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Overview of Marine Biosecurity Risks from Finfish Aquaculture Development in the Waikato Region

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RESEARCH BASED SOLUTIONS

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EXECUTIVE SUMMARY

Background

Interest in the development of finfish aquaculture in the Firth of Thames and southern Hauraki Gulf has led to the allocation by Waikato Regional Council of *c.* 390 ha of water space for 'fed aquaculture'. The primary use of this zone is expected to be the culture of yellow tail kingfish (*Seriola lalandi lalandi*) and hapuku (groper, *Polyprion oxygeneios*). The Council contracted the Cawthron Institute to undertake a preliminary desktop assessment of the marine biosecurity issues that could be associated with the culture of these species, to inform decision-making as the industry develops. This report presents a broad discussion of biosecurity hazards, in which our definition of biosecurity relates to any marine pest[1], pathogen or parasite with the potential to adversely affect the uses and values of the Waikato region. Internationally, these groups of biosecurity risk organisms have all been known to cause adverse effects on finfish culture operations or the wider environment.

Sources of biosecurity risk

Biosecurity hazards from specific finfish culture activities could arise in a number of ways. Transfer pathways associated with finfish culture could introduce new pests or disease agents to finfish farms from external source regions. Potential risk pathways include juvenile fish stock and associated transport water, transfers of equipment (*e.g.* fouled sea cages or harvesting gear), transfers of feed, and vessel movements (*e.g.* fouled hulls or contaminated bilge water). International transfers of kingfish stock (from Australia) and finfish feed are controlled by Import Health Standards that outline stringent quarantine and control procedures to minimise the risk of disease transfer. Other pathways are largely uncontrolled at present, but a number of simple mitigation approaches are possible.

Finfish farms could also become infected from local or external sources that are unrelated to culture activities, such as natural dispersal from established populations or as a result of other anthropogenic pathways. In relation to marine pests, the Waikato region already has two non-indigenous species that have been designated as Unwanted Organisms under the Biosecurity Act 1993, namely the sea squirt *Styela clava* and the Asian kelp *Undaria pinnatifida*. Both species are likely to infect the structures of any finfish farms that are developed. In the case of pathogens and parasites, local infection sources are probably more important than external sources, as cultured fish will be susceptible to the same disease agents as their wild conspecifics. In the case of kingfish, diseases of commercial importance are relatively well understood, whereas for hapuku there remains considerable uncertainty regarding which pathogens or parasites will become commercially significant to culture operations.

As well as the potential for a range of adverse effects on culture operations, an infected finfish farm may pose a biosecurity risk to other uses and values by acting as a reservoir from which marine pests or disease agents spread to the environment, potentially leading to irreversible regional-scale effects. A range of mechanisms could contribute to spread; including the natural dispersal of risk organisms via planktonic life-stages that drift with water currents, the transport or risk organisms by anthropogenic pathways such as vessel movements, and pathogen or parasite transfer as a result of interactions between cultured fish and wild finfish or other wildlife (*e.g.* sea birds). An additional way

[1] We use the term 'marine pest' to encompass fouling organisms and other macroscopic species (*e.g.* predators), as well as microscopic algae associated with biotoxin production and harmful algal blooms.

that a finfish farm could give rise to wider biosecurity risk is by creating environmental conditions that facilitate the establishment of pest species; for example nutrient enrichment may initiate or exacerbate blooms of harmful algal species that are already established in the region.

Implications for the Waikato region

Our discussion of implications for the uses and values of the Waikato region highlights many direct and indirect ways that adverse effects from pest or disease organisms could arise, but there is considerable uncertainty in this assessment for a range of reasons discussed in the report. The potential for finfish farms to contribute to the spread and establishment of fouling organisms in the wider environment is an incremental risk to that which already occurs, and is arguably of limited significance provided any new pathways of introduction are managed. By contrast, we consider that present understanding of the potential for harmful algal blooms (HABs) to develop or be exacerbated as a result of finfish farm nutrient enrichment is insufficient to gauge the level of threat. However, as HABs have the potential to affect natural ecosystems, aquaculture, human health, recreational uses and aesthetic values, mitigation and monitoring of HAB risk will be an important consideration.

In relation to pathogens and parasites, the value most clearly at risk from disease outbreak is finfish aquaculture itself. Generally, cultured fish are expected more at risk from disease agents transferred by wild conspecifics, than vice versa. In the case of kingfish, some parasite species may be especially problematic, and costs associated with control at kingfish farms may be significant. In addition to the use of therapeutant treatments, increased infrastructure maintenance may be required. Although many of the therapeutant treatments used in kingfish culture are relatively benign (*e.g.* freshwater or hydrogen peroxide baths), a wide range of chemical compounds can potentially be used in disease management in finfish aquaculture, some of which may be of greater environmental significance than those in common use at present.

In terms of disease risk to the wider environment, uncertainty regarding potential effects arises from the fact that the suite of disease agents in culture will not be clearly understood until commercial operations are underway. Furthermore, for some potential risk species, basic biology, life cycle characteristics (*e.g.* the intermediate host requirements for some parasites) and mechanisms of spread are poorly understood. Although significant disease risk in the wider environment as a result of finfish aquaculture is uncommon, there are sufficient examples internationally to highlight that environmental effects can be unpredictable and occasionally far-reaching.

Approaches to mitigation and management

Given that significant commercial cultivation of kingfish and hapuku has not yet occurred in New Zealand, the need to manage new pests or disease outbreaks in finfish culture will clearly involve considerable learning for growers, regulatory agencies and scientists. One way to deal with uncertainty and help safeguard against the potential for catastrophic unforeseeable events would be to develop the culture zones in stages, within an adaptive management framework that included appropriate monitoring, related research as necessary, and clear criteria for up-scaling to successive stages. Not only does staging provide a means of reducing environmental risk, but helps to ensure that the infrastructure, expertise and institutional arrangements are available to support the pace of development.

Additionally, detailed consideration needs to be given to the feasibility and efficacy of the broad range of mitigation strategies and related recommendations that we outline in the report. These include strategies to manage pathways of pest or disease introduction and facilitate the early detection of risk organisms, as well as measures to eradicate, control or contain outbreaks. To better understand and help prioritise key risks, information needs, and mitigation approaches, the issues outlined in this report would benefit from the application of a systematic risk assessment process, in which the likelihoods and consequences (and associated uncertainties) of different biosecurity issues were evaluated. Such a process would benefit from the input of a range of experts (scientists, industry, Council) using structured elicitation methods.

The importance of careful planning and development cannot be overemphasised; as a worst-case scenario, the introduction or exacerbation of significant biosecurity risk species, even if very low likelihood, has the potential to irreversibly affect the values of the Waikato region.

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1. INTRODUCTION

1.1. Background

Aquaculture in New Zealand has a market revenue in excess of $360 million per year and a sales target of $1 billion per year by 2025 (NZAS 2006). Finfish aquaculture is expected to be an important part of the industry growth required to meet this target, and will involve diversification from King salmon (*Oncorhynchus tshawytscha*) into new finfish species and new growing areas. One of the key areas is the Firth of Thames and southern Hauraki Gulf in the Waikato region, where water space has recently been zoned to allow 'fed aquaculture' such as finfish farming. The two finfish species of most interest are yellow tail kingfish (*Seriola lalandi lalandi*) and hapuku (groper, *Polyprion oxygeneios*). These are species for which preliminary analyses suggest aquaculture is technically feasible and economically viable (Zuccollo 2010; Zeldis *et al.* 2011). There is immediate interest from industry in farming kingfish in the Waikato region, as commercial scale production for this species has been trialled in the Marlborough Sounds and is already established in southern Australia. As such, Waikato Regional Council anticipates receiving resource consent applications for kingfish farms within the next year. The timeframe for hapuku is likely to be longer, as commercial trials have not yet been undertaken.

A recent study conducted for the Ministry of Fisheries provided an overview of existing knowledge and potential issues arising from finfish aquaculture in New Zealand (Forrest *et al.* 2007). For many issues, the Forrest *et al*. report highlights a good base of existing knowledge, with the findings from overseas studies, and from studies of salmon farm effects in New Zealand, generally applicable across different locations and finfish culture species. By contrast, the potential for finfish aquaculture development to introduce or exacerbate marine biosecurity risks from pests, pathogens or parasites, is a situation-specific issue. Studies of other types of aquaculture highlight that biosecurity risks can be relatively important, given that consequences can be widespread and irreversible (*e.g.* Forrest *et al.* 2009). As such, Waikato Regional Council has contracted the Cawthron Institute to undertake a preliminary desktop assessment of biosecurity issues relating to finfish culture to inform decision-making as the industry develops. This work complements a range of other studies that have considered various environmental issues associated with finfish aquaculture in the Waikato region (*e.g.* Kelly 2008; Zeldis *et al.* 2011).

1.2. Definition of terms and scope of report

Marine biosecurity in New Zealand has been defined as management of the risks posed by introduced (*i.e.* non-indigenous) species to environmental, economic, social and cultural values (Hewitt *et al.* 2004), and tends to focus on management of macroscopic organisms. By contrast, the word biosecurity when used in relation to finfish aquaculture often refers to protection of hatchery or culture operations from microscopic pathogens or parasites (Peeler *et al.* 2007; Arthur *et al.* 2008), which may include not only non-indigenous species (NIS), but also indigenous species already present in the culture environment that become enhanced as a result of culture operations. In this report, we take the broadest view and consider biosecurity risks posed by *any* marine pest, pathogen or parasite with the potential to cause adverse environmental effects as a result of finfish culture. We use the term 'marine pest' to include any species that is not a pathogen or parasite[2]; hence the term encompasses macroscopic species (*e.g.* fouling organisms) that have effects such as smothering, competition and predation; as well as microscopic algae associated with biotoxin production and harmful algal blooms (HABs).

This report provides a broad discussion of biosecurity risks (*i.e.* hazards) associated with finfish aquaculture development, focusing on sea-cage grow-out rather than issues with land-based hatchery production of stock. The report should not be regarded as a systematic risk assessment in which the likelihoods and consequences of the hazards identified, and their associated uncertainties, would be considered. Nonetheless, sufficient information is provided to enable Waikato Regional Council to identify the main issues that should be addressed as part of specific applications for resource consents for finfish culture sites, as well as identify key knowledge gaps or areas of uncertainty. Invariably, there will be situation-specific issues from particular culture operations that cannot be addressed or even foreseen at this stage.

In this report, we first provide background information on the proposed culture species, then we give an overview of values of the Waikato region, and describe a framework for understanding biosecurity risk from finfish culture development. Subsequently, we discuss separately[3] for marine pests and pathogens/parasites:

- The high risk species that may be associated with finfish aquaculture; including their distribution and effects in the Waikato region where such information is available.
- The pathways that could lead to the infection of finfish culture sites by risk species.
- The processes by which finfish culture could spread or enhance risk species in the wider environment.

Using this information, we consider collectively for pests, pathogens and parasites the possible implications of finfish aquaculture development for values in the Waikato region, based on a generic consideration of values rather than a spatially explicit assessment. Finally we discuss possible approaches to the management and mitigation of biosecurity risks. This component is largely an overview, as specific mitigation and management plans will need to accompany consent applications. However, we do consider in some detail the possible use of chemical therapeutants to combat pathogens and parasites of the finfish candidate species, and discuss environmental risks associated with their use.

[2] At times throughout the report we use the term disease agents (or similar) when referring to pathogens and/or parasites.

[3] Marine pests are considered separately as their biosecurity risk is independent of culture species, and more related to culture practices. However, hazards from pathogens and parasites depend in part on the particular disease agents to which the culture species are susceptible.

2. OVERVIEW OF POTENTIAL DEVELOPMENTS

2.1. Finfish culture locations

In total, *c.* 390 ha of water space is allocated or proposed for 'fed aquaculture', which for the purposes of this report we assume will be exclusively finfish (Figure 1). Once approved by plan change in July 2011, this area will represent *c.* 22% of the total aquaculture area in the Waikato region (see aquaculture values in Section 3.1). As the 390 ha will need to allow space for anchoring systems, navigation, *etc*., the area occupied by finfish sea-cages will be less; however, the actual farmed area is yet to be determined. Nonetheless, it appears that the scale of finfish farming at full development will be unprecedented in New Zealand, as to date only 10-15 ha of sea-cage area has been developed for commercial-scale marine finfish (salmon) culture in the South Island. Figure 1 indicates that the new development in the Waikato region will occur in two zones, as follows:

Zone 1: This is in the Wilsons Bay Marine Farming Zone (WBMFZ), in a location *c.* 15-25 m deep overlying muddy sediments and subject to strong tidal currents oriented approximately north-south. The WBMFZ is in two main blocks (Areas A & B) having a collective farmable space (*i.e.* excluding space between farms) for longline culture of green-lipped mussels (*Perna canaliculus*) of 1210 ha. Area A is 690 ha of which *c.* 85% is already developed in mussel farms. Area B is undeveloped but the Council has an application in the process to start mussel farm development there. At the north end of the west block, *c.* 90 ha has been allocated for fed aquaculture. Hence, present plans would result in mussel and finfish farms in close proximity along the main axis of tidal current flows.

Zone 2: This is a new proposed location of 300 ha situated in the southeastern Hauraki Gulf to the west of Coromandel township (Figure 1). This zone is *c*. 35 m deep and overlies soft sandy-mud sediments containing shell material (Grange *et al.* 2011). As for Zone 1, the area is subject to strong currents, with median velocities of *c.* 0.2 m s^{-1} oriented NNW-SSE (Zeldis *et al.* 2010).

At this stage, there are no detailed proposals for specific finfish farms in these zones. As such, the exact nature and methods of farm development and ongoing operation are unknown. However, based on methods used elsewhere, it is reasonable to assume that the two candidate finfish species would be grown in floating sea-cages, with juvenile stock sourced from land-based seawater hatcheries. Zeldis *et al*. (2011) have recommended the use of plastic circular cages (typically 28-51 m diameter), on the basis that wave energy may be too great for the square metal cages used at South Island salmon farms.

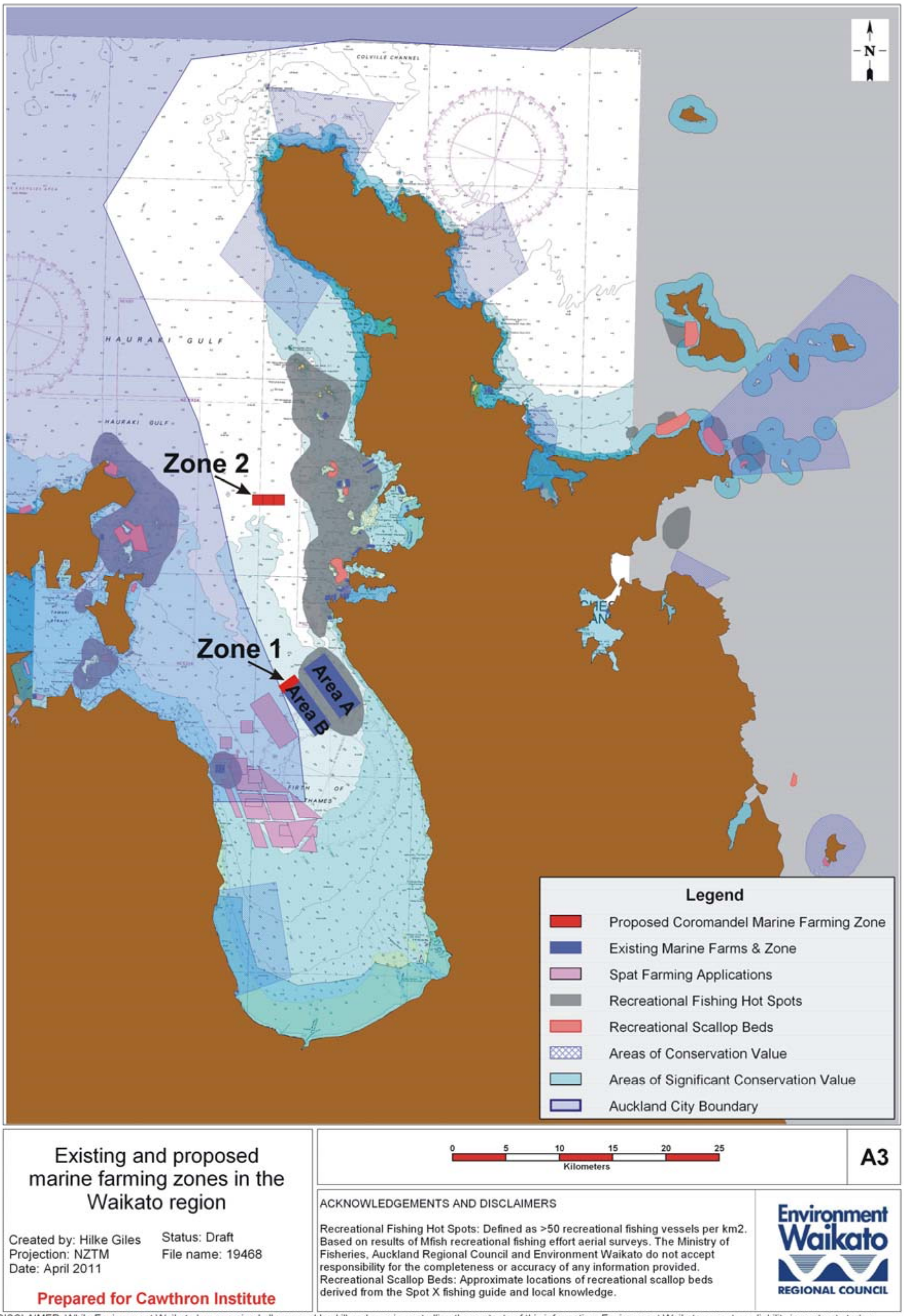

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Figure 1. Draft constraints map indicating zones for finfish aquaculture development. The location and size of Zone 1 has been annotated to a base map provided by Waikato Regional Council, and is approximate.

2.2. Background on candidate species

Yellow tail kingfish (*Seriola lalandi lalandi*; hereafter referred to as kingfish) are a subspecies described from Australia and New Zealand. The reported New Zealand distribution ranges from Foveaux Strait to the Kermadec Islands, but they are most common north of Cook Strait (Francis 2001). Limited trans-Tasman migration between Australia and New Zealand also appears to occur in the case of larger kingfish (Gillanders *et al*. 2001), and Diggles (2002) suggested that it may be possible for larval and juvenile fish associated with surface flotsam (surface debris) or macroalgae to disperse between east Australia and New Zealand on water currents. Kingfish are fished commercially and recreationally in New Zealand. *Seriola lalandi* (and sub species) are already being cultured in South Australia (de Jong & Tanner 2004) and on a large scale in Japan (Poortenaar *et al.* 2003). A trial kingfish farm in the Marlborough Sounds was discontinued in part because winter temperatures were too cold and a diet formulation suitable for cooler conditions was not available (Zeldis *et al*. 2011). NIWA has developed hatchery technology for kingfish in New Zealand, and maintains broodstock in its Bream Bay Aquaculture Park in Ruakaka, Northland.

Hapuku (*Polyprion oxygeneios*; hereafter referred to as hapuku) is one of three related groper species in New Zealand; the other two being *P. moene* and *P. americanus*, although there appears to be some confusion over the taxonomy of the latter two (Ball *et al*. 2000). Hapuku aquaculture has never been commercially trialled, but proof of concept has been developed at the hatchery scale, with a commercial production system anticipated by 2012 (Zeldis *et al.* 2011). Hapuku are fished commercially and recreationally in New Zealand, and the species is reported to inhabit the subtropical and temperate southern Indo-Pacific area (Francis *et al*. 1999). Although hapuku are reported to be capable of extended migration around the New Zealand coast, Beentjes & Francis (1999) describe limited movement between populations in the Poor Knight Islands, and results from their tagging study showed no interaction with Cook Strait or south-east South Island populations. Juvenile fish are thought to occur in surface waters well offshore, often associated with flotsam (Roberts 1996). However, at the end of their pelagic stage they become demersal (50-600 m).

3. OVERVIEW OF REGIONAL VALUES AND BIOSECURITY HAZARD PATHWAYS

3.1. Values of the Waikato region

An exhaustive review and description of the uses and values of the Waikato region is beyond the scope of this report. Rather, we provide information and examples to gain an appreciation of what might be at risk if new finfish culture developments resulted in increased biosecurity risk. Some of the important values of the region are indicated on Figure 1. Waikato Regional Council has provided other information or reference sources from which the summary below has been made, and some information has been derived from the Council website.

Ecological and conservation values
The Firth of Thames and southern Hauraki Gulf region includes a range of physical habitats: expansive tidal flats, extensive subtidal soft-sediments (muddy to sandy), and fringing rocky reef in some areas. Associated habitats include mangroves, saltmarsh, wetland and shell banks; intertidal or shallow subtidal seagrass beds; a range of soft-sediment habitats that can include physical and biogenic structure such as shell, Pacific oysters, horse mussels, bryozoan reefs and sponge gardens; and rocky reef-associated habitats.

Figure 1 includes areas considered to be of particular importance for their conservation and ecological values, which are based on Lundquist *et al*. (2004). One of these areas is at the south end of the Firth of Thames, which among other things is highly valued as a significant habitat for endemic and international migratory wading birds. This area has *c.* 8,500 ha designated as a Ramsar wetland of international importance (Gibbs 2007) and has nationally significant mangrove and mudflat communities. Twenty five of the bird species in this area are classified as nationally threatened.

Other areas in the vicinity of the proposed aquaculture zones that are classified in Figure 1 as being of particular importance for their conservation and ecological values, and key reasons, include the following:

- Manaia Harbour: this is considered as an unmodified and representative estuarine system, with saltmarsh, seagrass and mangrove communities, as well as threatened wading and coastal bird species.
- Inner Coromandel Harbour: this area is valued for its saltmarsh, seagrass and mangrove communities, as well as resident threatened wading and coastal bird species.
- Colville Bay: this area is valued for its migratory or resident bird species, including the New Zealand dotterel.
- Cape Colville: this area is valued for its resident rare and threatened wading bird species and is described as having “unique subtidal environments”, including extensive rocky reef habitats and associated assemblages.

Fisheries and aquaculture

Snapper is the most important commercial finfish species in the Firth of Thames and southern Hauraki Gulf, followed by kahawai and flatfish. Other species that make up the commercial catch include pilchard, john dory, gurnard, rig, grey mullet, leatherjacket, blue cod and tarakihi. Most of these species are also recreationally important, and kingfish are part of the recreational catch. In addition to finfish, there are commercially important wild fisheries for scallops and rock lobster. Recreational scallop beds are located to the east of Zone 2 (Figure 1). Other important recreational non-finfish species are cockles, pipis, green-lipped mussels, Pacific and rock oysters, paua, tuatua, kina, crabs and horse mussels. Recreational fishing hot-spots identified on Figure 1 show key areas to be east of Zone 2 and around the mussel farms in Wilsons Bay Area A.

Figure 1 shows existing areas designated for aquaculture in the Firth of Thames and southern Hauraki Gulf, dominated by WBMFZ Areas A and B. Outside of Wilsons Bay, 300 ha of space is presently allocated for aquaculture, mostly in Coromandel and Manaia Harbours. This includes smaller sites for long-line mussel culture and 70 ha for intertidal rack cultivation of non-indigenous Pacific oysters (*Crassostrea gigas*). In addition to ongrowing, there is some mussel spat catching in the region, and applications for large spat catching areas. To our knowledge, Pacific oyster spat are sourced externally. According to figures in Brangenberg & Morrisey (2010), aquaculture production in the region is about 22% of the national total for mussels and 21% for Pacific oysters.

Other values

Areas in the Firth of Thames and southern Hauraki Gulf of cultural significance to Hauraki iwi include the Firth of Thames to Tararu, Manaia Harbour, inner Coromandel Harbour and Colville Bay. The region also has a range of values for recreation, tourism *etc.*, many of which rely on attributes such as aesthetics and natural character.

3.2. Framework for assessing biosecurity risks to Waikato values

As depicted in Figure 2, for biosecurity hazards from specific finfish culture activities to threaten Waikato region values, and translate to adverse environmental effects, the culture site needs to present a biosecurity hazard in the first instance. For a hazard to be present, the culture site or environs needs to become infected by pests or disease agents; for example through: (i) the inadvertent transfer of risk organisms as a result of finfish farm activities (*e.g.* risk species associated with the transfer of juvenile fish or equipment from external sources), or (ii) local or external infection sources that are unrelated to finfish culture (*e.g.* natural dispersal from established populations, other anthropogenic pathways). Once infected, a given finfish farm site poses a wider biosecurity risk if marine pests or disease agents are spread to the environment. Alternatively, the culture site may create conditions that facilitate the emergence of biosecurity risks; for example nutrient enrichment may exacerbate a HAB species that is already established in the region.

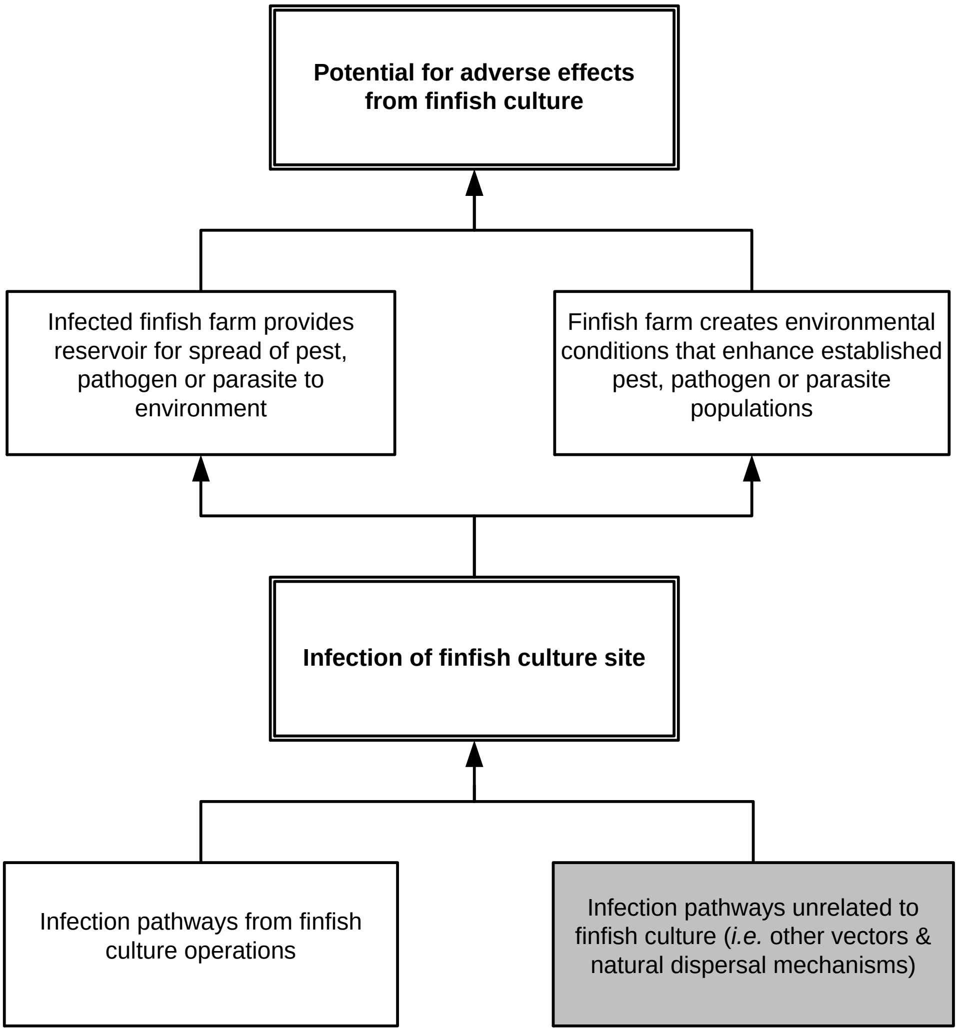


Figure 2. Overview of the main stages and sequence of events leading to the potential for adverse biosecurity effects from finfish aquaculture. The key components that contribute to each of these main stages are detailed in subsequent figures and associated text. The grey shaded box illustrates that biosecurity hazards can exist from sources in addition to finfish culture.

4. MARINE PESTS AND BIOSECURITY RISKS

4.1. Background

Human activities in the marine environment, especially trans-oceanic movements of vessels, have long been recognised as a major pathway for the inadvertent spread of marine organisms well beyond their natural dispersal ranges (*e.g.* Chilton 1910; Elton 1958; Skerman 1960). However, more recent literature suggests that the rate at which non-indigenous species (NIS) are being transported around the globe, and establishing adventive populations outside their natural range, is steadily increasing (Ruiz *et al.* 2000a; Harris & Tyrrell 2001; Grosholz 2005; Hayden *et al.* 2009b). Among other things, this reflects a greater frequency of vessel movements, changing patterns of shipping trade that open up new source regions (Taylor *et al.* 1999; Kolar & Lodge 2001; Perrings *et al.* 2002), and changing environmental conditions that allow the successful invasion of species that have previously failed to establish (Diederich *et al.* 2005; Grosholz 2005; Nehls *et al.* 2006).

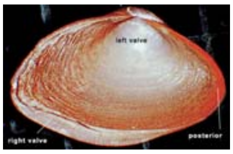
NIS are now considered a major threat to marine environments globally. More than 200 such species have been introduced to New Zealand, most of these via shipping-related mechanisms such as ballast water and hull fouling (Hayden *et al.* 2009a). There are numerous additional species classified as cryptogenic, which is a term that describes species whose geographic origins (*i.e.* whether they are native or non-indigenous) are uncertain. Following introduction from overseas source regions, most NIS that establish in the New Zealand marine environment continue to spread domestically, both by natural dispersal mechanisms and by anthropogenic transport pathways such as vessel movements and aquaculture transfers (Dodgshun *et al.* 2007).

In the following sub-sections we describe recognised high risk marine pests, the pathways by which pest species could be introduced or exacerbated by finfish culture, and the processes by which they could interact with Waikato region values. A broader synthesis of implications for Waikato region values that combines pests, pathogens and parasites, is provided in Section 6.

4.2. Potentially high risk marine pests

Despite the high number of introductions nationally, only a few species have been recognised as showing invasive or 'pesty' behaviour. Waikato Regional Council does not have an inventory of such species in its region. Earlier reviews in New Zealand identified 39 NIS in Waitemata Harbour (Hayward *et al.* 1997) with > 70 such species in the Hauraki Gulf area (Cranfield *et al.* 1998). Of the recorded NIS in the wider region, three are listed as Unwanted Organisms under New Zealand's Biosecurity Act 1993 (Table 1): the Mediterranean fanworm, *Sabella spallanzanii*; the sea squirt, *Styela clava*; and the Asian kelp, *Undaria pinnatifida*.

Table 1. Non-indigenous species designated as Unwanted Organisms in New Zealand under the Biosecurity Act 1993, and their recorded distribution. Of these, *Styela clava* and *Undaria pinnatifida* have established in the Firth of Thames/Hauraki Gulf region, while *Sabella spalanzanii* occurs in Waitemata Harbour (modified from Piola & Forrest 2009).

Scientific name	Common name	NZ distribution	Example
Asterias amurensis	Northern Pacific seastar	Not recorded	
Carcinus maenas	European shore crab/green crab	Not recorded	
Caulerpa taxifolia	Green aquarium weed	Not recorded	
Eriocheir sinensis	Chinese mitten crab	Not recorded	
Potamocorbula amurensis	Asian clam	Not recorded	
Sabella spallanzanii	Mediterranean fanworm	Lyttelton, Waitemata Harbour	
Styela clava	Clubbed tunicate (also known as a sea squirt or ascidian)	Whangarei, Tutukaka, Nelson, Lyttelton, Otago	
Undaria pinnatifida	Asian kelp	Widespread in harbours between Stewart Island and the Hauraki Gulf	

As the biosecurity risk posed by finfish aquaculture in the Waikato region depends in part on the existing distribution of high risk species, we have summarised distributional information for the Unwanted Organisms and other species where such information is available. Note that much of the focus of New Zealand's marine biosecurity system in terms of surveillance, incursion response and post-border pest management is on conspicuous NIS that have been associated with adverse effects in New Zealand or overseas. As such, there is considerable information on some of these NIS, of which we only provide a sample, focusing on species associated with aquaculture in New Zealand. We also highlight examples where native or cryptogenic species have become problematic in relation to aquaculture or the wider environment.

4.2.1. Aquaculture-related fouling pests

From an aquaculture perspective, species of particular interest are those that are clearly associated with artificial habitats. A synthesis from North America described 232 NIS from hard substratum habitats, of which > 200 were associated with artificial structures (Ruiz *et al.* 2009). Specific studies of the biota on artificial structures in the marine environment (*e.g.* Hughes *et al.* 2005; Glasby *et al.* 2007) make it clear that any suspended structure in the sea can provide a habitat that enables many fouling species (both indigenous and non-indigenous species) to proliferate. As finfish farm structures are likely to be colonised by a wide range of species, culture-related transfers (*e.g.* of cages) among locations have the potential to transfer any associated fouling pests. Excessive fouling can also be operationally significant in areas of high current flow or wave exposure by increasing drag on cages and anchoring systems. Fouling of nets can be especially problematic if it is sufficient to reduce water flow through cages, hence reduce oxygen supply to the stock and removal of their waste products. Reduced water quality can directly stress the fish stock, and make then susceptible to pathogens and parasites (see Section 7.4.3).

The Asian kelp *Undaria pinnatifida* (see Table 1) and the sea squirt *Styela clava* (Figure 3A) are already associated with aquaculture in New Zealand. *Undaria* can be a prolific fouler of mussel and salmon farms, and other artificial structures. In the Marlborough Sounds, excessive drag caused by *Undaria* fouling in high current areas has at times led to breakage of mussel farm anchor ropes. *Undaria* is already established in the Waikato region, being first discovered in the Firth of Thames on mussel lines in 2002, to which it was likely introduced with mussel seed-stock transfers from the Marlborough Sounds (Forrest & Blakemore 2002). *Undaria* is now present on mussel farms throughout the Firth of Thames (Kelly 2008), but is not thought to have established in natural habitats in the Waikato region (Hilke Giles, Waikato Regional Council, pers. comm.). However, elsewhere in New Zealand *Undaria* can be highly invasive in natural rocky habitats (Forrest & Taylor 2002; Russell *et al.* 2008; Hunt *et al.* 2009). Its distribution extends from the Hauraki Gulf to the sub-Antarctic Islands, and it occurs in most East Coast ports and harbours. Increasingly, *Undaria* is spreading from sheltered to more wave-exposed localities (Russell *et al.* 2008), where its vertical distribution can range from the neap low tide level to around 20 m deep in areas of high water clarity.

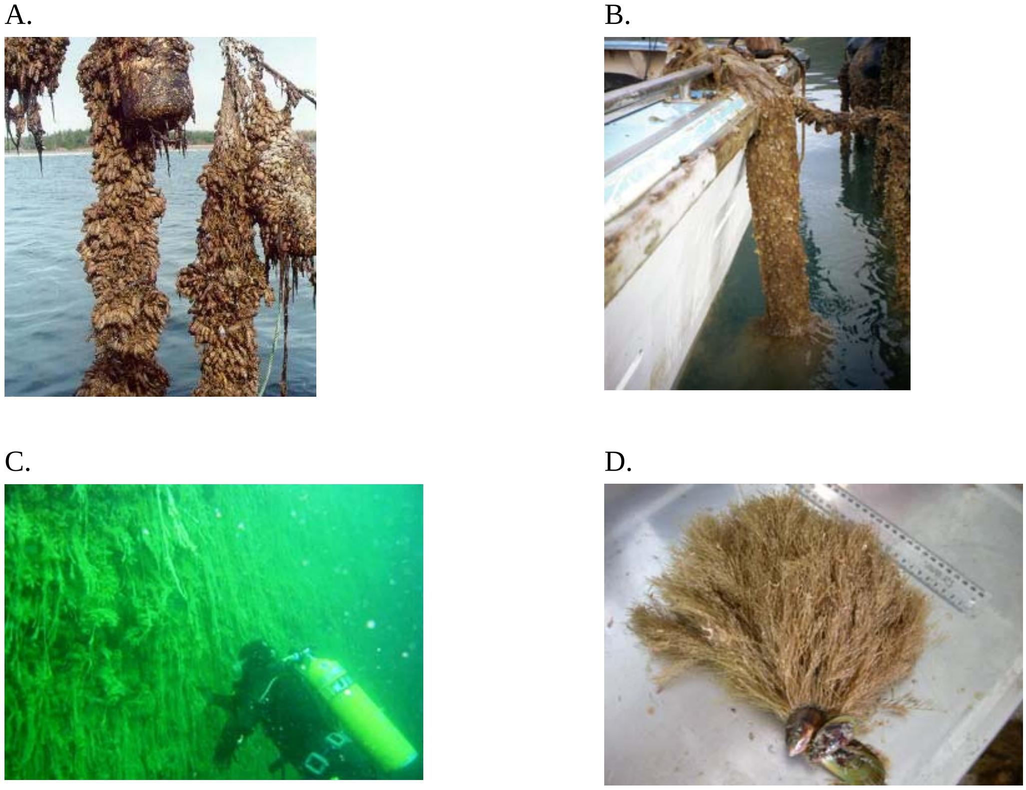


Figure 3. Examples of aquaculture fouling pests that are established in New Zealand: (a) the sea squirt *Styela clava* on mussel lines in eastern Canada (Neil McNair); (b) the sea squirt *Ciona intestinalis* on mussel lines in Marlborough (Barrie Forrest); (c) the sea squirt *Didemnum vexillum* on salmon farm predator exclusion nets in Marlborough (Bruce Lines); (d) the hydroid 'mussel beard', *Amphisbetia bispinosa*, on mussels in the Firth of Thames (Kevin Heasman).

Styela clava has been associated with prolific fouling and crop losses in shellfish aquaculture overseas (Carver *et al.* 2003; Ramsay *et al.* 2008). In New Zealand, this species has recently become problematic on Coromandel mussel farms, after being first recorded in Waitemata Harbour in 2005 (Gust *et al.* 2005). *Styela* is becoming increasingly widespread in the southern Hauraki Gulf, and occurs commonly on the seabed beneath Zone 2 (see Figure 1), where it is mainly attached to scallop shell (Grange *et al.* 2011). It has also been observed intertidally in the southern Hauraki Gulf region (B. Forrest, pers. obs.). We are unaware of any previous interactions between *Styela clava* and caged finfish culture. However, given the prolific fouling ability of this species in New Zealand and overseas, it could be a major fouling nuisance on finfish farms. In Zone 2, the existing seabed population of *Styela clava* will almost certainly act as an ongoing infection source for any finfish farms that are developed in that zone.

In addition to the Unwanted Organisms, the non-indigenous sea squirt *Ciona intestinalis* and cryptogenic sea squirt *Didemnum vexillum* (see Figure 3B-C) have both been associated with pronounced fouling and adverse effects in shellfish aquaculture in New Zealand and overseas (Carver *et al.* 2003; Coutts & Forrest 2007; Ramsay *et al.* 2008). *Ciona* was first described in New Zealand from Lyttelton Harbour in the mid-20th century (Brewin 1950), and later in Waitemata Harbour (Dromgoole & Foster 1983) although a more recent baseline port survey in the Waitemata did not record it (Inglis *et al.* 2006). *Ciona* appears to only be described from artificial habitats in New Zealand, but to our knowledge has not been recorded on mussel farms in the Firth of Thames or Coromandel. Following localised smothering of cultured mussels in the Marlborough Sounds, the New Zealand mussel industry implemented a code of practice that attempts to minimise the risk of *Ciona* and other target pests being transferred among the main growing regions with mussel seed-stock movements. More recently, a new *Ciona* species (*Ciona savignyi*) has been described from Nelson and Lyttelton and, based on overseas studies, has the potential to become a nuisance fouling species.

Didemnum vexillum has caused significant localised fouling of mussel lines and salmon culture cages and predator exclusion nets (*e.g.* Figure 3C) in the Marlborough Sounds since 2003, but has not been reported from aquaculture sites in the Waikato region despite being present in Whangamata since 2001 (Coutts & Forrest 2007). In the top-of-the-South, *Didemnum* was initially considered to primarily be invasive on artificial structures (Coutts & Forrest 2007). However, it has now been documented over-growing high value biogenic habitats (such as macroalgal beds) or erect species like horse mussels, fingers sponges and hydroid trees (Forrest *et al.* 2011), and overseas has invaded seagrass habitats. *Didemnum* ranges from neap tide level to greater than 40 m deep. *Didemnum* was transported to the Marlborough Sounds from Whangamata on the hull of an infected barge. The spread of *Didemnum* within the Sounds initially resulted from the movement of an infected salmon farm pontoon, but was later greatly exacerbated by multiple transfers of infected mussel seed-stock, highlighting a key role for anthropogenic vectors in the spread of this species.

A lesser known sea squirt that was recently discovered in New Zealand is *Pyura praeputialis*, a species first recorded in rocky intertidal habitats in Northland. In Chile this species is considered to be an 'ecosystem engineer' in the rocky intertidal (Castilla *et al.* 2004), and was reported by Zapata *et al.* (2007) to cause serious fouling problems in scallop aquaculture, although we were unable to verify this statement. Staff from MAF Biosecurity New Zealand are presently working with Northland locals to trial control measures for this species.

4.2.2. Other non-indigenous or cryptogenic fouling or benthic pests

There are a range of additional non-indigenous or cryptogenic species in the wider Hauraki Gulf that are of interest because they are (or may be) aquaculture-related, and have been associated within known adverse effects, or have the potential to reach high densities from which adverse effects can be inferred. Examples include:

- *Balanus trigonus*: this cryptogenic barnacle has become a fouling pest on cultured mussels in the Firth of Thames, as it impedes processing operations (Jeffs & Stanley 2010), and leaves a scar on the mussel shell which decreases marketability and value. The proliferation of this barnacle appears to have occurred only over the last 1-2 years, despite the species being described in the Hauraki Gulf for many decades (Moore 1944).
- *Chaetopterus* sp.: this tube-dwelling parchment worm is a non-indigenous mat-forming species that has a patchy distribution in northeast New Zealand, including in the Firth of

Thames and Hauraki Gulf. It lives in a range of hard and soft-sediment habitats and can reach very high densities that cover the seabed, hence clearly has the potential to displace other species. It has been reported that "*Chaetopterus*....renders dredging for scallops impossible (because the dredge fills with tubes and therefore cannot catch scallops)" (Morrison & Cryer 2003). Tubes can also wash up on beaches in substantial amounts. *Chaetopterus* is anecdotally reported to colonise mussel lines, hence has the potential to also be associated with finfish culture structures.

- *Crassostrea gigas*: the Pacific oyster *Crassostrea gigas* is cultivated in many New Zealand harbours north of Nelson-Marlborough, and has formed naturalised wild populations in these areas, including in the Firth of Thames. Farmed and naturalised populations can have a range of ecological effects, which were described in a recent review (Forrest *et al.* 2009). Its sharp shell can adversely affect amenity values (*e.g.* recreational use), especially in intertidal locations (Hayward 1997).

Finally, the region has a range of additional species in the Firth of Thames or wider Hauraki Gulf that contribute to the existing level of risk from NIS. Examples are: the non-indigenous portunid crab *Charybdis japonica*, which is a predatory species considered to have the potential to cause adverse affects on benthic ecosystems (Gust & Inglis 2006); and the Asian date mussel *Musculista senhousia*, which forms high density patches in intertidal and shallow subtidal sediments. These patches can accumulate mud and reduce densities of other infauna (Creese *et al.* 1997). Similarly, the infaunal bivalves *Theora lubrica* and *Limaria orientalis* can reach high densities in soft sediments, hence would be expected to play an important ecological role. The latter species can also be associated with suspended mussel culture.

4.2.3. Indigenous fouling pests

Although national interest in marine pests has focused on non-indigenous and cryptogenic species, native species also have the potential to cause adverse effects where human activities inadvertently lead to their enhancement. This situation is particularly evident in aquaculture, where native species can show invasive behaviour and become prolific. Examples include the common hydroid 'mussel beard' (*Amphisbetia bispinosa*), which has caused fouling problems for mussel culture in the Firth of Thames (see Figure 3D above), and the common sea tulip *Pyura pachydermatina* (a type of sea squirt) which is a fouling pest on mussels farms in Banks Peninsula. Such examples suggest that many (perhaps any) fouling species have the potential to cause adverse effects, given circumstances that are favourable for population outbreaks. A corollary is that the 'next pest' may not always be recognised until it exhibits pesty behaviour for the first time. As these fouling organisms are sedentary species having drifting planktonic dispersal stages, an important but unresolved issue is whether vast populations on structures such as marine farms could lead to non-natural abundances in local ecosystems.

4.2.4. Harmful algal bloom (HAB) species

Harmful algal blooms (HABs) include various species of microscopic phytoplankton that are of particular concern because they produce biotoxins. Biotoxins are compounds that can adversely affect humans or resources during HAB events. HABs have had a range of adverse effects in New Zealand. For example, some HAB species produce toxins that accumulate in filter-feeding shellfish and make people ill who eat the shellfish, or have been linked to respiratory problems in humans. Other species have caused significant mortality of wild shellfish resources and other marine biota, and some are ichthyotoxic (*i.e.* toxic to fish) which is clearly important from a finfish industry perspective. A summary of HAB events in New Zealand and their environmental effects can be found in Rhodes (2001). There are a wide range of species associated with past bloom events in New Zealand, and for many their status as native versus NIS is unclear. For present purposes, we have considered HABs as a biosecurity hazard of relevance to understanding finfish culture risk, as culture-related processes have the potential to introduce HAB species to the Waikato region or contribute to blooms of existing species (see Sections 4.3 & 4.4).

While finfish culture and other sources of anthropogenic nutrient enrichment may contribute to HABs, it is important to recognise that phytoplankton blooms are natural phenomena associated with both seasonal conditions (*e.g.* changes in light and temperature) and longer-term climatic and oceanographic patterns or anomalies (Heath 1993; Rhodes *et al*. 1993). In relation to the Waikato region, a 2004 State of the Environment Report (SER)[4] for the Hauraki Gulf (SER 2004) indicates that algal blooms are driven by the influx of nutrient-rich oceanic waters, coinciding with strengthened northwest winds during El Niño Southern Oscillation events. Significant HAB events in the Hauraki Gulf appear to have been few, but may be significant when they do occur. For example, there have been at least two major *Karenia* (formerly *Gymnodinium*) species blooms in the Hauraki Gulf and Firth of Thames regions over the last couple of decades (Chang & Ryan 2004; MacKenzie *et al*. 1995) that have resulted in widespread mortalities of marine fauna. The first event led to the development of the New Zealand Marine Biotoxin Monitoring Programme, which is managed by the New Zealand Food Safety Authority. Since 1993, the programme has involved weekly collection of water samples from aquaculture and shellfish gathering sites around New Zealand, with microscopical analysis for target HAB species (Table 2). The target HAB species tend to be those associated with biotoxins that contaminate cultured or wild shellfish and lead to illness in human consumers. The aim of the Marine Biotoxin Monitoring Programme is to minimise the risk that people will eat shellfish (recreational or commercial) that may be unsafe, with the weekly monitoring being a first step. If monitoring determines that particular HAB species (or species groups) are present above a certain concentration, specific biotoxin analysis is undertaken to determine shellfish safety for human consumers.

The Marine Biotoxin Monitoring Programme includes sampling at 12 sites in the Hauraki Gulf area, with 3 sites in the general environs of the proposed fed aquaculture zones

[4] The State of the Environment Report (2004) for the Hauraki Gulf can be accessed at http://www.arc.govt.nz/environment/coastal-and-marine/hauraki-gulf-forum/hauraki-gulf-state-of-the-environment-report.cfm

(Waimangu Point, Wilsons Bay, Tamaki Strait), and an additional site at Esk Point further to the north. Data for these sites are readily available from October 2008 to the present, which we have summarised in Table 2 in order to further elucidate the incidence of HAB species in relation to the Waikato fed aquaculture zones.

Table 2. HAB species targeted under the New Zealand Marine Biotoxin Monitoring Programme. Also shown is the type of biotoxin or shellfish poisoning (SP) each target species causes in humans who eat infected shellfish, and the incidence of detection (post-October 2008) out of a cumulative total of 7305 samples across four sites in the Firth of Thames and southern Hauraki Gulf. A summary of the health effects of the different types of SP can be found in SER (2004).

Biotoxin/effect	Target species	No. occasions detected at four sites in Waikato region of interest
Paralytic SP	*Alexandrium minutum*	0
Paralytic SP	*Alexandrium ostenfeldii*	2
Paralytic SP	*Alexandrium catenella*	0
Paralytic SP	*Alexandrium tamarense*	0
Paralytic SP	*Gymnodinium catenatum*	0
Amnesic SP	*Pseudo-nitzschia australis*	0
Amnesic SP	*Pseudo-nitzschia pungens*	1
Amnesic SP	*Pseudo-nitzschia multiseries*	0
Amnesic SP	*Pseudo-nitzschia turgidula*	0
Amnesic SP	*Pseudo-nitzschia fraudulenta*	1
Amnesic SP	*Pseudo-nitzschia delicatissima*	0
Amnesic SP	*Pseudo-nitzschia pseudodelicatissima*	0
Amnesic SP	*Pseudo-nitzschia multistriata*	1
Neurotoxic SP	[1]*Karenia brevis*	0
Neurotoxic SP	[2]*Karenia/Karlodinium/Gymnodinium group*	128
Diarrhetic SP	*Dinophysis acuta*	1
Diarrhetic SP	*Dinophysis acuminata*	4
Diarrhetic SP	*Prorocentrum lima*	1
Yessotoxin[4]	[3]*Gonyaulax spinifera*	0
Yessotoxin	*Protoceratium reticulatum*	0

[1] *Karenia brevis* has not been isolated in New Zealand to date.
[2] All records in the Waikato region are *Karenia c.f. mikimotoi* which is also an ichthyotoxic species.
[3] *Gonyaulax c.f. spinifera* recorded at significant cell count on one occasion at a site in Firth of Thames.
[4] The human health and other implications of yessotoxins are unclear.

Since October 2008, 7305 samples have been analysed from the four sites, and eight of the target HAB species detected, but only very infrequently (Table 2). The two records of *Alexandrium ostenfeldii* had cell counts at levels that were high enough to trigger further testing procedures to determine toxicity. However, all other HAB species were detected at cell counts that are not regarded as significant in terms of biotoxin production. Despite the low cell counts, of interest in relation to finfish culture development is the relatively frequent occurrence of *Karenia c.f. mikimotoi*. This is an NSP-producing species that is of potential concern not only in relation to human health issues, but also because it is ichthyotoxic.

Analysis of records pre-October 2008 may reveal the occurrence of other HAB species in the Waikato region, or a greater frequency of occurrence for those already detected. However, analysis of earlier records would involve obtaining permission for a significant data extraction effort[5] and is not essential for present purposes. The readily available data are sufficient to indicate that there are many HAB species present in New Zealand that have not yet been recorded in the Waikato region, and some already present that could become problematic if intensive finfish culture led to excessive nutrient enrichment and a greater occurrence of HABs.

Finally, it is important to recognise that algal blooms can affect coastal uses and values in a variety of ways, and not simply as a result of biotoxin production by HAB species. In terms of direct effects on the finfish industry, for example, high density plankton blooms have led to cultured fish mortality by asphyxiation from clogging of gills (Stickney 2009). In relation to the wider environment, blooms may physically smother marine biota, reduce dissolved oxygen concentrations through decay of microalgal detritus, and have a range of aesthetic effects such as water discolouration and slime or foam formation. As such, there is a clear need to better understand the potential for HABs in relation to finfish culture development, and to undertake appropriate monitoring (see Section 7.4.2).

4.3. Marine pest infection pathways for finfish culture sites

4.3.1. Pathway overview

Historically, inadvertent transfers of NIS internationally have been associated with various types of aquaculture pathway (Naylor *et al.* 2001; Minchin 2007). An overview of the recognised pathways that could lead to the infection of finfish culture sites by marine pests is provided in Figure 4, with the following sub-sections providing greater detail on these. We have identified three main pathways in Figure 4 that are directly associated with finfish culture and have the potential to transfer pests from external source regions. These are transfers of finfish stock and equipment, as well as culture-related vessel movements. To date, these types of transfer pathway within the New Zealand salmon industry (*e.g.* of sea-cages, vessels) have tended to occur within rather than between growing regions (Forrest *et al.* 2007). Salmon

[5] The HAB data belong to members of the shellfish industry (or NZFSA for non-commercial results) who pay for the monitoring. The contact person varies according to location. Records pre-2008 are on a different database and require considerably greater effort to extract.

farm-related transfers to New Zealand from overseas source regions are not known to have occurred, except for dry feed sourced from Australia and Chile. Although we do not have the detailed knowledge of industry operations necessary to understand pathway risk to the Waikato region, we can identify situations where the potential for risk is greatest, hence should be considered at the consent application stage. These are culture related activities that involve:

- Pathways from international source regions.
- Pathways from domestic source regions known to be infected by recognised high risk pests, especially pest species that do not already occur in the Waikato region.
- Pathways that are novel; *e.g.* involve methods of transfer that do not already occur as a result other human activities in the Waikato region.
- Pathways along which the frequency of transfers is considerably greater than occurs as a result of other human activities in the Waikato region.

An analysis of risk requires specific information on pathway source regions, frequency of movements, and the distribution of risk species. The latter will change over time or may be poorly understood. Where such factors complicate specific pathway risk analysis, or where analysis reveals culture-related risks that are incrementally important, mitigation may be appropriate. There is considerable scope for effective mitigation for the pathways highlighted in Figure 4 (see Section 7.3). Hence, we concentrate below on outlining the types of risks that could arise in the absence of effective mitigation, in part to make it clear that there are merits in the implementation of pathway management strategies as standard operational practice.

4.3.2. *Finfish culture pathways for marine pests*

Finfish stock transfer

The potential stock-related risk pathway for marine pests is associated with the water in which the fish are transferred (in relation to disease, in Section 5.3.1 we discuss the additional risk that may be associated with the transfer of the stock itself). It is assumed that finfish stock will be sourced from New Zealand hatcheries, although the importation of juvenile kingfish from South Australia has previously been proposed (Diggles 2002). MAF has recently (28 January 2010) developed an Import Health Standard for "Importing Juvenile Yellowtail Kingfish from Australia", which specifies stringent biosecurity procedures for fish stock sourced from that country[6]. For the associated transfer water, the following requirements must be met:

- The kingfish must be transported in water sourced from the hatchery where the kingfish originated.
- Before the water is placed in the transport container, the water must: (i) have been filtered to at least 1 µm; (ii) have a salinity of at least 30 parts per thousand; and (iii) have been subject to UV sterilisation greater than 35 mWs/cm^2.
- Water must not be exchanged during transport.
- The transport container must be sealed with an AQIS approved seal.

[6] For the Import Health Standard, see: http://www.biosecurity.govt.nz/imports/animals/standards/kngfisic.aus.htm)

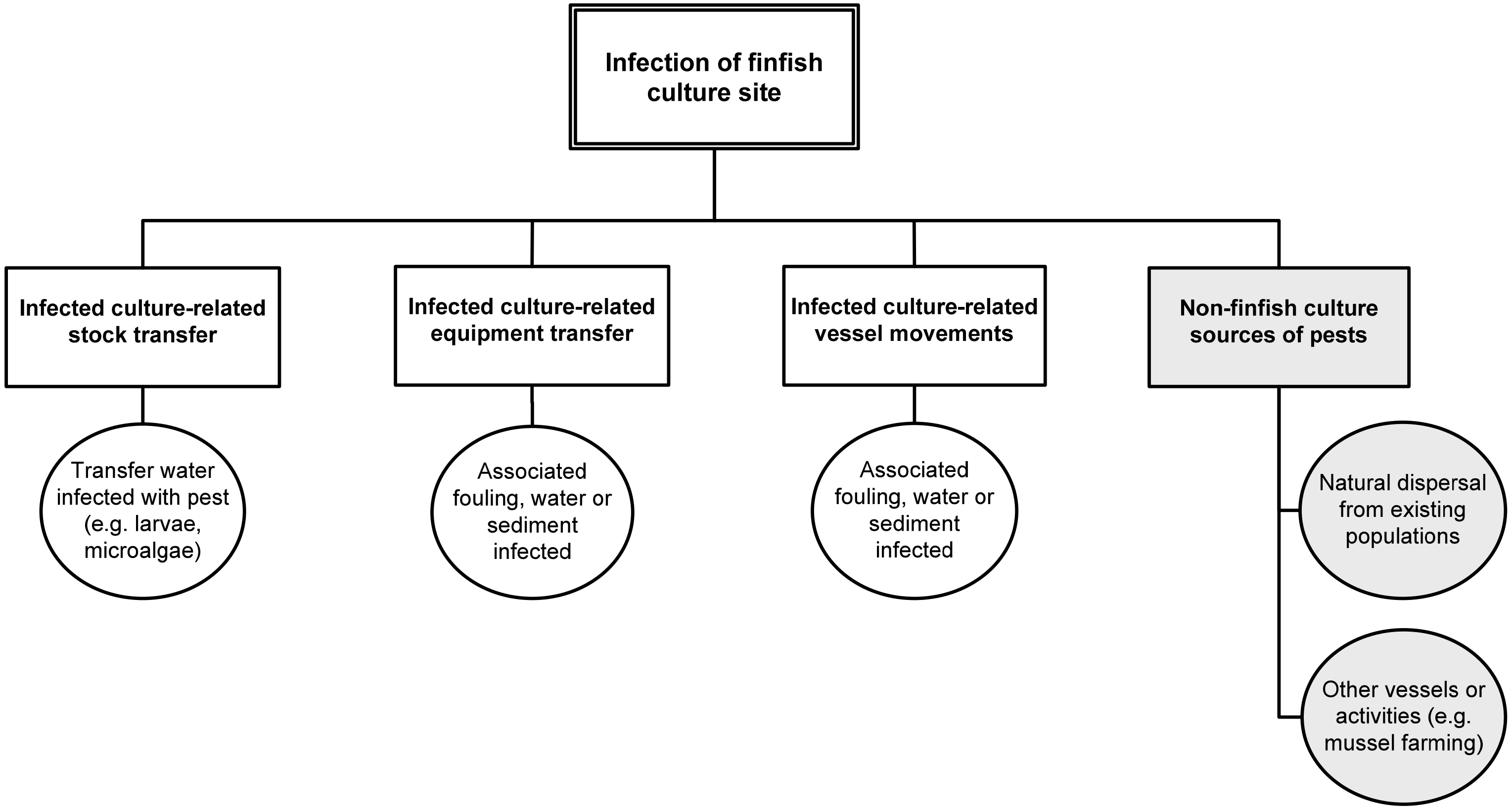


Figure 4. Summary of key pathways and related mechanisms that could lead to the infection of finfish aquaculture sites by marine pests. The grey shaded elements illustrate that biosecurity risk can arise from natural and anthropogenic sources in addition to finfish culture.

These measures are expected to be highly effective at mitigating biosecurity risk. However, in the event that transfers (*e.g.* from domestic hatcheries) were undertaken in raw or inadequately treated seawater, that water could theoretically carry potentially harmful pest species or their dispersive life-stages. Examples include:

- Planktonic dispersal stages (hereafter referred to as 'propagules') of marine organisms (*e.g.* invertebrate larvae or seaweed spores).
- Fragments of colonial organisms; *e.g.* fouling sea squirts.
- HAB species and other plankton, including cyst stages.

These same infective life-stages also have the potential to be transferred in water carried by other vectors (*e.g.* ballast and bilge water associated with vessels) as we discuss in subsequent sections. Greater detail, including evidence highlighting how these infective stages could be transferred in water, is given in Box 1.

Box 1. Life stages of marine pests potentially associated with transfers of untreated water

Planktonic dispersal stages of marine organisms: Most seabed-dwelling marine algae and invertebrates have dispersal stages (*e.g.* algal spores, invertebrate larvae; referred to in this report as propagules) that drift as plankton with water currents. These stages can be carried in water with anthropogenic vectors, with pathway risk depending on their competency period in relation to transport time from the source region to the culture site. For some recognised risk species, competency periods are short; for example around 1 day for some sea squirts (*e.g. Didemnum vexillum*; Fletcher *et al*. 2011). On the other hand, there are a number of globally recognised marine pests, which have planktonic competencies periods of weeks to a few months. Examples (see Table 1) include the fanworm *Sabella spallanzanii* (Currie *et al.* 2000), the Northern Pacific seastar, *Asterias amurensis* (Byrne *et al.* 1997) and the European shore crab, *Carcinus maenas* (Audet *et al.* 2008).

Fragments of colonial organisms: Fragmentation is a key mechanism for dispersal and establishment in some species. Among the non-indigenous and cryptogenic marine fouling species in New Zealand, establishment by fragments has been documented for the sea squirts *Didemnum vexillum* and *Botrylloides leachi*, and the bryozoans *Watersipora subtorquata* and *Bugula neritina* (*e.g.* Hopkins *et al.* 2011b). Entrainment of fragments in water has the potential to transfer risk from source regions to finfish culture areas, although recent research by Hopkins *et al*. (2011b) suggests that fragments would need to be several millimeters in size to effectively reattach.

Holoplankton and HAB species: The term holoplankton refers to organisms that are planktonic for their entire life cycle, and comprise phytoplankton and zooplankton. Few such organisms are recognised as risk species, although some such as the Mediterranean comb jelly *Mnemiopsis leidyi* are well known (*e.g.* this species occurs on the National Geographic's '100 least wanted' list of invasive species). Phytoplankton includes some of the HAB species discussed above. The HAB species themselves, or the cysts of HAB species having such stages, could be entrained with transported water if present in the source region.

Culture-related equipment and vessel transfers

In addition to finfish stock transport water, Figure 4 identifies the potential for marine pests to be transferred with movements of infected equipment and vessels. External fouling is a globally well-recognised mechanism for aquaculture-related transfers of marine pests. In New Zealand, this process was described in Section 4.2.1 in relation to spread of the sea squirt *Didemnum*, and has been described for aquaculture transfers at regional or greater scales in relation to mussel seed-stock and equipment (Forrest & Blakemore 2006).

The spread of fouling species by vessel movements is also well-recognised. This mechanism can be especially important for vessels (*e.g.* barges, yachts) that travel at speeds that are sufficiently slow (< 10 knots) to enable the survival of a diverse range of associated fouling (*e.g.* Coutts *et al.* 2007; Coutts *et al.* 2010). A range of other vessel-related mechanisms may be significant in certain circumstances. For example, entrainment of pest organisms (or dispersive life-stages and fragments) in bilge water can be important (Darbyson *et al.* 2009). Similarly, entrainment of fouling, sediments and water (and any associated infective organisms or life-stage) on anchors, ropes and deck spaces are recognised as potential mechanisms of marine pest transport, although evidence is lacking as to their importance (Acosta & Forrest 2009; Sinner *et al.* 2009).

4.3.3. Non-finfish culture pathways for marine pests

The grey boxes in Figure 4 illustrate that finfish culture sites could become infected by pathways that are unrelated to culture activities. These pathways include the spread of risk species from existing local sources, including natural habitats and marine farms. For example:

- At Zone 1, *Undaria* is likely to spread to finfish cages from adjacent mussel farms, as the two activities will be contiguous along the main axis of tidal flow.
- At Zone 2, the seabed population of the sea squirt *Styela clava* is likely to provide a propagule supply for infection of finfish cages in that zone.

Infection of culture sites may also occur from vessel movements (*e.g.* via fouling, bilge water, and other mechanisms described above), especially if finfish farms create a hub of recreational fishing activity as occurs at existing mussel farms (Figure 1). Beyond specific culture sites, biosecurity risks may also arise from a range of other natural and anthropogenic pathways. For example, at a broad scale, discharge of ballast water from vessels transiting the Hauraki Gulf is a potentially important source of risk from international source regions. In terms of domestic risk, mussel and oyster farming activities in the region involve seed-stock, equipment and vessel movements from aquaculture regions around New Zealand (Forrest & Blakemore 2002), some of which have been implicated in the spread of pest species such as the kelp *Undaria*. Hence, the background marine pest risk relative to the finfish culture pathways in Figure 4 is probably quite high.

4.4. Spread or enhancement of marine pests by finfish culture

Potential processes by which finfish culture could spread marine pests to the wider environment, or exacerbate existing biosecurity hazards, are depicted in Figure 5 and discussed below.

4.4.1. Spread of marine pests from infected finfish farms

An infected finfish farm is likely to act as a reservoir from which marine pest species could spread in a number of ways (see Figure 5). In Box 2, we detail some of these mechanisms of spread, and discuss factors likely to be important in subsequent establishment. The discussion in Box 2 highlights that rocky habitats, or soft-sediment habitats with physical or biogenic structure, are probably more susceptible to invasion by aquaculture-associated species than relatively featureless soft-sediments. In this respect, the spread of sedentary fouling species to such habitats by planktonic dispersal mechanisms is likely to be one of the most important risks to consider. However, providing the Council with advice on the level of risk is quite difficult. The infection of a culture site by a high risk pest could represent a significant risk to Waikato region values if that pest was absent from the region and finfish culture sites provided the source population for spread. However, the reverse is probably more likely; *i.e.* pest populations already established will provide the source of infection of culture sites. In this regard, a key issue is the *incremental* effect of the infected farm as a reservoir for the subsequent spread of marine pests to the wider environment.

At the scale of an application for an individual small finfish farm, the incremental reservoir risk may be relatively unimportant. However, at full development with *c.* 390 ha of water space used for finfish culture, the surface area of artificial structures (hence the propagule reservoir) will presumably be considerably increased. It is difficult to estimate the extent of increase as it is unclear how much space and surface area will be occupied by finfish structures (cages, anchor ropes, *etc*.), and the importance relative to existing structures in the region. Hence, to an unknown extent, the increase in finfish farm structures (at full development) means that associated fouling pests are likely to become more abundant, or more widespread regionally, representing an increased biosecurity risk.

The basis for increased risk with increased surface area lies in the idea of ‘propagule pressure’ (*i.e.* the type, magnitude, number and frequency of propagule releases). It is generally considered that invasion risk increases as propagule pressure from established marine pests increases (Lonsdale 1999; Johnston *et al.* 2009; Lockwood *et al.* 2009). For marine systems, it has been highlighted that invasion success for some non-indigenous fouling species (*Undaria*, *Didemnum* and the bryozoan *Bugula neritina*) can increase with propagule pressure (Clark & Johnston 2005; Clark & Johnston 2009; Forrest *et al.* 2011). Moreover, the greater the propagule pressure the more likely it is that an invasive species will overcome factors (*e.g.* predation) that might otherwise limit its establishment in habitats within its dispersal range.

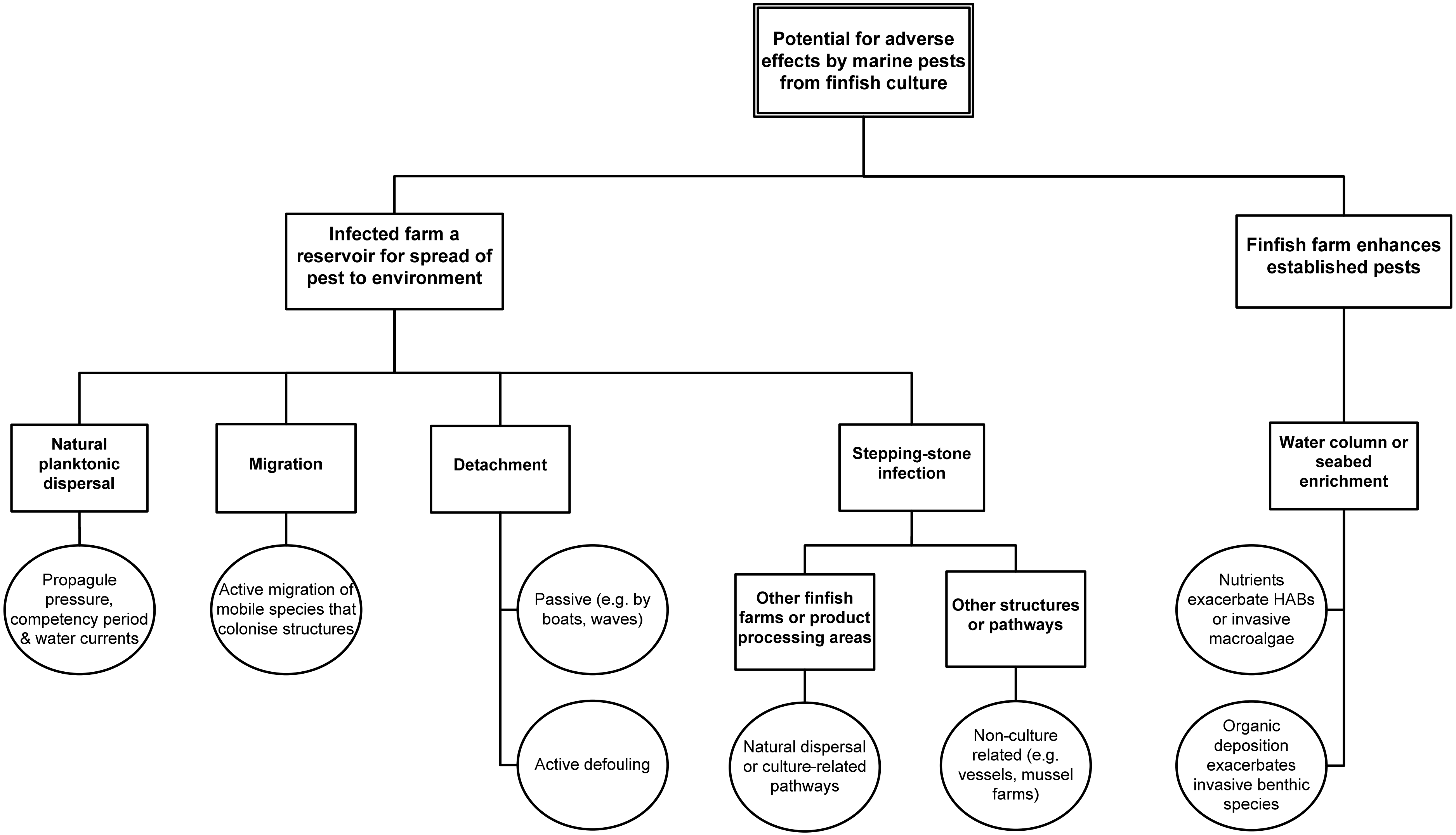


Figure 5. Summary of key processes by which an infected finfish culture site could result in the spread of marine pests, or create conditions that exacerbate pest establishment.

Box 2. Examples of mechanisms of marine pest spread from infected finfish culture sites

Planktonic dispersal of propagules and fragments of sedentary species: Sedentary fouling species will release planktonic dispersal phases or produce fragments (see Box 1). Among other things, the potential for establishment and adverse effects depends on whether high value habitats suitable for establishment, or their associated resources, are within dispersal range; which depends on factors such as planktonic competency period, the speed and direction of water currents, and the availability of suitable habitat. In the Waikato region, muddy habitats will conceivably act as a barrier to dispersal for species with a limited planktonic duration, unless significant hard substrata (*e.g*. shell or biogenic habitat) are available for colonisation and spread, as appears to be the case for the sea squirt *Styela clava* at Zone 2. Structured soft-sediments and rocky habitats are probably the most at-risk habitat types for invasion by the types of species likely to colonise finfish farm structures.

Dislodgement of sedentary species: Fouling and associated organisms could also be released from an infected culture site by dislodgement, which could occur accidentally (*e.g.* by boat rubbing) or deliberately through active defouling of farm nets and structures. Active defouling (*e.g.* scraping, water blasting) without collection of defouled material is a routine practice for all aquaculture operations in New Zealand. Results of recent research in New Zealand indicate that sessile organisms defouled to muddy sediments may not survive, except perhaps in the case of colonial species where hard substratum is available for reattachment (Hopkins *et al.* 2011b). However, there are exceptions; for example, Hopkins *et al.* (2011a) described the survival of a non-indigenous brown mussel (*Perna perna*), and several sedentary biota (both native and non-indigenous) when an oil rig was defouled over soft-sediments in Tasman Bay near Nelson. Hence, the nature of the soft-sediment habitat (sediment texture, sedimentation rate, turbidity, *etc*.) and the extent to which it structured by physical or biogenic features are likely to be important characteristics that determine post-defouling survival for sedentary species.

Potential for invasion by mobile pest species: Unlike many sessile species, a number of the mobile species regarded as high risk pests (see examples in Table 1) tend to be habitat generalists capable of invading both hard substrata and soft-sediments (*e.g.* the seastar *Asterias amurensis* and crab *Carcinus maenas*). Although such species are not typically regarded as being associated with suspended structures, anecdotal reports indicate that *Asterias amurensis* recruits from its planktonic life-stage to mussel farms in Port Phillip Bay, Australia. Presumably this species can then migrate to the seabed. Such observations highlight a potentially important ecosystem role for marine farms (and other artificial structures) as beach-head habitats that mediate the recruitment of mobile species from the water column to the seabed. Detachment of such species from a marine farm to the seabed could conceivably occur by active migration or dislodgment.

Additionally, Figure 5 highlights that pest species may spread among finfish farms, to other artificial structures (*e.g.* other mussel farms), or to vessels. Structures and vessels can therefore act as ‘stepping-stones’ that facilitate marine pest spread at regional or greater scales, as described in various studies (Floerl & Inglis 2005; Floerl *et al.* 2009; Bulleri & Chapman 2010; Forrest *et al.* 2011). In relation to finfish culture in the Waikato region, marine pests may:

- Infect industry vessels and equipment by the various mechanisms described above (*e.g.* fouling, bilge water): This may lead to farm-to-farm spread of marine pests, or spread to processing facilities or home ports industry-associated vessels.
- Infect non-industry vessels and equipment: The infection of non-finfish pathways may be important processes for marine pest spread if, for example, finfish farms created a hub of recreational fishing activity and such vessels were infected by pests established on farms. Similarly, finfish farms may infect shellfish aquaculture (although see earlier comment that the reverse is probably more likely), and lead to the spread of pests with inter-regional transfers of seed-stock and equipment.
- Naturally disperse among structures: The extent to which natural stepping-stone dispersal is likely to spread marine pests among finfish farms (and across the wider area) can be a gauged from results of preliminary particle dispersion modelling conducted for Zone 2 (Zeldis *et al*. 2010). That work indicates that marine pest propagules are likely to be transported throughout Zone 2 and beyond within hours of release. The work also suggests that propagules could be transported throughout much of the Firth of Thames and southern Hauraki Gulf in as little as two days.

Based on the particle dispersion modelling, we suggest that for most of the recognised pests species described in Section 4.2, it is quite likely that the infection of a single site will lead to widespread infection of finfish culture structures across both zones; certainly within them. The reason is that most marine pests have planktonic competency periods of at least 1 day (often longer), hence will be capable of dispersing over scales of kilometers or more in the strong currents within and between the farming zones. The kelp *Undaria* is at least one exception, as its natural dispersal capacity is more limited (Forrest *et al.* 2000) and there may be relatively low connectivity between Zones 1 and 2. However, dispersal within each zone is almost assured by the fact that this species (and other short-dispersing pest species) can incrementally spread among structures over multiple generations. The implications of these findings for farm management and spacing are discussed in Section 7.5.

4.4.2. Exacerbation of marine pests

This term describes processes whereby marine finfish cultures create environmental conditions that exacerbate existing biosecurity risks, and is distinct from the idea of culture sites being a marine pest infection reservoir *per se*. A key regional issue in this category is nutrient enrichment in the water column as a result of finfish culture, but seabed organic enrichment may be locally important (Forrest *et al.* 2007).

Nutrient enrichment and HABs

As noted in Section 4.2.4, water column nutrient enrichment has the potential to contribute to HAB formation. Although phytoplankton blooms (including HABs) are natural phenomena, point source nutrient inputs to coastal areas, especially of dissolved inorganic nitrogen from finfish culture, have the potential to exacerbate established blooms, for example by intensifying or prolonging the duration of bloom events. However, causal links between finfish farm enrichment and the formation or occurrence of blooms have not been made in overseas studies (La Rosa *et al.* 2002; Tett & Edwards 2002). Similarly in New Zealand, evidence to date from the Marlborough Sounds and Stewart Island suggests that bloom formation is a regional phenomenon unrelated to point source nutrient inputs from salmon farms (Chang *et al.* 1990; Hopkins *et al.* 2004; Forrest *et al.* 2007).

Nonetheless, it is theoretically possible for incremental increases in nutrient concentrations from finfish farms to affect the magnitude or duration of natural bloom events. A preliminary assessment of nutrient enrichment effects associated with finfish culture development in Zone 2 concluded that, under a worst-case scenario, phytoplankton biomass in some parts of the wider region (*i.e.* spatially removed from the immediate environs of culture sites) could increase by 5-10% (Zeldis *et al.* 2011). These authors also noted that there may be an increased likelihood of intermittent phytoplankton blooms, although their modelling approach was not designed to address that issue.

Clearly, if a HAB species was dominant within a phytoplankton bloom, it could be highly significant to regional uses and values, including the finfish industry. In addition to risks associated with biotoxin production, blooms can have a range of other effects noted in Section 4.2.4. Given such risks, additional consideration of bloom (especially HAB) potential is warranted, although we note that even with considerably greater effort, predictions of HAB occurrences in relation to point source nutrient inputs may not be particularly reliable. Hence, a precautionary approach to farm development, and associated monitoring of HAB risks may be desirable (see Section 7).

Nutrient enrichment and invasive macroalgae

In the same way that nutrient enrichment has potential links with HABs, it has also been suggested that high dissolved inorganic nitrogen loads may promote the productivity of benthic macroalgal species. In relation to finfish culture development in the Firth of Thames and southern Hauraki Gulf, Kelly (2008) suggested that nutrient inputs could promote Unwanted species such as the kelp *Undaria*. While such possibilities cannot be discounted for some species, experience elsewhere in New Zealand with *Undaria* suggests invasiveness in both artificial and natural habitats varies naturally across small spatial scales as well as inter-annually (Forrest & Taylor 2002). On artificial structures throughout the Marlborough Sounds, *Undaria* is not visibly more abundant or luxuriant in close proximity to salmon farms or other point source nutrient inputs (B. Forrest, pers. obs.).

Other mechanisms of exacerbation

Environmental disturbance, induced for example by pollution, is a recognised factor that can contribute to the invasion or proliferation of NIS (*e.g.* Piola & Johnston 2008). One of the localised disturbance effects of finfish culture is the development of a strong organic enrichment gradient and associated faunal responses in sediments beneath and adjacent to cages (Forrest *et al*. 2007). A number of New Zealand studies highlight that the non-indigenous soft-sediment bivalve *Theora lubrica*, a species already widely established in the Hauraki Gulf (Hayward 1997), can occur at greatly enhanced abundances at intermediate levels of enrichment or disturbance from finfish and oyster culture (Forrest & Creese 2006;

Keeley *et al.* 2011). Enhancement of this and perhaps other NIS is likely with the development of finfish culture in the Waikato region, but the significance of such effects is reduced by the fact that benthic enrichment is a highly localised impact (typically restricted to a few tens or hundreds of metres from cage sites). Furthermore, numerous other sources of disturbance or enrichment may already have enhanced such species.

5. PATHOGENS AND PARASITES

5.1. Background

There are many known diseases and parasites associated with finfish (Blaylock & Whelan 2004; Hutson *et al.* 2007a), and the spread of parasites, viruses and bacterial infections between caged and wild fish populations (or vice versa) is a significant concern for the fish farming industry worldwide. Diseases and parasites can detrimentally affect stock, which can adversely affect production (*e.g.* through reduced growth rates, unmarketable fish, and mass mortalities). For example, copepod sea lice infestations have hampered development of the salmon farming industry in Europe (particularly Scotland), North America, Chile and Far East Asia (Butler 2002; Nagasawa 2004; Yatabe *et al*. 2011). However, there is also the potential for pathogens and parasites to impact on wild fish populations (including conspecifics) and the wider environment. While documented cases of such occurrences are relatively uncommon, finfish culture nonetheless has the potential to impact a wide range of values at a regional or even national scale (Kelly 2008).

Despite there being several reported diseases in three species of New Zealand resident salmon, *Oncorhynchus* spp. (Diggles *et al*. 2002), cultured King salmon (*Oncorhynchus tshawytscha*) in this country have been largely free from problems with pathogens or parasites (Forrest *et al.* 2007). However, based on the available literature this low-risk scenario is unlikely to be the case for kingfish and hapuku culture, as they are indigenous species that will be susceptible to the pathogens and parasites of their wild conspecifics. In this section, we overview the pathogens and parasites of kingfish and hapuku, identify key infection pathways for the proposed finfish farming sites, and describe how disease agents may be enhanced or spread from farming activities in the Waikato region. Implications for Waikato region values are discussed in Section 6. Mitigation measures referred to below are considered further in Section 7.

5.2. High risk pathogens

5.2.1. Kingfish

Globally, a broad range of parasites and pathogens are described for cultured finfish belonging to the *Seriola* genus; including viral, bacterial and fungal disease agents (*e.g.* Egusa 1983; Stephens & Savage 2010), and protozoan and metazoan parasites (Rigos *et al*. 2001; Diggles 2002; Diggles & Hutson 2005; Hutson *et al.* 2007a, b).

Kingfish in Australasia have a range of known pathogens and parasites (Table 3), but it is apparent that the monogenean (flatworm) ecto-parasites are the most problematic in Australian kingfish culture. This situation arises because monogeneans have direct, single-host life-cycles (*i.e.* do not require an intermediate host; see Box 3) and can multiply rapidly in high-density aquaculture environments (Tubbs *et al*. 2005). Furthermore, their eggs become entangled in fish nets and fouling, leading to high re-infection rates of cultured fish (Ernst *et al*. 2005).

Hutson *et al*. (2007) undertook a risk assessment for metazoan parasites of *Seriola lalandi* in South Australia sea-cage culture, and identified the monogeneans *Benedenia seriolae* and *Zeuxapta seriolae* as “extremely likely to establish and proliferate” at new farm sites. *Benedenia seriolae* (skin fluke) inhabits the skin and fins of kingfish (Figure 6), and can negatively impact fish growth and marketability (Egusa 1983; Chambers & Ernst 2005). Similarly, the gill fluke *Zeuxapta seriolae* can significantly affect the health of cultured fish (Mansell *et al*. 2005).

The cost of managing monogenean parasites such as *Benedenia seriolae* and *Zeuxapta seriolae* is seen as a significant barrier to the expansion of kingfish farming in Australia (Hutson *et al*. 2007b) and potentially New Zealand (Leef & Lee 2009), with estimates of 20% of total production costs to control these parasites cited in the literature (*e.g.* Ernst *et al*. 2005). Control measures are described in Section 7.4.3.

Table 3. Some diseases of cultured kingfish in Australia and their occurrence in New Zealand kingfish (modified from Table 1 in Diggles & Hutson 2005). Except for pathogenic viruses and bacteria (*), the remainder are parasites[1].

Group	Disease agent	Australia	New Zealand
Virus*	Nodavirus	√	
Bacteria*	Epitheliocystis	√	√
	Vibrosis		√
Protozoa	Scuticociliate infection		√
Myxozoa	*Myxidium* sp.		√
	Ceratomyxa seriolae	√	
	Ceratomyxa buri	√	
Metazoa			
Monogenea	*Benedenia seriolae*		√
	Zeuxapta seriolae	√	
	Paramicrocotyloides reticularis	√	
Digenea	*Paradeontacyliz* sp.		√
Crustacea	*Caligus epidemicus* [2]	√	
	Caligus lalandei		√
	Caligus spinosus	√	√
	Caligus sp.	√	
	Naricolax sp.	√	
	Neobrachiella sp.		√
	Lernanthropus sp.		√

[1] Protozoa and Myxozoa are single celled and multicellular parasites, respectively. Monogenea and Digenea (flukes) are classes of parasitic flatworms. The various genera listed under Crustacea are all types of parasitic copepods (*e.g.* ‘sea lice’, *Caligus* spp.) in sub-Class Copepoda.

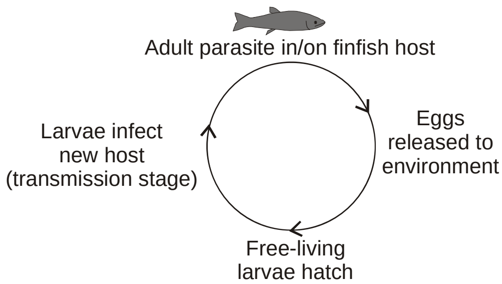
[2] *Caligus epidemicus* described in flounder in New Zealand (Diggles 2008).

Figure 6. Infection of a kingfish by the monogenean fluke (*Benedenia seriolae*), and a close-up of the parasite.

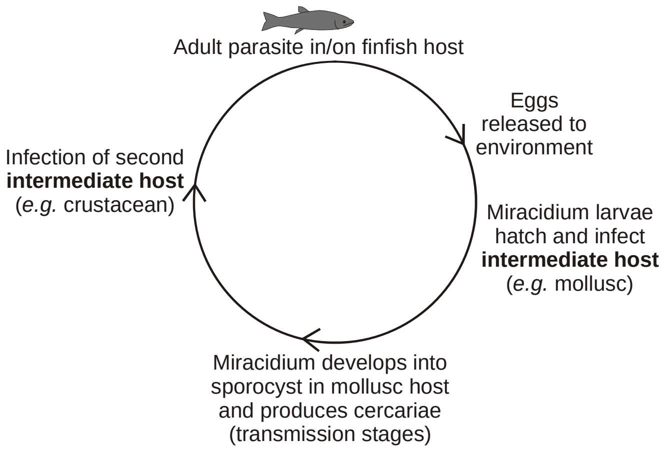
Box 3. Stylised examples of simple and complex parasite life cycles

Parasites have a life-cycle that can be simple (example A below) or complex (example B below). Monogeneans (example A) lay eggs directly in the water column that are then dispersed by tidal currents. After several days they hatch into a ciliated larva (oncomiracidium) and swim until they encounter a suitable host. Because they are host-specific, they will soon die if a suitable host is not encountered (Ernst *et al*. 2002). Other groups (*e.g.* cestodes, nematodes, myxozoans and digeneans) are characterised by having at least one intermediate host, but generally have complex multi-host life cycles as shown below (example B). Fish may be the final host in some digenean and myxozoan infections. For some nematodes and cestodes, fish are themselves intermediate hosts. The final hosts in these cases include marine mammals and sharks. Simple life cycles allow more direct fish-to-fish transmission; complex life cycles require other hosts and the control of these hosts can be a method of reducing the impact of the parasites on the culture species.

(A) SIMPLE LIFE CYCLE



(B) COMPLEX LIFE CYCLE (E.G. TWO HOSTS)



Other metazoan parasites identified as posing a risk to kingfish aquaculture in Australia include *Paradeontacylix* spp. (Trematoda), *Kudoa* sp. and *Unicapsula seriolae* (Myxozoa), as there is currently a lack of treatment methods for these species (Hutson *et al*. 2007b). Smith *et al*. (2009) identify the ciliate *Miamiensis avidus*, a protozoan pathogen found in New Zealand *Polyprion* spp., as a potential threat. This protozoan caused mortalities in juvenile hapuku and adult kingfish in a Northland hatchery, which has implications for the culture of kingfish and hapuku in close proximity (see Section 7.5).

Many known disease groups in *Seriola* spp. (including viruses, opportunistic bacterial pathogens, obligate parasites, myxozoan groups and sanguinicolid digeneans) are under-represented in New Zealand (Diggles 2002), with Table 3 revealing a number of species associated with culture in Australia that are not reported for New Zealand kingfish. However, farming fish at high densities can result in the concentration and emergence[7] of diseases; for example, diseases that occur at such low prevalence in wild populations that they are undetected (Weaver 2001; Diggles 2002). Furthermore, the likelihood of disease increases as aquaculture expands and intensifies (Bondad-Reantaso *et al*. 2005; Stickney 2009).

5.2.2. Hapuku (*Polyprion oxygeneios*)

Only limited grow-out trials have been undertaken in New Zealand for hapuku, and thus there remains considerable uncertainty regarding which pathogens or parasites will become persistent commercially significant diseases (Zeldis *et al*. 2011). During preliminary trials, the only infectious disease identified was a bacterial infection resulting from handling stress (Zeldis *et al*. 2011). However, the available literature identifies *Vibrio ichthyoenteri* (Anderson *et al*. 2010), *Uronema marinum* (Anderson *et al*. 2009), *Miamiensis avidus* (Smith *et al*. 2009), *Allocotylophora polyprionum* (Hewitt & Hine 1972) and *Lepeophteirus polyprioni* (Hewitt & Hine 1972) as the pathogens and parasites most likely to pose a threat to farmed hapuku (Table 4).

Although likely to be of lesser importance, the following organisms may also be significant, hence could be considered as part of routine surveillance (see Section 7.4.3): (i) the digeneans *Neolepidopdeon polyprioni* and *Tubovesciula angusticauda* (Hewitt & Hine 1972) are a threat because, being indigenous, they are likely to have their intermediate hosts nearby; (ii) the cestode *Hepatoxylon trichiuri* (Waterman & Sin 1991) is not transmissible to other fish but it could present an aesthetic threat to marketability should significant infection occur; and anisakid nematodes such as *Anisakis* sp. (Hewitt & Hine 1972) present a similar aesthetic threat and also can cause human anisakidosis that would also reduce marketability of cultured fish.

[7] An emerging disease is defined as a new disease, a new presentation of an existing disease (*e.g.* increased severity), or the appearance of an existing disease in a new geographic area (Brown 2000 cited in Murray & Peeler 2005).

Table 4. Significant pathogens and parasites of *Polyprion* spp. identified from New Zealand studies (unless otherwise indicated). A description of the common name/group for these organisms is given in the caption and footnote to Table 3, except for Cestoda which refers to tapeworms.

***Polyprion* host**	**Group**	**Parasite**
Polyprion oxygeneios	Bacteria	*Vibrio ichthyoenteri*[1]
	Protozoa	*Uronema marinum*[2], *Miamiensis avidus*[3]
	Digenea	*Neolepidopdeon polyprioni*[4], *Tubovesciula angusticauda*[4]
	Monogenea	*Allocotylophora polyprionum*[4]
	Cestoda	*Hepatoxylon trichiuri*[5]
	Nematoda	*Anisakis* sp.[4], *Contracaecum* (*Thynnascaris*) sp.[4] *Cucullanus* sp.[4], *Ascarophis* sp.[4], *Hysterothylacium* (= *Thynnascaris*) sp.[6]
	Copepoda	*Lepeophteirus polyprioni*[4], *Lepeophteirus selkirki*[7] (Chile), *Jusheyus shogunus*[8]
Polyprion moene	Myxozoa	*Ceratomyxa moenei*[6]
	Copepoda	*Lepeophteirus polyprioni*[6]
Polyprion americanus	Copepoda	*Jusheyus shogunus*[9] (Atlantic USA)
	Monogenea	*Calicobendenia polyprioni*[10,11] (Atlantic USA)

[1] Anderson *et al*. (2010), [2] Anderson *et al*. (2009), [3] Smith *et al*. (2009), [4] Hewitt & Hine (1972), [5] Waterman & Sin (1991), [6] Hine *et al*. (2000), [7] Romero & Kuroki (1981), [8] Deets & Benz (1987), [9] Benz *et al*. (1999), [10] Kritsky & Fennessy (1999), [11] Perkins (2010).

5.3. Infection pathways for marine pathogens and parasites

Figure 7 highlights a number of potential infection pathways for marine pathogens and parasites that mirror those for marine pests (*e.g.* stock transfer water); however additional pathways related to the culture species or farm practices also need to be recognised, such as feed imports. For finfish culture-related activities to result in a new parasite or pathogen being introduced into the environment, a chain of events must occur (Figure 8), beginning with the disease agent being present in the source region (*i.e.* where fish stocks or feed originate), through to the pathogen or parasite coming into contact and infecting a susceptible host. There are various opportunities for finfish farm operators and environmental managers to disrupt the chain of events and prevent new incursions or outbreaks, which are discussed in Section 7.3.

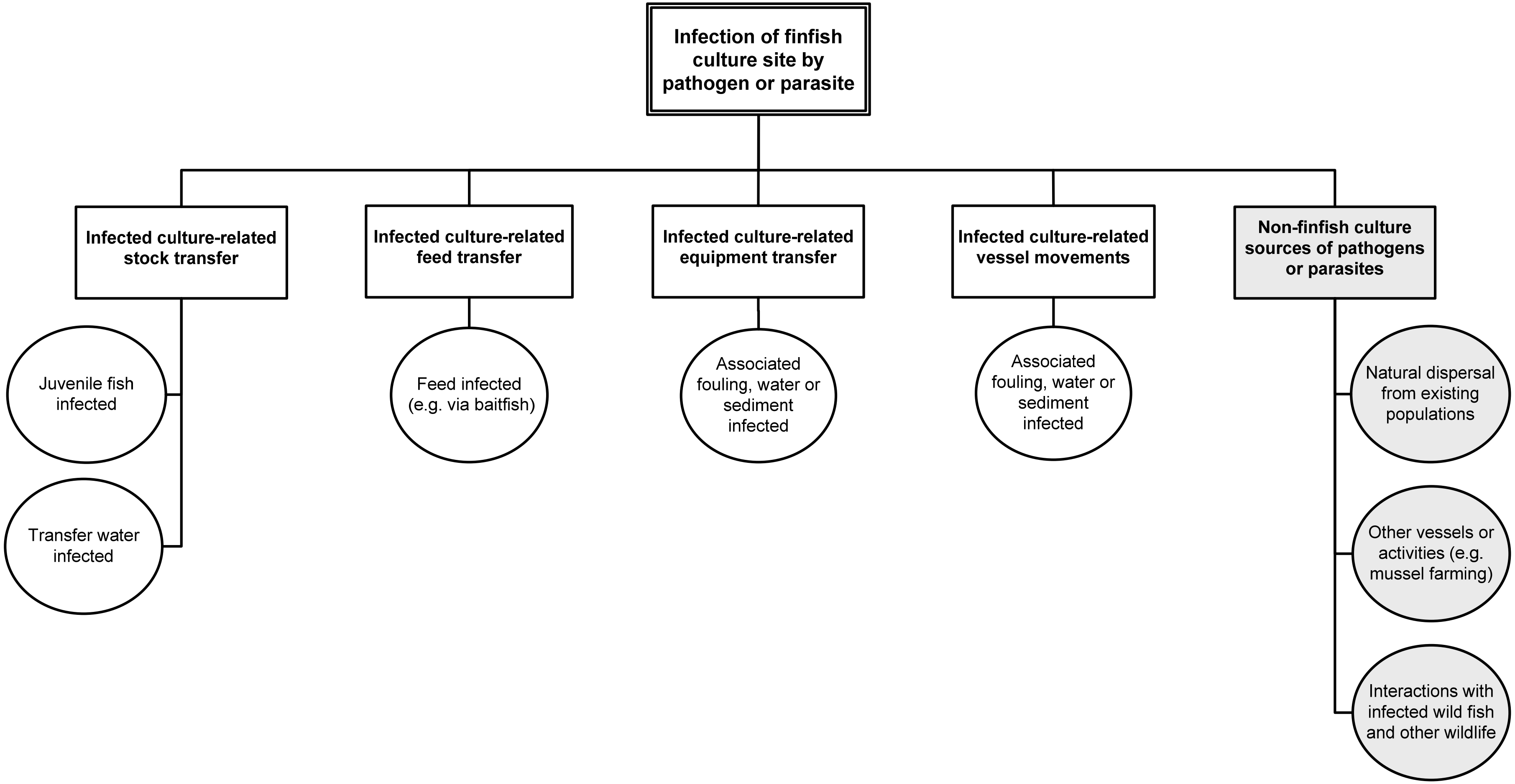
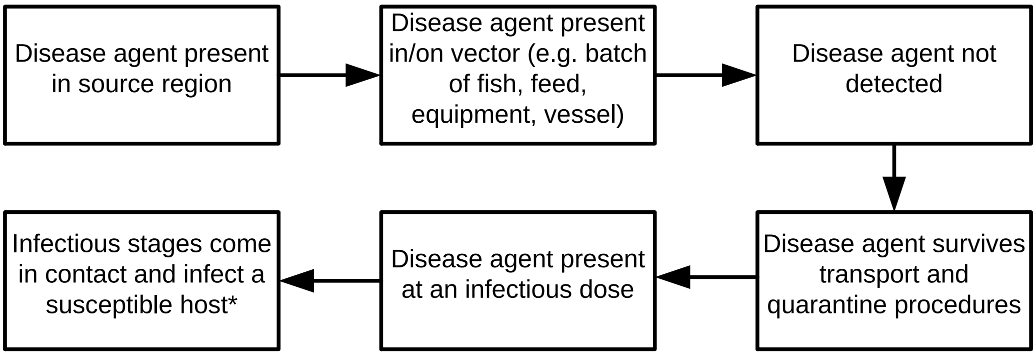


Figure 7. Summary of key pathways and related mechanisms that could lead to the infection of finfish aquaculture sites by pathogens or parasites. The grey shaded elements illustrate that biosecurity risk can arise from natural and anthropogenic sources in addition to finfish culture.



*For parasites with complex life cycles (e.g. digenean trematodes), intermediate hosts must also come into contact with transmission stages.

Figure 8. Chain of events for a pathogen or parasite infection to occur.

5.3.1. Finfish culture pathways of pathogens and parasites

Stock transfers

Stock transfers can occur across a range of spatial scales (*e.g.* sourcing overseas fingerlings, moving stock between cages within a farm) and have the potential to introduce disease into a new region via infected fish or infected transfer water. Bondad-Reantaso *et al*. (2005) cite many examples where international transfers of juvenile fish have led to the inadvertent transfer of associated pathogens or parasites. A pertinent example is a monogenean parasite of groper and other marine fish that was introduced to Japan with importation of *Seriola dumerili* fry; this parasite now apparently causes serious problems for groper culture throughout Southeast Asia.

As noted in Section 4.3.2, international kingfish stock transfers to New Zealand are tightly controlled by a MAF Import Health Standard. In addition to biosecurity procedures for stock transfer water described in Section 4.3.2, the Import Health Standard outlines stringent quarantine and control procedures to minimise the risk of disease transfer with the fish stock, including:

- Four weeks quarantine in New Zealand in an approved facility.
- Reporting and follow up procedures in the event of unexplained mortalities or signs of infectious disease.

Routine biosecurity controls to prevent disease in land-based hatcheries (*e.g.* water filtration, disease surveillance) would similarly be expected to minimise disease risks associated with domestic transfers of kingfish stock and associated water (Diggles 2008). Assuming hapuku stock were subjected to comparable biosecure rearing regimes, a similarly low pathology threat might be expected as a result of fish transfers.

Feed transfers

Finfish feed transfer is a possible pathway for infection of culture sites by disease-agents. Transmission to cultured fish can occur if the feed contains a pathogenic agent that is consumed by the farmed fish (*i.e.* direct transmission), or if the feed contains a pathogen that enters the environment or infects a non-target species, establishing a mechanism for indirect infection (OIE Aquatic Animal Health Code 2010). For example, a non-indigenous herpes virus was considered to be the cause of large-scale pilchard mortality across Australasia in 1995 and 1998-99 (Ward *et al.* 2001; Whittington *et al*. 2005). The disease originated in Australia, with possible causes considered to be ships' ballast water or imports (without quarantine) of frozen pilchards that were fed to caged tuna (Whittington *et al*. 1997). *Vibrio ichthyoenteri* in live brine shrimp *Artemia salina* has also led to fish mortalities (Anderson *et al*. 2010). Scombrid and clupeid fish are common bait fish and worldwide they carry high levels of *Kudoa* spp. (S. Webb, pers. obs.), thus their use could theoretically result in the introduction of myxozoans to cultured fish (assuming that a local intermediate host was available).

By contrast with tuna and shrimp operations, kingfish and hapuku farms in New Zealand are likely to use formulated feeds. While feed pellets appear to pose considerably less disease risk than bait fish; on rare occasions they have been associated with disease transfer to cultured fish. For example, massive mortalities of farmed turbot in China were linked to feed pellets infected with a bacterium that caused white faeces disease (Yang *et al*. 2009). In New Zealand, MAF has developed an Import Health Standard (dated 24 November 2010) to minimise the risk of such eventualities. The Standard covers constituents such as fish oil, fish meal and marine fish, and specifies key responsibilities of fish feed importers along with eligibility criteria (*e.g.* health certification) that need to be met before clearance will be given at the border (http://www.biosecurity.govt.nz/imports/ animals/ standards/fisfooic.all.htm). Examples include requirements to ensure imported feed materials are pathogen free, for example using heat treatment (fish oil/meal) and freezing or irradiation (marine fish).

Equipment and vessel transfers

As for marine pests, there exists the potential for disease transmission by equipment transfers and vessel movements via fouling, or contaminated sediments or water (Figure 7). For example, based on evidence for marine pests (see Section 4.3), we suggest that the bilge water of industry vessels could be a transport mechanism for pathogens and parasites. However, by comparison with the knowledge-base for marine pests, the importance of bilge water and other mechanisms for disease agents is not well understood. There is evidence of the transport of pathogens in ships' ballast water (Ruiz *et al.* 2000a; Drake *et al.* 2007), and at least one finfish industry example highlighting the potential importance of industry activities in the spread of disease agents. Murray *et al*. (2002) linked the spread of infectious salmon anemia, an economically significant disease in salmon aquaculture overseas, to vessels moving fish between sites and transporting harvested fish to factories. The source of pathogens for the service vessels used to transport fish was considered to be: (i) ballast water contaminated with effluent from a processing plant or an adjacent harvest station, or (ii) infected fish remaining in wells, pumps or pipework of the vessel following discharge. In Norway, there was a marked reduction in outbreaks of this disease following the introduction of stricter regulations to control vessel hygiene.

An additional consideration for pathogens and parasites is that fouling, detritus and farm structures can act as a reservoir of parasites and pathogens for cultured fish (Tan *et al*. 2002; de Jong & Tanner 2004; Whittington & Chisholm 2008). In South Australia, anecdotal evidence suggests that controlling fouling biomass on kingfish farm nets can influence the frequency and severity of monogenean parasite infections (*Benedenia seriolae* and *Zeuxapta seriolae*) (Zeldis *et al*. 2011). Hence, if structures are moved to a new farming area without appropriate mitigation measures, they may result in the inadvertent spread of not only marine pests, but also pathogens or parasites associated with the structure and its fouling assemblages.

5.3.2. Non-finfish culture sources of pathogens and parasites

Natural dispersal

Of some relevance to understanding kingfish culture risk is evidence that larger fish can migrate between Australia and New Zealand (Gillanders *et al*. 2001). Hence, it is theoretically possible that natural kingfish movements could lead to disease risk to New Zealand irrespective of anthropogenic pathways of juveniles for stocking purposes. Further discussion on this issue can be found in Diggles (2002). However, it is more likely that the majority of pathogens and parasites associated with kingfish and hapuku aquaculture will occur naturally in the marine environment, with transmission to farmed finfish occurring through: (i) contact with disease agents present in the water column, (ii) contact with infected wild finfish (including conspecifics), and (iii) contact or dispersal from infected intermediate hosts (*e.g.* bivalves, crustaceans).

The potential for finfish farms in the Firth of Thames to be infected by parasites and pathogens occurring naturally in the water column is poorly understood. However, examples exist of finfish infection via contact with disease agents in the water column, both in marine and freshwater environments. For example, in North America, the myxosporean parasite *Ceratomyxa shasta* infects freshwater salmonids. Actinospores (transmission stage) released to the water column from the intermediate host (a polychaete worm) infect other salmonids upon contact (Bartholomew *et al*. 1997). In the marine environment, it is currently thought that the trematode worm *Bucephalus longicornutus*, which can infect dredge oysters (*Ostrea chilensis*), releases tadpole-like larvae (cercariae) that are dispersed by currents and can infect finfish species.

Infection by wild fish

Compared with water column infection sources, the infection of farmed fish by wild species (particularly conspecifics) is relatively well documented, and likely poses the greatest disease risk to finfish operations (Diggles 2008). Finfish aquaculture structures can lead to the attraction or aggregation of wild fish (Dempster *et al*. 2002), which may result in pathogen or parasite transfer from farmed fish (or from uneaten feed) to wild stocks, and vice versa. As kingfish are a wide ranging and important recreational species in the Firth of Thames and southern Hauraki Gulf, their interactions with cultured fish seem highly likely. For hapuku, anecdotal evidence indicates that local populations occur in deeper water off the Coromandel Peninsula, but their likely association with sea-cage structures is unknown.

An assessment in Australia by Hutson *et al*. (2007b) reveals that a diverse range of metazoan parasites infect *Seriola*; however, a much lower diversity of parasites infect cultured kingfish stocks compared with wild conspecifics (Table 5). Thus, local kingfish populations can be a major source of parasites for the cultured kingfish, rather than vice versa (Hutson *et al*. 2007b). The same will possibly be true for the Waikato region, as wild kingfish populations in New Zealand have a high incidence of infections by many metazoan parasites of the skin and gills. In fact, of 46 kingfish inspected from four regions around New Zealand by Sharp *et al*. (2003), all were infected with the commercially significant monogeneans *Benedenia seriolae* and *Zeuxapta seriolae*.

Table 5. Overview of metazoan parasites described from wild and farmed *Seriola lalandi* in Australia (modified from Table 1 in Hutson *et al*. 2007b).

Group	No. of taxa	Infection ratio (wild:farmed)
Acanthocephala	3	3:0
Cestoda	4	4:2
Copepoda	11	11:3
Monogenea	3	3:2
Myxozoa	4	4:2
Nematoda	6	6:0
Trematoda	21	21:5

Disease interaction between wild conspecifics and farmed fish is expected to mainly be limited to taxa with direct life cycles that can be transmitted (horizontal transmission) into a sea-cage environment (Diggles 2008). As well as the monogeneans, this category includes protozoan and copepod parasites. Disease agents with complex multi-host life cycles (*e.g.* cestodes, nematodes, myxozoans and digeneans) appear less likely to infect cultured finfish in this way, except where intermediate hosts are present. Finfish in culture may become infected by infective life stages of disease agents released by intermediate hosts, or by direct consumption of infected intermediate hosts (Hutson *et al*. 2007b). The Hutson *et al*. study provides a detailed assessment of such risks to kingfish culture in Australia. For the Waikato region, assessment of infection risk for disease agents having complex life-cycles will likely be hampered by the lack of knowledge of the intermediate host species. Intermediate hosts could be associated with fouling, sediments beneath cages, and perhaps cultured bivalves (see Section 5.4.4).

Other sources of risk

As with vessels servicing finfish culture sites (see previous section), local vessels such as recreational craft operating near finfish farm sites have the potential to transport disease agents via the variety of mechanisms described above, but their potential importance is unknown.

As was noted for marine pests in Section 4.3.3, at a broad geographic scale it is hypothetically possible that disease agents could be introduced through discharge of ballast water from vessels transiting the Hauraki Gulf (Drake *et al.* 2007; Raynard *et al.* 2007). While it is unlikely that free-swimming stages of monogeneans would survive long in ballast water, viable eggs waiting for a hatching cue could be transported in this way (Whittington & Chisholm 2008). Another possible but poorly understood mechanism is the potential for infected fish being transported into new regions via the sea chests (hull recesses) of large vessels. A New Zealand study documented several fish species inside vessel sea chests while in dry-dock (Coutts & Dodgshun 2007).

It is also possible for pathogens to be transmitted via the faeces of birds and other wildlife. For example, seagulls in Norway have been implicated in the spread of the bacteria *Yersinia ruckeri*, the causative agent of enteric redmouth disease (ERM) in salmonids (Willumsen 1989). Sea gulls scavenging on shrimps imported for human consumption were also believed to have introduced WSSV (white spot syndrome virus) to shrimp farms in the USA (Lightner *et al*. 1997).

5.4. Spread or enhancement of marine pathogens and parasites by finfish culture

5.4.1. Overview

Several cases are described in the literature where diseases have spread from farmed finfish to the natural environment and have had significant effects on wild fish stocks. For example, the monogenean parasite, *Gyrodactylus salaris*, was thought to have been introduced to Norway via infected salmon stock, and subsequently spread into Norwegian wild salmon stocks causing a major decline in their numbers (Heggberget *et al.* 1993). Similarly, infectious hematopoietic necrosis (IHN; a viral pathogen) was introduced into the Japanese marine environment via infected salmon eggs, causing significant mortalities in three species of wild salmon (Waknitz *et al*. 2003). The initial 1995 outbreak of a pilchard herpes virus across Australasia (see above) led to a dramatic decline in wild pilchard populations, which resulted in two years of reduced breeding success and prey-switching in a small Australian penguin species (Chiaradia *et al.* 2010). Given such examples, it is clearly important to consider whether the occurrence and outbreak of disease agents in cultured finfish in the Waikato region could lead to wider environmental risk. The processes by which an infected finfish culture site could spread pathogens or parasites to the wider environment are depicted in Figure 9 and discussed below.

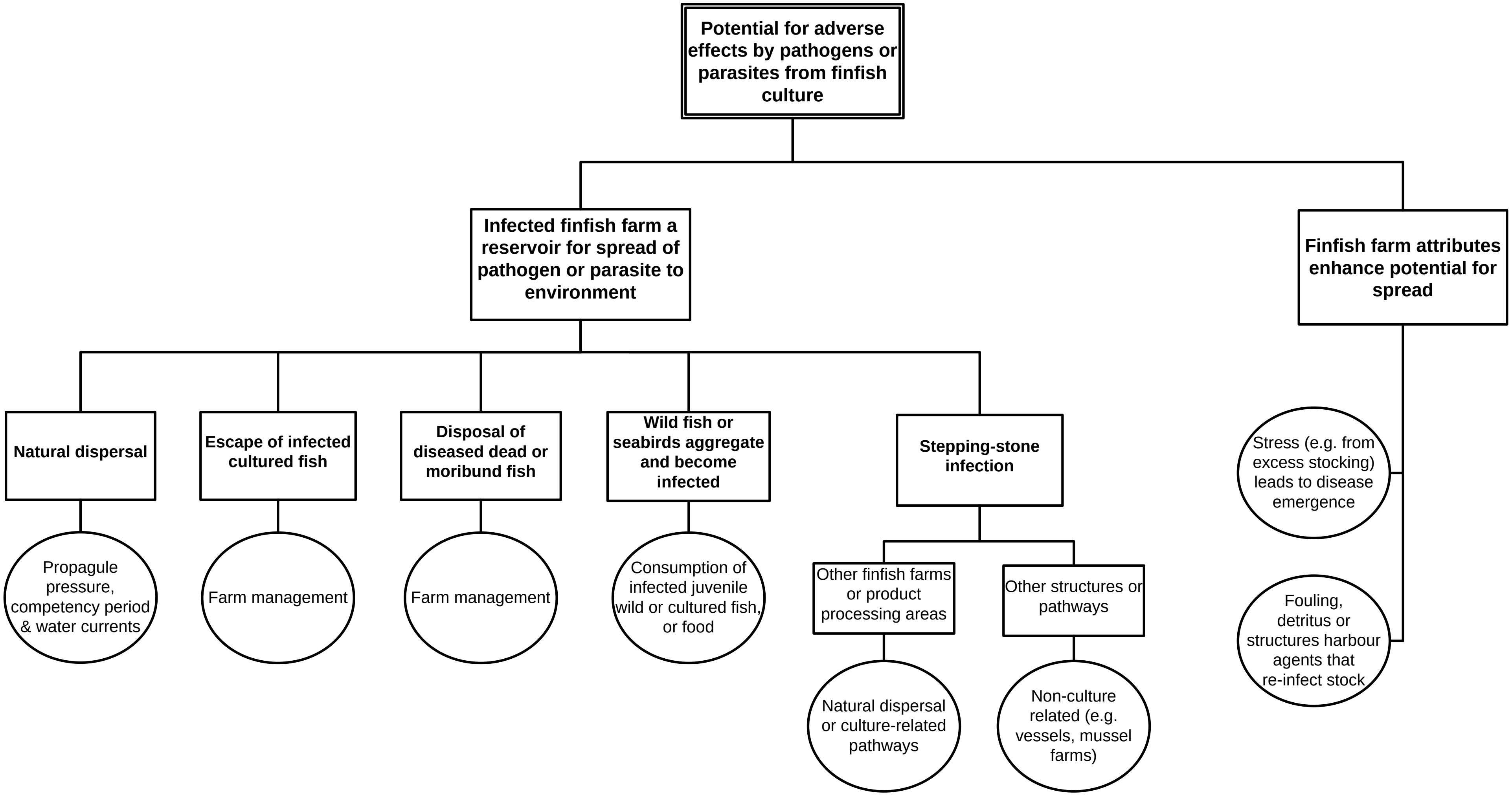


Figure 9. Summary of key processes by which a finfish culture site infected by pathogens and parasites could create the potential for adverse environmental effects.

5.4.2. *Direct spread by natural dispersal and fish or bird interactions*

Disease agents in culture could be transmitted directly into the wider environment by:

- Natural dispersal of disease agents from culture sites.
- Direct interactions between cultured and wild fish.
- Direct interactions with other wildlife such as birds.

Natural dispersal mechanisms

Pathogens and parasites may be spread from finfish farms via water currents (Murray & Peeler 2005). Potential dispersive stages include freely suspended pathogens and parasites searching for a new host, and larval or intermediate life-stages of parasites (Pike & Wadsworth 1999; Podolska & Horbowy 2001). Micro-pathogens (*e.g.* viruses and bacteria) are completely passive in their movement and are at the mercy of water currents for dispersal. Larger parasites have some swimming ability; however like smaller pathogens their fate is also largely driven by water currents (Murray *et al.* 2005). For example, transmission of sea lice (*Lepeophtherius salmonis* and *Caligus elongates*) between salmon populations in Scotland is thought to occur during the planktonic stages, and given that planktonic stages can last in the water column for two weeks, significant transport and dispersion by currents is possible (Amundrud & Murray 2009). Similarly, pancreas disease caused by salmonid alphavirus (SAV) is presently thought to spread passively between salmon farm sites in Norway (Viljugrein *et al*. 2009). We discuss the implications of natural dispersal in Section 7.5 in relation to farm spacing.

Interactions between cultured and wild fish

Direct interactions between cultured fish and wild fish populations may arise through the aggregation of wild fish to farm structures (see Section 5.3.2). This could lead to the direct transfer of disease agents by natural dispersal, or via the wild fish consuming infected cultured fish (dead or diseased) or infected feed. Hence, farm management and appropriate disposal of moribund or dead fish (including those killed for disease control) is important (Raynard *et al.* 2007; OIE Aquatic Animal Health Code 2010).

Fish escapes are another source of interaction, as escapee fish are almost inevitable despite economic incentives to manage such events (*e.g.* systematic dive inspections, prompt repairs, recapture of escaped fish that remain in the vicinity) (de Jong & Tanner 2004). The significance of these interactions will be species-specific. For kingfish, it was suggested in Section 5.3.2 that wild populations may be a source of pathogens and parasites to cultured kingfish (because of aggregation to farms), rather than vice versa. For hapuku, the likely extent of association with sea-cage structures is unknown, but if it is negligible then fish escapes may be a greater source of interaction between cultured and wild fish.

Interactions with other wildlife such as birds

Direct interactions with other wildlife such as birds are possible, but risk of disease transmission is poorly understood. The rapid spread of the Australasian pilchard virus led Whittington *et al*. (1997) to hypothesise that piscivorous birds were a possible transmission vector. Birds may be attracted to finfish farms to scavenge on uneaten feed; however this is likely to be less pronounced if pelleted feed (as opposed to baitfish) is used (Harrison 2003; de Jong & Tanner 2004). Pathogen/parasite transfer to birds attracted to finfish farms could occur via the consumption of infected uneaten feed, juvenile cultured fish and infected wild fish aggregating around farm sites (de Jong & Tanner 2004). As discussed above, commercially-sourced pelleted feeds from overseas must meet stringent criteria, and are therefore unlikely to pose a disease risk.

5.4.3. Implications for wild fish populations

A number of examples exist of disease in cultured finfish leading to effects on wild stock. Koi herpes virus (KHV) was thought to have spread from cultured ornamental fish to cultured food fish (common carp) and then into wild carp populations (Bondad-Reantaso *et al*. 2005). Indirect correlations have also been used to link copepod sea lice infestations with salmon farming in the northern hemisphere (Bjorn & Finstad 2002), but such studies fail to provide evidence for a causal link (deJong & Tanner 2004; however see also Krkošek 2010). For monogeneans, the most likely problematic parasite group in kingfish culture, there appears to one published report of mass mortalities in wild fish populations (mullet) attributed to the monogenean *Benedenia monticellii*. However, in that example heavy oil pollution appears to have confounded the cause of fish mortality (Paperna & Overstreet 1981).

Diggles (2008) specifically considered the potential for transfer of a broad range of pathogens and parasites (viruses, bacteria, protozoans, myxozoans, cestodes, monogeneans, digeneans, acanthocephalans, nematodes and copepods) between cultured and wild fish in the Waikato region, with reference to kingfish, snapper and flatfish. That study indicated that risks to wild populations are likely to be quite low. At worst, in the immediate vicinity of sea cages elevated infection rates may occur for disease agents with direct life-cycles (*e.g.* monogeneans). For example, high densities of the economically significant monogenean *Benedenia seriolae* were found within 1 km of kingfish cages in Australia, raising the possibility that wild kingfish in the immediate vicinity could experience higher infection rates (Chambers & Ernst 2005).

However, Diggles (2008) considered that the risk of monogenean hyper-infection (the prerequisite for disease transmission in wild populations) developing in wild species as a result of finfish culture was minimal due to the mobility of wild fish. Furthermore, monogeneans are highly host-specific, hence unlikely to be transmitted among different finfish species. Diggles considered that hyper-infection could only occur if wild conspecific fish became resident in the immediate vicinity of sea-cages, but such effects could in part be mitigated by fallowing.

Other key conclusions of the Diggles (2008) report are as follows:

- Threats posed by viruses and bacteria to cultured fish are expected to be greater than the risk to wild fish. For example, bacteria are ubiquitous in the environment but do not significantly affect wild populations. They are opportunistic disease agents that only adversely affect cultured fish that are stressed or injured.

- Myxozoans, cestodes, acanthocephalans, digeneans and nematodes appear to generally pose a low risk to wild fish. Many of these species have a high host specificity and complex multi-host life cycles, hence are unlikely to be transmitted directly from sea-cages to wild fish.
- Protozoans are not considered a threat to wild fish but cultured fish may be more susceptible. This has now been demonstrated in the case of the protozoan *Miamiensis avidus* (Smith *et al*. 2009), a species with potential to affect both kingfish and hapuku culture. While protozoans have direct life cycles and low host specificity, they seldom cause disease in wild fish populations. As for monogeneans, the mobility of wild fish is expected to minimise the risk of hyper-infection in the vicinity of infected cultures.
- Copepods are considered low risk. Although parasitic copepods can often move between hosts, the Diggles (2008) report indicates that there is no evidence that infected cultures lead to increased copepod infection in wild populations.

5.4.4. Shellfish/finfish culture disease interactions

Given that the Firth of Thames is a major mussel and oyster growing region, the potential for interactions between fish and bivalves merits consideration, especially considering that high densities of bivalves and finfish will be in close proximity, which may facilitate transmission potential. In the same manner that shellfish can accumulate biotoxins, filtration by bivalves means they have the potential to accumulate microbes (*e.g.* viruses and bacteria) that may be pathogenic to other species. Human health effects from pathogens that have accumulated in bivalves are long recognised. In relation to finfish culture, some related interactions are:

- Pathogen accumulation and the role of finfish cultures as reservoirs for bivalve infection, and vice versa.
- The role of bivalves as intermediate hosts allowing fish disease agents to complete their life cycle (*i.e.* enabling fish-bivalve-fish transmission).

The cursory overview below reveals a lack of information on these interactions, hence further investigation of situation-specific risks is probably warranted.

Pathogen accumulation and finfish/bivalve susceptibility

Bivalves have a recognised but poorly understood role as reservoirs for viral and bacterial pathogens of finfish, which has potential implications for culturing the two groups in close proximity (Meyers 1984 and references therein). Bacteria and viruses pathogenic to fish have been found in bivalves (*e.g.* Mortensen 1993). As reservoirs for finfish pathogens bivalves may be asymptomatic, although the potential exists for shellfish and finfish to be affected by the same pathogens. For example, bacterial agents such as *Vibrio* spp. can be pathogenic to both fish and shellfish. While this group is ubiquitous in the environment, pathogenic species have been described in ships' ballast water (Ruiz *et al.* 2000b; Drake *et al.* 2007).

In New Zealand, viruses closely related to infectious pancreatic necrosis virus (an internationally significant finfish disease) have been reported in healthy King salmon (*Oncorhynchus tshawytscha*) returning from the sea on the east coast of South Island. Despite there being no reported association with disease outbreaks in New Zealand (Diggles *et al*. 2002), this virus has caused disease in Taiwanese clams (VPS 2000) and has been claimed to reside in the scallop *Pecten maximus* (Mortensen 2000). Thus, there is appears to be the potential for viral transmission between vulnerable finfish and certain bivalves.

Bivalves as intermediate hosts

A number of examples indicate that bivalves may act as intermediate hosts for some disease agents. For example, Kitamura *et al*. (2007) report an aquatic birnavirus (ABV) in the blue mussel *Mytilus galloprovincialis*, where the mussel was a reservoir host for infections in the Japanese flounder *Paralichthys olivaceous*. For parasites the situation is less clear; the required host might be highly specific (*i.e.* only a single species) for each life stage, or the parasite may be able to infect closely related groups of species (*e.g.* bivalves generally). Among the New Zealand digenean parasites, *Cercaria haswelli* (larva of *Tergestia agnostomi*) is reported in green-lipped mussels, *Perna canaliculus*, and blue mussels, *Mytilus* spp. (Angel 1960; Jones 1975; Hickman 1978, Hine & Jones 1994; Hine 1997). Adult *Tergestia agnostomi* are reported from the yellow-eyed mullet, *Aldrichetta forsteri* (Jones 1978), hence it appears that mussels may act as an intermediate host for this parasite.

5.4.5. Other processes leading to the spread or exacerbation of disease agents

There are a variety of additional ways in which marine parasites and pathogens could spread or be exacerbated by finfish culture activities (Figure 5). As noted above, inappropriate disposal of dead fish has the potential to introduce disease agents into the wider environment. Additionally, the same stepping-stone processes of spread described for marine pests in Section 4.4.1 may facilitate the spread of diseases agents at regional or greater scales, for example as follows:

- Infection of industry vessels (*e.g.* bilge water, fouling) and equipment (*e.g.* sea-cages) may occur. It may be important to manage pathways of spread between farm and processing facilities, and also disinfect processing waste to manage disease spread (Murray & Peeler 2005).
- As noted for marine pests, culture-related infections of non-finfish pathways could be important in the spread of disease agents if, for example: (i) recreational fishing in the vicinity of farms led to infection of recreational vessels, or (ii) in the event that cultured shellfish became infected and inadvertently enabled inter-regional disease spread with seed-stock or equipment transfer.
- Relatively strong water currents in the vicinity of the fed aquaculture zones (see Section 4.4.1) are likely to widely disperse some parasites and pathogens (*e.g.* those viable in the water column for hours to days or longer). Implications for farm management and spacing are discussed in Section 7.5.

6. IMPLICATIONS FOR WAIKATO REGION VALUES

6.1. Overview

The sources of biosecurity risk outlined in this report add another layer to the mosaic of existing anthropogenic pressures on the Waikato region and coastal values generally (*e.g.* Elmetri *et al.* 2005; Gibbs 2007; MacDiarmid *et al.* 2010). However, an important difference is that adverse environmental effects arising from uncontrolled outbreaks of pests or disease agents have the potential to affect values at-risk at regional scales or greater (Forrest *et al.* 2009).

Equally sobering is the widely held view that once novel risk species are introduced and become established into the natural environment, there is little or no possibility of eradication or widespread control. The New Zealand experience with local- and regional-scale management of macroscopic pests certainly reinforces this view. For example, intensive regional-scale management efforts for the kelp *Undaria* (Hunt *et al.* 2009) and the sea squirt *Didemnum* (Pannell & Coutts 2007) were quite successful in reducing the human-mediated spread of these species and in greatly suppressing established populations. However, these programmes failed to achieve eradication, hence they were discontinued in the face of increasing containment and control costs.

This situation highlights the importance of understanding biosecurity risks to Waikato region values that could arise if marine pests, pathogens or parasites were introduced or became more prevalent as a result of finfish culture. However, any attempt to assess potential effects has some key limitations that need to be recognised. In overview, these limitations amount to a lack of robust information on actual impacts, and inherent difficulties in making reliable predictions regarding the invasiveness of difference species, and hence inferences regarding their direct or indirect effects. We discuss some of these limitations for marine pests in Box 4.

The situation of pathogens and parasites is even more complex given that:

- There remains considerable uncertainty regarding which pathogens or parasites will become problematic as finfish farming grows and intensifies in the Waikato region (Zeldis *et al*. 2011).
- There is no information on the prevalence and distribution of disease agents in the Waikato marine environment, and a paucity of information regarding transmission pathways and host specificity for some of the disease agents that could be associated with finfish operations in the region.
- Knowledge of the ways in which aquatic disease agents in aquaculture can affect the wider environment is limited (Murray 2008). Except for a few examples (*e.g.* the virus-pilchard-penguin food web cascade referred to in this report), the indirect effects are complex and poorly understood (Bondad-Reantaso *et al*. 2005).

Box 4. Assessing the effects of marine pests: issues and limitations

Evidence clearly describing adverse effects from invasive species in New Zealand is limited. The direct local scale consequences of *Undaria* establishment in natural low shore habitats have been assessed (Forrest & Taylor 2002) and the effects of *Didemnum* on mussel crops have been evaluated to a limited extent (L. Fletcher, Cawthron, unpubl. data). By contrast, the effects of HABs (especially in relation to seafood safety) are relatively well researched and documented (Rhodes *et al.* 2001). However, for most macroscopic marine pests, risk to New Zealand is assumed for conspicuous species that become highly invasive (*e.g.* become dominant) in natural or artificial habitats, or inferred from recognised impacts in other countries.

Additionally, the effects of marine pests on many of the values described for the EW region (except perhaps natural character) will be density-dependent. A problem in making inferences from studies elsewhere is that, even when the effects of a given pest in one location are relatively well understood, invasiveness may differ considerably at other locations or other times. Predicting invasiveness and thus invasion consequences remains a significant challenge. A related issue is that many non-indigenous species in New Zealand, especially more recent arrivals, are still spreading (*e.g.* Russell *et al.* 2008). Hence, observations of invasiveness are based on only a subset of the habitats the pest species will encounter within their potential distributional range; their invasiveness may differ considerably as they encounter new environments.

It is also important to recognise that there are many indirect or cascading ways in which marine pests could affect coastal uses and values. Many of these mechanisms are only hypothetical, poorly understood, highly complex and situation dependent. Indirect effects on marine biota from pests could occur if food supply was adversely affected and became limiting (a bottom-up effect). On the other hand, an adverse effect on an important predator (*e.g.* predatory wild fish) could lead to a top-down cascading effect throughout the food-web.

6.2. Approach used to assess effects on Waikato region values

Despite the above limitations, in order to provide the Council with guidance on what *might* be most at risk from finfish culture development, we have assessed threats in a matrix of '*hazard* x *values*', consisting of categories of Waikato region values and categories of hazard posed by marine pests, pathogens or parasites. This matrix should be regarded as illustrative rather than exhaustive, for the following reasons:

Hazards: Rather than focus on specific marine pest risk species, we have generically considered the types of effects marine pests associated with aquaculture are known to have. Broadly these are: effects of fouling by sedentary species, which incorporate processes such as competition and smothering; predation effects by mobile species; and effects of HABs. The latter not only includes the direct effects of biotoxins, but also the range of other ways that HABs could affect the environment (*e.g.* Box 4). In relation to pathogens and parasites, it is more difficult to identify generic categories of effects, hence we have selected three risk groups (monogeneans, digeneans, viruses) with potential effects on kingfish culture, or that may be associated with hapuku, to illustrate possible environmental interactions and their significance.

Values: Uses and values of the marine environment have been defined in many different ways (Inglis 2001). For the purposes of this report, we have developed a list of uses and values for the Waikato region, based on the summary in Section 3.1. However, this is a relatively high level list that is not exhaustive or refined. For example, the term "structured soft-sediment habitats" may incorporate structuring by keystone species that could in themselves be regarded as important values. Similarly, "wild fishery resources" encompasses species that will differ in their susceptibility to biosecurity risk. The term "other uses and values" is somewhat arbitrary and high level, and includes highly subjective categories (*e.g.* aesthetic value). Additionally, many of the values will overlap or interact. For example, recreation or tourism values are often dependent on aesthetic values and natural character. Furthermore, in Section 3.1 we did not attempt to explicitly define recreational and tourism uses. Finally, our list is not inclusive of some of the ecosystem services that are provided by the marine environment (*e.g.* nutrient cycling).

Based on this simplistic approach, and the subjective assessment of two of the report authors (Forrest & Hopkins), the *hazard* x *values* matrix is shown in Table 6. Shaded cells indicate situations where we consider that hazards can directly influence values, with indirect associations designated by "I". In Table 6 we have attempted to provide a sense of whether each direct effect is new and important (***), may be an important incremental risk above that already occurring (**), or is probably a minor incremental risk (*). The base *assumption is that pathway management mitigates the introduction of new high risk species*. Hence, in the case of marine pests the main effect considered under "fouling" and "predation" is the incremental increase in artificial habitat provided for pest species by finfish culture at full development, whereas for pathogens and parasites it is the new situation in which outbreaks may occur as a result of having farmed finfish at artificially high densities. We stress that *this matrix does not constitute a risk assessment*; it is merely a guide for Council staff and a basis for further discussion.

6.3. Marine pest: hazards x values

Reasons for the marine pest scores in Table 6 will largely be apparent from Section 4 of this report. Rather than fully describe the results, we instead highlight the following key points:

- We identified no threats from marine pests that we consider to be novel impacts of potential significance (***). This status would clearly change if specific plans for new developments revealed new pathway risks that could not be effectively mitigated.
- Effects of fouling on natural benthic habitats and associated important species (including shellfish resources) were generally scored at an intermediate level of significance. This score reflects that finfish aquaculture at full development may enhance established macroscopic marine pests to the detriment of Waikato region values (through increased propagule pressure for spread to natural habitats). Such effects may be of particular significance in relation to Zone 2, given the absence of existing artificial habitat in the environs of that Zone, and the Zone's proximity to values of conservation and fishing significance (see Figure 1).

- A corollary of the potential for enhanced invasion of natural habitats by increased propagule pressure from infected structures, is that the presence of conspicuous invasive species can alter the natural character of the seascape. This has been a key impact recognised for the kelp *Undaria*, as this species can be visually dominant (Sinner *et al.* 2000).
- In addition to natural values, fouling pests have the potential to influence a range of other values; including finfish culture itself, various stages of the shellfish aquaculture production chain, and infrastructure related to aquaculture and other marine uses. However, despite enhanced propagule pressure, we did not consider that finfish culture was likely to exacerbate fouling issues on other sectors or structures beyond present levels. Many of the most significant fouling species are already present including two Unwanted Organisms (the sea squirt *Styela clava* and kelp *Undaria*) or could be introduced to the Waikato region irrespective of finfish aquaculture development (*e.g.* the sea squirt *Didemnum vexillum* and *Pyura praeputialis*, and the fanworm *Sabella spallanzanii*).
- Compared with fouling, the effects of predatory invasive species were generally scored lower, reflecting less evidence that such species are strongly associated with suspended aquaculture structures in New Zealand. However, if new non-indigenous introductions with an apparent greater affinity for suspended structures (*e.g.* the Unwanted seastar *Asterias amurensis*) are discovered in New Zealand, the significance of this risk would increase. *Asterias amurensis*, for example, has a range of ecological impacts and effects on other values. One of these is an interference effect on fishing in which the seastar takes bait from long lines (Dommisse & Hough 2004), which serves as a useful illustration of the novel ways that invasive species can affect environmental uses and values.
- There are many indirect interactions, as well as direct interactions for which we felt that there was insufficient cause-effect knowledge to meaningfully assign scores. This was the case for HABs in particular. HABs have the potential to affect natural ecosystems, aquaculture, recreational uses and aesthetic values. However, present understanding of the potential for HABs to develop or be exacerbated as a result of finfish farm nutrient enrichment is insufficient to gauge the level of threat.

Table 6. Matrix with examples of direct interactions (shaded cells) between potential biosecurity *hazards and values* in the Waikato region, and indirect effects (I). Direct interactions designated as: likely to be new and important (***), may be an important incremental risk above that already occurring (**), and probably a minor incremental risk (*). ? = direct interaction possible but significance unknown.

Potentially affected uses and values	Component directly affected	Marine pests			Pathogens or parasites		
		Fouling	Predation	HABs	Virus	Monogenean	Digenean
Ecological							
Habitats and their biodiversity	Unstructured soft-sediment habitats	*	**	?			
	Structured soft-sediment habitats (physical or biogenic)	**	**	?			
	Zostera meadows	*		?			
	Saltmarsh			?			
	Rocky reef	**	**	?			
	Water column (plankton communities)			?			
Wildlife of conservation importance	Wading and seabirds	I	I	I	? + I		?
	Marine mammals	I	I	I	? + I		?
Wild fishery resources and fishing							
Finfish populations of commercial, recreational or customary importance	Conspecific finfish populations (kingfish or hapuku)			?	?	*	*
	Pelagic finfish populations (e.g. snapper, kahawai)			?	?	*	*
	Benthic finfish (e.g. flatfish) or reef-fish populations	I	I	?	?	*	*
Shellfish populations of commercial, recreational or customary importance	Infaunal soft-sediment shellfish (e.g. cockles, tuatua)	*	?	?	?		?
	Epibenthic soft-sediment shellfish (e.g. scallops)	**	?	?	?		?
	Reef-associated non-finfish species (e.g. paua, crayfish)	**	?	?	?		?
Harvesting of fish/shellfish (interference)	Pelagic finfish populations (e.g. snapper, kahawai)						
	Benthic finfish (e.g. flatfish) or reef-fish populations	*	*				
	Infaunal soft-sediment shellfish (e.g. cockles, tuatua)		*				
	Epibenthic soft-sediment shellfish (e.g. scallops)	**	*				
	Reef-associated non-finfish species (e.g. paua, crayfish)	*	*				
Harvesting of fish/shellfish (contamination)	Finfish or shellfish harvestability for human consumption			?	?	?	?

Continued on next page

Table 6. Continued.

Potentially affected uses and values	Component directly affected	Marine pests		HABs	Pathogens or parasites		
		Fouling	Predation	HABs	Virus	Monogenean	Digenean
Aquaculture							
Other finfish culture: kingfish	Cultured finfish health or abundance	I		?	?	**	?
	Harvesting or processing costs						
	Product value and marketability (incl. perception)	I		?	?	**	?
	Infrastructure maintenance costs	*			?	**	?
Other finfish culture: hapuku	Cultured finfish health or abundance	I		?	?	?	?
	Harvesting or processing costs						
	Product value and marketability (incl. perception)	I		?	?	?	?
	Infrastructure maintenance costs	*			?	?	?
Suspended mussel culture	Spat or seed supply	*			?		?
	Cultured mussel health or abundance	*		?	?		?
	Harvesting or processing costs	*					
	Product value and marketability (incl. perception)	*		?	?		?
	Infrastructure maintenance costs	*					
Intertidal Pacific oyster culture	Cultured oyster health or abundance	*	*	?	?		?
	Harvesting or processing costs	*					
	Product value and marketability (incl. perception)	*		?	?		?
	Infrastructure maintenance costs	*			?		?
Other uses and values							
Seawater supply or discharges	Intake or discharge pipes	*					
Marine infrastructure	Wharves, marinas, moorings, vessels, etc	*					
Recreation (land-based)	Intertidal areas (e.g. walking)	*		?			
Recreation (water-based)	Subtidal areas (e.g. boating)	*					?
Tourism	Tourist operations or tourism values	?	?	?			?
Aesthetics and natural character	Aesthetics and natural character	**	*	?			

6.4. Pathogens and parasites: hazards x values

The following key points can be taken from Table 6 and the text in Section 5 of this report:

- Generally, the spread of parasites or pathogens from finfish farms to the wider Waikato environment has the potential to affect a broad range of values (hence the many grey boxes in Table 6). However, many of the potential interactions are poorly understood (hence the many question marks in Table 6). Even though some interactions are probably low risk, there is insufficient information to make such a definitive judgment.
- The value most at risk from disease outbreak is finfish aquaculture itself. Generally, cultured fish are expected more at risk from disease agents transferred by wild conspecifics, than vice versa. In the case of kingfish, monogenean parasites may be especially problematic, and costs associated with control at kingfish farms may be significant. In addition to the use of chemical treatments (*e.g.* hydrogen peroxide or freshwater baths), increased infrastructure maintenance (*e.g.* removal of fouling and parasite eggs from nets) may be required.
- The potential for parasites and pathogens to spread from cultured fish to wild conspecifics and other finfish (*e.g.* snapper, kahawai) is expected to be low (or at worst localised) on the basis that wild finfish mobility is likely to prevent hyper-infection. Nonetheless, uncertainty arises from the fact that the suite of disease agents in culture will not be clearly understood until commercial operations are underway, especially in the case of hapuku. Furthermore, the susceptibility of hapuku to diseases known to kingfish (and vice versa) needs to be clarified given that these two species may be cultured in close proximity.
- There is uncertainty as to nature and significance of interactions with shellfish aquaculture. Parasites with complex life cycles (*e.g.* digenean trematodes) can have bivalve intermediate hosts and a finfish as a final host. Given culture of finfish and mussels in close proximity at Zone 1, the possibility of fish-bivalve-fish transmission for complex parasites needs further evaluation, in order to better understand the potential for the spread of problematic species. Furthermore, the implications for mussel and oyster aquaculture, and for other bivalve resources, require further investigation.
- Wider environmental effects are possible but poorly understood. Ecological impacts of disease outbreaks (*e.g.* virus outbreaks) have been shown to be unpredictable and potentially far-reaching; an example being the virus-pilchard-penguin food wed cascade in Australia. Furthermore, some pathogens and parasites are known to affect values such as recreation and tourism. For example, cercariae stages of digeneans can cause 'swimmer's itch' (a form of dermatitis), although we are unaware of any associations of this problem with finfish aquaculture.

7. MITIGATION OF RISKS TO WAIKATO REGION VALUES

7.1. Overview

Successful commercial cultivation of kingfish and hapuku has not yet occurred in New Zealand. Given uncertainty regarding the full suite of problematic species that will emerge in culture, it is likely that a developing industry may face unexpected issues in relation to biosecurity risks. This is especially the case for hapuku, as the candidate species has never been grown commercially anywhere and the problematic pathogens and parasites are unknown. Recent work by Stephens & Savage (2010) described > 70% mortality in sea-cage kingfish in Western Australia, for which a clear cause was not determined, although a combination of stress and *Vibrio* infection were considered major contributors. Such events, and others cited by those authors, highlight that biosecurity risk in the context of diseases in finfish culture can be highly unpredictable.

The possibility of having to manage new pests or disease outbreaks in finfish culture in the Waikato region will clearly involve considerable learning for growers, regulatory agencies and scientists. New Zealand has had little experience with serious pathogens or parasites in aquaculture, with the salmon industry being largely problem-free for various reasons (Forrest *et al.* 2007). Probably, the most significant aquatic disease event in New Zealand is the recent unforeseen emergence of the ostreid herpes virus (OsHV-1) in Pacific oysters, which last summer was associated with significant mortality (especially of oyster spat) on farms. With finfish culture, even though many of the better known risks (*e.g.* disease transmission to wild fish) appear to be relatively low, experience elsewhere highlights the possibility that biosecurity issues could emerge that have unforeseen implications for culture operations and the wider environment.

One way to deal with uncertainty and help safeguard against the potential for catastrophic unforeseeable events would be to develop the culture zones in stages, within an adaptive management framework that included appropriate monitoring, related research as necessary, and clear criteria for up-scaling to successive stages. Not only does staging provide a means of reducing environmental risk, but helps to ensure that the infrastructure, expertise and institutional arrangements are available to support the pace of development.

Notwithstanding this general situation, at various stages in the chain of events that lead to disease risk there are opportunities to mitigate risk. Hence, for specific proposals there will need to be a case-by-case evaluation of risk pathways, site-specific factors that contribute to the emergence of problems, and development of specific mitigation strategies and emergency response plans. As situation-specific assessment is necessary, the sub-sections below provide only an overview of the types of mitigation approaches that could be considered.

7.2. Points of intervention for mitigation

The stages of the finfish culture process where intervention can be undertaken to mitigate risk are broadly as follows:

- Management of pathways where this reduces the risk of infection of culture sites.
- On-farm management to reduce risk to other finfish farms and the wider environment, including:
  - Surveillance for early detection of pests and disease.
  - Implementation of measures to eradicate, control or contain outbreaks.

The finfish culture industry has a strong economic incentive to prevent introductions of risk species and manage established population of pest or disease agents to a level that minimises adverse effects on their operations. In most cases such efforts will also reduce risk to the wider environment, although these wider benefits will be difficult to quantify.

7.3. Pathway management

In Section 4.3.1 we outlined the culture related activities for which pathway mitigation should be considered. To recap, these were:

- Pathways from international sources regions or pathways that are novel, hence may be associated with new risks to the region.
- Pathways from domestic source regions known to be infected by recognised high risk pests, especially species not known to occur in the Waikato region.
- Pathways along which the frequency of transfers is considerably greater than that occurring as a result of other human activities in the Waikato region.

Broadly there are two approaches to management of pathway risk described by Forrest & Blakemore (2002): (i) avoid transfers on high risk pathways, or (ii) treat pathways to minimise risk. Both strategies have been used to date in relation to the New Zealand mussel industry. Examples are as follows:

- During the southern New Zealand eradication programme for the kelp *Undaria*, the mussel industry introduced a voluntary ban on movements of mussel seed-stock from the Marlborough Sounds to Big Glory Bay in Stewart Island, as this was recognised as a high risk pathway by which the microscopic life-stage of *Undaria* was transferred.
- A PSP-producing HAB species, *Gymnodinium catenatum*, bloomed off New Zealand's northwest coastline in 2000, with high densities of *Gymnodinium* cysts detected in cultured shellfish (mussel and oyster) spat (MacKenzie & Beauchamp 2000). This led to a voluntary ban on spat movements to all aquaculture regions in New Zealand. Treatments were subsequently developed to minimise cyst densities within infected spat so that inter-regional transfers could continue (Taylor 2000).

- Some resource consents for 'offshore' mussel farm blocks around the New Zealand coast have conditions requiring farm development with equipment (*e.g.* ropes, floats) that is either new or has been treated to remove risk organisms.
- In terms of ongoing pathway management, a mussel industry code of practice for seed-stock requires mussels to be subjected to a declumping and washing process before transfer, to restrict the transport of fouling species with inter-regional movements (Forrest & Blakemore 2002).

For finfish culture operations, if risk avoidance is not operationally feasible, then risk minimisation measures similar to mussel industry approaches may be the best available option.

7.3.1. Culture-related stock and feed transfers

Particular regard should be given to stock transfers in water, as this is a new pathway to the Waikato region. Based on the discussion earlier in this document, it is expected that stringent biosecurity measures required as part of the MAF Import Health Standard for kingfish stock transfers from Australia would adequately mitigate risk from that pathway. It may be appropriate to implement similar procedures for domestic fish stock transfers, depending on the level of associated risk that is determined during consent applications for specific operations. As with stock transfers, the MAF Import Health Standard controlling the importation of fish food and bait that was described in Section 5.3.1, may be an appropriate benchmark for all transfers of fish feed (*e.g.* in the event of domestic manufacture).

7.3.2. Culture-related transfers of equipment and vessels

If necessary, control of fouling on vessels or equipment transferred from external source regions may be desirable. There are a range of methods that can be applied to effectively treat fouling on vessels and equipment, such as application of biocidal antifouling coatings and treatment in-water by plastic encapsulation and application of 'eco-friendly' chemicals (*e.g.* bleach, detergent, vinegar). Particular methods suitable for different needs can be found in various documents cited in a synthesis by Piola *et al.* (2009).

There may be other mitigation methods that could be implemented as part of routine operational hygiene practices, to minimise the likelihood of culture-related activities spreading risk species among finfish farms or to processing facilities. For example, consideration should be given to a possible role for mechanisms such as bilge water discharge, and whether simple management or treatment protocols can be implemented (*e.g.* Sinner *et al.* 2009). For general disease prevention or response to outbreak there may be a host of other mitigation and quarantine strategies that are desirable, including treatments for equipment and personnel (*e.g.* boot washes) moving among sites. These are details that should accompany specific consent applications, or be developed as part of Biosecurity Management Plans.

7.3.3. *Efficacy of pathway management*

One of the considerations for managing finfish culture pathways is whether mitigation is necessary or justified if there remain significant sources of unmanaged pathway risk to the Waikato region (*e.g.* from unrelated vessel movements or mussel farming activities) or directly to finfish culture sites (*e.g.* background infection by pathogens or parasites). It may be appropriate to only target finfish culture pathways if they represent a high level of *relative* risk; for example because they arise from source regions with new risk species are present. On the other hand, there are good reasons to consider general measures to manage pathways irrespective of their known or inferred risk, such as:

- Focusing on pathways with which known risk species may be associated does not cater for the fact that the 'next pest' is not always recognised until it exhibits invasive behaviour for the first time.
- The risk profile for the Waikato region will change over time as species distributions change within New Zealand. Distributional changes may arise as a result of species range expansion (*e.g.* as a result of climate change), and human-mediated spread on domestic pathways.
- The risk profile will also change as new risk species from overseas source regions arrive and establish (*e.g.* via shipping-related introductions to adjacent ports such as Auckland).

Ideally, any decision to focus on management of finfish culture-related pathways should also address other significant sources of risk. As noted by Forrest *et al*. (2007), attempts by the industry to manage risks may be futile if such efforts do not have the support and participation of other key exacerbators. Essentially, any efforts may be undermined by the uncontrolled spread of pest and disease species nationally, as New Zealand has no national-scale approaches to management of pathway risk. In fact, the shellfish aquaculture industry provides the only example for which ongoing voluntary national-scale biosecurity measures are in place.

7.4. Surveillance and response to incursions/outbreaks

When pathway management fails, or its merits are undermined by background sources of risk, the next best line of defence in the management of risk species is surveillance to ensure early detection, and implementation of effective response measures. In this respect, the formulation of surveillance and response plans, having clear goals and performance criteria, would be appropriate prior to industry development. Additional considerations, including the types of management measures that may be specified in such plans, are discussed below for marine pests and pathogens/parasites.

7.4.1. *Macroscopic marine pests*

Active surveillance for macroscopic marine pests in New Zealand is limited to the main ports and is conducted every six months (funded by MAF Biosecurity New Zealand) for a small target list of macroscopic species, mainly those shown in Table 1. If new high risks pests are detected, MAF makes a decision on whether and how to respond based on a range of factors. There are currently no national marine pest management strategies in New Zealand, although there are local-scale efforts for some species.

From a wider environmental perspective, control of pest populations on structures will reduce propagule pressure for spread to other habitats (including other finfish farms) or other vectors (*e.g.* vessels). However, for this wider purpose, experience with *Undaria* and *Didemnum* management indicates that, to be effective, control efforts may need to aim to almost completely eliminate target pest populations (B. Forrest, unpubl. data).

From a culture perspective, it is expected that some level of pest control will be necessary for operational reasons, such as:

- Defouling nets to maintain water flow, maintain water quality, reduce parasite reservoirs and reduce stress on farmed fished.
- Defouling sea-cage pontoons, nets and anchor warps to reduce drag.

For example, in South Australia, standard operational procedures for kingfish farms include changing of sea-cage nets every two months to manage fouling (de Jong & Tanner 2004).

There may also be circumstances in which it is worthwhile undertaking surveillance and responding to *new* high risk species detected on finfish farms (*e.g.* attempting to eradicate them), but assessment of efficacy will require consideration of other sources of risk (*e.g.* background risk and re-infection potential). Some of the broad criteria for considering whether surveillance and response may be worthwhile at a regional level are described elsewhere (*e.g.* Forrest *et al.* 2006).

The application of biocidal (*e.g.* copper-based) antifouling coatings to structures may provide a complementary method for fouling control, and is used on predator (fur seal) exclusion nets at Marlborough Sounds salmon farms. However, the ability of such coatings to resist fouling can be reduced under static conditions, and recolonisation may begin again relatively quickly. Furthermore, copper can accumulate in sediments and potentially affect benthic infauna. For such reasons, and because of the logistics and costs associated with removal of cages for land-based cleaning and antifouling, mechanical methods (*e.g.* water blasting) remain the primary means of fouling control within the New Zealand salmon industry.

ANZECC (1997) guidelines on in-water cleaning are currently under review, and it is unclear what the future implications will be for defouling of aquaculture structures, especially where NIS are present. The Waikato Regional Coastal Plan does not include specific rules for in-water defouling. However, in-water cleaning of surfaces to which antifouling coatings have been applied is covered by Section 15 of the RMA (discharge of contaminants into water), which prohibits such activities unless allowed by a national environmental standard or other regulations, a rule in a regional plan, or a resource consent.

7.4.2. HAB species

In Section 4.2.4 and Table 2 we described the weekly surveillance for target HAB species conducted under the New Zealand Marine Biotoxin Monitoring Programme. The related discussion highlighted the occasional detection of HAB species in the Waikato region, and the relatively frequent occurrence of an ichthyotoxic species. Given the importance of cultured and wild shellfish to the Waikato region, and the uncertainty as to the risk of HABs as a result of finfish culture development, the merits of co-ordinating increased surveillance for target HAB species with existing sampling under the national programme should be considered. It is certainly in the interests of a developing finfish industry to ensure that culture operations do not cause or exacerbate the occurrence of HABs that may be harm their finfish stock. In the Marlborough Sounds, for example, additional monitoring for ichthyotoxic HAB species is conducted by The New Zealand King Salmon Co. Ltd.

7.4.3. Pathogens and parasites

Finfish farmers have a strong incentive to ensure that pathogen or parasite outbreaks do not occur, as they can have a significant economic impact. As for marine pests, surveillance to ensure early detection of the most high-risk pathogens or parasites of the proposed culture species is likely to ensure the best chance of successful management. Surveillance could include ongoing routine health surveys of stock (including behavioural assessment), assessment of the incidence of disease, and pathology examination to determine the cause of any mortalities. Appropriate disposal of dead fish (or body parts), including those that have been killed for disease control purposes, is an important element of disease management (Murray & Peeler 2005).

Where disease symptoms and associated risk species are detected, there are a number of strategies that may be appropriate to minimise the risk of outbreaks. Stickney (2009) repeatedly emphasises the importance of avoiding culture conditions (*e.g.* degraded water quality) or management practices (*e.g.* high stocking density, over-handling) that stress the stock. For the monogeneans, considerable information on mitigation options is available, with a useful review by Whittington & Chisholm (2008).

Some general farm management options include:

- Limiting stocking density or fish farm density: As well as reducing stress, limiting fish density may mitigate other factors than make fish more susceptible to disease (*e.g.* fish injury). Diggles (2008) notes that parasite outbreaks might not occur until farm fish numbers exceed a critical density.
- Vaccination: This approach is used to increase fish resistance to viral and bacterial disease, and is typically supplied orally or by dip treatments (Bondad-Reantaso *et al.* 2005; Stickney 2009). There are examples of the use of vaccines to control disease in cultured *Seriola* species overseas (Sano 1998), but we are unaware of their application in Australia. Vaccination can decrease reliance on the need for other therapeutant (*e.g.* antibiotic) treatments (Shoemaker *et al.* 2009).

- Application of treatments to control outbreaks: Skin and gill fluke infections can be managed by bathing fish in freshwater (Figure 10) or hydrogen peroxide (de Jong & Tanner 2004; Hutson *et al*. 2007b), or through the use of therapeutants (Egusa 1983; Poortenaar *et al.* 2003; Williams *et al*. 2007). We specifically consider therapeutants and the environmental implications of their use in Section 8.
- Finfish stock cohort management: A common recommendation is that farms should be stocked with only single year classes at any one time to minimise pathogen or parasite transmission (Stickney 2009). Zeldis *et al*. (2011) suggest for the Waikato region that fish stock of differing origin or age should be separated by at least 1 km to minimise the transmission of infectious agents.
- Fallowing: When caged fish are the primary infection source, fallowing of sites (*i.e.* leaving them unstocked) for 10-30 days has been successful as a mitigation strategy for monogeneans in salmonid culture. This approach requires multiple sites (depending on production cycles), hence has implications for other environmental effects (*e.g.* benthic footprints).
- Related husbandry practices, such as regular antifouling and net changes, are important given that fouling and cage structures are potential reservoirs for pathogens and parasites.

Figure 10. Freshwater bathing of kingfish (*Seriola* spp.) in Japan to reduce infection by the monogenean skin fluke *Benedenia seriolae* (photo: Ian Whittington, The South Australian Museum).

The above management options are not mutually exclusive, as best results are likely to be achieved when they are applied as an integrated package (Ernst *et al*. 2002). According to Chambers & Ernst (2005), single year class stocking and fallowing of sites has been important for managing sea lice infections in salmonid culture, but these strategies have not been used for kingfish species in Australia or Japan. These authors report that *Benedenia seriolae* infections in Australian kingfish farms are managed using coordinated treatments that are timed to interrupt the parasite's life cycle. This approach appears to be a preferred to reaction to outbreaks. Such approaches require definition and treatment of farm management units (see next sub-section), and co-ordination among operators (Murray & Peeler 2005). The efficacy of any treatments may be undermined if there is a strong background influence by wild finfish on the incidence of infection. Hence it has been recognised that "Prevention of infections by Monogenea in an open system….is virtually impossible with our current level of knowledge" (Whittington & Chisholm 2008).

Part of on-farm management could include approaches that aim to reduce interactions between wild and cultured fish. Such interactions are probably inevitable, at least for kingfish, but can be reduced to the extent practicable where benefits in doing so are clear. For example, where wild fish are attracted to culture sites because of uneaten food, minimising food wastage may reduce such interactions. Management to reduce fish escapes from culture may be important if this was a recognised mechanism for the transmission of pathogens or parasites to wild fish or the wider environment. The potential for disease transmission to shorebirds, seabirds, and in fact other wildlife is unknown, but if it was important, it could be partially mitigated through use of netting (de Jong & Tanner 2004; Murray & Peeler 2005). Figure 11 shows examples of bird and predator (fur seal) exclusion netting used at some South Island salmon farms.

A.

B.

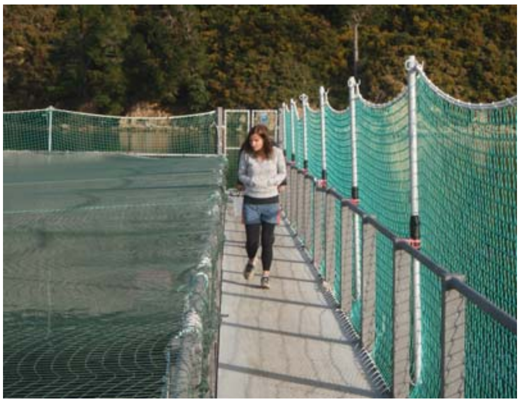


Figure 11. Example of wildlife exclusion netting used on cages at South Island salmon farms for birds (A, B) and fur seals (green netting in B).

7.5. Farm spacing as a mitigation tool

The Council has a particular interest in whether farm spacing can be used as a management strategy to contain marine pest populations, and pathogen or parasite outbreaks. In the case of HAB species, farm spacing is irrelevant as the consequences of nutrient enrichment (in terms of increased phytoplankton production) are likely to be spatially removed from nutrient sources (Zeldis *et al.* 2011). By contrast, for macroscopic marine pests, and pathogens or parasites, an understanding of the spatial scales at which the spread of risk species is likely among farms or between zones, makes it possible to define management blocks for the control of risk species, sometimes referred to as "independent management units" or "epidemiological units" (*e.g.* Chambers & Ernst 2005).

In other countries where finfish cage separation requirements are specified, minimum distances vary widely; for example, ranging from 300 m in parts of eastern Canada, to Scottish requirements for a minimum of 8 km between finfish farms and 3 km between finfish and shellfish farms. These overseas requirements are of little use in the Waikato region context, except to highlight that a robust assessment of farm spacing requires considerable site-specific information.

In relation to the Waikato region, the discussion in Section 4.4.1 of preliminary particle dispersion modelling for Zone 2 (Zeldis *et al.* 2011), highlighted a relatively high connectivity within and between the culture zones. Hence, for most marine pests, parasites or pathogens with a viability of a day or more in the water column, finfish farm sites will probably be connected by water currents to the extent that the definition of management units is unrealistic. This view is supported by a concurrent project funded by MAF on "Aquaculture Readiness", which aims to identify management units for aquaculture facilities in New Zealand (Brangenberg & Morrissey 2010). That work includes existing aquaculture areas in the Firth of Thames and southern Hauraki Gulf, although does not incorporate proposed finfish Zone 2. Progress to date recommends division of the Firth into two management areas (Don Morrissey, NIWA, pers. comm.): one in the northwest corner, and the other on the northeast corner (that encompasses Wilsons Bay and Coromandel Harbour). Waiheke Island would be a third area. This delineation is based on a simple tidal excursion model that highlights strong north-south tidal currents but weaker east-west flows in the region, consistent with Zeldis *et al*. (2011).

Based on the preliminary findings of these relatively simple modelling exercises, the question for the Council is whether there is merit in further investigating farm spacing as a mitigation tool? Present information certainly suggests that there is little merit in attempting to identify management units *within* each zone. However, it may be worthwhile further considering the possibility of Zone 1 and 2 (which are *c.* 16 km apart) as separate management units. While this may be of no benefit for some species, it may be effective for risk species with the following attributes:

1. *Unable to spread between the zones by planktonic dispersal or progressive spread across the seabed.*
   Although we have not extensively searched the literature, we would be surprised if the biological information necessary to predict (*e.g.* model) dispersal was available for many species, in particular many of the lesser known pathogens and parasites identified in this report. Moreover, whereas we have identified the most common problematic species (*e.g.* for kingfish), we have recognised that other species may emerge as important once commercial culture is underway. Essentially we do not yet even know the suite of risk species that will be most important to manage.
2. *A low background risk of ongoing infection.*
   In several places in this report we have highlighted examples of pest and parasites for which background infection risk is probably high. For many other actual or potential

risk species, we have little or no understanding of occurrence or prevalence in the wider environment.

3. *Detected early enough to enable an effective response.*
   Early detection would require a robust and regular surveillance programme for high risk species, ideally co-ordinated between the mussel and finfish industries and other marine users. Finfish farmers have a clear incentive to undertake surveillance and to respond to incursions or outbreaks of species that threaten their operation. Although connectivity among farms and zones could theoretically be reduced by stringent population or biomass controls on farms to minimise propagule pressure, for some species such approaches may not be feasible or affordable.
4. *Unacceptably high impact on culture operations or the wider environment.*
   In such cases, the merits of managing particular species would in part depend on whether their effects in isolation or in combination with other biosecurity risks were great enough to justify the effort.

To illustrate the previous points for a marine pest; excessive fouling by *Undaria* on mussel lines in the Marlborough Sounds has led to line breakages in high current areas. Assuming the same type of effect is possible at Zone 2 (to which *Undaria* is unlikely to spread except by human vectors), the operational significance and the merits of spread management (irrespective of feasibility) would in part depend on whether the other fouling species that are certain to establish (*e.g.* the sea squirt *Styela*) have a similar impact anyway.

For a parasite example, consider that monogeneans will be problematic to kingfish culture. In this case background infection is probably high (Sharp *et al*. 2003), and interactions with infected wild fish will likely be the source of cultured fish infection. Even in the event that background infection rates were low, a study by Chambers & Ernst (2005) showed considerable dispersal of eggs of *Benedenia seriolae*, indicating a need for separation of kingfish farm management units in their study region by at least 8 km. It appears that eggs remain viable for days, and hatch into larvae that have an estimated duration of 24 hours. Based on such information, we would expect the planktonic stages of this species to naturally disperse between zones in the Waikato region.

Additional particle dispersion modelling may help to clarify the likely efficacy of farm spacing as a mitigation tool. However, as well as hydrodynamic information, such a model would ideally incorporate factors such as propagule pressure, propagule viability with time, vertical position in the water column, planktonic predation, natural die-off, the availability of intermediate hosts (where necessary), the infective dose, and the susceptibility of the receiving location to infection.

A related spatial planning consideration for the Council is the proximity between kingfish and hapuku cultures. If they share significant disease agents, consideration of independent management units may be especially important. Among other things, assessment of such risks will require further research into the host-specificity of the disease agents these fish are susceptible to.

8. ENVIRONMENTAL IMPLICATIONS OF THEREPEUTANT USE FOR PATHOGEN OR PARASITE CONTROL

The majority of fed aquaculture operations include the use of agrochemicals and antibiotics along with other inputs, for disease management and other reasons, which can result in the presence of many chemical and biological contaminants around aquaculture facilities (Sapkota *et al*. 2008). In addition to prescribed pesticides and drugs to combat infestations of ecto-parasites and bacterial infections, aquaculture activities may include the use of antifouling agents, anaesthetics and disinfectants (Burridge *et al*. 2010). The main risks associated with the use of chemicals in aquaculture are the potential accumulation of residues in the environment, the development of drug resistance, effects on non-target fauna and flora, and risk to human health, principally the workers and ultimately the fish consumers (Rigos & Troisi 2005).

A broad overview of chemical use in finfish aquaculture was provided in the review by Forrest et *al*. (2007), which considered nutritional supplements, antifoulant compounds, persistent toxicants and therapeutants. Below we narrow the focus and specifically consider the implications of using therapeutants to control disease outbreaks, under the assumption that this will be a necessary mitigation strategy for the two candidate finfish species; this is a new issue for New Zealand as the salmon industry has not needed to use therapeutant compounds.

Therapeutant use in aquaculture has a notorious history. There are many examples of antibacterial drug misuse in the aquaculture industry resulting from actions by ill-informed farmers to address disease outbreaks (Rigos & Troisi 2005). Stickney (2009) suggested that volumes of antibiotic use in fish culture were insignificant by comparison with amounts likely to enter the environment by other means (*e.g.* wastewater discharges), but recognised the issue of antibiotic resistance as being particularly important. Historically, resistance has emerged in intensive aquaculture as a result of ongoing prophylactic use of antibiotics rather than reactive use to disease outbreaks (Stickney 2009). More recently, the development of avermectin resistance in sea lice has led to some finfish farmers in eastern Canada using alternative banned pesticides, with significant adverse consequences. In one very recent instance, this practice led to a major lobster kill in the Bay of Fundy (M. van de Heuvel, University of Prince Edward Island, pers. comm.).

In relation to kingfish aquaculture, Forrest *et al*. (2007) summarised the common therapeutants used, with preliminary information on their potential environmental effects (Table 7). There are a variety of ways in which therapeutants may be administered in sea-cage systems, for example orally (via food) or via bath treatments. Oral treatment can be more efficient than bathing and involves no fish handling hence minimises stress. However, as efficacy depends on food consumption, oral treatments may not be as effective as bath treatments (Stickney 2009). Freshwater, formalin and hydrogen peroxide emerged as relatively benign options, reflecting (in the case of the latter two compounds) their high solubility in water and low persistence in the environment. Environmental information on other common treatments for

Table 7. Common treatments for kingfish parasites and their potential environmental risk (modified from Forrest *et al*. 2007).

Treatment	Application	Properties / environmental fate	Restrictions on use
Hydrogen peroxide H_2O_2 bathing	Effective in the treatment of monogeneans in Japan for *Seriola* sp. It is a common treatment for the control of both skin and gill flukes in the South Australian kingfish industry as it is effective and presents no food safety issues.	Highly soluble in water and degrades rapidly. No significant adverse environmental implications.	No relevant environmental restrictions.
Fenbendazole ($C_{15}H_{13}N_3O_2S$) Bathing or oral	A broad spectrum antihelminthic (anti-worm) compound which was introduced in the mid-90s for fish culture. Effective against endo- and ecto-parasites in salmon, cod and rainbow trout.	Insoluble in water, high stability. Commonly used in humans, sheep, cattle and horses. Limited withdrawal time is needed for treated fish destined for human consumption.	No relevant environmental restrictions. NZFSA limit of 0.5 mg/kg residual content in animal livers.
Praziquantel ($C_{19}H_{24}N_2O_2$) Bathing or oral	Used to control monogenean diseases in fish by bath treatment. Also used to treat skin and gill flukes of farmed kingfish, and infestations of several monogenean species. Highly effective for removing *Benedenia seriolae* from kingfish. Treating for a longer duration aids the removal of flukes and allows lower drug concentrations to be used. Single treatments not so effective in reducing the viability of the eggs; so both a primary and secondary treatment are recommended. In Japan, Hadaclean® (active ingredient praziquantel, Bayer Ltd.) is used for the oral treatment of *B. seriolae* infections. In a New Zealand trial kingfish farm, 50 mg/kg administered orally for 8 days was effective in eliminating *Zeuxapta seriolae* and reducing the intensity of *B. seriolae*.	Poorly soluble in water, partially solved by new liquid form (Prazipro). Binds strongly to lipids, soils and biodegraded by microflora. Part of avermectin family, LCD50 for Rainbow trout 0.000025 g/m^3. Studies have indicated minimal praziquantel accumulation with the body tissues of fish at operational doses. Using a 24 hour dosing interval, praziquantel appears only likely to accumulate in a very limited manner in the skin or plasma of kingfish, which is believed to be due to the rapid clearance of the drug, either via hepatic metabolism or renal excretion, rather than poor absorption.	No relevant environmental restrictions. NZFSA limit of 0.1 mg/kg residual content in flesh.
Formalin (CH_2O) Bathing	A saturated solution comprised 37% formaldehyde by weight, and 6 to 13% methanol in water. Bath treatments are used to control external parasitic infections of fish. Two brands of formalin, Formalin-F and Paracide-F have been approved for use in fish aquaculture by the US Food and Drug Administration. The toxicity of formalin increases with increasing water temperature. The concentration of formalin used should be decreased when water temperature exceeds 21°C.	Highly soluble in water and not likely to accumulate in sediments. Breaks down rapidly, and does not usually persist in the environment. Approx. 50 mg/kg of bioavailable formaldehyde is required to inhibit the tactile response of snails. Each 5 g/m^3 of formalin applied removes 1 g/m^3 of dissolved oxygen. If treatment is needed within an enclosed environment, additional aeration of the water is required.	ANZECC (2000) guideline for formaldehyde for the level in water found to cause the tainting of fish flesh or other aquatic organisms is 95 g/m^3.
Fresh water bathing	Freshwater baths effective in treating some salt water parasites.	Highly soluble in salt water.	None

monogeneans, such as Fenbendazole and Praziquantel, is relatively limited. The Department of Primary Industries and Resources of South Australia (PIRSA) and CSIRO have recently undertaken a pilot ecotoxicological study to assess these two compounds, as well as two antibiotics (oxolinic acid and oxytetracycline) used in kingfish culture. That research was part of a strategy for sustainable growth of the South Australian industry, and involved conducting toxicity bioassays on Australian native species (Anu Kumar, CSIRO, pers comm.). Results, when available, should be informative as to environmental risks in the Waikato region.

However, the full range of other chemicals needed to manage disease risk as finfish aquaculture develops in the Waikato is not yet known. Specific consent applications may propose the use of a broader suite of compounds than indicated in Table 7, and it is conceivable that the need for additional chemicals will arise due to unforeseen disease emergence. Some guidance in this respect would possibly be obtained through further evaluation (including consultation with the Australasian finfish industry), and perhaps by assessing chemical use in overseas aquaculture of closely related species.

Our preliminary assessment of the range of compounds commonly used to manage disease in aquaculture reveals that a wide range of chemicals may be involved (Table 8), some of which may be of greater environmental significance than those in common use at present. However, a cursory search of published literature, and enquiries with other scientists, revealed limited information on the environmental implications of some therapeutants (and other chemicals) in an aquaculture context. This context includes not just effects at growout sites, but also in relation to hatchery use and the effects of fish processing wastewater (Jamieson *et al*. 2010).

To assess specific risks as part of consent applications, information will be needed on likely therapeutant and other chemical amounts used, fate in the environment and hence potential effects. Specific assessments would benefit from knowledge gained from a more in depth literature review as well as specific ecotoxicological studies, ideally including indigenous biota. In parallel with industry development, the following should also be considered:

- Monitoring, where appropriate, of the presence and potential accumulation of chemicals in sediments and biota. With the use of antibiotics, consideration should be given to monitoring the development of resistance.
- The development of best practice procedures by finfish operators. Among other things, such protocols should aim to ensure the minimal/optimal use of each chemical, recognising that over-use can lead not only to greater environmental risk, but also greater risk to the culture operation (*e.g.* by causing increasing stress and further disease; Stickney 2009).

Such information would provide the basis to develop rules/guidelines for the use of such compounds in finfish aquaculture in the Waikato region. For example, Norway now regulates antibiotic use in aquaculture and this has led to a significant reduction in the classes and volumes of antibiotics used (Burridge *et al*. 2010).

Table 8. Chemicals that may be used in aquaculture practices, in addition to the common ones described in Table 7 for kingfish culture, and their potential environmental risk.

Chemical	Examples	Use	Environmental risk
Antibiotics	Amoxicillin, oxytetracycline, erythromycin	Inhibit the growth and kill pathogenic bacteria	Antibiotics are often stable in the environment; may affect Biodiversity; selection of antibiotic resistant bacteria
Parasiticide	Avermectins	Control of internal and external parasites	Development of resistance; effects on non-target organisms
Pyrethroids	Cypermethrin, deltamethrin	Sea lice treatment	Incidence of resistance; potential to affect non-target invertebrates
Hydrogen peroxide		Treatment of ecto-parasites	Low risk
Organophosphates	Malathion, trichlorfon, dichlorvos (DDVP) and azamethiphos	Treatment of sea lice	Development of resistance common in sea lice; low risk with single treatments
Chitin synthesis inhibitors	Teflubenzuron, diflubenzuron	Treatment of sea lice	Can accumulate in sediments; potential risk to sediment-dwelling species
Metals	Copper	Antifoulant paints	Toxic particularly to algae, molluscs and crustaceans
	Zinc	Supplement of fish food	Toxic, but at higher concentrations than Cu
Disinfectant	Iodine, detergents, ethanol	Treatment of nets, boats, and other equipment	Some components like surfactants are endocrine disruptors
Anaesthetics	Benzocaine, MS-222, clove oil	For handling fish, vaccination, transport, and to enable sea lice counts	Low risk

9. CONCLUSIONS AND FURTHER CONSIDERATIONS

This report has outlined sources of biosecurity risk that could arise with finfish culture development in the Waikato region. Despite that fact that some risks are relatively well understood and not expected to be a significant environmental concern (*e.g.* disease transmission to wild fish), many of the direct and indirect ways in which pests, pathogens and parasites could affect the uses and values of the Waikato region are uncertain. Moreover, we have highlighted uncertainty regarding the full suite of problematic species that may emerge in culture, and indicated that the industry may face unforeseen and unpredictable biosecurity risks that have significant implications for culture operations and the wider environment.

New Zealand is inexperienced in the culture of finfish species for which disease issues will almost certainly arise and need to be closely managed. Hence, we reiterate the comment in Section 7.1 that to help safeguard against the potential for catastrophic biosecurity events, the culture zones could be developed in stages, accompanied by monitoring and research, as well as risk-based criteria for taking development to the next stage. This approach provides a means of reducing environmental risk, and helps to ensure that infrastructure, expertise and other support keep pace with the developing industry's needs. The importance of careful planning and development cannot be overemphasised. As a worst-case scenario, the introduction or exacerbation of significant biosecurity risk species, even if very low likelihood has the potential to irreversibly affect the values of the Waikato region and beyond.

Hence, for both proposed culture species, there is a need to consider the further information required to assist the Council and consent applicants to better understand specific risks to the region, and the priorities for obtaining such information. We have identified some key information needs at various stages of the report; however, a more systematic assessment of such needs is a significant undertaking that is beyond our present scope. The general areas for consideration include:

- Further literature review or research on the lesser know risk species and their biology, their prevalence in the environment, and potential significance in culture and more broadly.
- Development of guidelines or approaches for assessing pathway risk, and/or procedures to mitigate pathway risk.
- Development of optimal surveillance strategies for the known or anticipated problematic species; including initial definition of an appropriate target list.
- Development of response plans and approaches to contain the spread of outbreaks, with further consideration of the efficacy of developing Zone 1 and 2 as Independent Management Units. In addition to hydrodynamic model, the application and utility of other epidemiological modelling tools could also be evaluated (*e.g.* SIR models; Peeler *et al*. 2007).
- Further assessment of the expected nature and potential environmental effects of therapeutants and other chemicals, with development of guidelines for their appropriate use and disposal.

Even with an unlimited budget to address these areas, there will invariably remain uncertainties regarding the biosecurity risk from finfish culture development in the Waikato region. Hence, to better prioritise key risks, information gaps and information needs, the issues outlined in this report would benefit from the application of a more systematic risk assessment process, in which the likelihoods and consequences (and associated uncertainties) of different biosecurity issues were evaluated. Such a process would benefit from the input of a range of experts (scientists, industry, Council) using structured elicitation methods such as that outlined by ACERA (2010).

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