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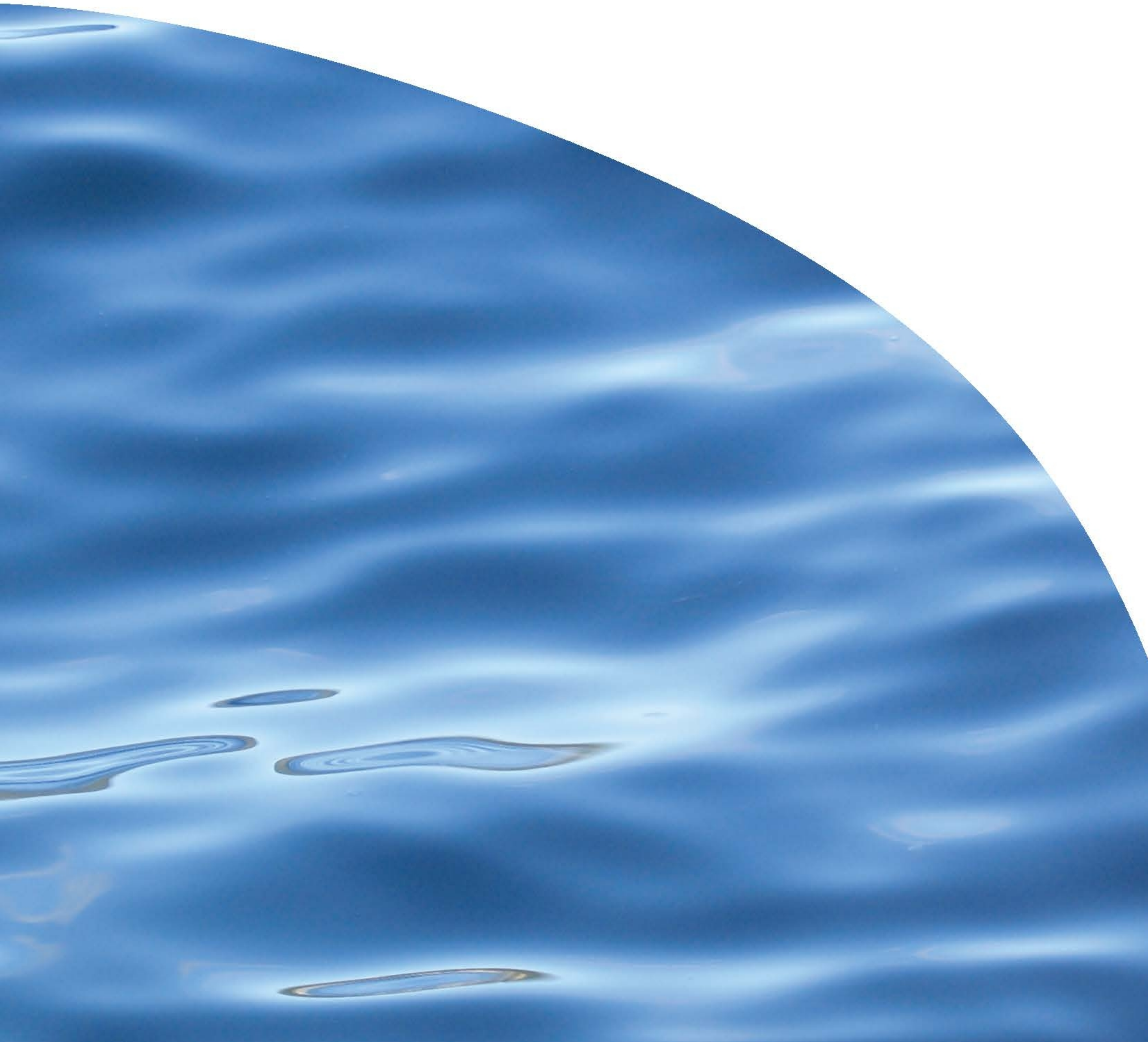
REPORT NO. 2429

MONITORING FRAMEWORK FOR THE WAIKATO COASTAL MARINE AREA: REPORT 2‑REGIONAL AQUACULTURE MONITORING PRIORITIES AND GUIDANCE



MONITORING FRAMEWORK FOR THE WAIKATO COASTAL MARINE AREA: REPORT 2–REGIONAL AQUACULTURE MONITORING PRIORITIES AND GUIDANCE

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EXECUTIVE SUMMARY

Waikato Regional Council (WRC) has recognised the need to rationalise and improve environmental monitoring for the Waikato coastal marine area (CMA). As part of WRC's steps towards meeting this need, the Cawthron Institute (Cawthron) has developed a framework that integrates consent-related and wider state of the environment (SOE) monitoring. Using aquaculture as a first case study for the framework, a three-report series has been produced to present the framework and develop ecological monitoring requirements and standards for aquaculture in the CMA. The three reports are as follows:

Report 1: Monitoring framework: Presents the rationale and key elements of a regional monitoring framework that integrates monitoring associated with consented activities and wider state of the environment (SOE) monitoring (Forrest & Cornelisen 2015).

Report 2: Regional guidance on priority issues and monitoring: Addresses the ecological effects of aquaculture in the Waikato CMA and identifies the priority issues that need to be addressed through industry best practice and reporting, and/or through monitoring of effects.

Report 3: Monitoring methodologies and standards: Recommends methodologies and standards for monitoring the seabed, water column and the wider environment in relation to the potential effects of aquaculture (Keeley *et al.* 2015).

This document is Report 2 in the series, and provides a case study for many (but not all) of the elements of the Report 1 framework. Following the key steps in the framework, Report 2 undertakes the following:

1. to identify key ecological effects of aquaculture that could arise with different culture methods or species, or sea-based production stages (spat and grow-out), and reveal the limitations of present monitoring in relation to these effects (Step 2; assess actual or potential effects on CMA)

2. to discuss the following aspects for each of the key ecological effects (Step 3; develop consent monitoring requirements and alignment with SOE):

    - approaches to mitigation of actual and potential effects, in particular via implementation of best management practices[1]

    - consent-related environmental monitoring and reporting that is necessary or desirable for the different industry sectors; and the need for (and benefits of) supporting regional SOE monitoring

[1] The best management practices and reporting that we outline are relatively 'high-level' and may need to be modified to reflect situation-specific circumstances, and following completion by Aquaculture New Zealand of a review of the industry's Environmental Codes of Practice and development of an Environmental Management System. For now, the ideas we outline should be regarded by WRC as a guide on management approaches that they should expect to see considered by a consent applicant.

- where a need for monitoring is identified, to describe (to the extent feasible at this stage) indicators and standards for evaluating environmental quality (Step 4). For water column and seabed effects, this report provides only the high-level ideas, with Report 3 providing a more in-depth analysis.

To varying degrees, many of the key effects associated with aquaculture (summarised in Table 1) can be mitigated through implementation of best management practices (BMPs), some of which are already embedded into environmental codes of practice (ECOPs) for each industry sector and will be refined following the Aquaculture New Zealand review (see footnote 1 previous). We have identified in Table 2 where that *ad hoc* record keeping and reporting (as distinct from environmental monitoring) of marine mammals and seabirds, and around biosecurity pests and diseases takes place in all aquaculture. It provides an important adjunct to minimising ecological risk or understanding of effects. Further record keeping occurs as a part of finfish farming and includes water column and seabed.

Situation-specific factors will alter the relative importance of the different aquaculture effects and the need for (and feasibility of) monitoring. These factors include the culture species, the type of culture method, and the attributes of the culture or wider environment that affect vulnerability to adverse effects. The aquaculture issues that are arguably of most importance are the ones whose effects (i) are of a high severity or magnitude, (ii) occur across broad spatial scales, and (iii) are persistent in the long term and are perhaps irreversible.

On the basis of these criteria, biosecurity issues relating to marine pests can be argued as being of high relative importance, largely reflecting that adverse effects may be irreversible and occur across regional scales. Once introduced to a region, a marine pest does not become diluted in the sense that a 'traditional' contaminant does, but usually becomes widespread and impractical to eradicate. Furthermore, marine pests have the potential to give rise to complex effects (*e.g.* direct and indirect effects, including cascading food-web effects) in a wide range of habitats.

Despite this general assessment, the incremental biosecurity risk from aquaculture development may be relatively minor where there is a high pre-existing risk. While long-term SOE monitoring is desirable in terms of facilitating understanding of the effects of marine pests, such monitoring cannot easily be linked with industry management actions that will reduce risk. Although wider ecological effects from biosecurity risks associated with aquaculture are possible, it is expected that effective stock health management will protect the wider environment.

Table 1. Key ecological issues and effects associated with aquaculture development of relevance to finfish and shellfish culture in the Waikato coastal marine area (CMA).

Category	**General description of effects**
Waves and currents	Physical effects of farm structures on attenuation or alteration of waves and currents can potentially lead to a range of ecological consequences. Water current speed has an important influence of the severity and spatial extent of seabed effects. However, the effects of a changed flow regime are not well understood for other issues, and require site-specific evaluation.
Water column	Finfish aquaculture has the potential to affect water quality and the water column (*e.g.* plankton communities) in a number of ways. A particularly important issue is nutrient enrichment and potential for eutrophication, including increased frequency and intensity of harmful algal blooms. Water quality from finfish farms may also be affected by additives (see below), 'greywater' discharge and harvest effects (*e.g.* blood). For shellfish aquaculture, water quality *per se* is not a significant issue; however, shellfish farms contribute to nutrient enrichment, but can simultaneously deplete plankton by filter feeding.
Seabed	Seabed habitats can be affected by deposition of organic waste (*e.g.* faeces, biofouling) and inorganic material (*e.g.* shell, litter). In finfish culture, organic enrichment results from fish faeces and waste feed, and seabed effects can be severe (*e.g.* near-complete loss of seabed fauna). Finfish culture can also lead to high seabed concentrations of certain toxic contaminants. In shellfish culture no feed is added, and seabed enrichment effects are far less severe than occurs with finfish. However, waste shell can accumulate beneath shellfish farms. In all types of aquaculture, the severity of seabed effects decreases as flushing increases (*e.g.* with increased water currents).
Marine mammals	A range of effects on marine mammals are possible, with the most important being the potential for exclusion from critical habitat, and death by entanglement in ropes and nets. These tend to be well managed issues (*e.g.* through BMPs), and arise infrequently in NZ. Wild fish aggregation and artificial lighting (on fish farms) may attract some mammal species to farms. The potential adverse effects of some sources of disturbance (*e.g.* noise, vessel traffic) are recognised but poorly understood.
Seabirds	The main issues relate to the exclusion of seabirds from feeding areas, and risk of mortality due to entanglement (in the case of finfish farms). Noise and boat traffic could disturb nesting and feeding birds. Structures for roosting and attraction to food (small fish) may result in the aggregation of seabirds around marine farms. Artificial lighting has been observed to have little effect on seabirds.
Aggregation of wild fish	The aggregation of wild fish around artificial structures can provide 'artificial reef' effects by enhancing local biodiversity and productivity. Aggregation may make fish more vulnerable to fishing pressure, as marine farms are often popular spots for recreational fishers. In terms of adverse effects, this issue is generally thought to be of minimal importance in NZ in terms of effects on wild populations.
Escapees and genetics	Potential effects include: genetic interactions that lead to reduced fitness and adaptability of wild conspecifics; ecological interactions from fish escapes (*e.g.* predation or competition), or shellfish loss or reproduction (*e.g.* enhanced shellfish abundance in natural habitats); and transfer of disease to wild populations of conspecific or related species (see below). In NZ most such effects are generally thought to be low risk, and manageable by minimising escapes.
Additives	Additives include various therapeutants (*e.g.* nutritional), medicines (*e.g.* antibiotics) and toxicants (*e.g.* copper), and detergents and disinfectants. These are important considerations for finfish culture, but not for shellfish. The use of synthetic materials (*e.g.* plastics) and associated waste production from all types of aquaculture can also affect marine wildlife (*e.g.* if ingested) and ecosystems.
Biosecurity (marine pests and disease)	Transfers of infected aquaculture gear or stock, and vessel movements can act as vectors for the spread of pests and diseases within and among farms or regions. Potentially harmful organisms can become prolific on marine farms, which then act as reservoirs for spread to the wider environment. Marine farms can also alter the local (*e.g.* through seabed effects) or regional (*e.g.* effects on phytoplankton) environment, creating conditions that facilitate the emergence of problem species.

Table 2. Aquaculture issues in the Waikato coastal marine area (CMA), highlighting the nature of reporting or monitoring to mitigate stressors or their effects. This is a high level guide, relevant to all types of aquaculture unless specified. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors. The need for water column and seabed monitoring is being further evaluated in Report 3. A detailed description of effect categories is provided in Table 3 in this report. Ratings in this table were derived from expert judgement in alignment with the approach taken in the MPI Aquaculture Guidance project.

Category	**Knowledge of ecological issues**	**Perceived ecological importance (see text)**	**Scope to mitigate stressors or effects**[1]	**Probable scale of measureable effects after mitigation**	**Probable reversibility of adverse effects**	**Sector requirement for *ad hoc* data collection, record keeping and reporting**	**Sector requirement for consent-related stressor or effects monitoring**	**Need for broad-scale SOE monitoring**
Water column	Med	High	Med-High	Farm to broad-scale	High	F	All	Essential
Seabed	High	High	Med-High	Farm-scale	High	F	All	Desirable
Marine mammals & seabirds	Med-High	High	Med-High	Farm-scale[2]	Low-High[2]	All	None	Desirable
Wild fish interactions	Low-Med	Low-Med	Low-Med	Farm-scale	High	None	None	Unnecessary
Escapee & genetic effects	Low-Med	Low-Med	Med-High	Farm-scale	High	F	None	Unnecessary (research desirable)
Biosecurity: pests	Med	High	Low-Med	Farm to broad-scale	Low	All	None	Desirable
Biosecurity: disease[4]	Low-Med	Med-High	Med-High	Farm-scale	High	All	F	Unnecessary (research desirable)
Additives	Low-High	Med-High	Med-High	Farm-scale	High	F	F	Unnecessary

Notes:

[1] Scope to mitigate adverse effects by appropriate site selection and planning, and requiring (as part of consent conditions) implementation of best management practices with associated record keeping and reporting where appropriate.

[2] Importance and scale of effects on mammals and seabird depend on species. For example, death by entanglement has a permanent local-scale effect on an individual, and would be significant for an endangered species because of potential broad-scale population-level effects; however, this effect is not expected given appropriate site-selection and BMP implementation.

[3] Disease is an issue where the measureable effect is most likely on the stock. Although wider ecological effects are possible, it is expected that effective stock health management will protect the wider environment.

Water column nutrient enrichment from finfish culture is a similarly significant issue, as it also has the potential to contribute to broad-scale effects (*e.g.* harmful algal blooms; HABs). However, it represents a situation where SOE monitoring is not only desirable, but is an essential part of a broader toolbox (*e.g.* including modelling) for management. Consent-related monitoring at the farm scale (*e.g.* of water column nutrient concentrations) is of little value if it is conducted in the absence information of the cumulative inputs of nutrients from other sources, the regional occurrence of HABs, or knowledge of environmental conditions that facilitate HAB formation. Water-column effects are likely to increase in importance with the intensity and spatial scale of regional aquaculture development. An approach to water column monitoring of aquaculture effects for the Waikato region is outlined in Report 3.

For the range of other categories depicted in Table 1, the ecological importance of potential effects is arguably less in relative terms than marine pest and water column issues, but may nonetheless be regionally important. For example, marine mammal entanglement may be a very low likelihood event, but could have high consequences if it resulted in the death of an endangered animal (*i.e.* because of population-level effects). Given this situation, it is clearly important that appropriate *ad hoc* record keeping and reporting is included in consent conditions (*e.g.* as part of a management plan), yet systematic monitoring at the farm scale is not justified. Similarly, while regional scale SOE monitoring of marine mammal population is desirable, it is arguably not critical. Even with a regional approach, it is likely to be difficult to link changes in seabird or mammal populations to adverse effects from aquaculture.

Seabed enrichment effects and related monitoring needs will be further considered in Report 3. This issue is well understood; the measureable seabed effects from aquaculture are more severe in the case of finfish than bivalve culture, and are localised in their spatial extent. Monitoring indicators are well understood, and environmental standards are in the process of being developed. Seabed monitoring is justified for any new finfish culture development, given that the Waikato region has no experience with this activity, and effects are subject to change with farming intensity. The relative benefits of ongoing seabed monitoring of mussel and oyster grow-out or spat-catching will be further evaluated in Report 3. State of the environment monitoring is arguably not an essential part of seabed monitoring, as with the geographic expansion of aquaculture the measureable effect of each farm unit still occurs at a local scale. Nonetheless, SOE monitoring is desirable, as it could provide reference sites against which farm-scale effects could be assessed, and could provide the regional baseline data necessary to develop and calculate certain types of biotic indices.

Two of the remaining categories described in Table 1 (*i.e.* wild fish interactions, escapees) tend to be perceived as of relatively minor importance given appropriate mitigation, and are typically not amenable to ecological effects monitoring in any case. The ecological implications of additive use will require BMPs, reporting and monitoring approaches to be developed based on food safety regulations and situation-specific information. The use of certain additives in finfish culture will largely depend on the disease issues that emerge, which at this stage is not well understood. However, even where consent-related environmental monitoring is needed, associated SOE monitoring is probably unnecessary in most instances.

This report provides the basis for WRC to develop guidance on BMPs, reporting and monitoring for aquaculture. In terms of understanding where SOE monitoring sits alongside resource consent monitoring, this report addresses SOE monitoring needs mainly in relation to specific effects of aquaculture activities. At some stage we would advise considering SOE requirements more holistically. There is scope for monitoring to be more efficient, robust and useful if SOE needs are considered across aquaculture and other anthropogenic or natural causes of environmental change. In this way, the cumulative effects of multiple activities and environmental stressors will be better understood.

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1. INTRODUCTION

Waikato Regional Council (WRC) has recognised the need to improve environmental monitoring within their coastal marine area (CMA; Figure 1). As defined in Report 1, we consider monitoring as an activity that can be conducted in a systematic manner and planned in advance, whereas reporting involves collection and recording of *ad hoc* data, which may be periodically collated by a consent holder and reported to WRC. Presently there is a lack of cohesion between resource consent-related monitoring undertaken for coastal developments and regional state of the environment (SOE) reporting. Through the development of an overarching framework, WRC aims to make monitoring more integrated and efficient, and increase the value and utility of the data that are acquired. Improvements in this regard will assist WRC in meeting its policy and planning goals regarding sustainable integrated management of the region's CMA.

As part of WRC's steps towards meeting these needs, the Cawthron Institute (Cawthron) has produced a three-report series aimed at developing monitoring requirements and standards for aquaculture in the CMA. The three reports are as follows:

- **Report 1: Monitoring framework:** Presents the rationale and key elements of a regional monitoring framework that integrates monitoring associated with consented activities and wider state of the environment (SOE) monitoring (Forrest & Cornelisen 2015).
- **Report 2: Regional guidance on priority issues and monitoring:** Covers the ecological effects of aquaculture in the Waikato CMA and identifies the priority issues that need to be addressed through industry best practice and reporting, and / or through monitoring of effects.
- **Report 3: Monitoring methodologies and standards:** Recommends methodologies and standards for monitoring the seabed, water column and the wider environment in relation to the potential effects of aquaculture (Keeley *et al.* 2015a).

This document is Report 2 in the series, and provides a case study for many (but not all) of the elements of the Report 1 framework (Figure 2). The focus on aquaculture in Reports 2 and 3 serves as a useful means of illustrating the issues that arise when developing a regional monitoring approach. Simultaneously, this focus assists WRC in its need to develop improved guidance for the aquaculture industry on consent-related environmental monitoring and reporting requirements.

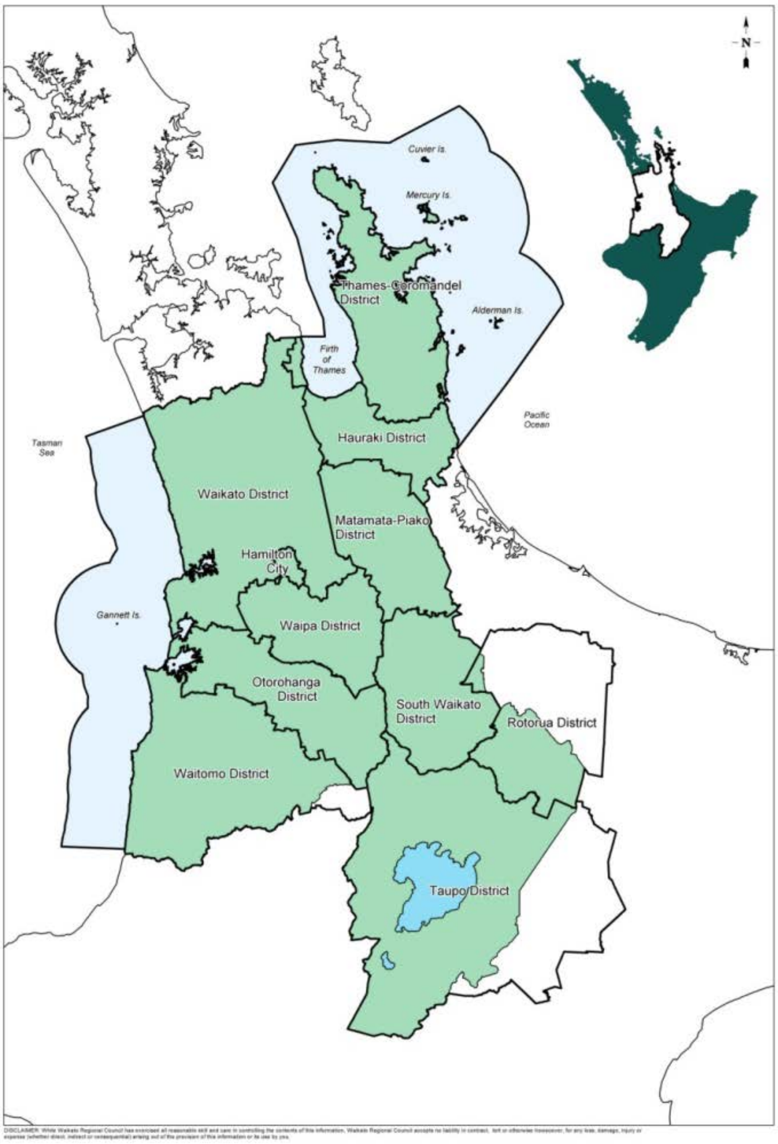

Figure 1. The Waikato coastal marine area (CMA; blue shading) includes west coast harbours, the Firth of Thames and south-eastern Hauraki Gulf, as well as the coastline and many estuaries along the eastern side of Coromandel Peninsula. (Source: Waikato Regional Council).

All three reports have been undertaken by Cawthron in collaboration with WRC, with support from the Ministry for Primary Industries (MPI) Aquaculture Planning Fund. It is expected that the ideas and approaches presented in the reports will be a starting point for consultation with the aquaculture industry and other stakeholders.

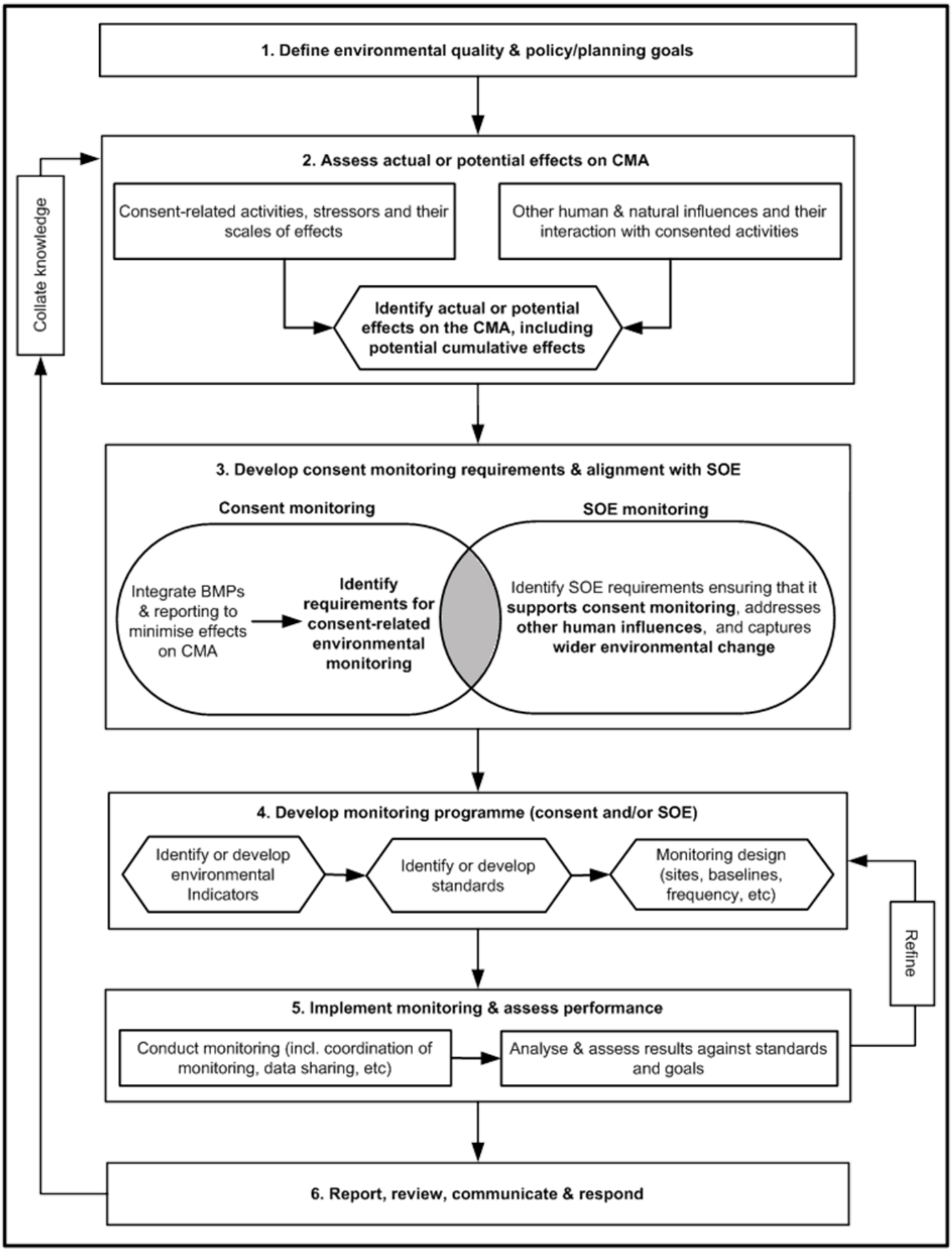

Figure 2. Regional monitoring framework described in Report 1.

1.1. Report scope and objectives

The project scope is limited to the ecological effects of aquaculture; other issues that arise with marine farming developments (economic, social, cultural, amenity) are not covered. Following the key steps in the Report 1 framework (see Figure 2) this second report undertakes the following:

1. describes WRC's goals for aquaculture development in the region's CMA (Step 1)
2. identifies the key ecological effects of aquaculture that could arise with different aquaculture methods or species, or sea-based production stages (spat and grow-out), and reveals the limitations of present monitoring in relation to these effects (Step 2)
3. discusses the following aspects for each of the key ecological effects (Step 3):
    - for each industry sector (mussel, oyster and finfish): approaches to mitigation of actual and potential adverse effects, in particular via implementation of best management practices
    - the nature and extent of consent-related environmental monitoring[2] and reporting that is necessary or desirable across the different industry sectors
    - the nature and extent of regional SOE monitoring that is desirable or necessary in order to provide a context for consent-related effects, or to make consent-related environmental monitoring more efficient or rigorous.
4. describes (to the extent feasible at this stage) suitable environmental indicators and standards for evaluating environmental quality for issues where a need for monitoring is identified (Step 4). For water quality and seabed effects, this report provides only the high-level ideas, with Report 3 providing a more in-depth analysis.

Related projects are currently underway with final outcomes that will be relevant to the content of this report. One of these is a review of the environmental codes of practice (ECOP) for each industry sector that has been commissioned by Aquaculture New Zealand, as part of the development of a comprehensive environmental management system. The Aquaculture New Zealand review will have a bearing on the various BMPs discussed in this report. The content of this report is based on existing sector ECOPs. A second key piece of related work is an ongoing MPI-led project that seeks to provide guidance to regional councils and unitary authorities on the ecological risks of new aquaculture proposals, and tools to assist them in their decision making. The present report for WRC extends the MPI project by considering BMPs, reporting and

[2] Following the definitions in Report 1, we consider monitoring as an activity that can be conducted in a systematic manner and planned in advance. By contrast, reporting involves collection and recording of *ad hoc* data, which may be periodically collated by a consent holder and reported to WRC.

monitoring needs in detail, which are tailored to the key types of aquaculture and related issues for the Waikato region.

1.2. Recap of rationale for regional monitoring framework

Report 1 showed that consent-related environmental monitoring and SOE monitoring in the Waikato CMA are minimal, and not presently integrated with each other. There is a lack of consistency in the monitoring of consented activities in terms of the depth and breadth of requirements (*e.g.* parameters measured, monitoring frequency), with the majority of activities (other than aquaculture) requiring no monitoring. Furthermore, there are few standards or limits against which monitoring data can be assessed. State of the environment monitoring is so limited in scope at present that the background state of the environment, the importance of various activities, and the relative importance of diffuse-source effects (*e.g.* from catchment inputs), is poorly understood. Additionally, there is limited recognition of the potential for cumulative effects on the CMA.

To address these shortcomings, the regional framework presented in Report 1 described a series of key steps towards the development of an integrated regional approach. As described above, the aquaculture focus of this report provides a case study for many of the frameworks elements. Particularly important steps in the framework are Steps 3 and 4 in Figure 2, which are a focus of much of this report. A key purpose of Step 3 is to understand whether and to what extent consent-related environmental monitoring is necessary and feasible, and to consider how such monitoring could be integrated with regional SOE efforts. Consent monitoring is generally targeted toward the effects of discrete point source anthropogenic activities, and often occurs at the local scale of the activity. Report 1 recognises that SOE monitoring has the potential to provide a direct context for understanding the effects of consented activities. If deliberately integrated with consent monitoring, SOE monitoring has the potential to provide a broad characterisation of background environmental change within which local-scale changes from consented activities can be assessed.

Report 1 also argues that monitoring would be greatly improved if it was based on a common set of indicators and methods, and coordinated by a single organisation. A standardised coordinated approach would enable scientific consistency (*e.g.* in terms of methods and timing of monitoring) and quality control, and provide a central repository for the data. Such an approach would also cater for a standardised approach to evaluation of results and assessment of environmental quality, and improve Council’s ability to detect spatial and temporal trends and cumulative effects.

Well-integrated monitoring would have a number of other benefits to WRC and consent holders. The background information provided by a well-integrated programme could provide the baseline data necessary for assessment of consented point-source effects. For example, as described below in Section 5, some of the key indicators and biotic indices that are widely used to evaluate point source seabed effects of aquaculture are benchmarked against regional reference site conditions. These reference conditions would most appropriately be characterised as part of the scope of SOE monitoring. Similarly, an SOE programme could provide a rationalised suite of reference sites, and possibly use representative impact sites, to improve the scientific rigour and efficiency of local-scale effects assessments.

2. ECOLOGICAL EFFECTS AND AQUACULTURE MONITORING IN THE WAIKATO REGION

2.1. Ecological issues associated with aquaculture development

New Zealand reviews of the ecological effects of aquaculture (Forrest *et al.* 2007; Forrest *et al.* 2009; Keeley *et al.* 2009; MPI 2013) highlight that marine farming can give rise to a range of potential effects that may be as important (or more important) than the seabed and water-column effects that are currently the focus of consent monitoring. In part, this situation has been driven by a historic lack of knowledge or feasible monitoring tools to address some of the broader issues. However, it is also true that there has been a lack of recognition of potentially important issues, or a lack of clarity regarding regional council and unitary authority responsibilities (*e.g.* regarding marine biosecurity).

The potential for, and severity of, adverse ecological effects due to marine farming depends on factors such as: the scale, type and intensity of farming; the species and culture method; the stage of production (spat *vs* grow-out); and the nature and resilience of the receiving environment, which itself can be influenced by other anthropogenic influences and natural processes. There are nonetheless some general issues that consistently arise across all types of aquaculture in New Zealand. These issues can be grouped into key themes that represent the various components of the environment that are potentially affected (*e.g.* seabed or water-column effects), or various sources of risk (*e.g.* additives, harmful aquatic organisms).

Table 3 describes the general nature of aquaculture effects in relation to these key issues, based on information extracted from the MPI (2013) document and related reviews[3]. Note that Table 3 uses less technical terms than the MPI report; in particular we refer to seabed rather than benthic effects, and water column rather than pelagic effects. Where relevant, we discriminate between the effects of spat catching and grow-out. Although we have grouped the issues into convenient categories, it should be recognised that many are interrelated. Figure 3 illustrates schematically the key issues and some of their interrelationships for the grow-out stage of oyster, mussel and finfish aquaculture. Table 3 and Figure 3 highlight some broad similarities in the way different aquaculture species or methods can cause ecological effects. However, there are also some important differences. For example, issues such as phytoplankton depletion and shell deposition are relevant to mussel and oyster farming, but not finfish aquaculture. In the case of intertidal oyster culture there is an additional effect from ongoing physical disturbance (*e.g.* by farm personnel walking beside/between racks).

[3] The MPI literature reviews are available at: http://www.fish.govt.nz/en-nz/Commercial/Aquaculture/Marine-based+Aquaculture/Aquaculture+Ecological+Guidance.htm

Issues include excessive water column enrichment of dissolved nitrogen (*e.g.* from fish excretion) and the associated potential for harmful algal blooms, and the use of various additives such as antibiotics, therapeutants and other chemicals. For example, the trace metals copper and zinc can accumulate at ecologically significant concentrations in seabed sediments beneath finfish cages. This is because copper-based coatings are sometimes used as an antifoulant on farm structures, and zinc may be used as a dietary supplement.

Table 3. Key ecological issues associated with aquaculture development of relevance to finfish and shellfish culture in the Waikato CMA. Note that some issues of ecological importance can also have a negative effect on production (*e.g.* water column algal blooms, pests and disease).

Theme	**General description of issue**	**Waikato CMA finfish (feed-added) issues**	**Waikato CMA shellfish (non-feed added) issues**
Waves and currents	Physical effects of farm structures on attenuation or alteration of waves and currents can potentially lead to a range of ecological consequences. Water current speed has an important influence of the severity and spatial extent of seabed effects. However, the effects of a changed flow regime are not well understood for other issues, and require site-specific evaluation.	Although the ecological consequences of changed wave or current regimes are poorly understood, they are probably of little importance in the Waikato CMA as proposed finfish farms will be discrete structures that are located away from shoreline habitats.	The ecological consequences of altered wave or current regimes from shellfish farms are poorly understood, but perhaps most important to consider in the case of multiple farms adjacent to the coast (*e.g.* oyster racks in estuaries).
Water column	Finfish aquaculture has the potential to affect water quality and the water column (*e.g.* plankton communities) in a number of ways. A particularly important issue is nutrient enrichment and potential for eutrophication, including increased frequency and intensity of harmful algal blooms. Water quality from finfish farms may also be affected by additives (see below), 'greywater' discharge and harvest effects (*e.g.* blood). For shellfish aquaculture, water quality *per se* is not a significant issue; however, shellfish farms contribute to nutrient enrichment, but can simultaneously deplete plankton by filter feeding.	Nitrogen enrichment from finfish farms has been recognised as a key issue, as the CMA already experiences harmful algal blooms. The Regional Coastal Plan (RCP) sets mass load limits on finfish farm nitrogen outputs. Such outputs are important to evaluate and monitor within the context of cumulative nutrient sources and sinks (including shellfish farms). Other water quality effects are expected to be localised and negligible, although there will be some need for situation-specific assessment (*e.g.* additives).	Shellfish farms can contribute to nutrient enrichment, but the issue of plankton depletion is an issue specific to shellfish aquaculture. Phytoplankton depletion is monitored around some existing mussel farms in the Waikato CMA. However, the ecological consequences are poorly understood, but could include cumulative effects on the food web. For a given location, it is likely that spat catching effects will be less that the effects of grow-out.
Seabed	Seabed habitats can be affected by deposition of organic waste (*e.g.* faeces, biofouling) and inorganic material (*e.g.* shell, litter). In finfish culture, organic enrichment results from fish faeces and waste feed, and seabed effects can be severe (*e.g.* near-complete loss of seabed fauna). Finfish culture can also lead to high seabed concentrations of certain toxic contaminants. In shellfish culture no feed is added, and seabed enrichment effects are far less severe than occurs with finfish. However, waste shell can accumulate beneath shellfish farms. In all types of aquaculture, the severity of seabed effects decreases as flushing increases (*e.g.* with increased water currents).	Based on experience elsewhere in NZ, it can be expected that finfish farming in the CMA could give rise to significant seabed effects. The severity and spatial extent of such effects will be influenced by site-specific factors (*e.g.* water depth, current speed). Effects can be managed (*e.g.* by setting limits on stocking densities or adaptive management) and monitoring can be conducted to evaluate whether environmental quality goals are being met.	Seabed enrichment effects from shellfish aquaculture are well-studied, and currently monitored for some mussel growing sites in the Waikato CMA. Oyster farms are not monitored, but it can be expected that their seabed effects will be generally comparable to that described for mussel culture. For a given location, it is likely that spat catching effects will be less that the effects of grow-out.
Marine mammals	A range of effects on marine mammals are possible, with the most important being the potential for exclusion from critical habitat, and death by entanglement in ropes and nets. These tend to be well-managed issues (*e.g.* through BMPs), and arise infrequently in NZ. Wild fish aggregation and artificial lighting (on fish farms) may attract some mammal species to farms. The potential adverse effects of some sources of disturbance (*e.g.* noise, vessel traffic) are recognised but poorly understood.	Farms may exclude some mammals from their habitat or modify the way they use their habitat, hence such issues need to be considered as part of specific site selection. There is potential for entanglement within predator nets and ropes, but such issues can be managed through best management practices (BMPs) (*e.g.* regarding net mesh size).	Mussel farms may exclude mammals from habitats or modify the way they use their habitat, hence such issues need to be considered as part of specific site selection. There is minimal potential for entanglement within mussel grow-out or spat lines, provided ropes are kept under strain. Oyster farm effects are less important because farms are located in estuaries, where they are spatially removed from important marine mammal habitat.

Table 3 (*continued*)

Theme	**General description of issue**	**Waikato CMA finfish (feed-added) issues**	**Waikato CMA shellfish (non-feed added) issues**
Seabirds	The main issues relate to the exclusion of seabirds from feeding areas, and risk of mortality due to entanglement (in the case of finfish farms). Noise and boat traffic could disturb nesting and feeding birds. Structures for roosting and attraction to food (small fish) may result in the aggregation of seabirds around marine farms. Artificial lighting has been observed to have little effect on seabirds.	Proposed locations for finfish farms in the CMA are spatially removed from ecological significant shorebird and wading bird habitats. Risks to some seabird species could arise by entanglement in nets, and need to be considered case-by-case. It is expected that risks can be managed via implementation of various BMPs.	Potential effects of shellfish spat catching or grow-out relate mainly to the effect of structures on accessibility and use of feeding habitat. Farms may attract seabirds by providing structures for roosting, or to feed on fish that are attracted to the farm structures.
Aggregation of wild fish	The aggregation of wild fish around artificial structures can provide 'artificial reef' effects by enhancing local biodiversity and productivity. Aggregation may make fish more vulnerable to fishing pressure, as marine farms are often popular spots for recreational fishers. In terms of adverse effects, this issue is generally thought to be of minimal importance in NZ in terms of effects on wild populations.	Fish association with finfish farms in NZ is not well understood. Structures and waste feed may enhance wild fish aggregation. Artificial lighting may also influence attraction of fish, but this effect appears to be negligible. Overall this was not viewed as a significant issue by MPI (2013) and is unlikely to be particularly significant for the Waikato region.	Mussel spat and grow-out farms are known to attract fish, and to be a focal point for recreational fishers. The effects on fish populations will be species and situation-specific and difficult to determine. Fish association with spat-catching and grow-out of oysters in NZ is unknown.
Escapees and genetics	Potential effects include: genetic interactions that lead to reduced fitness and adaptability of wild conspecifics; ecological interactions from fish escapes (*e.g.* predation or competition), or shellfish loss or reproduction (*e.g.* enhanced shellfish abundance in natural habitats); and transfer of disease to wild populations of conspecific or related species (see below). In NZ most such effects are generally thought to be low risk, and manageable by minimising escapes.	MPI (2013) concluded that the likelihood of adverse effects from escapees in NZ is low; for example, because of the broad home range of likely culture species (*e.g.* kingfish). Nonetheless, risk needs to be assessed case-by-case, and uncertainty over the issue justifies implementation of appropriate BMPs.	The most relevant effect is gamete release and larval dispersal from grow-out sites, potentially leading to the establishment of culture species in natural habitats. Due to a long history of stock transfer around NZ, mussel and oyster population genetics are already well mixed between regions.
Additives	Additives include various therapeutants (*e.g.* nutritional), medicines (*e.g.* antibiotics) and toxicants (*e.g.* copper), and detergents and disinfectants. These are important considerations for finfish culture, but not for shellfish. The use of synthetic materials (*e.g.* plastics) and associated waste production from all types of aquaculture can also affect marine wildlife (*e.g.* if ingested) and ecosystems.	Additive use is an important but manageable issue for finfish culture. In the Waikato CMA the need for and use of additive compounds will depend on species and situation-specific needs (*e.g.* disease management). As such, the main text provides only a generic assessment and related guidance.	The only additive issue relates to potential toxicant effects from the leaching of timber treatment chemicals from oyster spat or grow-out racks. The issue is perceived as minor, but is not well understood in NZ. The use of treated timber is restricted in parts of Australia.
Biosecurity (marine pests and disease)	Transfers of infected aquaculture gear or stock, and vessel movements can act as vectors for the spread of pests and diseases within and among farms or regions. Potentially harmful organisms can become prolific on marine farms, which then act as reservoirs for spread to the wider environment. Marine farms can also alter the local (*e.g.* through seabed effects) or regional (*e.g.* effects on phytoplankton) environment, creating conditions that facilitate the emergence of problem species.	Finfish culture may exacerbate the spread of marine pests, but there are many sources of biosecurity risk and aquaculture is unlikely to significantly alter the level of risk. The emergence of disease in culture of new finfish species is possible (quite likely for some candidate species), and will need to be managed. To address uncertainties, it is important that management practices are put in place to minimise future threats.	Mussel and oyster spat-catching or grow-out may exacerbate the spread of marine pests, but there are many sources of biosecurity risk and aquaculture is unlikely to significantly alter the level of risk. Disease is an existing threat to oyster spat and grow-out, but has not been important to date for mussels. To address uncertainties, it is important that management practices are put in place to minimise future threats.

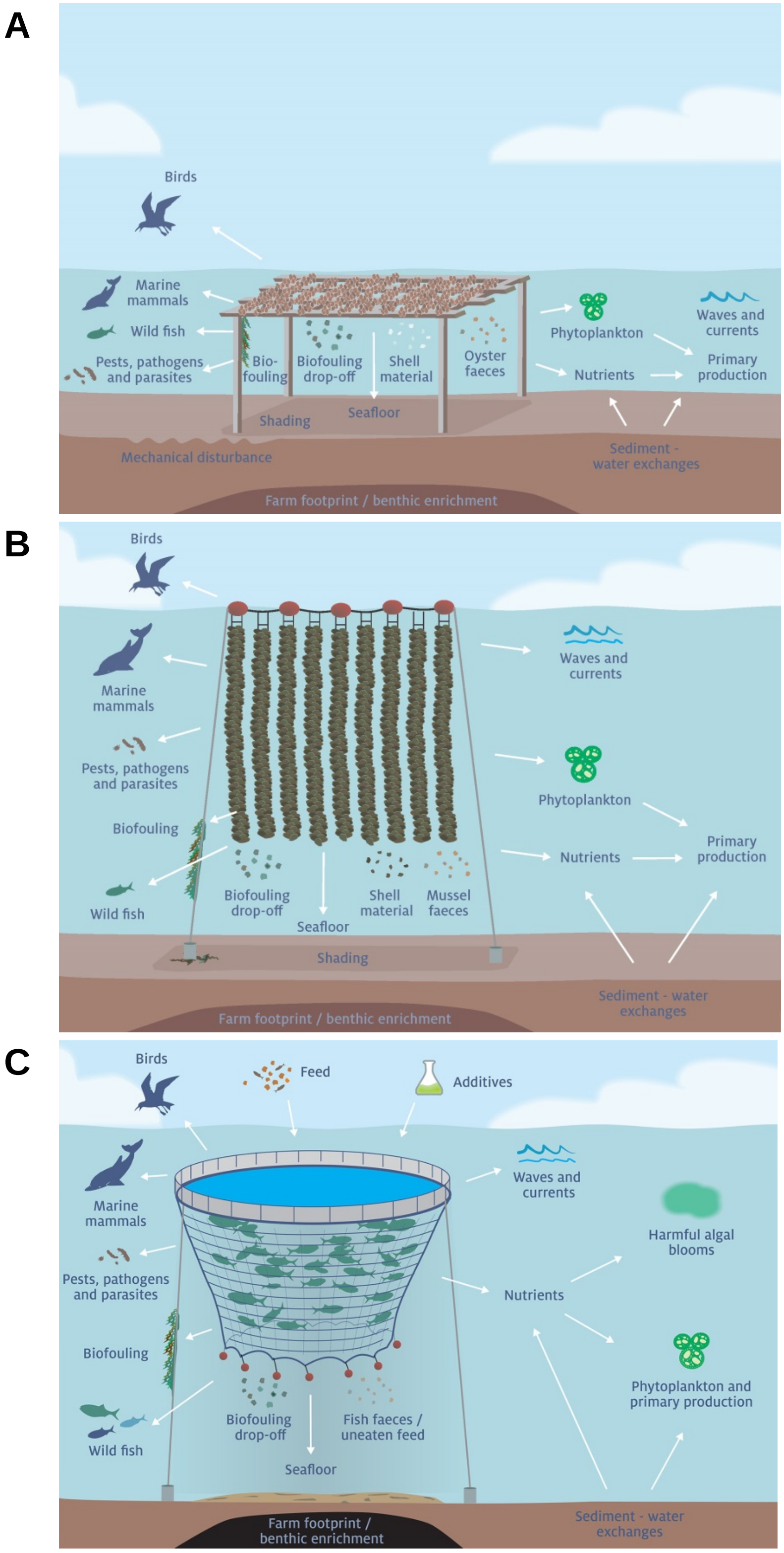

Figure 3. Schematics depicting the ways that ecological effects can arise from aquaculture of: (A) Pacific oysters, (B) green-lipped mussels, and (C) finfish. Schematics created by Waikato Regional Council.

2.2. Aquaculture activities and present monitoring in the Waikato region

2.2.1. Aquaculture types and locations

Aquaculture in the Waikato CMA is presently dominated by mussel farming, based on 'longline' floating subtidal culture of green-lipped mussels (*Perna canaliculus*), also known as Greenshell™ mussels. Some oyster farming is conducted in estuaries and consists of intertidal culture of non-indigenous Pacific oysters (*Crassostrea gigas*) on wooden racks.

Recently, new space has been designated for feed-added or 'fed' aquaculture, which may be developed at some stage for sea-cage finfish. It is not known which species will be farmed in this space, but candidate species include yellowtail kingfish (*Seriola lalandi lalandi*) and hāpuku (groper, *Polyprion oxygeneios*). The seawater temperature in the Waikato CMA is considered too high for farming of salmon.

The main aquaculture areas and their culture species are shown in Figure 4 and 5, and are as follows.

- **The Wilson Bay Marine Farming Zone (WBMFZ).** This is the largest mussel aquaculture area in the Waikato CMA, in a Firth of Thames location *circa* 15–26 m deep, overlying muddy sediments and subject to strong tidal currents. The area is oriented approximately north-south (Zeldis *et al.* 2010; Figure 4A). The WBMFZ is set up in two separate parts having a collective farmable space (*i.e.* excluding space between individual farm blocks) of 1,210 ha (Figure 5). The part closer to the shore is Area A[4]. It is 690 ha in size of which *c.* 85% is already developed in mussel farms. The part further into the Firth of Thames contains 610 ha of farm space and comprises Areas B and C. Area B is currently being developed for mussel farming. Area C, at the north end of Area B, consists of 90 ha that has been allocated for fed aquaculture (*i.e.* is expected to be developed for finfish farming).
- **Harbours of the western Coromandel Peninsula.** Outside of Wilson Bay, a total of *c*. 300 ha of space along the west coast of Coromandel Peninsula is presently allocated for aquaculture, mostly in Coromandel and Manaia harbours (Figure 4A). This includes smaller sites for mussel culture, some mussel spat-catching, and 70 ha for intertidal Pacific oyster cultivation.
- **Harbours of the eastern Coromandel Peninsula.** This area includes small mussel and oyster farms. Oyster farms are located in Whangapoua and Whitianga harbours, and mussel farms in Port Charles and Kennedy Bay (Figure 4A, circles).

[4] The area shown as Area A includes 220 ha of mussel farming space that had already been developed before the formal establishment of Area A. This space does not officially form part of Area A but for simplicity is included in Area A in this map.

- **West coast.** One mussel and spat-catching farm is consented in Aotea Harbour and one oyster farm in the adjacent Kawhia Harbour.
- **Coromandel Marine Farming Zone (CMFZ).** This is a new area of 300 ha situated in the south-eastern Hauraki Gulf, which is designated for fed aquaculture and will most likely be developed for finfish (Figure 4A, red rectangle). This zone is *c*. 35 m deep and overlies soft sandy-mud sediments containing shell material (Grange *et al*. 2011). As for Area C in the WBMFZ, the area is subject to strong currents, with median velocities of *c*. 0.2 m s^{-1} oriented NNW-SSE (Zeldis *et al.* 2010).

Additionally, WRC has received (and anticipates) consent applications that include extensions to existing mussel farms (Taylor *et al.* 2012) and mussel spat-catching areas. Waikato Regional Council also anticipates applications for additional mussel farms in the region and there is a possibility that the industry may seek consent to convert some of the spat-catching sites to grow-out areas.

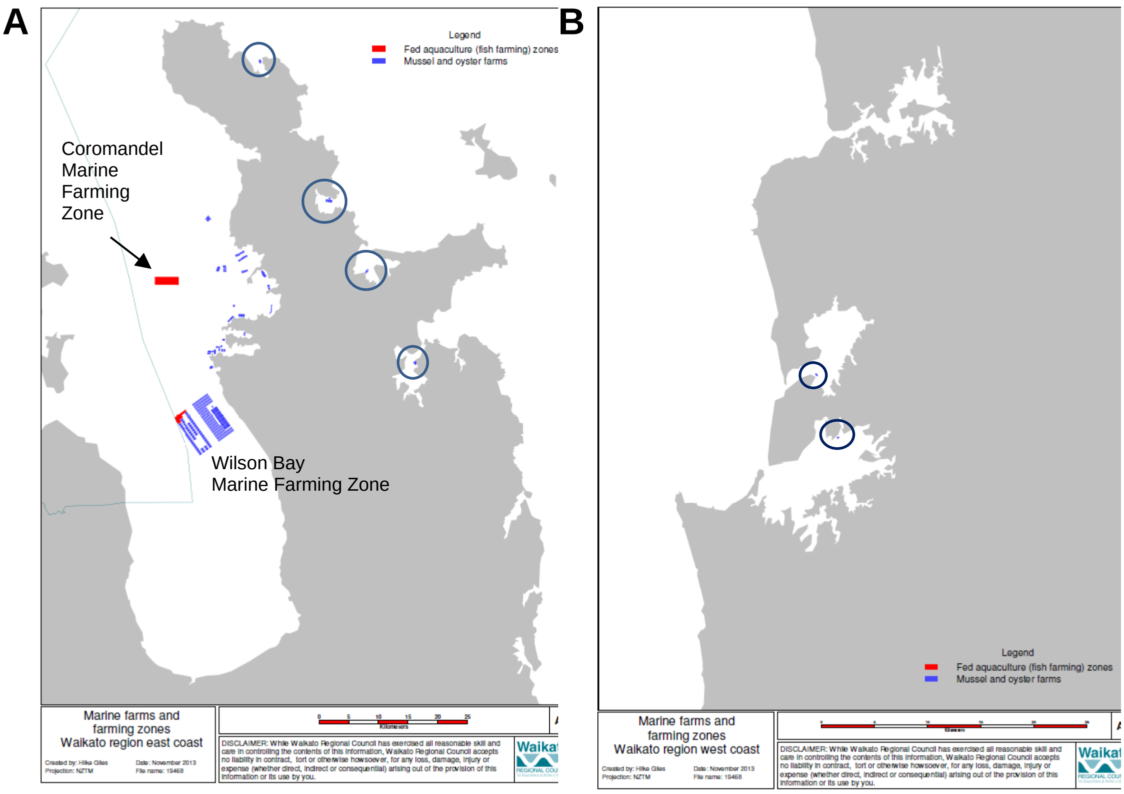

Figure 4. Existing mussel and oyster farms (blue) and fed aquaculture zones (red) in the (A) eastern and (B) western Waikato areas. Note that the latter area is barely visible. Maps are at different scales.

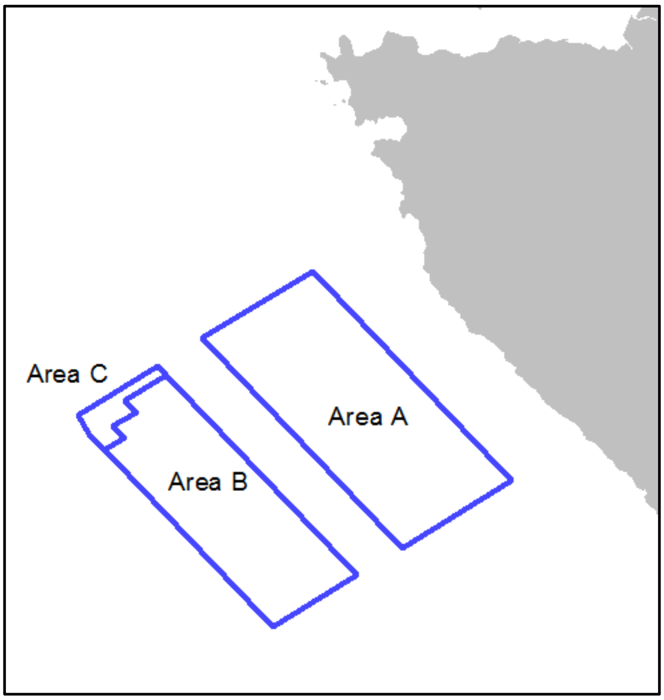

Figure 5. Wilson Bay Marine Farming Zone showing Areas A, B and C. Note that the area shown as Area A includes 220 ha of mussel farming space that does not officially form part of Area A.

2.2.2. Aquaculture monitoring

Report 1 provided an overview of aquaculture and other monitoring associated with resource consents in (and adjacent to) the Waikato CMA. The majority of consents within the CMA are for marine farming, primarily for mussels. However, existing monitoring of effects is limited in its scope. Key features are as follows.

- Monitoring focuses on seabed effects of mussel farms, and in some areas on near-field water quality indicators of primary productivity, mainly in WBMFZ Areas A and B. These two areas also have a requirement for assessment of physical effects on hydrodynamic characteristics at successive stages of development. Monitoring of mussel farms in WBMFZ Areas A and B is conducted through a consortium approach. In each area only a few farms are monitored to represent effects of the whole area. In general, monitoring requirements (including parameters and sampling design) are inconsistent among farms in the Waikato CMA.
- Monitoring is required in the vicinity of the farms only, without the regional context. Limited monitoring is required for mussel farms outside the WBMFZ. These farms include: mussel spat-catching and grow-out sites in Kennedy Bay; recently consented mussel farm extensions in Coromandel Harbour; and a communal mussel farm at the mouth of Coromandel Harbour.
- No monitoring of oyster farm effects is required, even though the nature and magnitude of effects from oyster culture in New Zealand can be comparable to

that for mussel culture (Forrest & Creese 2006; Forrest *et al.* 2009; Keeley *et al*. 2009).

Despite the limited ongoing consent-related environmental monitoring, a reasonable knowledge base of the effects of aquaculture on the seabed, and to a lesser extent water quality, has arisen from underpinning scientific research as well as projects commissioned by WRC, aquaculture companies and others. In the Waikato region these include past research in relation to development of mussel aquaculture available in WRC technical reports (*e.g.* Broekhuizen *et al.* 2005; Zeldis 2005; Giles 2010) and other reports or publications (*e.g.* Coffey 2001; Giles *et al.* 2006; Chamberlain & Stucchi 2007; Clearwater 2010; Taylor *et al.* 2012). Elsewhere in New Zealand the seabed effects of mussel, oyster and salmon culture have also been researched to varying extents (see reviews in Forrest *et al*. 2007; Forrest *et al*. 2009; Keeley *et al*. 2009; MPI 2013).

Despite the focus of aquaculture monitoring in the Waikato CMA on seabed and water-column effects, the broad issues referred to in Section 2.1 are well-recognised by WRC, and to some extent in Waikato's Regional Coastal Plan. This is especially the case for finfish aquaculture, for which WRC has already undertaken a number of related studies in anticipation of future development (Kelly 2008; Oldman 2008; Sagar 2008; Forrest *et al.* 2011). Nonetheless, there is considerable potential for the relatively limited and narrow focus of existing farm-scale monitoring to be expanded and incorporated into a regional framework.

The next sub-sections separately discuss each main aquaculture issue and its significance in the context of the Waikato region, and describe related management practices, and consent-related or SOE monitoring needs.

3. APPROACH TO DEVELOPMENT OF REPORTING AND MONITORING GUIDANCE

3.1. General approach

The remainder of this report considers how monitoring of aquaculture effects in the Waikato CMA could be improved. For each of the key issues listed in Table 3, we follow some of the main elements of the framework described in Report 1, and consider the following:

- the importance of each issue in relation to aquaculture in the Waikato region, the nature and spatial scale of actual or potential effects, and the potential for cumulative effects
- the suite of best management practices (BMPs) that could be adopted to reduce effects, irrespective of actual or potential risk. The BMPs and reporting requirements that we outline[5] reflect (to varying degrees) existing industry environmental codes of practice for mussels, oysters and finfish (AQNZ 2007a, 2007b; NZSFA 2007; NZ King Salmon 2012), or reflect international best practice (*e.g.* Sim-Smith & Forsythe 2013). The BMPs listed in this report will require review from industry representatives before being incorporated into practical guidance.
- consent-related reporting and monitoring requirements, and the nature of supporting regional SOE monitoring.

3.2. Structure and scope of Sections 4 to 10

In Sections 4 and 5 we address water column and seabed reporting and monitoring, as they are the focus of existing requirements. However, we only flesh out a possible approach to monitoring for these two issues within this report, as for both there is a need for more comprehensive assessment of existing studies and data to enable monitoring requirements and associated standards to be developed (*i.e.* Part 5 of the framework). These matters are explored in Report 3.

The remaining ecological effects are addressed in Section 6–10. We provide sufficient detail around ideas for mitigation and reporting / monitoring in order that WRC will have a basis for discussion with stakeholders. For issues perceived as being of minimal importance, or for which monitoring is not feasible, we describe instances where it may be adequate to require implementation of BMPs alone. If an issue is

[5] The best management practices and reporting that we outline are 'high-level' and may need to be modified to reflect situation-specific circumstances,and also following completion by Aquaculture New Zealand of a review of the industry's Environmental Codes of Practice and development of an Environmental Management System. For now, the ideas we outline should be regarded by WRC as a guide on management approaches that they should expect to see considered by a consent applicant.

considered of potential importance, but practical monitoring tools are unavailable, we describe where further research may be advisable.

To the extent feasible, we discuss how mitigation and monitoring needs differ for the different geographic areas where aquaculture is undertaken or planned in the Waikato region (described in Section 2.1), and for each culture type (*i.e.* mussels, oysters and finfish). To avoid repetition, we do not always discuss issues and options for mussels, oysters and finfish separately. Instead, for each significant issue we:

- provide a summary table of ideas for BMPs, reporting and monitoring
- identify the aquaculture sector to which the ideas are relevant. For this purpose, in all tables below we identify the sector types as: F = finfish, M = mussels, O = oysters, All = all sectors.

Note that the BMPs we outline are relatively high level, and are a general guide to WRC as to the types of practices they should expect to see developed by consent applicants. For a given sector, the actual BMPs will probably be more detailed than outlined here. For example, the current ECOP developed by the New Zealand Salmon Farmers Association (NZSFA 2007) is quite comprehensive in recognising the breadth of issues in Table 3 and Figure 3. It is a 27-page document that details the regulatory context for salmon farming, a comprehensive range of BMPs, staff training and communications requirements, and audit and review requirements.

With respect to shellfish (mussel and oyster) culture, our focus is on requirements for the grow-out stage of production. Our assumption is that spat-catching effects will be no more significant, and will often be of lesser severity for certain issues (Keeley *et al.* 2009), unless we specifically state otherwise.

Although it is hoped that the guidance is sufficiently generic to be useful for new aquaculture developments in the Waikato CMA, we recognise that in some instances (especially with respect to finfish aquaculture) it is not possible to develop specific mitigation and reporting / monitoring requirements at this stage. The detail on such matters will need to accompany consent applications for specific developments.

4. WATER-COLUMN EFFECTS

4.1. Overview of ecological issues

Maintaining good conditions within the water column is paramount to sustaining a productive aquaculture industry and a healthy surrounding environment. There are a number of factors that can affect water quality[6] and water column processes (see Table 3). These can be roughly categorised as local-scale issues that affect water quality in proximity to aquaculture farms and broad-scale issues that can affect characteristics (*e.g.* plankton communities) and conditions of the wider ecosystem.

4.1.1. Local-scale issues

Local-scale water quality issues are most important to consider in the case of finfish farms, which involve addition of feed and in some cases additives (*e.g.* trace metals, therapeutants, antibiotics). Fish farms often have staff living on site, which results in 'greywater' discharge, and toilet or harvest effluents. Local-scale issues and potential effects include the following.

- Increased oxygen consumption: High densities of fish in the water column and the addition of feed leads to increased consumption of dissolved oxygen (DO) through direct respiration by the fish and increased oxygen demand as a result of organic enrichment of the seabed and associated decomposition. This can affect health of the farmed fish; consequently, DO levels are typically monitored and managed by industry to ensure productive farms.
- Ammonium toxicity: High densities of fish and the addition of feed results in high amount of fish excretion, which in turn has the potential to elevate ammonium concentrations close to the farm. Elevated ammonium concentrations can be toxic to organisms; however, this is not typically an issue with appropriate site selection and stocking densities.
- Additives: The ecological effects of additives are expected to be manageable to acceptable levels, but require situation-specific assessment based on the projected nature and extent of additive use (see Section 9).
- Greywater: This includes wastewater from baths/showers, hand basins, washing machines, *etc*. Water quality effects potentially arise from increased temperature, reduced oxygen, nutrient enrichment, microbial contaminants, and aesthetic effects from foams and floatables. In the case of NZ King Salmon, greywater is discharged on site, as it is not considered to be significant from an environmental perspective (Barter 2011).
- Toilet and harvest effluents: Water quality effects could arise from discharge of toilet waste and harvest effluents (*e.g.* blood). In the case of NZ King Salmon, all such wastes are retained for appropriate off-site disposal.

[6] Effects on the water column and water quality were covered in the 'pelagic effects' and the 'cumulative effects' chapters in the MPI (2013) review.

4.1.2. Broad-scale issues

In contrast to the local-scale issues described above, broad-scale issues associated with nutrient enrichment (mainly with addition of feed) and depletion of plankton communities (in the case of shellfish culture) are more difficult to monitor and manage in relation to consents. This is because conditions in the water column in any one location constantly change as water masses move and mix in response to tides, wind and waves. Near the coast, river inputs also mix with seawater, thereby influencing water column conditions following rainfall. The area of water column influenced by aquaculture is also potentially much larger (albeit more diffuse) than the area affected on the seabed. As a result, any potential changes to water column properties from an aquaculture farm combine with those associated with other activities, thereby creating the potential for cumulative effects in the wider ecosystem.

In feed-added aquaculture, farmed fish excrete dissolved inorganic nutrients such as ammonium (NH_4-N). Smaller particles of feed in the water column can be consumed by other organisms such as zooplankton and shellfish, which in turn contributes to the dissolved nutrient pool. Shellfish aquaculture also influences nutrient dynamics in the water column. Filter-feeding mussels and oysters convert suspended particulate matter (including plankton) into faeces and pseudofaeces that are deposited on the seafloor. Feeding by shellfish also releases dissolved forms of nitrogen into the water column. The dissolved inorganic nutrients from aquaculture combined with other sources of nutrient inputs can enhance growth of phytoplankton, macroalgae and some bacteria in the wider environment.

Nutrient emissions (primarily nitrogen) from aquaculture represent only one source of nutrients in the marine environment, and like other sources, their inputs vary over time. However, it is widely recognised that nutrient enrichment from aquaculture, in particular that associated with addition of feed, has the greatest potential to contribute to the cumulative effects associated with coastal eutrophication (SEPA 2000; Hargrave 2005; Diaz *et al*. 2012). The risk of exceeding the assimilative capacity and accelerating eutrophication will be dictated by many factors, which are further discussed in the MPI aquaculture guidance chapters on pelagic and cumulative effects and in Report 3.

When cultured in high densities, shellfish have the potential to deplete natural plankton stocks and alter plankton community composition in the wider ecosystem. Depletion effects from mussel farming have been thoroughly monitored for both phytoplankton and zooplankton effects at the local and wide scale in the Wilson Bay management area. Over a decade of monitoring involving intensive 2-weekly plankton surveys in this region has not detected significant effects of mussel farms on plankton communities (Stenton-Dozey *et al*. 2005; Zeldis 2008; Stenton-Dozey & Zeldis 2012). Water column surveys conducted in Nelson bays, as well as around mussel farms as part of past Fisheries Resource Impact Assessments (FRIAs) have provided mixed results, with phytoplankton depletion shadows around farms only occasionally detectable (see Keeley *et al*. 2009). The extent of water-column effects associated with shellfish aquaculture will ultimately depend on farming intensity (density of shellfish per unit volume of water), harvesting regimes, and natural variability in phytoplankton as well as the level of tidal flushing.

4.2. Best management practices and reporting

Local (and to some extent broad-scale) water quality issues can be managed through BMPs with regard to siting farms in appropriate locations (*e.g.* highly flushed waters) and managing stocking densities (Table 4). In the case of finfish farming, the amount of feed addition and wastage is also important in reducing both seabed enrichment and water-column effects.

Table 4. Possible management goals, best management practices (BMPs), and reporting to minimise water-column effects. For new finfish species, many of the BMPs for salmon farming are relevant, for which greater detail on requirements can be found in NZSFA (2007). Specific requirements will need to be worked out case-by-case. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Management goal		BMP	Reporting	Sector
1.	Minimise local-scale effects on water quality	1a. Retain sewage and harvest effluents for appropriate off-site disposal.	No reporting envisaged	F
		1b. Appropriate controls on additives as per Table 11.	See Table 11	F
		1c. Appropriate controls on feed and feed wastage as per Table 6.	See Table 6	F
		1d. Appropriate limits on stocking densities	See Table 6	All
2.	Minimise broad-scale effects on the water column and wider ecosystem	2a. Appropriate controls on feed addition and wastage as per Table 6.	See Table 6	F
		2b. Appropriate limits on stocking densities.	See Table 6	All

The level of nitrogen loading from a finfish farm will be heavily dependent on the nitrogen content of the feed along with the feed conversion ratio. The feed conversion ratio is the amount of feed that is added to a farm and the amount of fish harvested; hence working toward lower FCRs equates to lower wastage and reduction in environmental effects.

4.3. Consent and state of the environment monitoring

Water column monitoring associated with aquaculture consents is typically conducted at the local scale (*i.e.* < 1 km from a farm boundary). In New Zealand, consent requirements placed on the water column (if they exist) are usually based on the range of observed baseline conditions measured in the region and / or ANZECC guidelines, which in many cases may not be appropriate for New Zealand situations. In the case of the Wilson Bay water column monitoring, comparison to 'trigger point' standards was specifically developed in response to the large application for water space (Turner & Felsing 2005). These standards were developed within a 'limits of acceptable change' framework described by Zeldis *et al.* (2006) that ensures scientifically-based standards are implemented in consultation with stakeholders.

Monitoring of water-column effects associated with aquaculture involves the measurement of physico-chemical and biological parameters that provide an indication of water quality. These include parameters that reflect changes in nutrient levels and resultant shifts in primary production, or in some cases changes in the composition of plankton communities (Table 5). In terms of localised water quality effects of additives, it is probable that the episodic nature of additive use would make routine water quality monitoring difficult. It may be sufficient to develop guidance for use, for example based on predicted total volumes or mass loads that can be discharged (*e.g.* hourly, daily) while ensuring that water column concentrations are at acceptable levels after 'reasonable mixing'.

In most cases, requirements around water column monitoring will be case specific, and will also vary depending on whether the consent involves feed-added aquaculture, or non-feed added aquaculture such as mussel farms. For example, the global Aquaculture Stewardship Council (ASC) standard for salmon farming recommends weekly water column monitoring of macronutrients (nitrogen [N] and phosphorus [P]) as well as dissolved oxygen (DO). In the case of shellfish aquaculture, the parameters measured focus on the effects of filter feeding on plankton communities, including the depletion of phytoplankton and the effects on specific plankton such as fish eggs (Zeldis *et al*. 2005; Stenton-Dozey & Zeldis 2012).

In the Marlborough Sounds, water column monitoring at each salmon farm varies according to farm location and the level of farming (*e.g.* fallowed sites require less water column monitoring than active sites). In 2013, proposed water column monitoring to meet consent conditions for fully operational farms used a sampling design aimed at maximising the likelihood of detecting water-column effects from the farms. Water samples for determining nutrient concentrations (total phosphorus [TP], dissolved reactive phosphorus [DRP], ammonium [NH_4-N], nitrate and nitrite [NO_3-N, NO_2-N], total nitrogen [TN]) were collected during annual surveys. Samples were collected at mid-water depths at a number of locations along the downstream gradient from the pen edges and set distances from the farms (*e.g.* 50 m and 150 m for low-flow sites, and 90 m and 300 m for high-flow sites). During sampling, depth profiles of salinity, temperature, chlorophyll-*a*, turbidity and DO were also measured using a sensor array (CTD; conductivity, temperature and depth). Sensors were also deployed on the salmon farms for providing continuous measurement of DO levels to ensure good growing conditions are maintained within the pens.

Consent-related monitoring frequently demonstrates that water-column effects (*e.g.* elevated nutrient concentrations) are detectable only a small distance (10s to 100s of metres) downstream of farms. This is due to the large amount of dilution and exchange with surrounding waters and nutrient cycling processes that rapidly assimilate farm-derived nutrients into the wider ecosystem. Determining the fate and consequences of nutrients released into the water column from feed-added aquaculture therefore presents a challenge in terms of monitoring and managing aquaculture consents and provides the rationale for moving toward the integration of consent and broader-scale SOE monitoring.

Table 5. Potential indicators for water-column effects and rationale for their inclusion. These indicator categories apply to all aquaculture sectors and could be included in consent monitoring. In addition, they may be combined into composite indicators that provide a description of trophic status.

Indicator category	**Monitoring indicator**	**Rationale**	**Sector**
Physico-chemical	Dissolved inorganic nutrients	Feed-added aquaculture results in waste production and new inputs of nutrients (primarily nitrogen) into the water column. Grazing by shellfish can also affect the form and concentration of nutrients in the water column, making them available for uptake by primary producers.	All
	Dissolved oxygen	Presence of large numbers of biological organisms (*e.g.* fish, shellfish or macroalgae) within a small volume of water results in high rates of respiration (oxygen consumption). In the case of feed-added aquaculture, continuous measurement of dissolved oxygen for both farm management and environmental monitoring purposes is common practice.	All
Biological	Phytoplankton production (chlorophyll-*a*)	Nutrients are rapidly assimilated into the marine food web. Primary producers such as phytoplankton are the most immediate sink for dissolved nutrients and therefore are monitored to assess carry-on effects of changes in nutrient concentrations (as in the case of increased nutrients associated with feed-added aquaculture). Filter-feeding aquaculture has the potential to significantly deplete phytoplankton biomass and associated chlorophyll-*a* concentrations.	All
	Plankton community composition	Nutrient loading from feed-added aquaculture has the potential to increase production of species known to form harmful algal blooms (if present). Filter feeding organisms such as mussels also have the potential to affect plankton composition by feeding on a range of organisms, including fish eggs, zooplankton and larvae.	All

Assessing the role of aquaculture in driving broad-scale effects on the water column and the wider ecosystem requires the alignment of local-scale monitoring with broad-scale monitoring aimed at assessing environmental change over time (*e.g.* SOE monitoring programmes). For example, in the absence of regional-scale monitoring of water column conditions it is not possible to draw connections between finfish farms and the frequency and magnitude of harmful algal blooms.

In the case of nutrient loading, the cumulative effects of eutrophication can occur gradually over long time periods (Armitage *et al*. 2011) and cascading effects to the environment (*i.e.* shifts in habitats and community composition) can last for decades (Herbert & Fourqurean 2008). Therefore, establishment of long time-series of environmental indicators is critical to establishing appropriate baselines and for understanding the variability of the wider system in response to drivers operating over long time scales (*e.g.* seasonal shifts in nutrient inputs versus climatic and oceanic processes).

Beyond chemical measures of water quality, potential water column indicators can include phytoplankton biomass and community metrics, and frequency of algal blooms (King & Pushchak 2008; Volkmann *et al*. 2009). Composite indicators such as trophic state indicators (*e.g.* TRIX, Giovanardi & Vollenweider 2004) can combine results from several parameters into a single metric for comparison with other systems. Some indicators such as ASSETS, based on combined physico-chemical and biological parameters, are able to draw connections between catchments and coastal receiving waters (see Borja *et al*. 2011; Ferreira *et al*. 2011). In the development of finfish aquaculture in Tasmania a range of stakeholders, including industry, were involved in the selection process. They ranked potential indicators according to criteria such as sensitivity, applicability, correlation to actual environmental effects, cost effectiveness, social relevance, ease of measurement *etc*. (see Chapter 8 in Volkmann *et al*. 2009). A more detailed review of indicators and recommendations for their application in the Waikato CMA is provided in Report 3.

Possible components of long-term monitoring include permanent observation platforms (*i.e.* data buoys) with high frequency sampling capabilities, such as the coastal water quality monitoring buoy WaiQTahi, recently deployed in the Firth of Thames. Platforms with sensor arrays enable the collection of robust, time-series data for multiple purposes, including regional and national SOE monitoring and the validation of models and remotely-sensed imagery (see Jones *et al*. 2012 and Report 1).

5. SEABED EFFECTS

5.1. Overview of ecological issues

The key seabed effect common to finfish and shellfish culture is enrichment resulting from the deposition of particulate organic matter in the form of excretory products (*e.g.* faeces) and waste feed (in the case of finfish culture). This leads to some well-understood ecological responses, conceptualised for finfish culture in Figure 6. For example, extreme organic enrichment on the seabed as a result of finfish aquaculture (*i.e.* from waste feed and fish faeces) can lead to almost complete loss of sediment infauna (*i.e.* animals living within the sediment), whereas moderate-to-high enrichment can lead to population explosions of the more enrichment-tolerant species. Additional seabed effects may arise as a result of deposition of farm-derived biofouling, and trace metal toxicity may be an issue in certain circumstances (discussed below).

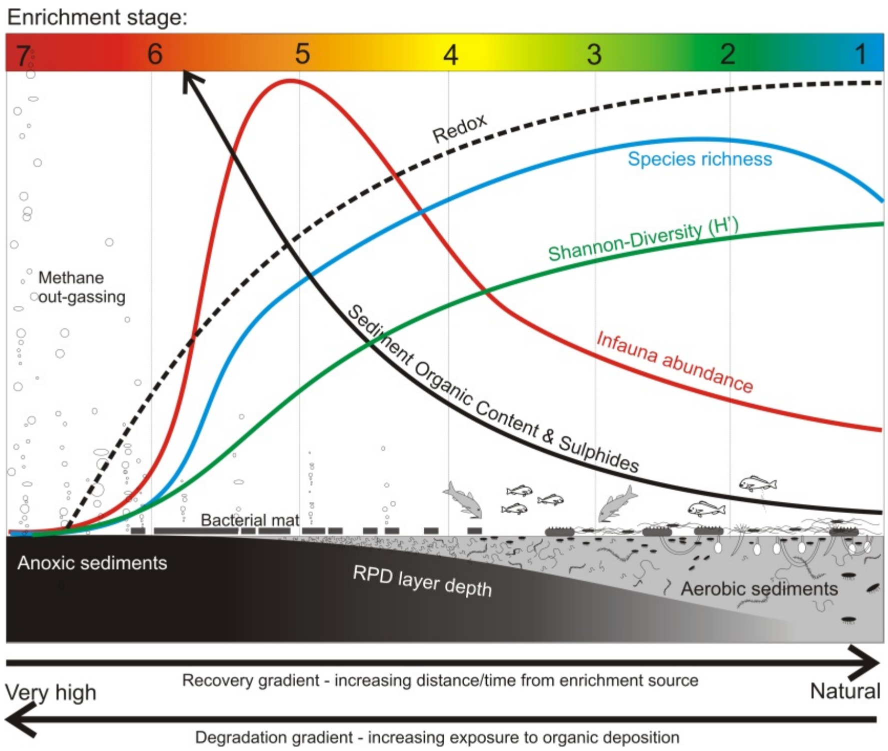

Figure 6. Schematic showing changes in key ecological and physico-chemical responses as a result of seabed organic enrichment from finfish aquaculture. These have been classified into seven 'enrichment stages' by Keeley *et al*. (2012). Stage 1 represents pristine natural conditions and Stage 7 represents the most extreme level of enrichment (which can occur on the seabed directly beneath finfish cages).

Seabed effects beneath finfish cages are considerably more pronounced than for shellfish culture, and while effects decrease with distance, they can still be detected several hundred metres away. Without stock or feed limits on finfish culture, the seabed can become highly anaerobic and azoic (*i.e.* devoid of infauna) due to severe organic enrichment. By contrast, shellfish culture effects tend to be much less severe and more spatially confined. However, in bivalve aquaculture there are additional seabed effects that are ecologically relevant, such as the deposition of shell material.

In the Waikato region there have been a number of research and monitoring studies of the seabed effects of mussel farms (Coffey 2001; Clearwater 2010; Giles 2010; Taylor *et al.* 2012). In the case of the Wilson Bay Marine Farming Zone, the post-development assessments have relied on sediment profile imagery to evaluate the biochemical status of the sediments, in conjunction with sediment organic matter and macrofaunal composition data (Clearwater 2010). Minor increases have been observed in organic matter within farms (*c*. 10% higher than reference sites). The sediment profile imagery method has been used to more comprehensively ascertain the spatial extent of changes to seabed sediments, which has been assessed to extend 25 to 100 m away from the Wilson Bay Marine Farming Zone Area A (Giles *et al.* 2012).

The nature and severity of mussel farm effects in Wilson Bay (*i.e.* very mild enrichment) are consistent with that described from elsewhere in New Zealand (Keeley *et al.* 2009). Although there has been no seabed monitoring at oyster farms in the Waikato region, the minor scale and magnitude of effects described elsewhere in New Zealand (Forrest & Creese 2006) and overseas (reviewed by Forrest *et al.* 2009) is probably indicative of the situation there.

Although fish farming does not yet occur the Waikato CMA, its potential seabed effects have been considered (Oldman 2008), and existing New Zealand studies (*e.g.* of salmon farm effects in the Marlborough Sounds) probably encompass the range of seabed effects that might be expected as this industry develops. The main difference is that the two candidate species (*i.e.* kingfish and hāpuku) have not yet been intensively farmed in New Zealand, and chemical compounds may need to be used for disease prevention and control that are not currently in use in New Zealand (Forrest *et al.* 2011). Depending on what (if any) compounds are used, cumulative effects on the seabed (*i.e.* in addition to primary organic enrichment effects) may need to be considered. Another potentially important species-related difference concerns feeding efficiency (and accordingly, the percent of waste feed and faecal production), which can strongly influence depositional fluxes and therefore the degree of seabed effect (Chamberlain & Stucchi 2007).

Overall, the seabed effects of finfish culture will almost certainly be more pronounced than in the case of shellfish culture, and be greater in terms of their spatial extent from a given farm and their temporal duration should farming cease (*e.g.* recovery of seabed biota takes around 5 years if farming ceases and cages are removed; Keeley *et al.* 2014b). This situation justifies a more stringent approach to seabed monitoring and reporting for finfish culture than shellfish culture; for example, in terms of both monitoring frequency and the range of indicators measured. Similarly, within shellfish culture there is justification for less intensive monitoring (if any) of the seabed effects of spat-catching *vs* grow-out, as spat-catching effects are likely to be minimal (Keeley *et al.* 2009; MPI 2013).This issue is addressed in greater detail in Report 3.

5.2. Best management practices and reporting

A range of on-farm best management practices could be adopted as part of an environmental management plan in order to minimise seabed effects (Table 6). In the table we have outlined where record keeping and reporting would be helpful (or otherwise) in relation to each BMP. Most conceivable practices to minimise seabed effects are already reflected in the current environmental codes of practice for the salmon and oyster sectors, and for mussel farming to a lesser extent. For finfish culture, the most important practices are already identified in Waikato's RCP, and are largely echoed in consent requirements imposed on salmon farms in the Marlborough Sounds. The RCP specifies record keeping and reporting of:

- quantities of feed discharged into the coastal marine area and its chemical content
- stocking densities, including times of stock additions and harvesting.

Ideally, site-specific consent limits would be set on these quantities / densities, with BMPs put in place to minimise food wastage (*e.g.* as per Table 6) such as implemented by NZ King Salmon under their environmental code of practice (NZSFA 2007) and according to international best practice (Sim-Smith & Forsythe 2013). With inexperienced operators, or inadequate technology, waste feed deposition to the seabed can be considerable and lead to extreme organic enrichment effects. Zinc may also accumulate in situations where it is used as a dietary supplement in feed. By placing limits on feed inputs and farm stocking, and minimising feed waste, seabed effects from finfish culture can be managed at a severity and spatial extent that is considered 'acceptable'.

Sim-Smith and Forsythe (2013) recommend additional BMPs in relation to finfish farm design and configuration, and suggest a minimum space of 5 m between nets and the seabed, to promote adequate flushing of farm wastes. With respect to salmon farms, they also suggest reducing or avoid feeding during periods of 'high current' or when dissolved oxygen and water temperature reach certain thresholds.

One of the issues recognised for all types of aquaculture is the discard of biofouling to the seabed; for example, resulting from deliberate defouling of farm structures (MPI 2013). For mussel culture, an additional issue is inadvertent crop loss (by sloughing) that results when heavily fouled lines are lifted from the water. In all cases, considerable fouling and related debris (*e.g.* calcareous shells & worm tubes) may accumulate on the seabed. Even though accumulated biofouling may contribute to seabed enrichment and habitat change, it would seldom be feasible to retain this material. An alternative would be to conduct frequent cleaning in order to prevent a high biomass of biofouling from developing. Again, this level of intervention would seldom be feasible with existing tools, but may be necessary for operational reasons (*e.g.* NZ King Salmon use remote devices to clean their grow-out nets every few weeks, in order to protect fish health).

Table 6. Possible management goals, best management practices (BMPs), and reporting to minimise seabed effects. For new finfish species, many of the BMPs for salmon farming are relevant, for which greater detail on requirements can be found in NZSFA (2007). Specific requirements will need to be worked out case-by-case. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Management goal		**BMP**	**Reporting**	**Sector**
1	Minimise seabed effects	1a. Maintain fish stocking densities at a level that meets standards for seabed effects stipulated by WRC, and is consistent with MPI guidance if appropriate.	Maintain records of farm stocking densities and times of stock additions and harvesting, and report to WRC annually or as requested.	F
		1b. Implement practices to minimise feed wastage, which may include: i. Developing feed management plans and on-going assessment of feed management. ii. Ensuring that feeds are formulated for the species, life-stage, environment and feeding system used. iii. Monitoring of feed consumption. iv. Securing feed storage and delivery systems to prevent catastrophic loss. v. Monitoring waste feed on seabed.	Maintain records of quantities and chemical composition of feed used and amount of waste feed on seabed, and report to WRC annually or as requested.	F
		1c. Maintain a minimum space of 5 m between nets and the seabed to promote adequate flushing of wastes.	No reporting envisaged.	F
		1d. Appropriate storage and land-based disposal of garbage and synthetic solid waste.	No reporting envisaged.	All
		1e. Minimise potential seabed effects of farm-derived trace metals.	Zinc inputs managed by minimising food wastage (as per 1b).	F
		1f. Implement practices to minimise seabed biofouling discards, where feasible.	No reporting envisaged.	All
2.	Minimise effects from trace metals	2a. Minimise potential seabed effects of food-derived zinc.	Zinc inputs managed by minimising food wastage (as per 1b).	F
		2b. Minimise use of copper as antifoulant, and cleaning of copper-coated structures (BMP requires development).	No reporting envisaged.	F
		2c. Minimise use of treated timber in intertidal oyster culture (BMP requires development).	No reporting envisaged.	O

In the case of finfish culture, copper coatings may be used as an antifoulant, leading to localised but high concentrations of copper in seabed sediments when in-water defouling is undertaken. Development of a BMP on the use of copper-based antifoulants is not provided in Table 6, as it requires further discussion. Globally BMPs guidance ranges from a prohibition of in-water cleaning of nets coated (or impregnated) with copper, to controls based on sediment quality standards (Sim-Smith & Forsythe 2013). MPI draft guidance bases mitigation options on sediment concentrations in terms of ANZECC interim sediment quality guideline values; hence, some monitoring may be advisable (see below).

Sim-Smith and Forsythe (2013) suggest that biofouling on nets should not be removed *in situ* (i) where nets have copper-based antifouling coatings (to avoid copper deposition to the seabed), or (ii) nets are in ‘low-flow’ environments (to avoid biofouling leading to excessive seabed enrichment or dissolved oxygen depletion). The requirement for land-based defouling and waste collection (alternatively *in situ* defouling with waste capture) would be an onerous undertaking, which is not practiced elsewhere in aquaculture in New Zealand. NZ King Salmon try to minimise the use of copper-based antifoulants, and as an alternative undertake regular in-water cleaning as noted above.

Seabed effects from trace metal contaminants also need to be considered in intertidal oyster culture, as oyster racks are generally constructed from timber treated with copper, chromium and arsenic (CCA). These trace metals have the potential to accumulate in sediments and associated biota, contributing to seabed effects. However, only low levels of CCA have been shown to leach into the environment, hence the associated ecological risk appears minor (Forrest *et al.* 2009). Nonetheless, CCA levels have not to our knowledge been assessed in the vicinity of oyster farms in the Waikato region or elsewhere in New Zealand. MPI draft guidance suggests mitigation options that depend on sediment concentrations of metals. Hence, an option for WRC would be to undertake a baseline survey of CCA concentrations in sediments around oyster farms, in order to determine whether regional guidance or ongoing monitoring, is necessary. In Australia, the Queensland Department of Primary Industries (DPI 2008) provides guidelines for the use of CCA-treated timber for oyster racks, and also on the use of creosote-treated materials.

5.3. Consent and state of the environment monitoring

As the seabed effects of marine farms have been well studied, environmental indicators are well developed. Potential indicators for ongoing monitoring, and the rationale for their use, are shown in Table 7. These include physico-chemical condition indicators, biological response measures, and ancillary variables that can be used to help interpret monitoring results, namely farm attributes (*e.g.* stocking and feed inputs) and environmental variables. The potential indicators for finfish farms reflect those used to monitor the local-scale seabed effects of salmon farms in Marlborough. Compared with finfish farms, a more limited suite of monitoring indicators is appropriate for mussel and oyster farms, on the basis that their seabed effects are relatively well known and tend to be moderate (at worst), and there are fewer contaminants of concern.

The use of these different seabed indicators varies regionally in New Zealand as well as internationally. Furthermore, for most indicators there are few existing (or widely accepted) quality standards. However, as a result of research conducted by Cawthron in the Marlborough Sounds, considerable progress has been made on identifying a minimum suite of indicators, and a method has been developed to integrate a number of indicators into a single index, for which quantitative environmental quality standards have been developed. This greatly improves on the current situation, in which interpretation of seabed effects requires expert judgement, and is often based on assessment against qualitative descriptors of environmental condition. Report 3 describes this work, and considers its application to monitoring the seabed effects of all types of aquaculture in the Waikato CMA.

As the seabed-effects footprint from a marine farm is generally obvious, effects can usually be determined by comparison of the seabed status beneath farms (and the gradient of decreasing effects from them) with multiple reference sites (*i.e.* sites where the seabed is not directly affected by aquaculture). Direct monitoring of farm effects (*i.e.* in the immediate farm footprint and adjacent reference sites) could be required of the industry as part of consent conditions. To make monitoring more efficient, it may be possible to reduce emphasis on monitoring every farm, and instead monitor representative sites (Report 1; Hopkins 2008).

Ideally monitoring would also include regional reference sites—such sites would provide a comprehensive understanding of background variation, and also account for the possibility of far-field cumulative seabed effects beyond directly measurable marine farm footprints. Sampling at regional reference sites would ideally be conducted as part of SOE monitoring; not only would such sites gauge broader changes in seabed habitats due to cumulative natural and anthropogenic drivers, but may also provide reference conditions for other point source seabed effects. These matters are further explored in Report 3.

Table 7. Potential indicators for key seabed stressors (including seabed effects from known additives) and rationale for their inclusion. Sector refers to aquaculture sector for which this indicator is most relevant and could be included in consent monitoring. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Indicator category	**Monitoring indicator**	**Rationale**	**Sector**
Physico-chemical	Organic matter content	Provides a simple and inexpensive quantifiable indicator of the level of sediment enrichment.	All
	Depth of redox potential discontinuity (RPD) layer (*i.e.* black layer)	The RPD layer represents the transition between unenriched and excessively enriched conditions, and can be visually estimated as the boundary between grey/brown unenriched sediments and anoxic black sediments. As the level of enrichment increases, and the sediment becomes increasingly anoxic, the RPD depth becomes shallower.	All
	Redox potential	A quantitative means of gauging the depth of the RPD or black layer, as well as redox status in the remaining sediment profile (or at a particular depth).	F
	Sulfide	A quantitative means of gauging the level of sediment enrichment, reflecting the final step in the process of sediment reduction (*i.e.* use of oxygen in the latter stages of microbial decay of organic matter converts sulfate to sulfide).	F
	Copper	A trace metal with eco-toxic properties that is the most common active ingredient of antifouling paint coatings. Used in fish farming to reduce the rate of fouling accumulation on metal sea-cages. Can accumulate in sediments beneath cages.	F (where necessary)
	Zinc	A trace metal with eco-toxic properties that is included in some fish feed formulations (*e.g.* for salmon) as a nutritional supplement. Can accumulate in sediments beneath cages. The need for its use in kingfish and hāpuku culture is unknown.	F (where necessary)
	Other additives	A range of other elements or compounds may be needed to manage biosecurity risk (*e.g.* disease) in finfish culture, and for those that are in particulate form or are sediment-associated, monitoring of their seabed extent and associated effects may be necessary.	F
Biological	Macrofauna (richness, abundance and related biotic indices)	Macrofauna are animals that live within the sediment matrix, and have been used for decades as ecological indicators on the basis that they provide a time-integrated impression of sediment condition. Macrofaunal richness (the number of different species) and derived diversity measures (*e.g.* Shannon-Weiner) typically decline as enrichment becomes severe, while total abundance increases initially before declining abruptly when effects are extreme (*e.g.* the 'worst-case' beneath finfish cages). Macrofaunal composition changes in recognised ways in response to enrichment, and several biotic indices have been derived with the aim of summarising the state of the macrofauna with a single value, *e.g.* AZITES Marine Biotic Index (AMBI), Infaunal Trophic Index (ITI), and Benthic Quality Index (BQI).	All
	Epibiota	Epibiota is a term that includes epifauna such as mobile (*e.g.* seastars, crabs) and attached (*e.g.* sponges, hydroid trees) animals living on the surface of the seabed, and in shallow locations (*i.e.* with sufficient light penetration) may also include marine vegetation like seaweeds and seagrasses. Whereas vegetation appears susceptible to marine farm effects, the response of epifauna is less well studied and can be highly variable. Their efficacy as quantitative indicators requires further research.	Needs further evaluation

Table 7, continued

Indicator category	Monitoring indicator	Rationale	Sector
Biological (*cont.*)	Bacterial mats	Mat-forming filamentous bacteria *Beggiatoa* spp. metabolise sulfide but require oxygen to live. Their presence, therefore, provides an indication that sediments are highly anaerobic and sulfide-rich at the sediment surface, but that the overlying water column is still oxygenated. Although the mat may be more extensive with increased enrichment, it may also decline if bottom-water anoxia occurs, or the mat is disturbed by strong 'outgassing' (bubbling in the water column when enrichment is severe).	F
Visual/subjective	Sediment 'rotten egg' odour	Unenriched sediments are typically relatively odourless, whereas excessively enriched and anoxic sediments have a strong 'rotten egg' smell due to elevated hydrogen sulfide concentrations, therefore can be used to gauge seabed enrichment.	F
	Sediment outgassing	Outgassing is visible as bubbles rising to the sea surface, and is a symptom of excessive enrichment. The gas bubbles are primarily methane, since this compound is relatively insoluble. Other products of excessive enrichment such as ammonia, sulfide, and carbon dioxide tend to dissolve readily in seawater.	F
	Waste feed (cover, pellet density)	Feed loss can be a major factor in causing excessive seabed enrichment beneath finfish farms.	F
	Shell cover	Shell accumulation can be a cause of local habitat change beneath oyster and mussel farms.	O,M
Ancillary environmental	Water temperature	Marine biota can be affected by fluctuations in temperature due to episodic events (*e.g.* rainfall), tidal state, seasonal patterns and inter-annual or longer term change. It is inexpensive and easy to obtain semi-continuous data (*e.g.* from loggers) and can sometimes be helpful in explaining patterns in monitoring results.	All
	Water salinity	Marine biota can be affected by fluctuations in salinity as a result of similar processes to that described for temperature. It is reasonably inexpensive and easy to obtain semi-continuous data (*e.g.* from loggers), although less straightforward than temperature as sensors need more regular maintenance. Salinity can sometimes be helpful in explaining patterns in monitoring results, especially in estuarine or river-dominated locations.	All
	Sediment grain size	Sediment grain size, especially silt-clay content, has a strong influence on the composition of the macrofaunal community and (to some extent) epibiota. As well as being an important ancillary variable, the silt-clay context of seabed sediments can be increased beneath mussel and oyster farms.	All
Farm management (from reporting)	Stocking biomass	Measure of farm input that can be used to interpret the severity of seabed effects.	F
	Feed use	Measure of farm input that can be used to interpret the severity of seabed effects.	F

6. MARINE MAMMAL AND SEABIRD INTERACTIONS

6.1. Overview of ecological issues

Marine mammals and seabirds, collectively referred to as 'wildlife' are considered together as many of the issues and mitigation measures are similar. Interactions between marine wildlife and aquaculture result from an overlap between the spatial location of the facilities and the habitats and / or migration routes of the species (MPI 2013). The physical location of the farm within important marine wildlife habitats (particularly endangered or threatened species) can lead to potentially adverse interactions (*e.g.* entanglements) or avoidance issues. As such, site-specific knowledge is required in order to undertake a robust assessment of risks. Site selection at the time of consent applications should involve consultation with the Department of Conservation (DOC) or other marine wildlife experts, specifically noting proximity of proposed sites to endangered or threatened populations, and pinniped haul-out or breeding sites.

In the case of marine mammals, there is some current overlap between aquaculture in the Waikato region and marine mammal habitats, but very little of this occurs in what may be described as critical habitat, with the possible exception of Maui's dolphins along the west coast (*i.e.* encompassing Aotea and Kawhia harbours). Within New Zealand aquaculture, marine mammal entanglement to date has been a relatively minor issue (MPI 2013), despite over 25 years of sea-cage salmon farming and several decades of oyster and mussel farming. The intertidal location of New Zealand oyster farms is thought to have little to no effect on marine mammals, as most species will only enter shallow or estuarine habitats through permanent and semi-deep channels.

With respect to seabirds, the location of finfish and shellfish farms in relation to breeding and feeding sites, and the operational procedures of regular farm activities, may lead to disturbance and / or entanglements, the consequences of which will depend upon the conservation status of the species affected (MPI 2013). Some effects (*e.g.* bird attraction to lighting) are poorly understood. In the Waikato, the most significant habitat regionally occurs in the southern Firth of Thames wetland and tidal areas, and is geographically removed from the main mussel and proposed finfish aquaculture areas. Effects on seabirds from intertidal oyster culture in estuaries of the Coromandel Peninsula conceivably arise from displacement of foraging habitat and as a result of disturbance (*e.g.* noise) related to farm activities; however, both positive and negative interactions have been described (Forrest *et al.* 2009). Addressing such issues relies on careful site selection and effects assessment during consenting.

For both marine mammals and seabirds, WRC should remain aware of final MPI guidance. In the latest draft project outputs, MPI provides guidance on site suitability, and the need for related management actions that depend on factors such as the status of the species (*e.g.* whether it is endangered) and the proximity of aquaculture to marine mammal or seabird habitat.

6.2. Best management practices and reporting

Waikato's RCP currently requires reporting of interactions with or entanglements of marine mammals, and seabird mortalities; this is the only reliable indicator of the consequences of marine wildlife interactions with aquaculture. If a fatal entanglement does occur, it is important that DOC is contacted and the carcass recovered while details around the incident are recorded (such procedures should be outlined in a wildlife management plan). Together, industry and DOC can use this information to reduce the risk of similar incidences in the future. A precedent for this cooperative process has been set by NZ King Salmon and DOC in the Marlborough Sounds. These organisations have worked together to improve net design and operational practices around changing predator nets, to minimise the risk of entanglement and reduce the need for acoustic deterrent devices (MPI 2013).

For both mammals and seabirds, there are a range of additional BMPs regarding the set-up and operation of marine farms that can reduce risks of entanglement and other adverse effects. These practices, and the management goals they support, are described in Table 8, and the aquaculture sector to which they are most relevant has been identified. For finfish farms, many of these practices are already reflected in the Finfish Aquaculture ECOP developed by the New Zealand Salmon Farmers Association (NZSFA 2007), although Table 8 includes some specific additional guidance (*e.g.* on net mesh sizes). To ensure that the most appropriate measures are in place, it is suggested that a wildlife management plan (agreed with DOC) containing procedures such as outlined in Table 8 (and NZFSA 2007 in the case of finfish farms), should be approved by WRC prior operations on newly consented farms[7]. Note that BMPs are suggested even where effects are uncertain, and for two of the issues (light and noise) it is suggested that WRC encourages or supports specific research into effects.

Baseline information on most New Zealand marine mammal and seabird species is sparse. Hence, basic reporting requirements at aquaculture sites (with appropriate staff training), especially coupled with broader-scale monitoring (see below), would greatly add to knowledge of wildlife home ranges, seasonality and aquaculture interactions.

[7] Draft guidance from MPI suggests that a management plan formulated with DOC may be necessary only where there are distinct concerns about specific species.

Table 8. Possible management goals, best management practices (BMPs) and reporting to minimise the risk of adverse effects on marine mammals and seabirds. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Management goal		BMP	Reporting	Sector
1.	Minimise the exclusion of marine wildlife from their critical habitat, or modification of such habitat	1a. Record marine wildlife interactions to build a regional picture.	Record and report the type and frequency of marine wildlife interactions, in a standardised format specified by WRC.	All
		1b. Avoid use of seal acoustic deterrent devices in favour of methods more effective and / or less harmful.	Keep records of the extent to which deterrent techniques were successful or unsuccessful.	F
2.	Minimise the attraction of marine wildlife to farms	2a. Secure feed storage and minimise wastage during feeding to reduce associated attraction of fish.	As per Section 5.2.	F
		2b. Collect and appropriately store and dispose of mortalities to reduce marine wildlife attraction.	As per biosecurity (disease) section.	F
		2c. Minimise above-water and underwater noise to reduce the exclusion (or attraction) of wildlife.	Require nothing, and encourage or support specific research into effects.	All
		2d. Minimise artificial lighting to reduce attraction of prey fish. To reduce seabird attraction to lights, use downward directed surface lighting where possible, with lights shielded from pointing in all but essential directions.	Require nothing, and encourage or support specific research into effects.	F
3.	Aim to minimise entanglement and aim for zero mortality	3a. Avoid loose rope and / or nets (*i.e.* keep all ropes nets taut).	Self-checking as part of ECOP.	All
		3b. Enclose predator exclusion nets at the bottom (base of net).	Self-checking as part of ECOP.	F
		3c. Use net mesh sizes < 6 cm.	Self-checking as part of ECOP.	F
		3d. Implement regime for net inspection, maintenance, and replacement to minimise the potential for adverse effects.	Self-checking as part of ECOP. Related to requirements to minimise fish escapes (1b, Table 10).	F
		3e. Minimise potential for loss of rubbish and debris from farms, and recover lost material.	Self-checking as part of ECOP.	All
		3f. Record all entanglement incidents regardless of outcome (*e.g.* injury or mortality).	Records available to WRC. In case of a fatal marine mammal incident, carcass(es) should be recovered and given to DOC, and steps taken by the farm in consultation with DOC to reduce the risk of future incidences.	All

Record keeping around sightings of marine wildlife in proximity to the farms would be ideal, as it would provide an important context for any future entanglement incidences as well as future decisions around site selection in nearby areas. For example, the fatal entanglement of a single animal after daily sightings of the species over the past 10 years demonstrates effective operational measures are in place. Being able to benchmark the expected levels of interaction with marine wildlife based on local knowledge from consent monitoring will provide a more realistic picture of species-specific risk for these industries within Waikato's CMA. At present, entanglement mortalities are very low, but it is unclear how this relates to the frequency of interactions.

We acknowledge that identification between species of marine mammals or seabirds can be difficult, but being able to identify the presence (or absence) of an at-risk species is important to the feasibility of this reporting requirement. Species reporting is worthy of further discussion given the internationally recognised importance of many bird populations associated with the Firth of Thames and the number of endangered or threatened marine mammal species within Waikato waters including Maui's dolphin (west coast only), bottlenose dolphins, orca, and Bryde's and southern right whales.

A consideration for WRC is whether, for certain more common wildlife species, limits should be set around a maximum allowable number of fatal entanglements. This approach is adopted as part of the Global Aquaculture Stewardship Council for salmon farming, and recommended by Sim-Smith and Forsythe (2013).

6.3. Consent and state of the environment monitoring

No specific consent-related monitoring of aquaculture effects on marine mammals and seabirds is suggested. However, the potential effects of aquaculture on such wildlife will need to be considered for specific developments, and in terms of the potential for cumulative effects. For instance, as multiple farms or several types of aquaculture begin to overlap in their locations, marine wildlife populations may be excluded from particular areas depending on the species and its sensitivity to such activities. In the case of depleted populations (*e.g.* Maui's dolphin), the issues of low population size and a fairly isolated population structure make these species more vulnerable to such effects than other species. Hence, the simple exclusion of a few individuals from important habitats, such as nursery grounds, could have much larger scale and longer-lasting repercussions on the population's recovery, making a previously minor effect much more serious and broader in its implications (MPI 2013). While records from consented coastal activities will be useful from operational and finer-scale planning perspectives, larger scale ongoing monitoring of these fairly widely-dispersed marine wildlife population would be needed to fully address these broader and longer-scale concerns. As marine mammals and seabirds are subject to effects from human activities in addition to aquaculture, a multiple-stakeholder approach will be necessary to address this need, of which SOE monitoring could form a part.

7. WILD FISH INTERACTIONS

7.1. Overview of ecological issues

Aquaculture can directly interact with wild fish populations in several ways.

- All types of aquaculture can adversely affect wild fish habitat.
- All types of aquaculture can lead to attraction and aggregation of wild fish.
- Shellfish culture has the potential to consume fish eggs and larvae.

These issues are considered below. Mitigation options are few, and the **recommended BMPs are the same as those addressed for other related issues**. Note that for finfish culture, additional wild fish interactions can arise due to fish escapes (and associated ecological or genetic effects) and disease transmission, but these are considered in separate sections.

Adverse effects on wild fish habitat can be minimised by appropriate site selection, which will be addressed by WRC in the consenting process, and be subject to an assessment by MPI of the potential for 'undue adverse effects' on commercial, recreational or customary fishing. Additional guidance will emerge from the ongoing MPI project; for example, draft guidance recommends that marine farms should not be placed over or adjacent to important fish habitat.

During operations, effects on seabed fish habitat in the case of finfish aquaculture can arise through excessive deposition of faecal and food waste. In the case of shellfish culture, routine defouling and crop harvesting may lead to alteration of fish habitat; for example, due to organic enrichment or the accumulation of shell and other biogenic material on the seabed.

The issue of attraction and aggregation of wild fish around marine farms is well recognised, and both positive and negative effects have been discussed by various recent reviews (MPI 2013). Fish may be attracted:

- by the structure itself. In the case of finfish farms, lights on the structure may need to be considered, although in a study for NZ King Salmon it was found to have a negligible effect on fish aggregation.
- to food sources provided by attached biofouling assemblages or cultured shellfish themselves; biofouling or cultured shellfish lost during maintenance and harvesting; and waste feed or dead farmed fish.

Aggregated fish may be subject to greater recreational fishing pressure, or exposed to disease transmission (see Section 7). In relation to finfish culture, the issue of shark attraction to farm cages was raised as part of the NZ King Salmon BOI process, but the concerns related to human safety rather than ecological issues.

Finally, the issue of consumption of fish eggs and larvae by cultured shellfish has been widely debated. Although it was considered in the MPI review as unlikely to be important given the scale of shellfish aquaculture in New Zealand, it is a theme that would benefit from further research.

On balance, even though the ecological significance of wild fish interactions is not well-studied or understood in New Zealand, the issues are generally perceived as of minor importance in terms of their potential to lead to adverse effects on wild fish populations (MPI 2013).

7.2. Best management practices and reporting

There are no practical measures for shellfish culture that would reduce fish attraction effects if they did arise, hence no specific BMPs and reporting are considered necessary for mussels and oysters. Although it might be theoretically possible to reduce fish attraction during routine defouling and crop harvesting (*e.g.* by requiring waste capture), such an approach would be impractical and is not justified based on the probable minor nature of the issue.

For finfish culture, the potential effects on wild fish habitat and wild fish attraction that arise from feed wastage and mortalities can be addressed by BMPs described in other sections of this report, and are summarised in Table 9. That is, BMPs to minimise feed wastage in relation to seabed effects as per Section 5 (Table 6), and minimise wildlife attraction as per Section 6 (Table 8) and Section 10 (Table 12).

Table 9. Possible management goals, best management practices (BMPs), and reporting to minimise interactions with wild fish populations. Specific requirements (*e.g.* to minimise effects on seabed habitat) may need to be worked out case-by-case. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Management goal		BMP	Reporting	Sector
1.	Minimise affects on fish habitat	1a. Based on minimising seabed effects, as per Table 6	As for BMPs for seabed in Table 6	F
2.	Minimise the attraction of wild fish to farms	2a. Based on minimising fish attraction, as per marine mammals and seabirds in 2a, b & d of Table 8, and disease management in 2e of Table 12	As per BMPs relating to 2a, b & d of Table 8, and 2e of Table 12	F

7.3. Consent and state of the environment monitoring

Because of the probable minor nature of this issue, no specific consent-related or SOE monitoring is suggested. However, this issue would benefit from further fundamental research.

8. ESCAPEES AND GENETIC EFFECTS

8.1. Overview of ecological issues

The issue of escapees encompasses the escape of cultured fish (*e.g.* through holes in nets) and the release of gametes (*i.e.* spawning) by reproductive shellfish. These are quite complex and convoluted issues, most of which are outlined in the MPI (2013) report. Potential effects include:

- genetic interactions that lead to reduced fitness and adaptability of wild conspecific populations
- ecological interactions resulting from fish escapes (*e.g.* predation or competition in natural ecosystems), or shellfish loss or reproduction (*e.g.* enhanced shellfish abundance in natural habitats)
- transfer of disease to wild populations of conspecific or related species. This issue is separately discussed in Section 10.

Ecological and genetic issues resulting from escapees vary according to a range of factors, such as:

- the number and location of escapees relative to the size and location of wild populations
- the ability of escapees to survive and reproduce in the wild. For example, it has been suggested that survival in the wild of farmed fish may be poor, as they may be unable to successfully switch from pellet-based farm diets
- the ability of the cultured species to reproduce before harvest
- whether the brood stock are sourced locally, from distant locations or from a hatchery.

With respect to finfish culture, the conclusion of the MPI (2013) report was that ‘the likelihood of escapee effects in New Zealand is low’, which, with specific reference to kingfish and hāpuku, was attributed to a broad home range and high genetic diversity. Nonetheless, the report recognised the need to assess risk case-by-case, and recognised a level of uncertainty over the issue that justifies implementation of appropriate risk minimisation practices.

In relation to shellfish aquaculture, genetic issues from escapes of Pacific oysters are of minimal relevance, as the species is non-indigenous. By contrast, the fact that Pacific oyster can dominate rocky shores in New Zealand estuaries where they are farmed is of interest, given the possibility that their occurrence and abundance may have been mediated by aquaculture. In the Waikato, this issue should be considered as part of site selection, in the event that applications to farm Pacific oysters are received for estuaries where the species is absent (if such a situation even exists).

For mussels in New Zealand there is an existing high level of connectivity between populations due to a long history of wild-sourced spat transfer; as such there is already a high degree of inter-regional mixing of population genetics. However, the effect (if any) that the mass transfer of spat around the country is having on the mean fitness of local stocks is unknown, and has previously been suggested as an area in need of further research (see Appendix 3 of Keeley *et al*. 2009). The MPI (2013) report suggests that, as the use of selectively bred hatchery-raised stock increases, the risk of altered genetic structure in wild populations may change. However, the ecological ramifications do not appear to have been considered.

8.2. Best management practices and reporting

For shellfish aquaculture, there are no on-farm management practices that are practical or necessary. For finfish aquaculture, effective management of fish escapes is the best strategy to mitigate any risk of adverse effects. Waikato's RCP already requires reporting of escapes, taking measures to recapture escaped stock, and identification of measures to prevent further escapes. Reporting requirements and related BMPs are summarised in Table 10.

Table 10. Possible management goals, best management practices (BMPs), and reporting to minimise fish escapes. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Management goal		BMP	Reporting	Sector
1.	Minimise fish escapes	1a. Net mesh size adequate to contain smallest fish in cage.	None required	F
		1b. Implement regime for net inspection, maintenance, and replacement, and procedures to minimise escape risk during different operations (*e.g.* harvesting, cage transfers).	Recording of incidences that could (or did) lead to escapes (*e.g.* holes in nets), and reporting to WRC annually or as requested.	F
		1c. Develop contingency plan that describes actions to be taken in the event of any mass escapes	Plan to be approved by WRC. Immediate reporting of mass escapes, measures taken to recapture escaped stock, and measures to prevent further mass escapes.	F

As the main factor controlling the risk of fish escapes is net integrity, measures to prevent escapes should involve a regime of regular inspection, maintenance or replacement of nets, and procedures to minimise escape risk during operations such as net changes or fish transfers. This is the approach taken by NZ King Salmon, who make ongoing improvements to net design and operational practices to minimise escapes. Under the Finfish Aquaculture ECOP (NZSFA 2007), NZ King Salmon also require a site-specific plan that describes actions to be taken in the event of any mass escapes.

8.3. Consent and state of the environment monitoring

No specific consent-related or SOE monitoring in relation to escapees and genetic effects is suggested. These issues can be addressed to the extent practical and necessary through appropriate site selection and situation-specific consideration of other approaches to mitigation, such as described above.

Ideally, baseline information on the distribution, abundance, seasonality and genetic structure of wild populations of proposed farm species would be acquired, as it would provide some indication of the likelihood of interactions with farmed populations. However, the acquisition of such information requires targeted research that falls outside the scope of routine monitoring. As such, consultation with MPI to identify specific research needs should be considered by WRC. In the case of finfish, knowledge of the frequency and magnitude of escapes will provide some indication of the need for wider research into ecological effects.

9. ADDITIVES

9.1. Overview of ecological issues

Various chemical compounds, referred to by MPI (2013) as 'additives' can be associated with aquaculture, primarily finfish culture. These include detergents and disinfectants, anaesthetics, therapeutants (antibiotics, nutritional supplements) and trace metals. These are primarily of interest for finfish aquaculture. MPI also categorised plastic debris and other synthetic solid materials used on marine farms as additives, which are relevant to all types of aquaculture. Details of the known ecological effects of these additives are provided in the literature review accompanying the MPI report, with a summary as follows.

- The use of detergents and disinfectants is not regulated in New Zealand. In shallow sheltered areas, like shallow bays and inlets, there are risks of accumulation effects, but these depend on how rapidly the compounds degrade in the environment.
- Anaesthetics are used during harvest and sorting of farmed finfish in New Zealand. Eugenol is the main active substance. It is the only licenced fish anaesthetic in New Zealand and has very little associated environmental risk.
- Therapeutants are used to treat fish diseases and parasites. A report for WRC by Forrest *et al*. (2011) discusses therapeutant issues with specific reference to finfish aquaculture development in the Waikato CMA. Some compounds (*e.g.* freshwater, formaldehyde, hydrogen peroxide baths) are water soluble and probably of minimal ecological risk when used appropriately. There is only one antibiotic currently licenced for use with fish in New Zealand (oxytetracycline). Overseas experience suggests that some therapeutants have potential to affect non-target organisms like plankton and bacteria, and there is some concern regarding their role in the rise of resistant bacteria and parasites.
- The use of trace metals can lead to local accumulation in seabed sediments at concentrations that are potentially ecotoxic. As discussed in Section 5, key issues are: (i) the use of zinc as a dietary supplement in finfish culture; (ii) the use of copper is an antifoulant; and (iii) oyster rack construction from timber treated with copper, chromium and arsenic.
- Plastic and other debris can be generated by all aquaculture sectors. Plastic debris from farms can have long-term ecological consequences depending on the types of plastics used, and can cause toxicity in marine animals through the release of plasticisers, particularly if ingested. Each sector already has its own ECOP that, among other things, seeks to minimise the use and loss of such materials.

With new finfish culture development in the Waikato region, the use of the above or new additives is difficult to forecast, and will need to assessed case-by-case. Future needs will depend on the extent to which disease issues emerge with the new culture species; hence, disease prevention and mitigation is of paramount importance (see Section 10).

9.2. Best management practices and reporting

The use of chemical therapeutants in animals in New Zealand is controlled by the Agricultural Compounds and Veterinary Medicines Act 1997, and if therapeutants pose a threat to human health and to the environment they should be assessed under the Hazardous Substances and New Organisms (HSNO) Act 1996. Food safety regulations also restrict the use of antibiotics and require consent for use.

BMPs are suggested in Table 11 for the various additives described, although some need further discussion before being developed. BMPs for synthetic solid wastes (plastics, *etc.*) apply across all industry sectors, and should reflect sector ECOPs which aim to minimise the use and loss of such materials. Other BMPs are primarily relevant only to finfish culture. Issues around trace metal accumulation were addressed in relation to the seabed (Section 5) and are not repeated below.

For finfish culture, BMPs have a role to play in terms of minimising the need for certain additives (*e.g.* antibiotics) in the first instance; for example, through management strategies aimed at preventing disease (*e.g.* vaccination, diet, stress management; see Section 10.2.2). Related BMPs are suggested that reflect Waikato's RCP requirement for reporting of the timing, types, quantity and method of discharge of medicinal and therapeutic compounds. The industry needs to recognise the importance of optimising the use of such compounds, as excessive use can lead to greater environmental risk and greater risk to the culture operation; for example, by causing increased stress and further disease (Stickney 2009). Globally, there are a wide range of approaches used to manage medicinal and therapeutic compounds in finfish aquaculture, and WRC is referred to Sim-Smith and Forsythe (2013) for key examples. These examples make it clear that the need for additional BMPs will require situation-specific evaluation.

9.3. Consent and state of the environment monitoring

Seabed trace metals, standards and monitoring were addressed in Section 6. For other additives, actual monitoring requirements will need to be considered case-by-case. The ecological effects of most conceivable additives will be relatively localised, and synthetic compounds will not be part of the natural background. As such, environmental monitoring may not require baseline data; it should be possible to measure most compounds relative to reference site conditions. As already discussed (*e.g.* with respect to seabed monitoring), SOE monitoring could contribute by providing regional reference site data. However, SOE monitoring is unlikely to be necessary for other purposes. Although some compounds have the potential for localised water quality effects, it is probable that the episodic nature of their use would make routine water quality monitoring difficult (see Section 4).

Table 11. Possible management goals, best management practices, and reporting for additives. Some of these are high-level or generic ideas (in italics), as they cannot be fully developed until site specific additive needs and usage is known. See Sim-Smith and Forsythe (2013) for BMPs used in different countries. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Management goal		**BMP**	**Reporting**	**Sector**
1	Zero loss of garbage and synthetic solid waste	1a. Retain all garbage and synthetic solid waste as per industry ECOP.	None required	All
2	Minimise use and effects of therapeutants and medicines	2a. Minimising the need for additives, for example through appropriate disease prevention strategies.	See Section 10.2.2	F
		2b. Select permitted therapeutants that are the most environmentally benign, and record the quantity and time of use.	Annual reporting to WRC	F
		2c. Develop BMP(s) around appropriate antibiotic use.	To be determined	F
		2d. Develop BMP(s) around appropriate storage, handling and discharge or disposal.	To be determined	F
3.	Minimise effects from trace metals	*3a. Develop BMPs around use of zinc and copper, and cleaning of copper-coated structures.*	See Section 5.2	F
		3b. Develop BMP(s) around use of treated timber in intertidal oyster culture.	See Section 5.2	O

10. BIOSECURITY: PESTS, DISEASES, PARASITES AND HARMFUL ALGAE

10.1. Overview of ecological issues

Biosecurity is the exclusion, eradication or effective management of risks posed by pests and diseases, including harmful algal bloom (HAB) species. Collectively, these groups can be referred to as harmful marine organisms (HMOs; Sinner *et al.* 2013). Harmful marine organisms are often considered one of the greatest potential risks from aquaculture, given that their adverse effects on ecological and other values may be widespread and irreversible (MPI 2013).

In New Zealand, the occurrence and actual or potential adverse ecological (and other) effects of marine pests and HABs are quite well recognised. The current situation in the Waikato region with respect to HMOs was detailed in Forrest *et al*. (2011), and is not repeated in this report. It is relevant to simply note that a number of recognised HMOs or potentially harmful species already exist in the Waikato region and Hauraki Gulf, and some are already associated with marine farms (*e.g.* the sea squirt *Styela clava* and the Asian kelp *Undaria pinnatifida*).

Disease has not been a significant issue in salmon or mussel aquaculture, but the northern Pacific oyster industry has been decimated in recent years by the unforeseen emergence of an ostreid herpes virus (OsHV-1). If the future development of aquaculture in the Waikato CMA involves kingfish or hāpuku, disease management is likely to be important, as these two species are vulnerable to a number of parasites and pathogens (Forrest *et al.* 2011). Although the value most at risk from a disease outbreak is the aquaculture operation itself, Forrest *et al*. (2011) provide examples where more widespread ecosystem effects have been linked to aquaculture-related diseases. Although adverse ecological effects may be a very low likelihood, it is nonetheless important that the risk is effectively managed.

International border management is the first line of defence against non-indigenous HMOs, and is addressed by MPI (*e.g.* via Import Health Standards). However, some types of border control are not always completely effective, meaning that non-indigenous HMOs continue to arrive in New Zealand. Furthermore, some indigenous species can thrive and become problematic in aquaculture environments, adding a layer of complexity to biosecurity risk management. The ways that aquaculture can contribute to the spread of proliferation of HMOs in the environment are as follows:

- transfers of infected aquaculture gear or stock and vessel movements can act as pathways for HMO spread within and among farms and growing regions
- HMOs can become prolific on marine farms, which then act as a reservoir for spread to the wider environment

- marine farms can alter the local or regional environment, creating conditions that facilitate the emergence of HMO problems.

These risks and their management will need to be assessed case by case, as they depend on the culture species, the nature of the transfer pathways associated with existing and new developments, the pre-existing level of risk to the Waikato region (*e.g.* from risk pathways unrelated to aquaculture), and the region's ever-changing profile in terms of existing high-risk species. The main approaches that can be taken to manage and monitor HMO risk from aquaculture, and the national management context, are described in Box 2. Broad approaches involve implementing:

- BMPs for risk pathways to reduce the introduction of HMOs to aquaculture sites in the first instance
- on-farm BMPs to reduce the risks of HMOs becoming established and causing adverse effects on aquaculture operations and the wider environment.

Generic BMPs and reporting ideas are outlined in Table 12. The situation-specific nature of risk and its mitigation means that this report can only provide general guidance. In any case, it is premature at this stage to propose detailed ideas for BMPs, reporting and monitoring, as this area will evolve as a number of related projects progress.

Box 2: General approaches and national context for aquaculture biosecurity risk management

The main approaches that can be taken to address HMO risk from aquaculture are based on the following:

- management of risk pathways to reduce the introduction of HMOs to aquaculture sites in the first instance, hence reduce risk to the wider environment.
- implementation of on-farm practices to reduce risk to other aquaculture sites and the wider environment, including the following, where feasible:
    - surveillance to detect of HMOs sufficiently early to enable effective management
    - implementation of measures to minimise the risk of farm-related emergence of HMOs
    - implementation of measures to control (*e.g.* eradicate, contain) HMO outbreaks, where necessary and feasible.

In New Zealand there is a growing emphasis on effective pathway management to reduce the risk of HMO spread with human activities. This situation recognises the difficulties in effectively managing HMOs after they have become well-established. It also recognises that the effects of known HMOs may vary greatly over time and among locations, and that HMOs with no designated or recognised status may emerge as problem organisms in aquaculture environments (*i.e.* the next HMO is difficult to predict). Additionally, the risk profile for the Waikato region will change over time as species distributions change within New Zealand, or as new risk species from overseas source regions arrive and establish (*e.g.* via shipping-related introductions). These scenarios favour the development of pathway-based management measures that are inclusive of all associated species, irrespective of their known status as HMOs.

The aquaculture industry has an economic incentive to prevent introductions of HMOs, and manage established HMO populations to levels that minimise adverse effects on operations. In most cases, such efforts will also reduce risk to the wider environment. However, the wider benefits are difficult to quantify, and in some situations it will not be feasible to manage HMOs to a level that completely negates wider ecological risk. Instead, risk reduction is usually a more realistic goal. A related point is that regional biosecurity risks unrelated to aquaculture (*e.g.* recreational vessel risk) need to also be managed for benefits to be fully realised; hence the regional and national management context is important.

Table 12. Possible management goals, best management practices, and reporting to minimise risk from harmful marine organisms (HMOs). These are some general approaches, but specific details will need to be worked out case by case. Additional relevant measures (*e.g.* to reduce fish interactions with wild populations, are discussed in other sections). Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors.

Management goal		BMP	Reporting	Sector
1.	Reduce pathway risks	1a. Implement practices (*e.g.* disinfection) to minimise the risk of HMO transfer with stock, gear and vessel movements into and among aquaculture zones, including shore-based facilities. Maintain fish in optimum health during transport.	Maintain records in a standardised format on: the type of stock or gear transferred and its origin/destination, the amount/volume moved, dates of movement, method of transfer, duration out of water, and any treatment measures implemented to reduce HMO risk.	All
		1b. Avoid transfer of stock with known (or suspected) diseases or parasites, or that is sourced from locations experiencing mortalities.	Maintain records that provide evidence for disease- and parasite-free status of transferred fish stocks and source areas.	F
2.	Early detection of HMOs on-farm	2a. Passive surveillance for potential HMOs and of stock health.	Record and report to WRC and MPI incidental finds of: suspicious organisms, designated HMOs not known in the region, and unexplained mortalities.	All
		2b. Systematic surveillance of fish stock behaviour and other gross signs of disease (daily). 2c. Regular (*e.g.* every 1-2 weeks) inspection for ecto-parasites such as sea lice.	Maintain records of surveillance undertaken, and report to WRC and MPI finds of designated HMOs not known in the region.	F
		2c. Regular (*e.g.* 1-2 times per week) removal of mortalities, with hygienic handling, storage and disposal.	• Maintain records of the frequency of removal, incidence of mortality, and the length and weight of dead fish. Any mass mortality to be immediately reported to WRC and MPI. • Post-mortem expert examination to determine the cause of unusual mortality, with reporting to WRC and MPI.	F (All if feasible)
3.	Minimise risk of on-farm disease emergence	3a. Maintain high water quality, with dissolved oxygen (DO) at ≥ 6 $g.m^{-3}$ and ≥ 80% saturation.	Maintain daily records of DO and water temperature.	F
		3b. Avoid management practices that stress fish stocks (*e.g.* high stocking density, over-handling).	No reporting envisaged.	F
		3c. Stock farms with single year classes at any one time to minimise pathogen or parasite transmission.	Maintain stocking records.	F

Table 12, continued.

Management goal		BMP	Reporting	Sector
		3d. Vaccinate where feasible if vaccines are approved for use.	Maintain vaccination records.	F
		3e. Implement husbandry practices to decrease risk of disease transfer to farmed fish and other wildlife.	Maintain records of practices relating to: fish escapes (Section 8), food wastage (Section 5.2), and other measures to reduce interactions with wildlife.	F
4	Effective control of outbreaks	4a. Reduce marine pest populations on farms where feasible.	No reporting envisaged.	All
		4b. Develop measures to contain and control disease outbreaks, including cleaning and disinfection.	Maintain records of treatments (*e.g.* treatment method, date, effectiveness) and numbers of stock slaughtered or disposed of.	All
		4c. If necessary for fish health management, fallow sites for ca. 4 weeks after every production cycle.	Maintain fallowing records.	F
5	Ensure efficacy of risk management	5a. Annual inspection of disease status and risk management measures by a suitably qualified expert.	Report from audit provided to WRC if required.	F

For example, in addition to MPI's aquaculture guidance project, MPI is developing regional aquaculture biosecurity plans as part of a government aquaculture strategy, and recently commissioned a project to investigate the industry's current biosecurity practices. In addition, Aquaculture New Zealand's review of industry ECOPs will address marine biosecurity more explicitly than existing documents (Colin Johnson, Aquaculture New Zealand, pers. comm.) and a biosecurity management plan being developed by NZ King Salmon will be relevant once it is publicly available.

10.2. Best management practices and reporting

10.2.1. Risk pathways

Aquaculture transfer pathways external to the Waikato region could introduce new HMOs to marine farms from external source regions. Risk mitigation options may include: (i) prohibitions of transfers on known high risk pathways, or (ii) application of pathway risk reduction measures.

Gear movements among farms or regions

Gear movements have the potential to transfer biofouling organisms, water or sediments that could be infected with HMOs (Forrest *et al.* 2011). Risk reduction measures range from using new gear, to relatively simple treatments (*e.g.* air drying, freshwater dips) or chemical disinfection for re-used gear. Except for air drying, the methods are not well-tested at operational scales.

Transfers of juveniles to farms for growout

Juvenile shellfish stock may be transported out of water among farms and regions, or from hatcheries, and there is a risk that associated HMOs will also be transferred. The oyster and mussel sectors have treatments that can reduce risk (*e.g.* for biofouling and HAB species), but possibly not negate risk. Complete negation of risk would require farms to be stocked with locally-caught spat, but that approach might not always be feasible. Finfish juveniles are likely to be transferred in tanks of sea water, and WRC will need to consider measures to minimise the risk of HMO transfer, and ensure there are fish health management procedures in place to keep fish in optimum condition (hence minimise the risk of disease occurrence).

Other pathways

As described by Forrest *et al*. (2011), there may be other pathway mitigation methods that could be implemented as part of routine operational practices. For example, consideration should be given to measures for vessel hull fouling, bilge water and associated gear, such as described by Sinner *et al*. (2009, 2013). For general disease prevention, a range of other mitigation and quarantine strategies are desirable, including treatments for personnel (*e.g.* boot washes) when moving among sites. These are details that should accompany specific consent applications, or be developed as part of an ECOP or site-specific environmental management plan.

Note that there may be justification for more stringent pathway measures in certain circumstances. If the Waikato region (or aquaculture areas within it) is free from particular HMOs that WRC wishes to exclude, stringent pathway management from infected source regions could be considered. For example, the ostreid herpes virus already occurs in the region, but has not been reported from Kawhia Harbour (Bingham *et al.* 2013), hence the oyster farm there would ideally be stocked with oysters from uninfected sources. Similarly, as part of disease risk management it would be appropriate to include a BMP to avoid transfers of stock for which unexplained mortality has occurred, or transfers of stock from regions experiencing unexplained mortality (1b of Table 12).

Reporting

In the event of an outbreak of an HMO, traceability can be an important tool for mitigation. That is, being able to determine the origin of the problem and the additional locations that may already be at risk or infected, for example, because of pathway transfers. Such knowledge would enable the industry and others (WRC and MPI) to implement measures to reduce risk to the extent practical; *e.g.* it may involve placing prohibitions or more restrictive mitigation measures on pathways among certain geographic areas. We suggest that WRC considers requiring recording and reporting on gear and stock movements (as per 1a and 1b of Table 11) intra-regionally (*i.e.* among the main aquaculture areas described in Section 2.1) and well as movements into the Waikato CMA. Most within the industry probably already keep records of movements, but ideally such information would be recorded consistently across the industry and, for the Waikato region, be collated by WRC.

10.2.2. On-farm biosecurity

It is almost certain that new HMOs will become established in the Waikato CMA, because of ineffective management of aquaculture or other risk pathways; natural spread of HMOs from adjacent established populations; or emergence of HMOs as a result of the culture environment. Appropriate surveillance and response procedures are therefore important.

Surveillance

Surveillance may be active or passive (*i.e.* based on incidental finds). Active surveillance is synonymous with monitoring in terms of our earlier definition (see footnote, p. 2) in that it involves planned systematic sampling. However, we use the term surveillance, as its purpose is early detection of HMOs to protect aquaculture, as opposed to monitoring for the presence of the HMO (or its effects) in the wider environment. MPI fund active surveillance every six months in New Zealand's main ports and harbours, targeting a few designated marine pests (Acosta *et al.* 2012). Additionally, MPI promotes passive surveillance and reporting of suspicious organisms via a pest and disease hotline, reflecting the obligation of Section 44(1) of the Biosecurity Act 1993 that:

> Every person is under a duty to inform the Ministry…of the presence of what appears to be an organism not normally seen or otherwise detected in New Zealand.

Due to the low feasibility and questionable benefits of active surveillance of marine farm structures (Sinner *et al.* 2012), we suggest that a passive surveillance approach is adopted for marine pests (*e.g.* biofouling species); for example, including suspicious organisms and the same species targeted by MPI-led national surveillance (see 2a of Table 12). It is in the interests of the industry to undertake at least this level of surveillance, as it may provide an early warning regarding the presence of an emerging threat, and enable them to react to protect other farms or growing regions.

By contrast with marine pests, there are a number of feasible approaches for active and passive surveillance of disease or its symptoms. These types of surveillance are particularly important in finfish culture. For example, cultured kingfish and hāpuku will be susceptible to the same disease agents as their wild conspecifics, such that local infection sources of pathogens and parasites may be more important to finfish culture than external sources in some instances (Forrest *et al.* 2011). Accordingly, a range of BMPs and associated record keeping and reporting requirements are suggested for any finfish culture development in the Waikato CMA (2a-c of Table 12). Disease surveillance is also important in shellfish culture, but it may be sufficient to undertake passive surveillance and recording of unusual or unexplained mortalities.

We do not consider on-farm practices for HABs in this section, as management from an aquaculture perspective is based on setting limits on nutrient loads from finfish culture, coupled with broad-scale environmental monitoring of HAB species (see Section 10.3 below).

Response

Aside from marine pest control for biosecurity reasons, some level of marine pest or general biofouling control is necessary on marine farms for operational reasons. Defouling infrastructure (*e.g.* floats, anchor warps, mussel backbone ropes, oyster racks, and fish cages or nets) is necessary to reduce weight and drag. In the case of finfish culture, defouling pontoons and nets maintains water flow and water quality, and reduces parasite reservoirs. Such practices reduce stress on farmed fish, which reduces their vulnerability to disease (Stickney 2009). As such, Table 12 contains a BMP (4a) regarding reduction of pest populations on marine farms, where this is feasible and necessary. The application of biocidal (*e.g.* copper-based) antifouling coatings to finfish culture structures can provide a complementary method for fouling control, but can lead to seabed contamination (discussed in Section 5).

A range of strategies and BMPs can be put in place for on-farm disease prevention and control in aquaculture. An overview of these, and the rationale for their use, was provided by Forrest *et al*. (2011), and only their intent (rather than the detail) is reflected in the BMPs in Table 12 (BMPs 3a-3e, 4b,4c & 5a). Waikato's RCP already has a requirement for reporting of pest or disease outbreaks and the measures taken to control them. The implementation of certain BMPs for disease and/or pest prevention or pest control may have negative implications for other ecological issues of which WRC should be aware, including:

- the potential for future additives in finfish culture (*e.g.* therapeutant treatments) to affect the seabed or water column (see Section 9)
- fallowing farm sites as part of disease control (*i.e.* leaving sites unstocked for 10-30 days) can be a successful mitigation strategy for certain parasites, but may require multiple sites, hence increases the extent of the seabed effects footprint
- defouling is important for disease and biofouling control, but could exacerbate the seabed deposition of organic material, and possibly antifouling compounds like copper (see Section 5).

Future considerations for WRC include whether thresholds can or should be set regarding acceptable levels of disease or stock mortality for finfish culture. Sim-Smith and Forsythe (2013) cite guidance or mandatory requirements from other countries, which we recommend WRC refer to if necessary.

10.3. Consent and state of the environment monitoring

For disease avoidance and management, there are some specific aquaculture surveillance activities suggested in Table 12, which for finfish culture require a systematic approach to data collection and record keeping. In terms of environmental monitoring, the only systematic consent-based farm-scale monitoring is the need to measure daily water column DO and temperature within finfish pens. This need is reflected in BMP 3a of Table 12, and is an important part of ensuring water quality is maintained for fish health, or order to minimise the risk of disease emergence.

It is important to recognise that the potential for aquaculture in the Waikato CMA to contribute to the spread and establishment of HMOs in the wider environment is in many instances an incremental risk to that which already occurs. Existing anthropogenic sources of biosecurity risk include international vessel arrivals into the Hauraki Gulf, and domestic vessel movements into the Waikato region or the immediate vicinity (*e.g.* recreational vessels, fishing boats, tourism operators, barges, merchant ships). As also discussed above, background risk occurs as a result of HMOs that already exist in the Waikato region (or sub-regions therein), as such species may increase in abundance as a result of aquaculture.

One of the considerations for managing aquaculture risk to protect ecological values is whether mitigation is likely to be effective or justifiable if there remain significant sources of unmanaged risk to the Waikato region. While there are some aquaculture-specific needs for disease risk management in finfish aquaculture, we suggest that other risk reduction measures for aquaculture need to be supported by parallel efforts by WRC to address other exacerbators of risk. Attempts by the industry to manage risks may be futile (and not supported by industry) if such efforts do not have the support and participation of other key exacerbators.

Of particular importance is effective management of risk pathways, even where specific risks are not known (for reasons described in Box 2). Approaches to managing risk pathways are presently being considered by MPI from a national perspective, and some councils (*i.e.* Northland, Southland, Top of the South councils) are closely looking at intra- and inter-regional pathway management options. To have effective biosecurity management in place that supports risk reduction practices by the aquaculture industry, WRC would need to develop and implement regional approaches to pathway management, preferably together with neighbouring councils. Clearly the evolving national context is a critical part of this.

Understanding the bigger picture is clearly important for marine biosecurity, and there is some scope to conduct SOE monitoring that would assist in understanding HMO occurrences or effects. Broad-scale monitoring of target HAB species already occurs in New Zealand. This is an industry programme of weekly monitoring conducted nationally as part of the New Zealand Marine Biotoxin Monitoring Programme. The programme already includes several locations in the Waikato region. It will be important that any aquaculture conversions or new developments in the Waikato CMA consider coordination with the existing programme.

Regional surveillance of marine pests and disease is not recommended at this stage. Ideally, regional marine pest surveillance would be conducted to support the national MPI-funded programme. However, limiting factors include difficulties with timely pest detection (*i.e.* to enable rapid and effective response) and the fact that not all risk species will first arrive at assumed 'high risk' points of entry (*e.g.* vessel hubs like marinas). As such, we do not consider there are sufficient benefits to justify formal regional surveillance for marine pests. With respect to disease, understanding ecological issues and risks is in the realm of basic research. In the absence of such knowledge, we suggest that the package of measures in Table 12, which aim to protect aquaculture, should also protect the wider ecosystem.

A final consideration for SOE monitoring is that a well-designed programme could capture trends in marine ecosystems, to better understand the long-term effects of HMOs. Aside from HAB species, there is little known about HMO effects on New Zealand's marine ecosystems. Acquisition of such knowledge would benefit from an understanding of long-term ecological changes in habitats with and without specific HMO species. Although not necessarily providing a clear indication of cause and effect, the background knowledge provided by a long-term SOE programme may at least provide some insight into marine pest effects, and natural habitats most at risk.

11. SUMMARY AND SYNTHESIS

This report has revealed a range of potential issues associated with aquaculture in the Waikato CMA. Many of the issues can be mitigated through implementation of BMPs, and we have discussed situations where consent-related and SOE monitoring could be undertaken to better understand or track effects.

Relevant BMPs and reporting requirements have been tabulated in such a way that the needs within each aquaculture sector (finfish, mussels and oysters) are evident. There is clearly overlap in some of these BMPs where issues and effects are inter-related. It would be helpful at some stage to produce a single summary of BMPs by sector. However, it is premature to do so at this stage given the ongoing work that will advance this area (*e.g.* Aquaculture New Zealand sector ECOP reviews).

It is clear that situation-specific factors will alter the relative importance of the different categories of ecological effect. These factors include the culture species, the type of culture method, and the attributes of the culture environment that affect vulnerability to adverse effects. With this variability in mind, we have provided in Table 13 some high level guidance. The table considers the issues and their importance, the potential for mitigation of adverse effects, the need for consent-related reporting and monitoring, and the extent to which SOE monitoring is needed as a context for understanding consent-related effects. The aquaculture issues that are arguably of most importance are the ones whose effects (i) are of a high severity or magnitude, (ii) occur across broad spatial scales, and (iii) are persistent in the long term and are perhaps irreversible.

The relative importance of each of the issues in Table 13 reflects the information in this report and the authors' own experience and views. However, the relative importance of the issues is consistent with previous aquaculture risk assessments conducted by New Zealand experts (Forrest *et al.* 2009; Stoklosa *et al.* 2012). Biosecurity risk from HMOs (especially marine pests) emerge as being of high relative importance, reflecting that adverse effects may be irreversible and occur across regional scales (MPI 2013). Once introduced to a region, marine pests usually become widespread and impractical to eradicate (Hunt *et al.* 2009; Forrest & Hopkins 2013). Furthermore, marine pests may give rise to complex effects (*e.g.* direct and indirect effects, including cascading food-web effects) in a wide range of habitats.

Despite this general assessment, the incremental biosecurity risk from aquaculture development may be relatively minor where there is a high pre-existing risk (Forrest 2011). Additionally, consent-related and SOE monitoring is not necessarily essential, but is desirable for reasons explained in Section 10.3. One of the peculiar challenges posed by marine pests is that even though long-term SOE monitoring would facilitate understanding of the effects of marine pests, monitoring results cannot easily be linked with management actions that will reduce risk. For example, if aquaculture risk pathway management fails to prevent the introduction of a pest, the pest has the capacity to become regionally widespread and affect natural ecosystems irrespective of further actions by the industry. Disease issues also form part of the biosecurity theme, but tend to be more an issue for aquaculture production. Although wider ecological effects are possible, it is expected that effective stock health management will generally protect the wider environment.

Water column nutrient enrichment from finfish culture also has the potential to contribute to broad-scale effects (*e.g.* HABs), but represents a situation where SOE monitoring is not only desirable, but is an essential part of a broader toolbox (*e.g.* including modelling) for management. Consent-related monitoring at the farm scale (*e.g.* of water column nutrients) is of little value if conducted in the absence of information on cumulative nutrient inputs from other sources, the regional occurrence of HABs, or knowledge of environmental conditions (*e.g.* temperature, turbidity, upwelling events) that facilitate HAB formation. Water column issues are likely to increase in importance with the intensity and spatial scale of regional aquaculture development. An approach to water column monitoring of aquaculture effects for the Waikato region is outlined in Report 3.

For the range of other issues depicted in Table 13, the ecological importance of potential effects is arguably less in relative terms than marine pest and water column issues, but may nonetheless be regionally important. For example, marine mammal entanglement may be a very low likelihood event, but could have high consequences if it resulted in the death of an endangered animal (because of population-level effects). Given this situation, it is clearly important that related *ad hoc* reporting is included in consent conditions (*e.g.* as part of a management plan). However, systematic monitoring at the farm scale is not justified, and in some instances (*e.g.* in finfish culture) is probably a less effective means of data acquisition. Even if regional scale monitoring of marine mammals was conducted, it would likely be difficult to link changes in bird or mammal populations to adverse effects from aquaculture.

Seabed enrichment effects and related monitoring needs will be further considered in Report 3. This is a well understood issue; for example, it is known that measureable seabed effects from aquaculture are more severe for finfish than shellfish culture, but both are localised in their spatial extent. Monitoring indicators are well understood, and environmental standards are in the process of being developed. Seabed monitoring is justified for new finfish culture developments, given that the Waikato region has no experience with this activity, and effects vary with farming intensity. However, the value of frequent or ongoing seabed monitoring of mussel and oyster farming effects is less clear, given that effects may change little over time. State of the environment monitoring is not an essential part of seabed monitoring, as the measureable seabed effect of each farm unit still occurs at a local scale as the number of farms increases geographically. Nonetheless, SOE monitoring is desirable as it could provide reference sites against which farm-scale effects could be assessed, and provide the baseline data necessary to calculate certain biotic indices.

Two of the remaining issues described in Table 13 (*i.e.* wild fish interactions, escapees) tend to be perceived as of relatively minor importance given appropriate mitigation, and are typically not amenable to ecological effects monitoring in any case. The ecological implications of additive use will require BMPs, reporting and monitoring approaches to be developed based on situation-specific information. The use of certain additives in finfish culture will largely depend on the disease issues that emerge, which at this stage are not well understood. However, even where consent-related environmental monitoring is needed, associated SOE monitoring is probably unnecessary in most instances.

We note that previous New Zealand reviews of aquaculture effects (Forrest *et al.* 2007; Keeley *et al.* 2009) have recognised potential ecological issues from aquaculture which are poorly understood, and have not been considered by the MPI (2013) review or in this report. The most notable is the issue of ecosystem effects resulting from the reef habitat provided by marine farms (especially subtidal structures). This is an obvious area where further research is desirable, and Table 13 indicates where that research would benefit greater understanding of the issues that are currently well-recognised. Waikato Regional Council should be open to revising monitoring needs based on future knowledge that alters current understanding, or based on the development of practical monitoring tools where they don't currently exist.

This report provides sufficient information on most issues to provide a basis for WRC to develop guidance on BMPs, reporting and monitoring for the aquaculture industry. This guidance can be updated when other ongoing reviews are completed (*e.g.* sector ECOP reviews). For the issues that need further analysis (water column and seabed monitoring), or for which monitoring requirements will need to be considered once situation-specific ecological risks are better understood (*e.g.* relating to additives in finfish culture), the process described in Report 3 provides a framework to guide WRC.

In terms of understanding where SOE monitoring sits alongside environmental monitoring required as part of resource consents, WRC should recognise that this report has discussed SOE monitoring needs mainly in relation to specific categories of aquaculture effect. At some stage we would advise considering SOE requirements more holistically. As noted in Report 1, there is scope for monitoring to be more efficient, robust and useful if SOE needs are considered across aquaculture issues collectively, or in fact, across aquaculture and other anthropogenic or natural causes of environmental change.

Table 13. Summary of aquaculture issues in the Waikato CMA, highlighting the nature of reporting or monitoring to mitigate stressors or their effects. This is a high level guide, relevant to all types of aquaculture unless specified. Sector-specific requirements coded as: F = finfish, M = mussels, O = oysters, All = all sectors. The need for water column and seabed monitoring is being further evaluated in Report 3. Ratings in this table were derived from expert judgement in alignment with the approach taken in the MPI Aquaculture Guidance project.

Category	**Knowledge of ecological issues**	**Perceived ecological importance (see text)**	**Scope to mitigate stressors or effects[1]**	**Probable scale of measureable effects after mitigation**	**Probable reversibility of adverse effects**	**Sector requirement for *ad hoc* data collection, record keeping and reporting**	**Sector requirement for consent-related stressor or effects monitoring**	**Need for broad-scale SOE monitoring**
Water column	Med	High	Med-High	Farm to broad-scale	High	F	All	Essential
Seabed	High	High	Med-High	Farm-scale	High	F	All	Desirable
Marine mammals & seabirds	Med-High	High	Med-High	Farm-scale[2]	Low-High[2]	All	None	Desirable
Wild fish interactions	Low-Med	Low-Med	Low-Med	Farm-scale	High	None	None	Unnecessary
Escapee & genetic effects	Low-Med	Low-Med	Med-High	Farm-scale	High	F	None	Unnecessary (research desirable)
Biosecurity: pests	Med	High	Low-Med	Farm to broad-scale	Low	All	None	Desirable
Biosecurity: disease[4]	Low-Med	Med-High	Med-High	Farm-scale	High	All	F	Unnecessary (research desirable)
Additives	Low-High	Med-High	Med-High	Farm-scale	High	F	F	Unnecessary

Notes:

[1] Scope to mitigate adverse effects by appropriate site selection and planning, and requiring (as part of consent conditions) implementation of best management practices with associated record keeping and reporting where appropriate.

[2] Importance and scale of effects on mammals and seabird depend on species. For example, death by entanglement has a permanent local-scale effect on an individual, and would be significant for an endangered species because of potential broad-scale population-level effects; however, this effect is not expected given appropriate site-selection and BMP implementation.

[3] Disease is an issue where the measureable effect is most likely on the stock. Although wider ecological effects are possible, it is expected that effective stock health management will protect the wider environment.

Despite the benefits of implementing these steps, Report 1 recognises that integrating consent-related and SOE monitoring across the CMA will be a significant undertaking, even for aquaculture, as it will require addressing some effects that occur across regional boundaries, or for which regional councils have no control (*e.g.* the seabed effects of fishing). There are also some practical issues and limitations that will need to be addressed if WRC is to achieve strong integration of consent-related and SOE monitoring across the CMA. For example, the expiry of existing consents or applications for new consents will provide an opportunity for WRC to revise or develop consent monitoring conditions that are better integrated within a regional SOE approach. However, many consents have a long term duration, and expire at different times. In these instances an alternative approach would be for WRC to work collaboratively with the consent holder(s) to revise consent monitoring conditions to obtain the mutual benefits generated by an application of the framework.

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