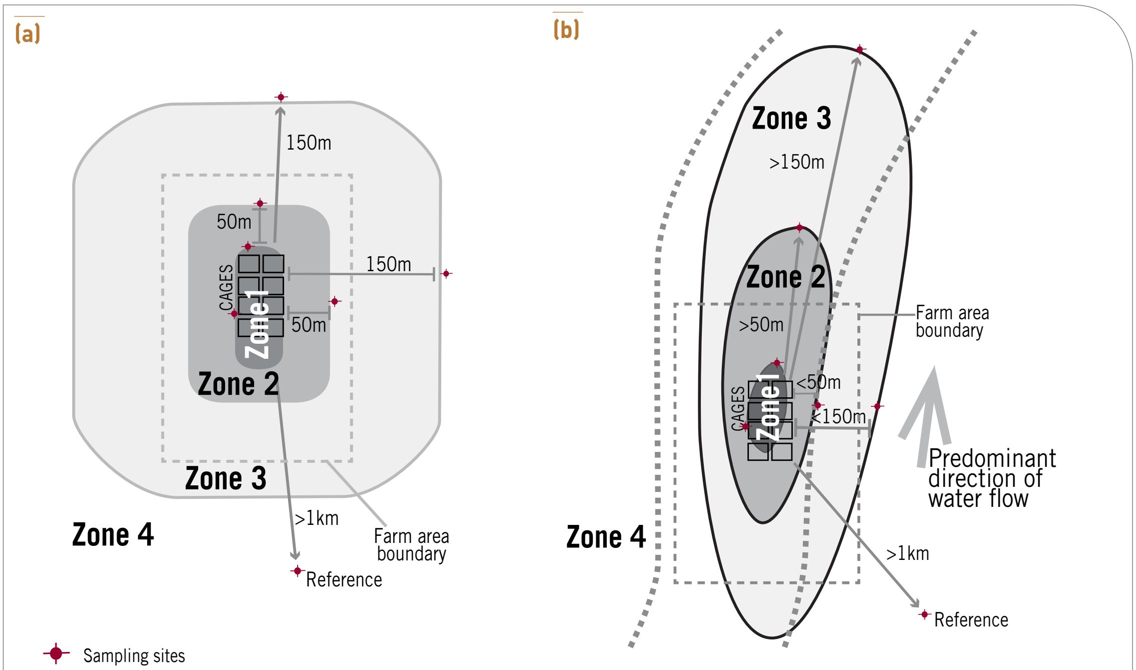
Monitoring of seabed health beneath existing or proposed finfish farms involves taking measurements of sediment properties inside and outside the farm site, to predict the level and the spatial extent of enrichment effects. Infaunal communities (animals living in the sediment) are well-recognised indicators of seabed health or enrichment status. 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 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 would be 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 EQS for compliance within each zone (see Figure 3.2 and text box on next page). 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 Chapter 5.

Figure 3.2: (a) Conceptual approach to defining seabed impact zone for low flow site, and (b) A proposed method for adapting seabed impact zones to high flow sites with permitted skew due to currents

Source: Based on Keeley, N., 2012.



Zone 1: Seabed beneath cages
Zone 2: Extends 50 metres from cage boundary
Zone 3: Extends 150 metres from cage boundary (and represents accepted maximum extent of measurable ecological effects)
Zone 4: Background (reference) conditions

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*.

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 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.

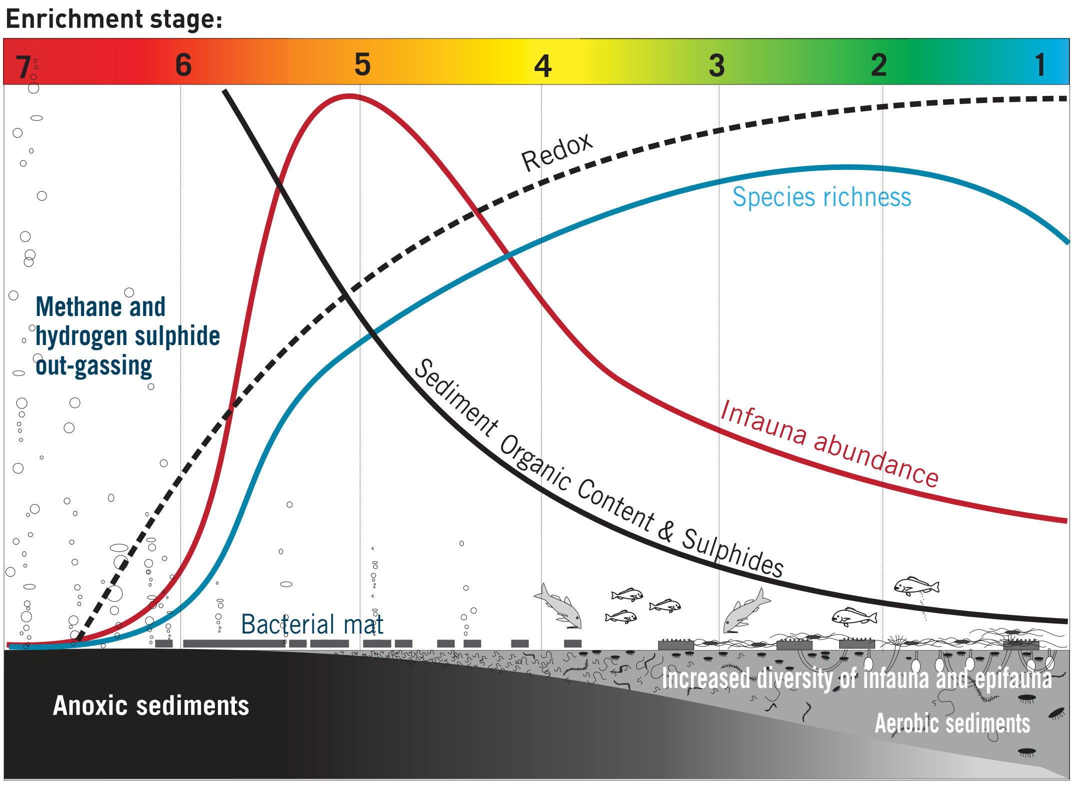
Enrichment stage 5 is the stage of greatly enhanced seabed productivity, showing extreme proliferation of one or a few enrichment-tolerant opportunistic species. Enrichment stage 5 is usually the recommended upper level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds. At enrichment 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, and sediment organic content for a typical low-flow site

Source: Based on Keeley, N., 2012



3.4 MARINE MAMMAL INTERACTIONS

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

Definition	Effects of aquaculture on marine mammals
Summary of potential effects	• Habitat exclusion or modification • Potential for entanglement • Underwater noise disturbance • Attraction to artificial lighting
Management and mitigation options	• Careful site selection • Predator net design • 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 • Monitoring and reporting of presence and behaviour of marine mammal species in vicinity of farm
Knowledge gaps	• Research into ranges and locations of important habitats of marine mammal species • Research into types of design and maintenance features to minimise entanglement risk • Research into reducing feed waste which will minimise fish aggregation and the amount of time some marine mammals spend near farms • Health implications of underwater noise exposure for marine mammals
Key terms defined in glossary	Cetacean, conservation status, habitat exclusion

3.4.1 Summary of potential effects

Interactions between marine mammals and aquaculture result from an overlap between the spatial location of the farm structures and the habitats and migration routes of the species. Such interactions have been relatively minor issues given the small scale and location of current aquaculture activities here. Overseas experience with these issues suggests the potential for adverse effects may increase with continued growth in marine mammal populations and larger scale, offshore farm developments.

Habitat modification or exclusion

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 has highlighted that the nature of the exclusion greatly depends on the type and scale of the farming method and the particular marine mammal species affected. Whales and particular dolphin species (such as dusky dolphins) tend to be more sensitive to such disturbances, while seals and other dolphin species (such as common and bottlenose dolphins) may actually be attracted to the novel habitat and food source (the farmed fish and aggregations of wild fish that may be associated with finfish farms).

There has been little overlap between aquaculture and the migratory paths of large whales in New Zealand waters to date. The development of large offshore finfish farms and the recovery of certain populations (notably humpback whales) may result in greater overlap with whale migration routes.

Entanglement

Physical interactions between finfish farms and marine mammals can lead to an increased risk of entanglement in structures, nets or non-biological wastes from farm production. The risk of entanglement also increases as some marine mammals tend to be attracted to the farmed fish themselves or the associated aggregations of wild fish (see Section 3.5).

Marine mammals in New Zealand

There are more than 50 species of cetaceans (whales, dolphins and porpoises), 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 Maui's dolphins; and
- those most likely to interact with manmade structures or fishing gear, for example, dusky, bottlenose and common dolphins; Bryde's, orca, southern right and humpback whales; and fur seals.

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.

Photos: Department of Conservation.

The risk of entanglement will vary between species depending on several factors including[8]:

- echolocation – dolphins and other toothed whales are able to echolocate and perceive obstacles with their sonar, whereas baleen whales cannot echolocate;
- behaviour – inquisitive or playful animals will be more at risk;
- propensity to roll – for example, humpback whales tend to roll when they become entangled; morphology and size – whales with large pectoral fins and tail flukes (for example, humpback whales) or large gaping mouths (most baleen whales) could be more at risk from entanglement in structures whereas dolphins and seals are more prone to entanglement in the mesh of predator nets; and
- agility – dolphins and smaller whales are more agile and therefore at less risk.

Marine farmers have observed that dolphins and seals are the most likely species to interact with salmon farms. There have been reported incidences of New Zealand fur seal and several dolphin species becoming entangled, or trapped in predator nets and drowning, at salmon farms.

Underwater noise

Underwater noise associated with regular, ongoing farm activities, including vessels, may either attract or exclude marine mammals. Whales and particular dolphin species tend to be sensitive to such disturbances. Seals and other dolphin species (such as common and bottlenose dolphins) may actually be attracted to the novel noise source.

Attraction to artificial lighting

The use of submerged lighting to aid in caged fish maturation may attract marine mammals to the associated aggregations of wild fish. As the footprint of submerged artificial lights is mainly confined within the cage structures and to mid-water depths, 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. While marine mammal attraction to farms using submerged lights will be highly localised in its effect, the greater risk is potential entanglement.

3.4.2 Significance of effects

The adverse effects of finfish aquaculture on marine mammals are not presently considered significant issues given the small size of the New Zealand finfish industry and the actions taken by the industry to manage entanglement issues at individual farms. While there is some current overlap with marine mammal habitats, very little of this occurs in what may be described as critical habitat (such as breeding and foraging grounds for cetaceans, and haul out sites and colonies for seals). In addition, the consequences of a physical interaction are considered minor in most cases, as the outcomes are generally expected to affect individuals or result in only small-scale avoidance or attraction.

The scale and magnitude of the effect of aquaculture on marine mammals depends largely on the species and its population range, particularly if it is an endangered, threatened, or range-restricted species. **Critical species** in this regard include Hector's and Maui's dolphins, bottlenose dolphins, orca, Bryde's whales, southern right whales and humpback whales.

The significance of these effects may need to be reconsidered in relation to any larger-scale and offshore aquaculture developments in New Zealand waters.

8 Personal communication Andrew Baxter, Technical Advisor, Department of Conservation.

3.4.3 Management and mitigation options

Farm locations need to be carefully selected to minimise the likelihood of overlap with important marine mammal migration routes and known habitats (species' home ranges, critical breeding and foraging habitats).

The large variation in the potential significance of aquaculture effects on New Zealand marine mammals (depending on the affected populations) makes developing and implementing one set of effective management guidelines or standards extremely difficult.

The risks associated with physical interactions can be further minimised by adopting best practice guidelines for maintenance and operation of farm structures, predator nets and the use of noise-generating equipment. Predator nets should be designed (including configuration, mesh size, twine diameter, net tension) in a way that minimises the risk of marine mammal entanglement.

Seals and dolphins may be attracted to the structures and wild fish aggregations that are often associated with the farms; therefore, any resulting entanglement risks can be minimised by keeping farm structures and nets well maintained, ensuring debris and waste material does not enter the water, keeping lines secured at all times, and ensuring anchor warps are maintained under sufficient tension. Also, efforts to reduce feed waste will minimise fish aggregation and may also reduce the amount of time some species (for example, dolphins) spend near finfish farms.

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.

Unfortunately, detailed information on abundance, distribution and critical habitats is available for only a handful of New Zealand's marine mammals. Where there are distinct concerns about a specific species a management plan could be developed, in conjunction with DOC. The purpose of a management plan is to help ensure that the adverse effects on marine mammals as a result of the operation of the marine farm are minimised. For example, New Zealand King Salmon has a specific seal policy in conjunction with DOC which provides guidelines for the handling of seals that enter the farm and includes recording and reporting requirements.

In general, monitoring records of the presence of marine mammal species in the vicinity of the farm site along with any detailed observations of their time spent around farm structures should be documented by the marine farmer, including night-time feeding activity around illuminated cages. The relevant DOC conservancy office should be contacted in the event of marine mammal entanglement.

3.5 WILD FISH INTERACTIONS

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

Definition	Effects of aquaculture on wild fish populations
Summary of potential effects	• Effects on existing fish habitats • Attraction of wild fish to farm structures • Consumption of waste feed
Management and mitigation options	• Careful site selection – avoid critical fish spawning grounds and nursery areas • Minimise the use of lights above and below the water line
Knowledge gaps	• Research into 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
Key terms defined in glossary	Benthic, biodeposition, ecological trap, UAE test

3.5.1 Summary of potential effects

Effects on existing fish habitats

The placement of a finfish farm directly above or adjacent to important benthic habitats 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).

Attraction of wild fish to farm structures

By adding three-dimensional structures to the marine environment, finfish farms create artificial habitats that attract 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).

The use of submerged artificial lighting, which is frequently used on 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 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.

The attraction of wild fish to aquaculture structures can result in enhanced predation by the cultured fish and other predators (for example, seals and dolphins). Sharks may also be attracted to finfish farms, particularly to the presence of dead fish.

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 (by acting either as ecological traps or possible sources for wild fish stocks). 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.

Consumption of waste feed

Feed loss from finfish farms has been identified as a primary driver of wild fish aggregation around farms overseas. 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 consumption of waste feed by wild fish can alter body condition and reproductive success (potentially both positive and negative).

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 a positive effect of enhancing wild fish populations through habitat created and increased food availability. Conversely, the effects could potentially be negative if they result in regional fish populations becoming displaced from other habitats or possibly more vulnerable to recreational fishing pressures.

At present, no specific information is available on how the existing finfish farms in New Zealand might affect wild fish populations (positively or negatively) in the vicinity of the farms.

3.5.3 Management and mitigation options

An important consideration when determining where to site a farm is to select a site that avoids spatial overlap with critical fish spawning grounds and nursery areas.

Careful consideration should also be given to the management of feed quality and feeding practices to ensure the feed waste is minimised. Other farm management practices, such as the prompt removal of dead fish, can minimise the attraction of sharks and other predators.

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 spot lights must be used, they should be positioned as high above the water as possible so that penetration is maximised and reflection is minimised.

UAE test

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 Chapter 1.

3.6 EFFECTS ON SEABIRDS

Table 3.5: Overview of effects on seabirds from finfish farming

Definition	Effects of aquaculture on birds
Summary of potential effects	• Entanglement (resulting in birds drowning) • Habitat exclusion • Providing roost sites closer to foraging areas • Aggregation of prey fish
Management and mitigation options	• Careful site selection – avoid critical breeding and foraging habitats • Good management of underwater nets and predator nets • Ensure waste material and debris are collected and disposed of correctly • Minimise lighting at night • Monitoring and reporting of 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 • Food 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, could drown as a result of becoming entangled in underwater nets used to contain the farmed fish and predator nets both above and below the cages. There have been very few reports of seabird deaths as a result of entanglement, however, in finfish farms in New Zealand.

The potential effect to breeding and feeding seabirds also includes reduced or altered habitat for feeding or displacement from feeding grounds. The physical presence of farm structures can reduce the habitat available for surface-feeding seabirds, such as gulls, terns and shearwaters, whilst a reduction in the clarity of the water column could potentially reduce the ability of diving birds to detect their prey.

Other potential effects include injury or death from ingestion of foreign objects, such as marine litter, collision with farm structures, and the attraction of seabirds to artificial lighting.

In contrast, a potential beneficial effect of aquaculture to seabirds includes the provision of roost sites closer to foraging areas, thus saving energy and enabling more efficient foraging. This is most likely to benefit shags, gulls and terns. Likewise, the attraction and aggregation of small fish to the farm to feed on organisms growing on the farm structures and to shelter under the farm structures may become potential prey of birds, 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. The scale and magnitude of the effect of aquaculture on seabirds depends largely on the location of the farm within the range of seabirds, the bird species, its conservation status, and the duration of the effect. Of particular concern are negative interactions with species that are threatened, endangered, vulnerable or range restricted. Learn more on the **conservation status** of New Zealand birds.

3.6.3 Management and mitigation options

Effective management can be achieved by careful site selection that avoids threatened, endangered or protected bird species' home ranges, critical breeding and foraging habitats and migration routes. Minimising the potential for rubbish to get into the sea and ensuring that minimal non-navigational lighting occurs at night and using downward-pointing and shaded lights are easily managed on a farm-by-farm basis.

To reduce entanglement, it is recommended that measures should be adopted, such as enclosing predator nets above and below cages, keeping nets taut and using small mesh sizes. Nets should also be well maintained.

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

If seabird interactions are identified as a concern, then reporting of any negative interactions of seabirds with aquaculture structures could be undertaken. Such information can then lead into species-specific management strategies.

King shags in the Marlborough Sounds

The New Zealand king shag (*Phalacrocorax carunculatus*) is a nationally endangered species found only in the Marlborough Sounds. There are estimated to be approximately 650 king shags left in the wild.

In considering the 2012 New Zealand King Salmon application for new salmon farms in the Marlborough Sounds, the **Board of Inquiry** noted that while the risk of new farms to the population of the king shag was likely low, the consequences of any adverse impact on such a small population could be serious. To mitigate this risk, the Board recommended the development of a King Shag Management Plan. The objective of this plan is to ensure that there is no significant decrease in the overall king shag population and the key breeding colony at Duffers Reef in the Pelorus Sound.

Photo: Department of Conservation.

3.7 BIOSECURITY

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

Definition	How 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 and placement • 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 • Predicting new risk species to New Zealand's aquaculture and environment • Environmentally friendly antifoulants that can prevent settlement of fouling species • The natural transmission mechanisms and farm-to-farm dispersal potential of many diseases. • Prevalence and consequence of disease in farmed indigenous finfish species • Effective and environmentally friendly therapeutants to manage finfish in culture and prevent disease outbreaks • Breeding for disease resistance
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 can be triggered by animals, plants and microorganisms which 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 *Syela clava*).

This section should be read in conjunction with the Escapee and genetic effects (section 3.8) and Effects from additives (section 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. 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. This can result in the full spectrum of ecological effects: from little or no disruption to species or ecosystem processes, through to disruptions to specific species or entire ecosystem processes.

3.7.2 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.

Finfish farms and other artificial structures provide a novel habitat for colonisation by fouling communities (including sea squirts, seaweed, tubeworms, barnacles and mussels). 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.

Marine farms can also be vulnerable to adverse effects as a result of 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.

Like pest infestations, diseases can be exacerbated by aquaculture operations and can reduce growth, condition and health of finfish stocks. 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.

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. 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.

The prevalence of pests and diseases occurring in New Zealand's aquaculture industry is low compared to other countries. The risk of a biosecurity outbreak or incursion, however, is generally considered serious to the aquaculture industry, given the potential consequences, both in terms of the ecology and the operations of the industry.

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 salmon farming regions and there are generally no transfers between them.

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.

Diseases

In terms of diseases, there have been significant disease problems encountered at overseas salmon farms. Many pathogens and parasites known to cause problems for salmon farms overseas, however, are not known to occur in New Zealand. New Zealand farms Chinook (or king) salmon, which is different from the Atlantic salmon that is predominantly farmed overseas. Emerging aquaculture species native to New Zealand are likely to encounter disease issues, as the fish will be cultured intensively and exposed to indigenous pathogens and diseases (see text box on next page).

Very few infectious diseases have caused salmon farm production losses in New Zealand and active surveillance has been undertaken for decades. Accordingly, there is currently minimal risk of antibiotic resistance due to low usage (no usage since 2000) and this situation is unlikely to change in the short term. In the case of disease outbreaks, interventions such as the use of antibiotics are controlled through the Agricultural Compounds and Veterinary Medicines Act 1997. Resource consent for therapeutant application will likely also be required (see Section 3.8).

Indigenous finfish farming and biosecurity risks

The farming of finfish species indigenous to New Zealand, such as kingfish and hāpuku, will require 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 hāpuku, for which only limited grow-out trials have been undertaken.

Risks to wild populations from transfer of diseases from farmed hāpuku and kingfish stock are likely to be quite low. Hāpuku and kingfish wild fish stocks are highly mobile, and this will minimise the risk of spread of disease from infected farm stock. As these species are indigenous, however, they are likely to be susceptible to the pathogens and parasites carried by the wild stocks (compared with non-indigenous salmon).

In the case of kingfish, diseases of commercial importance are relatively well understood, whereas for hāpuku there remains considerable uncertainty regarding which pathogens or parasites will become commercially significant to culture operations. The two most problematic parasites of cultured kingfish in New Zealand have been monogenean flukes which parasitise the skin and gills. These flukes are introduced to farmed fish from wild populations where they occur naturally, 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.

Photo: Dave Allen, NIWA.

3.7.4 Management and mitigation options

Biosecurity management and planning is crucial to limit the introduction of pests and diseases and to be able to respond quickly and effectively to biosecurity risks. Aquaculture has to have good biosecurity practice to avoid impacts to its operations as much as avoiding impacting the environment.

It is ineffective to manage biosecurity risks from aquaculture in the absence of managing the other pathways (or sources of risk) in the marine environment, for example, commercial shipping, recreational boating, marinas and ports, and tourism activities. Biosecurity management should ideally be a collaborative approach between central, regional and local government, affected industries, iwi and the public (see text box on next page).

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

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 or pathways that are novel, and from 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 the 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 and fish bait from all countries; import of juvenile yellowtail kingfish (*Seriola lalandi*) from Australia; 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 (from land-based hatcheries or between farms), equipment and industry vessel movements. These pathways are primarily managed through industry codes of practice and following internationally recognised best practices. For example, the Finfish Aquaculture Environmental Code of Practice (2009) directs best industry practices throughout the hatchery, growing and harvesting cycle to minimise biosecurity risks to the environment.

Finfish farms often use antifoulant treatments on their farm nets and predator exclusion nets to limit the amount of biofouling that grows on the structures (see Section 3.9). Farm cleaning guidelines as part of on-farm biosecurity management should deal with factors such as frequency and waste disposal. For vectors of spread such as service vessels and equipment, preventative options could include maintenance of effective antifouling coatings, hull inspections to check for the presence of risk species, and hull cleaning as necessary.

A biosecurity management plan or resource consent conditions to support prevention should include:

- cleaning requirements for equipment being moved 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).

Levels of biosecurity management

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

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.

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 amongst 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.

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 (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 (or disease symptoms). A preventative approach to disease management is routine monitoring of fish health and mortalities by personnel trained in the recognition of disease symptoms.

MPI also commissions targeted surveillance of high-risk areas such as ports and harbours around New Zealand.

It is recommended that, at a minimum, a biosecurity management plan or consent conditions should 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, anomalous mortalities, and allow incursions to be traced for source and possible recipient locations; and
- duties to report to MPI the presence or possible presence of pests and diseases (sections 44 and 46 of the Biosecurity Act 1993).

Control of populations and outbreaks

Incursions of pests or diseases can be managed for eradication, containment or spread limitation. Due to the connectivity of the marine environment, such activities are likely to require co-ordination with, and support from, all marine stakeholders (whose activities can spread unwanted organisms) and agencies at local, regional and national scales.

Biosecurity management plans or consent conditions should describe:

- the agencies and other users that will need to partner in any response situation;
- citeria for determining when eradication, control or containment should be undertaken;
- generic management actions for pests and diseases, such as appropriate disposal of wastes; and
- specific management actions for known pests or diseases, for example, testing protocols to ensure no 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 may include freshwater or acetic acid bath treatments, manual removal, or wrapping of structures.

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 on the next page contains an example of a company-wide biosecurity management plan.

In New Zealand, management of gear and vessel transfers between geographic zones by voluntary codes of practice developed by industry are used to minimise risks of inadvertently transferring infected stock, for example, the New Zealand Finfish Aquaculture Environmental Code of Practice (2009).

Company-wide biosecurity initiative

An example of a company-wide biosecurity initiative is the New Zealand King Salmon "bio-secure 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 bio-secure 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.

Photo: Richard Fraser.

Aquaculture Readiness Project

Having quality information about individual farms and aquaculture facilities easily accessible in case of a biosecurity investigation and response is a crucial part of industry best practice. This information should include the location of animals on farms, any transfers or movements, and production and processing activities. See Section 2.7 for more information.

The full report and a series of factsheets are **available**.

3.8 ESCAPEE AND GENETIC EFFECTS

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

Definition	The potential effects of escaped farmed species, genetic modification, and polyploidy on the environment
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 • Reporting of escapees • Use of therapeutants to treat disease • Transgenic organisms are prohibited in New Zealand
Knowledge gaps	• The effect of escapees on native species • Parasites and diseases of indigenous new aquaculture species • Sterilisation methods to minimise escapee effects on wild populations
Key terms defined in glossary	Genetic modification, polyploidy, therapeutant, transgenic organism

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 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.

The main cause of escapes from finfish farms 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 (for example, lifting). Research indicates that a focus on preventing large-scale escape incidents (generally resulting from structural failures) will have a great effect in diminishing the consequences of escapes.

Overseas experience suggests escape incidents may heighten the potential for the transfer of diseases and parasites from farmed stock to wild populations. Disease, however, is not a significant issue within the New Zealand finfish industry currently due to the geographic isolation of farms and the lack of diseases currently present. However, 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 are often bred from a small gene pool for selected traits (for example, fast growth) that can result in genetic divergence from the wild populations.

The use of transgenic (genetically modified) organisms is controlled by the Environmental Protection Authority (EPA) and it has not allowed any use of genetic modification in commercial aquaculture. 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 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 hāpuku).

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 from wild-sourced broodstock. 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 amount of escapees and to retain genetic diversity of cultured stock.

If escapee effects are seen on wild populations they are, however, likely to be irreversible and could potentially be at a national scale. At this time, limited knowledge is available on the potential effect that escaped farmed kingfish or hāpuku could have on the wild populations.

3.8.3 Management and mitigation options

The primary management approach to minimise escapes is to maintain net integrity (for example, regular maintenance of nets and structures). It is recommended that mandatory reporting of all escape incidents be required, along with training of fish farm staff in escape-critical operations and techniques. Minimising escapees is recognised by the New Zealand Salmon Farmers Association Inc in its Finfish Aquaculture Environmental Code of Practice, which contains practical advice for minimising escapes from salmon farms.

To reduce the risk of alteration of the genetic structure of wild fish populations due to escapees, the practice of triploidy (producing sterile fish) has been attempted in the past; however, in New Zealand it has been abandoned due to low viability of treated ova and poor growth of triploid fish.

Commercial marine farming of indigenous finfish species in New Zealand will require consideration of the risk for genetic effects on wild stocks. Measures to retaining the genetic diversity in cultured stock (such as by using wild sourced broodstock) will help minimise any adverse genetic effects. Furthermore, the expected harvest size for kingfish and hāpuku currently precedes the age or size of maturation so there will be little chance of released gametes from farmed stock.

3.9 EFFECTS FROM ADDITIVES

Table 3.8: Overview of potential effects of additives from finfish farming

Definition	The potential effect of chemicals used in 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
Management and mitigation options	• 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
Knowledge gaps	• Accumulation and interactions of trace contaminants • Effects of therapeutants on sediments and ecological processes
Key terms defined in glossary	Benthic, biodeposition, biofouling, micronutrient, phytoplankton, trigger level, water column

3.9.1 Summary of potential effects

Chemicals are 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 treat animals for bacterial diseases or parasites (such as antibiotics and parasiticides), 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 is the most commonly used compound to control biofouling on finfish farm structures and nets. It enters the environment mainly by leaching from antifouling paint or being deposited with paint flakes during mechanical cleaning of farm structures. The majority of copper remains on fish farm nets until they are cleaned onshore prior to recoating.

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 animals. They can be detrimental to organisms if, however, concentrations exceed (or fall below) those required for normal metabolism.

Therapeutants can be used to treat diseases and parasites in farmed fish stock. Most therapeutants have limited environmental ramifications as they are usually highly water soluble, disperse and break down readily and do not bind to sediments. Some therapeutants, however, are administered as feed additives and can be deposited on to the seabed.

The concentration (and hence toxicity) of chemicals is strongly influenced by the properties of water and sediments. For example, high-flow sites have higher dilution rates than low-flow sites.

3.9.2 Significance of effects

There is currently minimal use of chemicals such as antibiotics, parasiticides and other therapeutants in the New Zealand finfish farming industry; therefore, the risk of ecological effects from therapeutants is very low. Culture of indigenous finfish species such as kingfish and hāpuku, however, may lead to the emergence of diseases that may require new treatments (see Section 3.7).

Elevated metal concentrations (beyond background levels) have been recorded beneath finfish farm sites in New Zealand; however, these concentrations do not necessarily indicate adverse effects as metals bound to sediments are not usually considered highly bioavailable. High concentrations of metals may hinder long-term seafloor recovery after fallowing, but it is often difficult to differentiate these effects from 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.

3.9.3 Management and mitigation options

All species farmed for human consumption from aquaculture have to meet strict food safety standards that regulate the acceptable concentrations of metals, chemicals and additives in food products. New Zealand salmon farmers must also comply with the New Zealand Salmon Farmers Association's Finfish Aquaculture Environmental Code of Practice.

The New Zealand finfish farming industry and feed supply companies implement various measures to minimise contaminant inputs into the environment, which will likely lead to reduced contaminant loads in the future. For example, feed companies are presently investigating ways of reducing levels of zinc in feed and, consequently, minimising discharges to the seabed. Alternatives to copper antifouling, such as using in-water net cleaners, are also being trialled.

To minimise the effects associated with metals in antifouling paints, it is recommended that these paints are only used where essential, with manual defouling being used on other structures. Nets should be washed off-site to prevent particles reaching the seabed.

The management practices that minimise biodeposition and benthic enrichment on the seabed and allow impacted sediments to improve may also be effective to reduce 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 2000 (ANZECC guidelines). Monitoring can be reduced once it has demonstrated that sediment concentrations beneath farms are maintained below metal trigger levels. Alternatively, 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 avoidance of disease, controls on therapeutic use, hygienic measures in fish rearing and vaccination. Other biosecurity and disease management practices, such as spacing farms to prevent spread of diseases and the farming of single age classes (see Section 3.7), may also assist to maintain healthy stock and reduce the use of therapeutants.

The potential for environmental issues from theraputant 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 council consent for therapeutant use under appropriate conditions (such as veterinary prescription, with due regard to overseas data on safe discharge levels, and food safety requirements met).

3.10 HYDRODYNAMIC ALTERATION OF FLOWS

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

Definition	**Potential effects of aquaculture on the physical attributes of the water, including currents, stratification, and waves**
Summary of potential effects	• Finfish cages altering and reducing current speeds • Effects on stratification through vertical mixing and partial blocking of some water layers • Wave dampening may affect shoreline habitat 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. Generally the effect is strongest within the farmed area and decreases with distance from the farm.

Finfish cages can create drag which 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 as a result of 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 likely undetectable for individual cages, small farms or in sheltered areas.

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.

Small scale, local changes in currents as a result of the placement of cages are almost certain. Embayment-scale changes in circulation are highly likely in small bays or bays with several farms; however, the ecological significance of these changes is likely to be low.

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

CHAPTER 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	• Understanding of ecological effects of farming seaweeds and sea cucumbers is limited in New Zealand, but will grow with further experience in trialling and farming these organisms
Management and mitigation options	• Appropriate site selection • Permission from MPI to farm *Undaria*
Knowledge gaps	• Understanding of ecological effects limited as neither seaweed or sea cucumbers have been farmed at a commercial scale in New Zealand
Key terms defined in glossary	Epidemiological unit, habitat exclusion, IMTA, phytoplankton, staged development, stratification, subtidal, therapeutant, water column

4.1 INTRODUCTION

This section provides an overview of the potential ecological effects associated with farming sea cucumber and seaweed species in New Zealand, with a focus on the two species most likely to be farmed in the next five to 10 years: the sea cucumber *Australostichopus mollis* and the Asian kelp *Undaria pinnatifida* (*Undaria*) (Figure 4.1).

Figure 4.1: Sea cucumber (left) and *Undaria* (right).

Photo: Dave Allen, NIWA.

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 the 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 is currently under review by MPI. 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.

The Asian kelp *Undaria* grows on artificial surfaces like mussel farm backbones, droppers and anchor warps. *Undaria* is an introduced species and is classified as an Unwanted Organism under the Biosecurity Act 1993. In 2010, however, MPI introduced a policy that allows for commercial harvesting of *Undaria* from artificial surfaces and farming of *Undaria* in areas already heavily infested. The exact cultivation methods for *Undaria* in New Zealand are not developed, but based on grow-out trials in New Zealand and overseas culture methods it is likely that floating subtidal cultivation methods will be used.

Both sea cucumbers and *Undaria* are being considered for use in IMTA where they could assist to mitigate ecological effects of other aquaculture activities by assimilating detritus (sea cucumbers) and absorbing excess nutrients in the water column (*Undaria*).

This chapter summarises information contained in the *Literature Review of Ecological Effects of Aquaculture*. Readers are referred to the *Literature Review* for additional information and source references. The potential ecological effects associated with farming other emerging or experimental aquaculture species (including pāua, crayfish, scallops, and sponges) have been summarised in Keeley et al., 2009.

4.2 SUMMARY OF POTENTIAL EFFECTS AND SIGNIFICANCE

Our understanding of the ecological effects of farming of sea cucumbers and *Undaria* is limited as neither species is currently farmed on a commercial scale in New Zealand. Both organisms, however, have had initial research conducted on their life cycle in New Zealand. Our general understanding of associated ecological effects will grow with our experience in trialling and farming these organisms.

For emerging or experimental aquaculture species such as sea cucumbers and *Undaria*, we can only make 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 sea cucumber and seaweed species are likely to be less pronounced than those from shellfish or finfish aquaculture.

For both sea cucumbers and *Undaria*, there is very little that has been documented on the possible adverse interactions with marine mammals. The physical presence of farm structures will have similar risks (that is, potential exclusion, habitat modification and entanglement risks) to other types of aquaculture structures, and will depend on the size and layout of the farm and its components.

Similarly, the effects of farming sea cucumber and seaweed species on wild fish populations and seabirds have not been documented. The effects, however, are likely to be less pronounced than those associated with shellfish or finfish farming. Potential effects will likely stem from the addition of farm structures which may change the fishing pressure on local wild fish populations. For seabirds, farm structures may affect entanglement risk, potential habitat exclusion (significance would depend on scale of farm relative to available habitat), aggregations of prey fish, provision of roosting sites, or disturbance by farm activities.

4.2.1 Sea cucumbers

The ecological effects associated with culturing sea cucumbers are not well understood, as there are few studies on environmental effects of sea cucumber aquaculture. Instead, overseas studies tend to focus on the ability of sea cucumbers to mitigate the depositional effects from culturing other species (as they are deposit-feeders). For this reason, sea cucumbers are becoming a popular potential co-culture species in IMTA.

There is potential for minor seabed enrichment effects from biodeposition of sea cucumber faeces (if food is added). These effects, however, are likely to be significantly less than those described for 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 effect of structures on currents will be greatest in shallow sites. Altered current flows are likely to be greatest for suspended structures, followed by bottom structures. Structures on the seabed will decrease current velocities near the bed, with the possibility of local scouring around cages or piles, and near-bottom turbulence. Any local-scale changes in hydrodynamics from sea cucumber culture will be reversible on removal of all structures.

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 the intensive cultivation of sea cucumbers may induce outbreaks of diseases, requiring the use of therapeutants (mainly antibiotics).

4.2.2 Seaweeds (*Undaria*)

The cultivation of seaweeds such as *Undaria* will generally have minor ecological effects on the seabed and water column as they function at a lower trophic level and use dissolved nutrients (mainly dissolved inorganic nitrogen) for growth. Based on overseas studies, the only potential water column effect is nutrient extraction, with a possible flow-on effect of reduced nutrient availability for natural phytoplankton populations. Shading of the water column could affect light penetration to the seabed.

The effects of suspended subtidal ropes growing *Undaria* on the hydrodynamics (currents, waves, stratification) of the water column will be very similar to other suspended aquaculture activities, like mussel long-lines and fish cages, but the significance of any effects will depend on the scale of farming. Local farm-scale changes in current flow are almost certain, although they are reversible on removal of all structures.

Undaria can be considered a pest in its own right, as it is a non-indigenous seaweed regarded as both a fouling nuisance on marine farms and a threat to the ecology of high-value coastal areas of New Zealand (see Sections 2.7 and 3.7). The biosecurity risk arising from commercially farming *Undaria* itself will be reduced to some extent by the fact that culture is restricted to localities where the seaweed is already well established. If *Undaria* farming takes place, additional thought may also need to be given to whether any new *Undaria* risk pathways arise that do not already occur as part of aquaculture operations generally, and which are considered regionally or nationally significant.

Ecological effects from pest species associated with *Undaria* farming are likely to be generally similar to those of subtidal shellfish farming, given that the pathways, biofouling pests and other processes are likely to be comparable. There is currently a lack of knowledge of the ecological effects of diseases associated with *Undaria*. Potential diseases, pathogens and parasites of *Undaria* may be considered as potential biosecurity threats both to native seaweeds and also to the commercial use of *Undaria* in New Zealand.

Farming native seaweeds

While this chapter focuses on the potential effects of farming *Undaria*, there are a number of native seaweed species which may also have aquaculture potential in New Zealand (for example, kelp (*Macrocystis pyrifera* and *Ecklonia radiata*) and red algae (*Gracilaria* sp and *Pterocladia lucida*)). It is assumed that the effects of farming these native species will be similar to those for *Undaria* (with the exception of the biosecurity issues associated with *Undaria*), so long as similar farming methods are used.

Photo: Phil Kirk.

4.2.3 Management and mitigation options

Appropriate site selection is critical to avoid adverse ecological effects where possible. Both sea cucumbers and *Undaria* have been proposed as co-culture species for use in IMTA to mitigate the effects of the farming of finfish or shellfish, so the selection of sites in this case 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 localities where the seaweed is well **established**. To harvest and farm *Undaria*, permissions under the Biosecurity Act 1993 are required, as the organism is still considered an Unwanted Organism under the Act. Management options as part of farming *Undaria* 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.

Due to the substantial information gaps on the details of sea cucumber and *Undaria* culture methods and appropriate environments, the approach to the management of effects will need to be precautionary and adaptive (and tied to monitoring), to allow for a better understanding of effects as experience grows. Potential ecological issues such as genetic risks, biosecurity pests and diseases, and interactions with wild fish populations, will need to be assessed on a case-by-case basis as these issues are particularly species specific. Such considerations as farm spacing, staged development and epidemiological units should be considered if necessary.

CHAPTER 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
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 vs. 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 and coastal regions
Key terms defined in glossary	Adaptive management, anthropogenic, bay-wide, benthic, carrying capacity, cumulative effect, EQS, eutrophication, farm-scale, food web, IMTA, nutrient enrichment, oligotrophication, phytoplankton, staged development, stressor, water column

5.1 INTRODUCTION

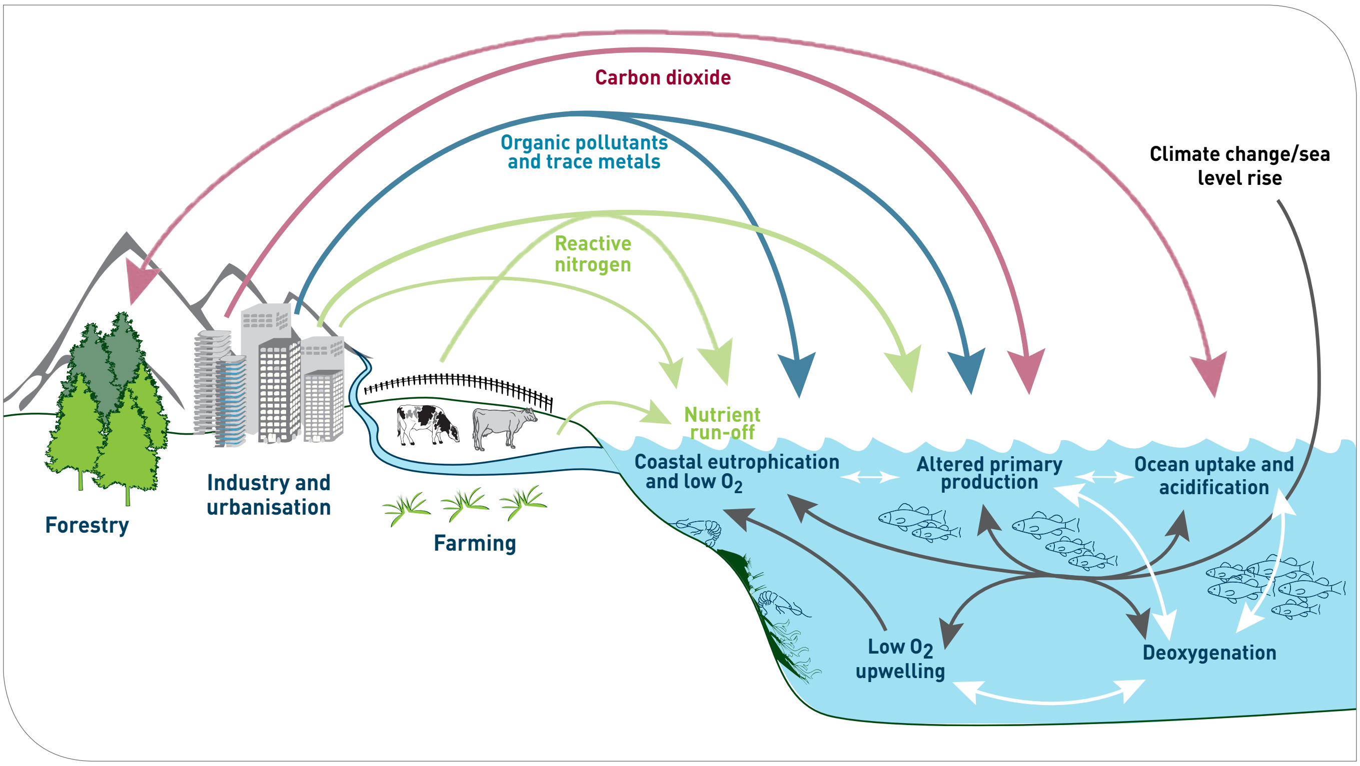
The farm-scale effects from aquaculture have been covered in previous chapters; however, potential bay-wide effects (for example, effects on the water column away from the farm, effects on wider ecosystem processes) although acknowledged, are far less understood.

Many human activities, including aquaculture, potentially affect the marine environment in often 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 a number of 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).

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: Based on Doney, SC., 2010.



5.2 SUMMARY OF POTENTIAL EFFECTS AND SIGNIFICANCE

There are 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). Alternately, they could be potentially large scale like 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 water bodies 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 (~one to 10 years) depending on the level of modification of the seabed.

5.2.1 Effects of shellfish and seaweed aquaculture

Multiple shellfish farms extracting plankton could potentially lead to wide-scale changes in plankton abundance and plankton community composition and, in turn, flow-on effects on the food web. 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.

5.2.2 Effects of finfish aquaculture

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

A range of the wider-ecosystem effects as a result of increased nutrient additions 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 process in coastal waters.

5.2.3 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 (from other anthropogenic influences, natural changes or a highly sensitive system). It is therefore important to have an understanding of 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.

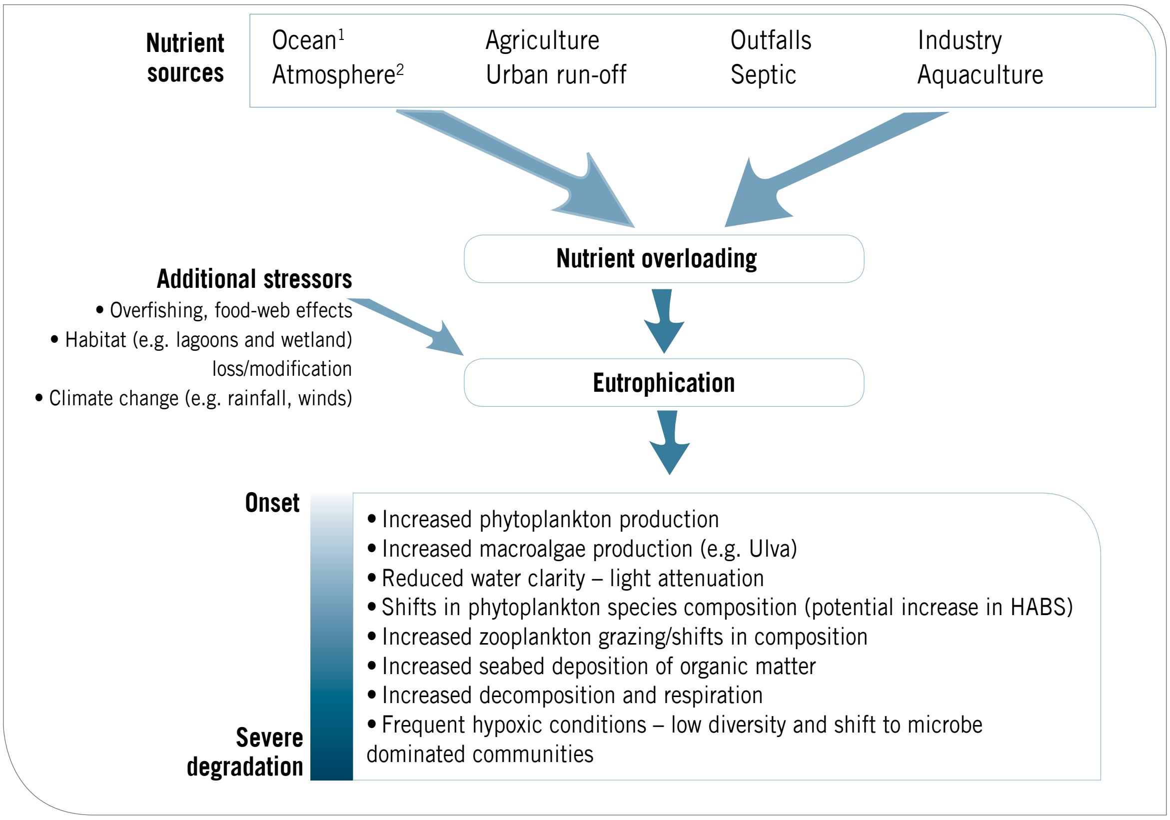
Efforts to address cumulative effects associated with multiple activities tend to lie outside the scope of individual marine farms; however, as outlined in the previous chapters, there are ways to manage and mitigate effects at the farm-scale, which in turn will contribute to minimising cumulative effects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

- reducing feed wastage and increasing feeding efficiencies;
- reducing stocking densities; or
- in theory, IMTA.

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, while dissolved nutrients from fish and mussels can be assimilated by adjacent seaweeds at the farm. In addition, co-cultured species could be harvested to improve the economic performance of the farm.

Figure 5.2: Diagram of the eutrophication process

Notes:
1) Ocean sources to coastal waters include dissolved nutrients through breakdown of organic matter, nitrification, and onwelling/upwelling of nutrient rich deeper waters.
2) Atmospheric deposition of nutrients from fossil fuel combustion, agricultural fertilizers and livestock operations can also significantly contribute to nutrients in coastal waters.
Source: Based on Diaz et al., 2012.



Mitigation of cumulative effects ultimately requires a wider ecosystem-based approach to planning and managing marine resources, and consideration of 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 Chapter 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 should be selected. Indicators and triggers should 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 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.

5.2.4 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 Chapter 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.

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

Wilsons Bay – aquaculture management area

The 3000-hectare Wilson Bay Aquaculture Management Area on the Coromandel Peninsula is home to the largest block of marine farms in New Zealand. This site uses an adaptive management approach called "limits of acceptable change (LAC)" to determine the limits of staged development.

Stakeholders engaged with scientists and regulators to collaboratively determine trigger points for actions (based on phytoplankton depletion at farm and Firth of Thames scale). If trigger points are exceeded, then agreed management responses occur, which range from meeting with other stakeholders to reviewing resource consents.

For more information see: **Trigger points for Wilsons Bay marine faming zone**.

CHAPTER 6: MONITORING THE EFFECTS OF AQUACULTURE

6.1 INTRODUCTION

Appropriate monitoring of the ecological effects of aquaculture is crucial to ensure 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 (see Chapter 5).

Regional coastal plans should 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 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.

Monitoring conditions should 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 likely be required.

In areas where the farm-scale effects of aquaculture are largely well known (for example, conventional long-line 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 aquaculture monitoring – Waikato Regional Council

With assistance from the MPI-administered Aquaculture Planning Fund, Waikato Regional Council is currently developing a guidance document for the aquaculture industry and other stakeholders in its region which aims to provide clear information on environmental monitoring requirements for aquaculture consents, as well as a methodology for integrating consent and state of the environment monitoring. The document will include a review of monitoring approaches in other New Zealand regions and overseas. While developed specifically for the Waikato region, the guidance document, which is due to be released in 2014, will contain useful information and principles of relevance to other regions.

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 so consents for new aquaculture involving new species or significant scale may require baseline monitoring. This position was reinforced by the **New Zealand King Salmon Board of Inquiry** in 2012.

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 that should 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; and
- hydrodynamic conditions.

6.4 STATE OF THE ENVIRONMENT AND REGIONAL MONITORING

Regional councils carry out state of the environment 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. The results of state of the environment 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.

6.4.1 Monitoring cumulative effects – additional considerations

Currently, it is difficult to determine the cumulative effects (see Chapter 5) of aquaculture using just the available regional monitoring. Crucial to regional assessments of cumulative effects in the marine environment is accessibility and co-ordination of datasets, including those derived from consent monitoring at individual farms, and long-term state of the environment monitoring programmes. Notably, an ongoing MPI Biodiversity project (ZBD2010-42) is starting to address the availability of monitoring datasets in order to build a national picture of the state of the environment. Standardised monitoring requirements for aquaculture is an important step to ensuring usefulness of consent monitoring datasets within broader-scale assessments.

Marine management model – Waikato Regional Council

To assist with state of the environment monitoring in its region, Waikato Regional Council is developing a marine management model for the Hauraki Gulf. The model, in conjunction with the deployment of permanent monitoring instrumentation, will be able to predict the fate of farm waste, nitrogen discharge from fish farms and disease risks. It will pave the way for environmentally sustainable economic development of aquaculture and other activities in the Hauraki Gulf, as well as supporting cost-effective consent monitoring and future plan development.

The data and model will be made freely available to the public, including, for example, the aquaculture industry and environmental interest groups. The project is due to be completed in mid-2014.

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. (New Zealand Biodiversity Strategy 2000)

Anoxic: Devoid of oxygen.

Anthropogenic: Caused or influenced by humans.

Assessment of Environmental Effects: 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. (**www.qualityplanning.org.nz**)

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 metres 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. (FAO)

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 fish that any particular body of water can support over a long period without negative effects to the fish or to the environment. (FAO)

Cetacean: Large aquatic mammals including whales and dolphins.

Chlorophyll *a*: The green pigment found in the chloroplasts of plants. (FAO)

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

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

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

Epidemiological unit: Epidemiological unit means 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, fish in a pond, caged fish in a lake), 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 ponds on a farm, all the ponds in a village system). (OIE)

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

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 metres from the farm structure.

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

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). (FAO)

Filter-feeder: An organism that strains water through its gill rakers to feed on 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 hāpuku. 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. (FAO)

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).

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.

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

Intertidal: The area between high and low watermarks.

Lower trophic: For the purpose of this document, lower trophic refers primarily to species such as sea cucumber and seaweed.

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

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

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

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.

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. (MPI)

Pelagic: Relating to living or occurring in 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: Floating microscopic algae that filter-feeders eat.

Polyploidy: Ploypoidy 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.

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.

Spat-catching: Spat-catching is the process of obtaining juvenile mussels and oysters (spat) by placing specialised structures (long-lines and ropes) in areas where there are large numbers of spat in the water. The spat attaches itself to the ropes and is then transferred onto growing structures. Note 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: Therapeutants are 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, have been genetically modified. (FAO)

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.

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. (MPI)

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.

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

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

SOE: State of the environment monitoring

UAE: Undue adverse effects on fishing test

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