Ministry for Primary Industries
Manatū Ahu Matua

LITERATURE REVIEW OF ECOLOGICAL EFFECTS OF AQUACULTURE

Biosecurity

CAWTHRON INSTITUTE

NIWA
Taihoro Nukurangi

AUGUST 2013

7

Biosecurity

Written by: Sean Handley, NIWA, Nelson
Reviewed by: Barrie Forrest, Cawthron Institute, Nelson

7.1 Biosecurity overview

The Biosecurity Strategy defines biosecurity as "the exclusion, eradication or effective management of risks posed by pests and diseases" (Biosecurity Council 2003). Biosecurity risk organisms include animals, plants and micro-organisms capable of causing diseases (e.g. the ostreid herpes virus in Pacific oysters) or otherwise adversely affecting New Zealand's natural, traditional or economic values (e.g. the sea squirt *Styela clava* and the red seaweed *Grataloupia turuturu*). In an aquaculture context, biosecurity also encompasses the protection of hatchery or culture operations from parasites, microscopic pathogens[1] or biotoxin-producing microalgae. These organisms may include not only non-indigenous species, but also indigenous species already present in the environment that become enhanced as a result of culture operations Forrest et al. (2011).

The primary source of entry for biosecurity risk organisms into New Zealand is through international shipping (Cranfield et al 1998; Kospartov et al. 2008). However, aquaculture production systems may increase biosecurity risk, through acting as reservoirs or exacerbators (Okamura & Feist 2011; Peeler & Taylor 2011), as follows.

- Reservoirs host risk organisms that can then spread by either natural or human-mediated mechanisms.
- Exacerbators create incubators and/or stepping stones for otherwise benign or low-impact pests, pathogens or parasites (either native or exotic species).

The introduction, proliferation and spread of risk species in New Zealand can lead to significant regional or national scale effects on ecological and other values. Once present, risk organisms can have effects on marine and freshwater environments that are often difficult to manage, resulting in permanent and irreversible impacts (Forrest et al. 2011). Consequently, considerable effort is placed on preventing incursions of pests, parasites and diseases into the New Zealand environment.

[1]Defined here as an agent of disease, e.g. a bacterium or virus.

Biosecurity control of aquaculture activities currently occurs through: resource consent conditions, farm practices and import health standards. The Ministry for Primary Industries (MPI) has the lead role in co-ordinating these interventions, and co-ordinating strategies between regional councils and marine farmers.

Under the Resource Management Act 1991 (RMA), Regional Councils have a duty to consider biosecurity during the marine farm consenting process. Such considerations as farm spacing, zoning, staged development and epidemiological units may be considered on a case-by-case basis.

On-farm practices are at the farm's discretion, but industry codes of practice are often developed by industry bodies to guide farm management (these are referred to in sections 7.2.3, 7.3.3 and 7.4.2). Farm practices are informed by an analysis of the potential hazards and options to mitigate them. For example, fallowing of sites to allow recovery from benthic organic enrichment.

The best approach to risk analysis is to follow these high-level principles (Aquatic Animal Health Code 2011):

- identify hazards (i.e. undesirable events such as disease occurrence);
- assess risks (i.e. consequences for the farm operations if the hazard occurs);
- manage the risks by implementing mitigation measures (e.g. cleaning and disinfection protocols); and
- communicate the risk (e.g. to staff taking part in the operations).

Non-native organisms for aquaculture (including organisms and/or products that will enter the environment as part of the aquaculture process) cannot be imported into New Zealand without undergoing a thorough risk analysis process. Import health standards[2] are controlled by MPI and include requirements that must be undertaken in the exporting country, during transit and on arrival. For example, current standards cover:

- import of juvenile yellowtail kingfish (*Seriola lalandi*) from Australia;
- the import of fish food and fish bait from all countries;
- the import of ornamental fish and marine invertebrates from all countries;

[2] For further information regarding import health standards and risk analyses, see: Import health standards: http://www.biosecurity.govt.nz/regs/imports/ihs
Risk analysis: http://www.biosecurity.govt.nz/regs/imports/ihs/risk

- the importation of equipment used in association with animals and water.

Aquaculture biosecurity has recently been covered by the reviews of Forrest et al. (2011) for finfish and Keeley et al. (2009) for other species, and this chapter draws heavily from these two sources.

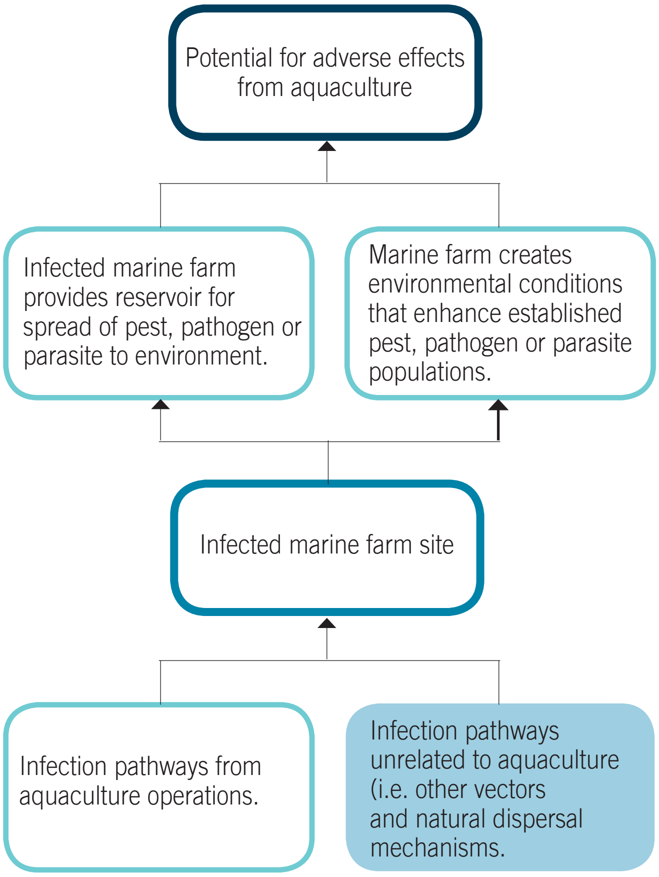
7.1.1 General role of aquaculture in relation to biosecurity risk

Aquaculture operations can advance biosecurity risks in a number of ways that have been conceptualised in Figure 7.1 as an event tree involving the following elements.

1. The introduction of risk organisms to aquaculture sites can occur either via aquaculture related pathways or infection pathways unrelated to aquaculture. Aquaculture related pathways (e.g. movement of equipment or stock transfers) may include domestic or international sources (e.g. imported feed). Infection pathways unrelated to aquaculture include movements of anthropogenic vectors (e.g. vessels, importation of ornamental fish) unrelated to aquaculture operations; and natural dispersal from source populations that are already established locally or perhaps regionally.
2. Aquaculture sites colonised by risk organisms can act as reservoirs of infection that facilitate natural or human-mediated spread to the wider environment, with contingent environmental effects.
3. The aquaculture site may create conditions that facilitate the emergence of biosecurity risks; for example, nutrient enrichment may exacerbate the occurrence of harmful microalgal species that are already established in the region.

In addition to facilitating the establishment and spread of risk species, aquaculture operations can also be vulnerable to their adverse effects. For example, detrimental effects on shellfish culture have been described for fouling organisms in New Zealand, and there are many known diseases and parasites associated with kingfish that can become problematic in a culture environment (Forrest et al. 2007b and references therein). Accordingly, the aquaculture industry in general has a strong incentive to manage important sources of biosecurity risk. The aquaculture industry's highest priority should be to grow product in optimal conditions best suited to maximising health (including minimising biosecurity risks), growth rate and condition, so as to maximise economic returns.

Figure 7.1. Overview of the main stages (double box) and sequence of events (single box) leading to the potential for adverse biosecurity effects from aquaculture.



Source: Adapted from Forrest et al. (2011).

Notes: The key components that contribute to each of these main stages are detailed in subsequent figures and associated text. The blue shaded box illustrates that biosecurity hazards can exist from sources in addition to aquaculture. Adapted from Forrest et al. (2011).

7.1.2 Environmental factors influencing susceptibility of aquaculture to risk organisms

Environmental factors acting on a given aquaculture operation are likely to be highly site dependent. For example, an intertidal oyster farm in Northland is likely to experience a very different set of environmental conditions to a salmon farm on Stewart Island.

Site selection, therefore, plays a key role in establishing a sustainable (economically, environmentally and socially) aquaculture venture (Kutty 1987). In terms of business planning, choosing the right site ranks second after identifying markets for the product. Locating the right site is considered less costly than trying to make a readily available site fit requirements later (Wurts, 1992).

Over the past decade, aquaculture space allocation in New Zealand has predominantly been driven by constraint mapping, allocating space in areas that does not conflict with other users and stakeholders (e.g. Handley & Jeffs 2002) rather than on the basis of a formal analysis of the sites' ecological suitability for aquaculture. This strategy increases potential biosecurity risks by encouraging development of aquaculture at environmentally less suitable sites.

While the RMA process seeks to address ecological effects (including biosecurity), stock health and condition in relation to site suitability are seldom given the priority they deserve (Handley, pers. obs.). This is possibly due to the absence of an established framework for new site evaluation and a paucity of data relating to new species or growing methods. Unfortunately, this means that often biosecurity risks are unlikely to become evident until aquaculture sites are partially or even fully developed.

The use of ecosystem-based approaches to aquaculture development that incorporate tools like GIS can incorporate biosecurity risks (if known) to optimise site selection even in cases of data poor environments (Aguilar-Manjarrez et al. 2010; Soto et al. 2008; Silva et al. 2011).

Environmental factors that are significant in determining the potential biosecurity risk for a given site include depth, wave climate, temperature regime and currents, that influence dispersal of waste, disease agents and pests.

The hydrodynamics (water movement patterns) at a site play an important role on several levels. On the sea bed, water currents affect mineralisation of wastes through oxygen supply to the sediment, which influences nutrient release. In the water column, tidal and wind-borne currents affect dispersion of pathogens, pests and parasites from the farm. For example, in finfish culture, infectious bacteria and viruses may be shed in fish faeces (Zeldis et al. 2011). The distance that they are dispersed will depend on the strength of water movement in the vicinity of the cages.

Dispersion potential will also be influenced by temperature, as this parameter can regulate metabolic growth and the proliferation of bacteria and/or viruses. that are shed as free-living single-celled organisms (Zeldis et al. 2011b). More complex organisms (such as protozoan parasites, parasitic worms and parasitic crustacea) that often have a free-living (perhaps actively swimming) stage can remain in the water-column for hours to days and travel significant distances depending on currents driven by wind, waves and tides. The location and extent of any pathogen plume will vary day to day, influenced by factors such as wind direction, strength of stratification and magnitude of river flows. (Zeldis et al. 2011b). On a regional scale in terms of pathogen dispersal (e.g. in the Nelson Bays), individual farms within any one Aquaculture Management Area (AMA) cannot be regarded as isolated from one another; for example, the AMA in Tasman Bay could function as a source of infection to AMAs in Golden Bay (Zeldis et al. 2011b) via the transfer of viral or bacterial pathogens.

Temperature and salinity can also affect the associated biosecurity risks associated with individual species. In the case of proliferation of invasive Pacific oysters, the southern distribution is limited to Nelson/Marlborough as water temperatures further south are too low for successful reproduction (Quale 1969; Askew1972; Dinamani 1974).

Exposure to freshwater (reduced salinity) may also increase the risk of disease occurrence by causing stress to cultured organisms. For example, reduced salinity causes immunosuppression in the Sydney rock oyster (*Saccostrea glomerata*), and hence the QX (Queensland unknown) disease usually occurs after summer rainfall events (Diggles, B, pers. com; Butt et al. 2006; Butt & Raftos 2007).

Salinity can also affect the spread and viability of Pacific oysters as an exotic species. The optimum salinity for larval development is 15–29 percent but at least some eggs develop normally at 36 percent (Amemiya 1928). Various authors state that Pacific oysters have been spawned at salinities ranging from 30–36 percent (Coleman 1996) but King (1977) found one successfully settled spat in a hypersaline pond, suggesting that at least some eggs will spawn outside the optimum range.

Salinity can also affect the spread of pest organisms by limiting or enhancing reproduction and larval dispersal. For instance, populations of the tunicate *Eudistoma elongatum* are reproductive for at least nine months of the year from October through to June (spring to late autumn). Onset of embryo production in late October can correspond with an increase in water temperature above 14°C (Page et al. 2011). Larval swimming experiments over a range of temperature-salinity treatments showed that larvae can swim for up to six hours, and appear to remain viable swimmers at temperatures as low as 10°C, but only at salinities above 20 psu.

Seasonally, environmental changes can affect fouling pest species through changes in temperature, salinity and wave climate. Salinity can vary with season, climatic variation (Scavia et al. 2002) and the catchment rainfall, with catchments that are dry in summer producing less runoff, elevating coastal salinities (Handley unpub. data).

Farm stocks that may be susceptible to stress from oxygen deprivation are at greatest risk. In summer when temperatures and, hence, metabolic rates of farmed animals are highest, dissolved oxygen levels in the water are lowest and the roliferation of fouling populations is also greatest (Handley, unpub. data).

Seasonal storm events, particularly on exposed culture sites, have the potential to add further stress to marine farm structures, which, if already under stress due to fouling arising from exotic foulers like *Undaria* or *Styela*, could result in gear failure during storm events and escape of finfish stocks to the wild (see Chapter 8 Escapee Effects), potentially causing ecological effects.

7.1.3 Ecological effects from pests, parasites and pathogens associated with aquaculture

Adverse ecological effects arising from pests, parasites and pathogenic species associated with aquaculture are less well understood than their impact on culture operations but, generally, it is recognised that such species can result in a range of potential ecological disruptions including (Molnar et al. 2008):

- disruptions to entire ecosystem processes with wider abiotic influences;
- disruptions to the wider ecosystem function and/or keystone species or species/assemblages of high conservation value (e.g. threatened species);
- disruptions to single species with little or no wider ecosystem impact;
- little or no disruption.

Research providing empirical evidence describing adverse ecological effects from invasive species in New Zealand is limited (Forrest et al. 2011).

7.1.3.1 Pests

The infection of marine farms by pest organisms can lead to the development of significant infestations on farm structures, which may then act as a reservoir for subsequent spread to natural ecosystems. Fouling pest organisms with limited ability to move within the water column may use marine farm structures (along with other suitable habitats) as "stepping stones" on which populations can develop and spread.

Fouling of marine farm structures can be operationally significant in areas of high current flow or wave exposure by increasing drag on cages and anchoring systems (Forrest et al. 2011), which in turn increases the risk of escapee effects if stocks are infected with pathogens or parasites (Forrest et al. 2011) (see Chapter 8). In areas of lower current velocity, fouling has the potential to significantly reduce the flow of water, carrying vital food and oxygen to cultured species.

Assessment of ecological risk from invasive marine pests may come either from examples of macroscopic marine pest invasions in New Zealand or from recognised impacts caused by similar pests or situations in other countries.

Examples of significant effects from pest fouling organisms on aquaculture activities in New Zealand include documented impacts from infestation of marine farms with *Undaria* and the colonial tunicate *Didemnum vexillum* (e.g. Forrest & Taylor 2002 and L. Fletcher, Cawthron Institute, unpublished data). An international example demonstrating the potential dire effects of pest invasions is that of *Didemnum vexillum,* which has a history of invading and overgrowing marine communities in temperate waters worldwide (Cohen et al. 2011). This species can colonise and dominate benthic habitats, smothering and displacing indigenous species in coastal bays and outer coastal areas, and causing concerns about potential long-term effects on community structure, critical habitats, and fisheries resources (Cohen et al. 2011; Lengyel et al. 2009; Mercer et al. 2009; Smith et al. 2010).

As well as structures hosting attached fouling organisms, aquaculture structures may also act as recruitment substrata for mobile pelagic or benthic species (e.g. jellyfish, ctenophores, sea star (*Asterias amurensis)*, sea cucumbers, crab (*Carcinus maenas)*, Forrest et al. 2009; 2011). 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 (Forrest et al. 2011). 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 conduits for the recruitment of mobile species from the water column to the seabed.

Aquaculture may also cause ecological effects through "exacerbation" (Forrest et al. 2011), whereby culture operations create environmental conditions that enable parasites, pathogens or pests to establish, or lead to enhancement of established populations (see Figure 7.1). For example, nutrient loadings from the release of inorganic nitrogen may increase the likelihood of harmful algal blooms (HABs) (Zeldis et al. 2011b) or increased production of benthic macroalgal species, including *Undaria* (Kelly 2008).

In contrast to fouling organisms, the effects of HABs, especially in relation to seafood safety, are relatively well researched and documented (Rhodes et al. 2001). HABs can include various species of microscopic phytoplankton, particularly those that produce biotoxins. Biotoxins are compounds that can not only adversely affect humans but can also cause significant mortality of wild shellfish resources and other marine biota including fish, which is clearly important from a finfish industry perspective (Forrest et al. 2011).

In terms of macro-algal abundance in relation to marine farms, it has been suggested that nutrient inputs could enhance *Undaria* growth around marine farms (Kelly 2008). However, Forrest et al. (2011) did not consider *Undaria* to be visibly more abundant or luxuriant in close proximity to salmon farms or other point source nutrient inputs. This matter deserves further research to include a larger range of macroalgal species.

Predicting the invasiveness and, thus, the ecological consequences of invasion of marine pests in relation to aquaculture remains a significant challenge, especially where more recent non-indigenous arrivals like *Undaria* are still spreading and their effects are not yet fully recognised (Russell et al. 2008). The effects of invasive species may differ considerably as these species encounter new environments, and there may be many indirect or cascading ways in which marine pests could affect coastal uses and values (Forrest et al. 2011). Many of these mechanisms are only hypothetical, poorly understood, highly complex and situation dependent. For example, indirect effects on marine biota from pathogens or pests could occur if food supply was adversely affected and became limiting (a bottom-up effect). Conversely, an adverse effect on an important predator (e.g. predatory wild fish) could lead to an increase in their prey (a top-down effect).

7.1.3.2 Parasites and pathogens

The occurrence of new pathogens or parasites into the environment as a direct or indirect consequence of aquaculture development can have wider ecological consequences. An outbreak of pilchard herpes virus was thought to have stemmed from pilchards imported for tuna aquaculture feed in South Australia. This event caused starvation and recruitment failure of little penguins that prey on pilchards (Dann et al. 2000).

7.1.4 Significance of ecological effects

Assessing the magnitude of potential effects of invasive pests, pathogens or parasites will be limited by the lack of robust information on the affected environments, inherent difficulties in making reliable predictions regarding the invasiveness of difference species and, hence, inferences regarding their direct or indirect effects (Forrest et al. 2011)

While examples already exist for interactions between pest species and aquaculture that allow some estimation of potential ecological effects to be made, the situation for pathogens and parasites has the added complexity that:

- there remains considerable uncertainty regarding the species that will become problematic as aquaculture grows and intensifies (Zeldis et al. 2011b);
- there is usually a paucity of information on the prevalence and distribution of disease agents in the marine environment, and a paucity of information regarding transmission pathways and host specificity for some of the disease agents that could be associated with aquaculture operations;
- 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, the indirect effects are complex and poorly understood (Bondad-Reantaso et al. 2005). To illustrate these complexities, following the spread of the pilchard herpes virus to New Zealand pilchards, large numbers of malnourished and dying little penguins were recorded in 1995 (Smith et al. 1996). During this same pilchard mortality event, it was concluded that pilchard scarcity resulted in unusually long foraging trips of little penguin at Motuara Island, Marlborough Sounds, leading to increased risk of egg desertion (Numata et al. 2000). These effects were not restricted to little penguins, with the highest mortality of Australasian gannets ever recorded in New Zealand occurring in 1995 and attributed to the pilchard mortality event (Taylor 1997). Diet switching to compensate for a lack of pilchards was thought to increase foraging efforts and feeding frequency, deleteriously affecting reproductive success (Bunce & Norman 2000).

It is difficult to predict the outcome of a parasite being introduced into a new environment with new potential hosts (Lafferty et al. 2004). High culture densities favour parasite transmission via higher levels of parasite release and/or greater contact between infected and uninfected organisms (e.g., Stiven 1964; Anderson & May 1981). In addition, with global climate changes, current host-parasite relationships that appear to be in equilibrium may shift in or out of favour for the parasite and result in epidemics or improved health in the host population(s) (NRC 2010).

The New Zealand ostreid herpes virus outbreak in Pacific oysters in 2010/11 illustrates the unpredictable nature of disease outbreaks and, how, through environmental change, the effect of this apparently latent virus was expressed during hot summer conditions (MAFBNZ 2010a). There will always be the risk that similar events can happen with other diseases or fouling, parasite or pest populations. Research on reducing stress and hence disease expression would be valuable to understanding future outbreaks and appropriate responses (e.g. Li et al. 2007).

In a risk assessment analysis, Forrest et al. (2011) populated a hazards by values table for the risks posed by finfish farm development in the Waikato Region (Table 7.1). For example, in relation to parasites and pathogens, Forrest et al. (2011) concluded, among other things, that:

- disease spread from finfish farms to the wider Waikato environment has the potential to affect a broad range of values. However, many of the potential interactions are poorly understood;
- the value most at risk from disease outbreak is finfish aquaculture itself;
- 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, unless escapes occur (see Chapter 8);
- there is uncertainty as to the nature and significance of interactions with shellfish aquaculture;
- wider environmental effects are possible but poorly understood.

Expansion and intensification of aquaculture may lead to exacerbation of ecological effects. This was demonstrated in Chile where uncontrolled expansion of salmon aquaculture in Chile resulted in a range of negative environmental effects including (Silva et al. 2011; Buschmann et al., 2006; Cabello, 2004, 2006; Soto & Norambuena 2004; Soto et al. 2001):

- significant loss of benthic biodiversity;
- localised changes in the physico-chemical characteristics of sediments;
- contamination by emergent chemicals, such as pharmaceuticals;
- increases in frequency and duration of dinoflagellate blooms;
- potential impacts of farmed fish escapees on native species;
- a two-to five-fold increase in abundance of omnivorous diving and carrion-feeding marine birds in salmon farm areas.

Table 7.1 Matrix illustrating the often unknown effects of pests, pathogens and parasites associated with finfish aquaculture in the Waikato region.

		Marine pests			Pathogens or parasites		
Potentially affected uses and values	**Component directly affected**	**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			?	?	?	?
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	*			?	?	?

Table 7.1 Matrix illustrating the often unknown effects of pests, pathogens and parasites associated with finfish aquaculture in the Waikato region (continued)

		Marine pests			Pathogens or parasites		
Potentially affected uses and values	**Component directly affected**	**Fouling**	**Predation**	**HABs**	**Virus**	**Monogenean**	**Digenean**
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	**	*	?			

Note: Examples are given 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. Source: Forrest et al 2011.

7.1.5 Impact mitigation and management options for all aquaculture operations

There is a 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 (Forrest et al. 2011). The New Zealand experience with local and regional scale management of macroscopic pests certainly reinforces this view. For example, species (AIS) have several common elements (Locke et al. 2009b):

- early detection and correct identification of the invader;
- pre-existing authority to take action;
- the AIS could be sequestered to prevent dispersal or else had very limited dispersal capabilities;
- political and public support for eradication,
- acceptance of some collateral environmental damage;
- follow-up monitoring to verify the completeness of the eradication.

Hence, to reiterate the point made in this section, the introduction and spread of risk species from aquaculture intensive regional-scale management efforts for the kelp *Undaria* (Hunt et al. 2009) and the tunicate *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. The few successful eradication efforts of aquatic invasive has the potential to cause regional or national scale effects on ecological and other values that may be irreversible from the point of view of cost or practicality. Considerable effort is therefore placed on preventing the incursion of pest species in New Zealand.

To illustrate mitigation and management options that could be adopted in New Zealand, Table 7.2 provides a summary of pertinent sections of international aquaculture standards and discussion documents with relevance to biosecurity. A summary of biosecurity risks and their associated prevention, detection and mitigation and management options is presented in Table 7.3. A matrix linking management options to key aquaculture groups is presented in Table 7.4.

Table 7.2: Summary of international aquaculture standards with relevance to biosecurity (see links in Appendix 1–2 Chapter 1)

Country/organisation	Examples of issues, mitigation and/or management options relevant to biosecurity in aquaculture
Norway/National Marine Fisheries Service	Biosecurity is not specifically mentioned, but rainbow trout is noted as an introduced species with issues around escapees with the potential for populations to establish. Preventions of disease/parasite transfer to wild salmon and sea trout is identified as a high priority. Management measures include: industry led escapee preventative measures; fishery authorities to control the system, set rules, technical requirements and standards; operational requirements and inspections to ensure that farming is operated on environmentally responsible lines; DNA marking and sterile fish development; research into genetic effects of escapees; requirement that farmer pays damages/compensation caused by escaped fish. **Discharge of nutrients** (eutrophication) is linked to increased algal growth; so there is regulation of discharge of environmentally harmful chemicals for cleaning, washing and impregnation of nets; and regulation of biomass farmed. **Disease/parasites** – antibiotic use as indicator of "aquaculture health"; Norwegian Food Safety Authority fish health surveillance, inspections of treatments and identification of resistance; salmon lice research; regulatory regime developed; potential regulation of cage size and regulating fish movements; dedicated boats for fingerlings versus fish for slaughter; encouraging industry codes of best practice; zoning of fish farm developments, to address lack of space, pollution and spread of disease; ability to withdraw zone location permits if biological diversity compromised ("safety valve"; compliant with Planning and Building Act (environmental impact assessments etc.))
World Wildlife Fund (WWF)/Draft Salmon Aquaculture Dialogue	Biosecurity management specifically listed: Standards aim, by minimising transmission, to ensure that farms don't harm the health of wild populations by amplifying the spread of **disease**. Notes that disease flow is bi-directional. Examples of management options include wellboats, with filtration necessary between management areas. Standards in the case of exotic disease and/or parasite detection, include: movement regulations, disease management, and culling. Area Based Management (ABM) zoning for managing disease and resistance to treatments, surveillance of sea lice levels and maximum sea lice levels/fish set for entire ABM. Testing, reporting, compliance.
WWF/Bivalve Aquaculture Dialogue Standards	Introduced **pests and pathogens** specifically mentioned: Documentation of compliance with established protocol or evidence of following appropriate best management practices required for preventing and managing disease and pest introductions with seed and/or farm equipment. For disease and pest management practices: only non-lethal management (e.g. exclusion, deterrents and removal) of critical species that are pests or predators.
Food and Agriculture Organization (FAO)/Ecosystem approach to aquaculture	Biosecurity frameworks should be in place to prevent and control **diseases** and potential health risks to the culture species or to the environment. Farms must avoid escapes, with mitigation measures for large-scale events, including reporting to authorities. Movement protocols, including quarantine. Protocols for effluent management and excess nutrient utilisation. **Management options** at water shed scale include: zoning or allocation of space as a mechanism for more integrated planning of aquaculture development, as well as its better regulation. **Cross integration** through **integrated coastal zone management** (ICZM) and integrated watershed management (IWSM). **Strategic environmental assessment** (SEA) focuses mainly on impact assessment, and its goal is predicting environmental impacts to establish prevention, mitigation and control measures to protect the environment in the waterbody of interest.

Table 7.2: Summary of international aquaculture standards (continued)

Country/organisation	Examples of issues, mitigation and/or management options relevant to biosecurity in Aquaculture
	Defining limits of change: Implies that we can define the point at which environmental change can threaten sustainable delivery of ecosystem services. Limits of "acceptable" change will depend on local social and economic conditions and perspectives. Maintaining an **"agreed" biodiversity** or ecological resilience. In setting limits of change, it is essential that some resilience is retained in terms of service provisions. This implies two things: (i) acceptable limits include a safety margin; and (ii) factors that strengthen system resilience, such as biodiversity and livelihood diversity, should be promoted as much as possible. Providing **"green infrastructure"**: Strategic allocation of significant patches or swathes of undeveloped land or waterbodies of different types that will increase biodiversity, underpin many other ecosystem services and increase the resilience of the whole system. **Acceptable water quality standards**, for example to prevent algal blooms.
International Union for Conservation of Nature (IUCN)/Guide for the Sustainable Development of Mediterranean Aquaculture	Issues regarding introduced marine species are specifically mentioned: Voluntary and accidental introductions, aquaculture as a vector via fish escapes outside natural range. In aquaculture, the use of introduced species is highly risky. The precautionary principle should be applied. Introduction of species should be carried out only in special cases and taking all required precautions. **Pathogen transfer:** Vector **pathways** include: Importation of alien organisms for culture, movement of cultured organism and amplification of existing pathogens. Escapees may also play a potential role. Recommendations: • Aquacultured organisms should be kept in the best possible health. • Disease outbreaks in aquaculture farms should be prevented, contained and managed. • Precautionary measures should be implemented to prevent disease transfer. • Special biosecurity measures to limit the introduction of pathogens in hatchery systems should be implemented. • The research and monitoring of the epidemiology of diseases in wild populations in the vicinity of aquaculture areas should be encouraged. **Fouling prevention and management:** • Eco-friendly antifouling coatings and products should be used. • Environmentally friendly procedures for preventing or eliminating biofouling should be encouraged.
United States of America (USA) code of conduct for aquaculture development	Biosecurity not specifically mentioned. Outlines planning, permitting, siting and zoning in the context of minimising the potential for any negative impacts on the environment. **Aquatic animal health**: All stakeholders should take any necessary action to minimise any potential for the transmission of diseases and parasites that may occur in aquaculture facilities, or associated with organisms released for stock enhancement, to wild populations. This can be achieved by using healthy stocks, maintaining good growing conditions and by frequent monitoring to facilitate early detection. **Conserving biodiversity**: Biodiversity in the territorial waters of neighbouring countries as well as the coastal states should be safeguarded when there is a significant potential for the spread of introduced and genetically altered species with reproductive capabilities. This can be achieved by sharing information and through consultation and co-operation on preventive and remedial measures.

Table 7.2: Summary of international aquaculture standards (continued)

Country/organisation	Examples of issues, mitigation and/or management options relevant to biosecurity in aquaculture
Scotland/Scottish Association for Marine Science and Napier University	Biosecurity not specifically mentioned. HABs noted but lack of long-term monitoring hinders testing any linkage to discharges from 30 years of aquaculture development. Cultivation of non-finfish species has few measured negative environmental impacts, except within the vicinity of the farm. Potential for disease/parasite transfer to wild salmon and trout. Escapees mentioned, but in genetic context. No management measures discussed.
Australia/Department of Primary Industries and Resources of South Australia	Code of practice stipulates that industry will work in conjunction with government and other stakeholders to ensure that aquaculture developments are managed sustainably (ecologically and economically) and that their considerable social, economic and environmental advantages are achieved. This will be accomplished through five guiding principles for environmental best practice, including: "comply with regulations" and "protect the environment". To comply with regulations, farmers will: expand self-management and co-regulation to include **industry-based codes of practice** that specifically address environmental issues. To protect the environment, aquaculturists will: • monitor and regularly review on-farm management practices to minimise the risk of ecological damage; • adopt farm design and on-farm management practices that encourage integration, recycling and reuse of effluents; • work in association with governments to develop appropriate protocols regarding the transfer and culture of **exotic species** and the **translocation** of live product within and between states; • support the maintenance of precise records regarding the **transfer** or translocation of stock between areas or operations.
Canada/British Columbia Salmon Farmers Association	Biosecurity section deals with disinfection protocols: To maintain healthy fish stocks and pathogen management, each company will maintain protocols designed to ensure the proper disinfection of employee's materials, equipment, vessels and site infrastructures when movement occurs between facilities. Importation protocols in place: Only certified disease-free eggs and milt may be imported with the permission of the Department of Fisheries and Oceans. Also, routine inspection and monitoring, including integrity of structures, environmental factors, presence/absence of predators. The BCSFA code incorporates principles, including: • to minimise impacts on the natural environment; • to ensure a healthy growing environment for farm stock and for the growth and production of healthy wholesome products; • to recognise that risk reduction is critical to the industry's operational success and public confidence.

A. Pathway prevention and management

The prevention of incursions is the most effective approach to biosecurity rather than reacting to outbreaks. Forrest et al. (2011) provide an outline of possible prevention approaches that could be considered, summarised here as:

i. management of pathways, where this reduces the risk of infection of culture sites;

ii. on-farm management to reduce risk to other farms and the wider environment, including both surveillance for early detection of high-risk pests and disease, and implementation of measures to eradicate, control or contain outbreaks.

Pathway management should focus on:

a. pathways from international source regions or pathways that are novel and, hence, may be associated with new risks to the region;

b. pathways from domestic source regions known to be infected by recognised high-risk pests, especially species known not to occur at the site in question;

c. pathways along which the frequency of transfers is considerably greater than that occurring as a result of other human activities.

Broadly there are two approaches to management of pathway risk (Forrest & Blakemore 2002):

i. avoid transfers on high-risk pathways;

ii. treat pathways to minimise risk.

Both strategies have been used to date in relation to the New Zealand mussel industry (see Section 7.3 or Forrest et al. 2011) and management of a specific pathway has been legislated by the MPI Import Health Standard for "Importing Juvenile Yellowtail Kingfish from Australia" (see Section 7.2.3).

B. Surveillance

Surveillance strategies are essential to detect the potential incursion of pests, pathogens and disease. Strategies may encompass point of entry surveillance, routine on-farm surveillance and targeted surveillance of high-risk areas.

Epidemiological surveillance networks encompass both endemic and exotic disease control efforts. However, animal health monitoring and disease surveillance systems must be described in terms of their specific goals and characteristics and are therefore defined separately. Animal health monitoring is the collection, analysis and dissemination of information about diseases that are known to occur in the population being monitored. Animal disease surveillance is the collection and analysis of information in order to support the claim that a country or region is free from an infection or disease; or to detect an exotic or new disease within a given population in a defined country or region.

Point of entry surveillance includes activities such as routine screening at airports, ports and mail centres. Many pests, pathogens and diseases can survive for considerable periods out of their natural environment, particularly if kept damp. Import health standards for live or fresh marine products include a requirement for surveillance for pests, pathogens and diseases.

Routine surveillance, undertaken on and around marine farms, is often the first point of detection of pests, pathogens and diseases. This most often takes the form of casual observation by marine farm staff for changes in fouling communities or stock infections or mortality events. MPI also commissions routine surveillance in ports and harbours around New Zealand.

Since 1998, the number of non-indigenous and cryptogenic marine species recorded in New Zealand has more than tripled as a result of surveys funded by MPI, other biodiversity-related research and reports made by members of the public. In 2010, a comprehensive review of existing data turned up records for more than 650 non-indigenous and cryptogenic marine species from New Zealand waters (www.marinebiosecurity.org.nz).

Targeted surveillance may be undertaken when activities such as harvest, grading or transfer of stock from hatcheries or between sites is undertaken. In most instances, it seeks to ensure that a predetermined list of potentially damaging pests, pathogens and diseases is not present within the stock. Routine post mortems from mortalities may also be included or required if an above-normal level of mortality is observed. Predicting invasions is not a precise science, and precaution is advised to guard against unpredictable incursions and the "Frankenstein effect" where unanticipated negative effects occur from an introduction (Moyle et al. 1987).

C. Control of populations and/or outbreaks

Recent New Zealand experience suggests that, even when pest organisms become well established, the benefits gained from even limited management success have the potential to greatly outweigh the consequences of uncontrolled fouling (Forrest 2007). To be effective, however, management requires buy-in from all marine stakeholders whose activities can spread pest organisms. There are a number of ways in which aquaculture companies can contribute to the effective management of fouling pests, such as:

- identifying existing and future pests that threaten the aquaculture industry;

- implementing surveillance of farm structures and vectors, such as service vessels and their associated infrastructure;
- developing co-ordinated response plans for high-risk species before they become established;
- preventing incursions of new pests onto aquaculture structures.

For vectors of spread, such as service vessels and farm equipment, preventative management options include:

- maintenance of effective antifouling coatings;
- hull inspections to check for the presence of target pests, and hull cleaning as necessary;
- eradication of pests from farm structures before they become well established.

However, once incursions have occurred, the use of eradication treatments is only advised if the risk of re-invasion can be managed. Re-invasion management options include a surveillance programme (as above) to detect pest incursions before they become widespread. If eradication is not possible, containing the further spread of pests from infested aquaculture structures may be warranted. For example, fouling pests should be reduced to a level that minimises the risk of natural dispersal to other vectors (e.g., vessels) or nearby structures, and pests should be eliminated from aquaculture vectors (equipment, vessels) before transport to other regions.

Setting a strict, non-subjective standard to ensure that direct control measures are done in an environmentally responsible manner is challenging (WWF 2010). Since any action will have some measurable impact, the challenge then is to ensure that any impacts are localised, temporary and reversible, and that the actions do not cause significant harm to endangered species or critical habitat.

Fouling and pests: Many methods have been used in an attempt to directly control fouling and pests, including chemical treatments with saturated brine, sodium hydroxide, hydrated lime, acetic and citric acids, formalin, detergents and chlorine, as well as physical treatments using air drying, ultraviolet light, steam, hot water, electricity, smothering, pressure washing, and puncturing (Carver et al. 2003; Coutts & Forrest, 2007; Locke et al. 2009a, Morrisey et al. 2009, Page et al. 2011). Indirect methods include avoidance of conditions that lead to infection and growth of pest populations. For example, avoiding the “density trap”, whereby oyster growers manually control the density of oyster spat on grow-out sticks to avoid infestations of mudworms, among other problems (such as overcrowding, misshapen oysters and marketing problems) (Handley & Jeffs 2002). Growing oysters at the correct intertidal level is also an indirect method of avoiding fouling and pest issues (Handley & Jeffs 2002; Handley 2002; Handley and Bergquist 1997; Curtin 1986).

Some growers have experimented with biological control agents, such as crabs, littorinid snails, and even fish, with poor uptake by industry (NRC 2010; Hidu et al. 1981; Enright et al. 1983, 1993; Cigarria et al. 1998). Exploitation of natural biological control mechanisms of organisms has been investigated in aquaculture (de Nys et al. 2010). For example, seaweed extracts have been incorporated into wax coatings to reduce fouling and mudworm infestations in pearl and edible oysters in Australia (de Nys pers. comm; Dworjanin et al. 2006). Physical removal of fouling organisms in situ has the potential effect of spreading marine invasive species and increasing the bottom deposition of organic material (NRC 2010). However, alternatives, such as collection of defouled material, are not often practical with current farming methods.

Parasites and disease: Perhaps the best method for controlling the spread of disease is through the use of management practices that call for the pathological inspection of animals to ensure that infected animals are not moved into areas that do not currently have endemic infections (WWF 2010). In New Zealand, in the absence of enforced stock transfer protocols, management of gear and vessel transfers between geographic zones by voluntary codes of practice developed by industry could be used to minimise risks. For example, the New Zealand Mussel Industry Council Ltd has a code of practice for transfer of mussel seed (NZMIC 2001). Long-term selective breeding programmes that mimic nature by amplifying the genetic tendencies for disease resistance are also showing promise in limiting the impacts of diseases that are already endemic, as long as the hatcheries are not acting as reservoirs of disease.

Regular antifouling and net changes (where nets are present) are recommended given that fouling and cage structures are potential reservoirs for pathogens and parasites (Forrest et al. 2011). Although net cleaning may also stress the fish, the threats of heavy fouling to farm structures, fish health and growth rates outweigh the cleaning costs. Controlling fouling levels is therefore beneficial for both the aquaculture operations and the potential ecological impacts, although the frequency of control (e.g. cleaning) might differ depending on whether it was done for culture purposes or to minimise ecological impacts.

In case of disease outbreaks, interventions such as the use of antibiotics are controlled through the Agricultural Compounds and Veterinary Medicines (ACVM) Act 1997. This means that antibiotics can only be used through veterinary prescription. Antibiotics are not specifically licensed for use on food fish but can be prescribed to be used "off licence" by a registered Veterinarian (see Chapter 10 – Additives). The use of chemicals in disease management is discouraged due to negative impacts on the aquatic environment, consumer reluctance, and because the frequent use of traditional therapeutics paves the way for the emergence of disease-resistant strains of pathogens (Harikrishnan et al. 2011).

D. Planning and zoning

In terms of aquaculture planning and broader management considerations, site selection is clearly important for reasons outlined in Section 7.1.2. Additionally, the World Organisation for Animal Health's (OIE's) online aquatic animal health code (www.oie.int/en/international-standard-setting/aquatic-code/access-online/) suggests establishing zones and using compartmentalisation (through geographical separation) to manage biosecurity and epidemiological risks (OIE 2011). There are benefits in maintaining subpopulations of culture organisms with known distinct aquatic animal health status. Factors contributing to effective management of compartmentalisation include physical and spatial factors that affect the status of biosecurity in a compartment, infrastructural factors (e.g. water supply, vessels and facilities for the introduction of equipment), a biosecurity plan (which involves screening for disease when stocks are moved between compartments) and a traceability system. Further elaboration and recommendations can be found in the OIE code.

With the desired expansion of the New Zealand aquaculture industry towards $1 billion by 2025 (NZAS 2006), not only do regulatory, planning and policy initiatives have to address biosecurity issues, but local body infrastructure and planning should also have a biosecurity focus. A precautionary approach from regional councils can include staged development of new species or large-scale ventures, and this, combined with monitoring and setting of limits of acceptable change (LACs) should trigger appropriate management measures and protect the environment from adverse effects (Zeldis et al. 2006). Should limits be exceeded, then permits to zones could be withdrawn as a "safety valve" (e.g. Norway/National Marine Fisheries Service – refer to Table 7.2). An overseas example of an infrastructure planning approach to reduce biosecurity risks comes from the proposed separation of inflow and outflow infrastructure recommended to reduce cross-contamination of feed, smolt and nets for the salmonid industry in St Johns, Newfoundland (Rutter Hinz Inc 2009).

Zoning has also been suggested to address issues of lack of waterspace (e.g. Norway/National Marine Fisheries Service – refer to Table 7.2). However, as limits to waterspace impede the expansion of existing industries like the Pacific oyster industry in Northland, developing new culture techniques (e.g. methods for growing oysters subtidally) may be the only viable alternative for short-term expansion of such industries. These measures are likely to increase biosecurity risks associated with pests and parasites (Handley & Jeffs 2002, also see Section 7.3).

Table 7.3: Summary of biosecurity risks, prevention, detection and mitigation options

Biosecurity risk	Description		Management options	
Pest/pathogen/parasite				
Introduction		**Prevention**	**Detection**	**Mitigation**
Invasive species (pests)	Non-native macroscopic species introduced	Import health standards	Routine surveillance	Early detection and removal
		Border surveillance, including targeted surveillance for high-risk species	Staff training	Eradication programmes
		Regulations on fouling of vessels/bilge water release	Targeted surveillance based on species-specific international experience	
Pathogen/parasite	New disease or parasite introduced or identified	Import health standards	Disease found in farmed stock	Treatment
		Use of processed feeds	Targeted surveillance based on international experience	Culling and fallowing
	Pathogen or pest becomes virulent due to environmental change. Often because stock become stressed	Routine environmental monitoring linked to husbandry activities	Seasonal or procedure related outbreaks	Treat and address environmental issues Culling and fallowing
Establishment				
	Environmental conditions allow pest/pathogen to become established and multiply. Reservoir effect	Appropriate stock husbandry (minimise stress, reduce risk of disease becoming established)	Routine or targeted observation of causes of mortality	Instigate containment and eradication measures/ procedures
		Site hygiene/biosecurity	Routine or targeted observation of “change” in fouling community	Prophylactic treatments (not normally recommended due to potential for resistance)
				Single year class sites
Spread				
Direct contact	Transferred by direct contact between farmed stock and wild stock	Site selection/planning and zoning	Mortality event in wild stock	None
		Appropriate husbandry		
Transport	Transferred on equipment of passive carriers (eg. boats, staff, birds)	Biosecurity/cleaning protocols	Spread between sites with clear direct connections	Identify, and if possible, mitigate vectors
		Codes of practice		Single year class sites
				Localised equipment transfer
				Correct disposal of mortalities
				Separation of commercial and recreational vessels/equipment
Environment mediated	Spawning, multiplication or fragmentation spreads agent through water currents	Site selection, planning and zoning	Spread between local sites with no “direct” connection	Eradication through equipment cleaning
		Anti-fouling		Fallowing
		Appropriate Husbandry		Mortality removal

Table 7.3: Summary of biosecurity risks, prevention, detection and mitigation optiions (continued)

Intermediate host	Transferred through an intermediate host	Antifouling	Spread between distant sites with no “direct” connection	Fallowing
Vertical transfer	Transfer from parent to offspring	Hatchery testing for disease	Mortality event with common source stock	No return of stock from sites to hatchery

Table 7.4: Matrix of biosecurity management options and their relevance to key aquaculture groups

Management measure	Description	Finfish	Shellfish	*Undaria*	Sea cucumbers
Import					
Import health standards	For import of seedstock	y	n	n	n
Border surveillance	Prevent import of macroscopic pests	y	y	y	y
Regulations on fouling on vessels/bilge water release	Prevent import of macroscopic pests/ fouling organisms/harmful algae	y	y	y	y
Planning and development					
Site selection	Sites with appropriate environment for biological requirements of stock	y	y	y	y
Zoning	Site location in relation to pathogen risks – other farms, processing plants, rivers, sewage discharge	y	y	y	y
Vessel berthing	Segregate local vessels from vessels that move regionally (commercial or recreational)	y	y	y	y
Targeted surveillance	Routine monitoring for predetermined range of species	y	y	y	y
Farm practices					
Fouling					
Management of nets and equipment to minimise fouling	Regularly remove fouling organisms from equipment	y	y	n	n
Anti fouling	Treat equipment with chemicals to prevent fouling	y	?	n	n
Transfer of equipment between sites/ regions	Prevent transfer of potentially contaminated equipment between sites				
Husbandry					
Appropriate stock husbandry	Minimise stress to reduce the risk of disease becoming established	y	y	y	y
Management of feed so as not to attract birds/fish	Limit opportunity for transfer between sites/wild stocks through direct contact	y	n	n	n
Routine environmental monitoring linked to husbandry activities	Manage stock within environmental limits	y	y	y	y
Remove mortalities	Limit opportunity for reservoir of disease to accumulate	y	n	n	n
	Reduce attraction of predators	y	n	n	n
Use of processed feeds	Heat treat feeds to kill pests/pathogens	y	n	n	y
Surveillance	Observe and record mortality causes, unusual fouling and so on.	y	y	y	y
Stock transfer		y	y	y	y
Hatchery testing for disease	Prevent diseased stock from being sent to sites	y	y	y	y
Single year class sites	Prevent disease transmission between year classes	y	n	y	y

Table 7.4: Matrix of biosecurity management options and their relevance to key aquaculture groups (continued)

Management measure	Description	Finfish	Shellfish	*Undaria*	Sea cucumbers
Harvest					
Isolate waste streams from growing areas	Prevent reintroduction of pests/pathogens to harvested sites	y	y	y	y
Fallow sites	Reduce opportunities for reintroduction of pests/pathogens from intermediate hosts	y	y	y	y
Education					
Codes of practice	Educate and alert staff to biosecurity requirements	y	y	y	y
Public notification	Alert public to biosecurity risks	y	y	y	y
Eradication					
Culling	Cull diseased stock to remove pathogen/pest	y	y	y	y
Fallowing	Remove stock from an area to allow host mediated pathogen to die out	y	y	y	y
Manual removal of macroscopic organisms	Eradication of individual pest organisms early in the invasion process	y	y	y	y
Treatment technologies	Treatment of whole farms or bays to remove pests	y	y	y	y
Pharmaceutical treatment	Treatment of individual affected stocks to remove pathogen/parasite	y	n	n	n

Note: y=yes, n=no

7.2 Feed-added species (salmon, kingfish, hapuku)

King salmon (*Oncorhynchus tshawytscha*) dominates finfish production in New Zealand, with farming in net cages in the marine environment in the Marlborough Sounds, Akaroa Harbour and Stewart Island, and limited freshwater production on land. Diversification to other finfish species is expected for yellowtail kingfish (*Seriola lalandi lalandi*) and hapuku groper, (*Polyprion oxygeneios*) with interest in farming these species in the Firth of Thames (Forrest et al. 2011) and the Marlborough Sounds and some preliminary cage culture trials in Wellington Harbour (NIWA trials). Preliminary analyses suggest that aquaculture is technically feasible and economically viable (Zuccollo 2010; Zeldis et al. 2011a) for both kingfish and hapuku. Land-based farming of yellowtail kingfish has also been trialled at Parengarenga, Northland.

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. 2007b). For many issues, the Forrest et al. (2007b) 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).

7.2.1 Biosecurity risk pathways specific to feed-added aquaculture

The main pathways (Figure 7.2) directly associated with feed-added aquaculture that have the potential to transfer risk organisms from external source regions are:

- transfers of finfish stock;
- transfers of equipment;
- culture-related vessel movements.

These risks are likely to be greatest where culture-related activities involve transfers from:

- international source regions;
- domestic source regions known to be infected by high-risk organisms, especially species that do not already occur at the site in question;
- novel pathways for example, involve methods of transfer that do not already occur as a result of other human activities;
- pathways of greater frequency than already occurring as a result of other human activities (Forrest et al. 2007a).

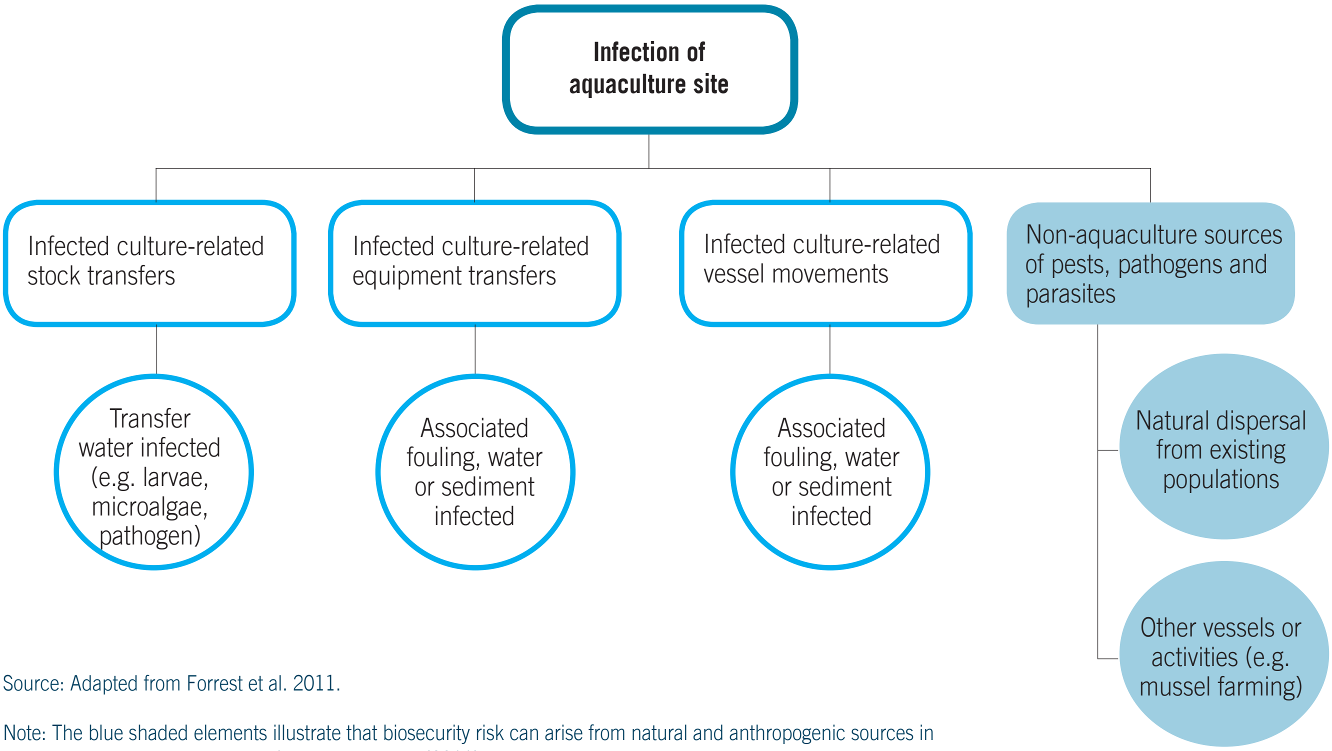
International pathways may include transfers of feed, finfish stock, reproductive material and equipment. A number of import health standards have been developed by MPI to manage biosecurity risks that have relevance to aquaculture (see www.biosecurity.govt.nz/ihs/search). Examples of these are import health standards for the importation of fish feed, ornamental fish and marine invertebrates, and aquatic equipment associated with animals and water. In the case of finfish feeds, the onus is on the supplier to meet stringent requirements such as the heat treating of fish meals and oils to 80°C for a minimum of 20 minutes (MAFBNZ 2010c).

Feed transfer risk can arise from direct transmission to cultured fish if the feed contains a pathogenic agent that is consumed by the farmed fish, or if the feed contains a pathogen that enters the environment or infects a non-target species, establishing a mechanism for indirect infection (OIE 2011). 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 was first identified in South Australia, with possible causes considered to be ships' ballast water or imports (without quarantine) of frozen pilchards that were fed to caged wild-caught tuna being conditioned for market (Whittington et al. 1997). The microbial disease *Vibrio ichthyoenteri* in live brine shrimp (*Artemia salina*) has also led to fish mortalities (Anderson et al. 2010).

The potential stock-related risk pathway for marine pests is associated with the water in which the fish are transferred and the fish stocks themselves (e.g. sourcing overseas fingerlings). This has the potential to introduce disease or other risk organisms into a new region. Most finfish stock transfers are likely to be from New Zealand hatcheries, although the importation of juvenile kingfish from South Australia has previously been proposed (Diggles 2002) with an appropriate import health standard developed (MAFBNZ 2010b).

Domestic pathways in New Zealand involving movements of finfish stock, feed and equipment, could also involve risk if mitigation methods are not implemented to avoid concurrent transfer of pests, pathogens and parasites. To date in New Zealand, domestic transfer pathways within the salmon industry (e.g. of sea cages, vessels) have tended to occur within, rather than between, growing regions, and hence have been relatively low risk from a biosecurity perspective (Forrest et al. 2007). Floerl et al (2009) noted that risk of transfer of pests between commercial vessels and recreational vessels sharing marina berthing facilities remained a distinct possibility and may lead to transfer of pest species between regions.

Figure 7.2. Summary of key domestic or internal pathways and related mechanisms that could lead to the infection of aquaculture sites by marine pests, pathogens and parasites.



Source: Adapted from Forrest et al. 2011.

Note: The blue shaded elements illustrate that biosecurity risk can arise from natural and anthropogenic sources in addition to aquaculture. Adapted from Forrest et al. (2011).

At **local** scales, the spread from pest or pathogen reservoirs on farms can take place via microscopic life stages (e.g. seaweed spores or animal larvae) that are released to the water column (Forrest et al. 2008). Alternatively, dispersal may occur via fragmentation and drift of viable fragments of the pest (Forrest et al. 2000; Bullard et al. 2007). Marine farms, jetties and vessel moorings can then act as "stepping stones" enhancing spread even if the source was not from aquaculture operations (Bulleri & Airoldi 2005; Forrest et al. 2008).

7.2.2 Descriptions of main effects and their significance

7.2.2.1 Effects from marine pests

Table 7.5: Ecological effects from marine pests due to feed-added aquaculture.

Description of effect(s)	**A. General biosecurity risks from marine pests** i. Finfish culture pathways lead to infection of farm sites by marine pests. ii. Infected farm acts as a reservoir for pest spread to wider environment. iii. Exacerbation; finfish farms alter environmental conditions and facilitate establishment of marine pests. For example, nutrients may enrich non-indigenous macroalgal growth and HABs. **B. Specific risks relating to pest and disease interactions** i. Fouling necessitates antifoulant applications, increases drag on sea-cage infrastructure, deforming cages and posing risks from gear failure and escapes, posing threats such as genetic transfer or disease/parasite transmission. ii. Fouling clogs nets and slows water exchange inside cages, resulting in poor oxygen exchange (especially in summer) and waste cleaning/removal, increasing the likelihood of fragmentation or spread. iii. Pests can act as potential intermediate hosts for pathogens and parasites. iv. Fouling attracts wild fish species that could become parasite/pathogen vectors or intermediate hosts.
Spatial scale	*Local* to *national* scale.
Duration	*Long term* – Irreversible if pest establishes a viable population and eradication is not feasible.
Management options	**A. Consenting and infrastructure considerations** • Farm spacing, zoning, staged development, identification of epidemiological units. **B. International: Import health standards** • Import health standards for example, for juvenile yellow-tail kingfish from Australia. **C. Domestic: Development of industry codes of practice:** i. Management of pathways to reduce the risk of infection of culture sites and/or the subsequent spread of marine pests, including: • risk reduction procedures for domestic stock transfers (including associated transfer water) that are consistent with MPI border standards; • procedures for vessels and/or the transfer of equipment to minimise the risk of marine pest transport with finfish culture pathways (e.g. vessel antifouling, cleaning, inspections).

Table 7.5: Ecological effects from marine pests (continued)

	ii. On-farm management to reduce risk to the wider environment, including: • education and surveillance to facilitate early detection of pest species; • routine farm management procedures for net and mooring line cleaning (e.g. application of antifoulants on predator nets, regular cleaning regimes); • application of pest response and containment procedures where feasible; • farm site selection and management practices that maximise growth and condition but minimise risks of pest infestations.
Knowledge gaps	• Implications for natural habitats of the development of marine pest populations on aquaculture structures. • The direct and indirect ecological effects of marine pests in the wider environment. • Effective and environmentally friendly mitigation methods for aquaculture pathways, and established pest populations on finfish farms and in natural habitats. • Transmission/vectors: Intermediate host status of fouling organisms for parasites and pathogens and interactions/links with other aquaculture species, but also wild species like seabirds and marine mammals. • Fouling recovery and waste recycling technologies. • Links between benthic effects/nutrient loadings and exacerbation/facilitation of marine pests and HABs. • Fragment or larval dispersal distances of some fouling species.

* Italicised text in this table is defined in chapter 1 – Introduction.

7.2.2.2 Effects from pathogens and parasites

Table 7.6 Ecological effects from pathogens and parasites due to feed-added aquaculture.

Description of effect(s)	**A. General biosecurity risks from marine pathogens and parasites** i. Finfish culture pathways lead to infection of farm sites by pathogens or parasites. ii. Infected farm acts as a reservoir for pathogen or parasite spread to wider environment. iii. Exacerbation; finfish farms alter environmental conditions and facilitate establishment of pathogens or parasites. **B. Specific risks relating to finfish aquaculture** i. Pathogens and parasite infestations reduce growth, condition and health of stocks, increasing the likelihood of spread to wider environment. ii. Increased handling associated with parasite/disease intervention may lead to heightened risk of escapes or increased stress on stock, both enhancing risk to the wider environment. iii. Increased waste production (mortalities), leading to potential environmental effects from disposal, and effects including disease transfer risk. v. Adverse effects of therapeutants.
Spatial scale	*Local* to *national* scale.
Duration	Irreversible if pest establishes a viable population and eradication is not feasible.
Management options	**A. Consenting and infrastructure considerations** • Farm spacing, zoning, staged development, identification of epidemiological units etc. **B. International: Import health standards** • Import health standards for example, for juvenile yellow tail kingfish from Australia.

Table 7.6: Ecological effects from pathogens and parasites (continued)

	C. Domestic: Development of industry codes of practice to address i. Management of pathways to reduce the risk of infection of culture sites and/or the subsequent spread of pathogens or parasites, including: • risk reduction procedures for domestic stock transfers (including associated transfer water), that are consistent with MPI border standards (including quarantine procedures); • procedures for vessels and/or the transfer of equipment to minimise the risk of pathogens or parasites with finfish culture pathways (e.g. vessel antifouling, cleaning, inspections). ii. On-farm management to reduce risk to the wider environment, including: • education and surveillance to facilitate early detection of sick stock infected by pathogens or parasites; • application of parasite or pathogen response, including therapeutant treatment, isolation/quarantine/culling of infected stocks. Farm site selection and management practices that maximise growth and condition but minimise risks of outbreaks.
Knowledge gaps	• **Identification of parasites and pathogens** likely to affect farmed species (in particular, hapuku) and their intermediate hosts. • The direct and indirect **ecological effects** of parasites and pathogens to non-cultured species in the wider environment, especially wild conspecific finfish. • Natural prevalence and distribution of disease agents in the New Zealand marine environment. • The natural **transmission mechanisms** and farm-to-farm dispersal potential of many disease agents. • **Effective and environmentally friendly therapeutants and other mitigation** methods to manage finfish in culture and prevent disease outbreaks.

* Italicised text in this table is defined in chapter 1 – Introduction.

7.2.2.3 Description of effect(s)

A. General biosecurity risks from marine pests, parasites and pathogens

i. Finfish culture pathways lead to infection of farm sites by pests, pathogens or parasites

Parasites and pathogens are commonly overlooked or under-appreciated as key drivers shaping local community structure and biodiversity (NRC 2010). The ecological effects from exotic parasites and pathogens are poorly understood, and much of the literature focuses on effects on wild fish stocks.

Finfish culture pathways for marine pests include the following:

- Finfish stock transfers of domestically raised juveniles shipped in water but also potentially imported from overseas. MPI has developed an appropriate MPI import health standard for the importation of juvenile yellow-tail kingfish (MAFBNZ 2010b; also see Section 7.1).
- Culture-related equipment and vessel transfers – especially important for vessels (e.g. barges, yachts) that travel at speeds that are sufficiently slow (less than 10 knots) to enable the survival of a diverse range of associated fouling (e.g. Coutts & Forest 2007; Coutts et al. 2010; Inglis et al. 2010). Other vessel-related mechanisms may be significant in certain circumstances, including entrainment of pest organisms (or dispersive life stages and fragments) in bilge water (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).
- Non-finfish culture pathways include the spread of risk species from existing local sources, including natural habitats and marine farms. Examples include the spread of *Undaria* to finfish cages from adjacent mussel farms, as the two activities may be cultured together, or seabed populations of the sea squirt *Styela clava* likely providing propagule supply for infection of finfish cages (Forrest et al. 2011).

ii. Infected farm acts as a reservoir for pest, pathogen or parasite spread to wider environment

The infection of marine farms by pest organisms can lead to the development of significant infestations on farm structures, which act as a reservoir for subsequent spread to natural ecosystems. In the case of fouling pest organisms, marine farm structures can act as “stepping stones” among which pest species can spread, thereby creating new populations from which spread to natural ecosystems can occur.

A number of examples exist of disease in cultured finfish leading to effects on wild stock (Forrest et al. 2011). Koi herpes virus 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), with some evidence for a causal link (Costello 2009; Krkošek 2010; Price et al. 2011). 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. This study indicated that risks to wild populations are likely to be quite low.

In the immediate vicinity of sea cages, elevated infection rates may occur for disease agents with direct life cycles (e.g. monogeneans with no intermediate host). For example, high densities of the 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). A summary of Diggles, (2008) analysis of the likelihood of infection by parasite and pathogen group is given in Forrest et al. (2011). With reference to hapuku and kingfish aquaculture, it is expected that the mobility of wild fish will minimise the risk of hyper-infection in the vicinity of infected cultures, especially of protozoans that have direct life cycles and low host specificity and seldom cause disease in wild fish populations (Diggles 2008). However, as these species are indigenous, they may be more susceptible to the pathogens and parasites carried by their wild conspecifics as compared with non-indigenous salmon. Despite there being several reported diseases 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. 2007b, 2011). 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. Although it may be noted that, in the case of hapuku interaction between deep water wild stocks and fish held in coastal cages is unlikely to be significant.

It should be noted that disposal of diseased dead fish in the marine environment also poses risks of disease transmission both through attraction of scavenging fish, including predators such as sharks (Handley pers. observ.).

Diseases and parasites that are problematic overseas and of concern were identified as part of the aquaculture readiness project in consultation with stakeholders run by MPI (Morrisey et al. 2011). These included:

- viral diseases such as viral hemorrhagic septicaemia and infectious salmonid anaemia which have potentially significant impacts;
- bacterial diseases, such as furunculosis, where identifying risk areas can provide information that can aid decisions such as vaccination and vector control treatments;
- amoeba, including amoebic granulo;
- Sea lice, Gyrodactyilus, and Myxosoma.

iii. Exacerbation; finfish farms alter environmental conditions and facilitate establishment of marine pests, parasites or pathogens

Finfish aquaculture has the propensity to exacerbate biosecurity risks as artificial farm structures provide habitats for colonisation. A synthesis from North America described 232 non-indigenous species from hard substratum habitats, of which more than 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) show that any suspended structure in the sea can provide a habitat that enables many fouling species (both indigenous and non-indigenous) 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, reducing oxygen supply to the stock and removal of their waste products. Reduced water quality can directly stress the fish stock and make them susceptible to pathogens and parasites (Forrest et al. 2011).

Finfish farms can potentially lead to the spread and enhancement of marine pests as they create environmental conditions that exacerbate existing biosecurity risks, for example:

- nutrient enrichment in the water column potentially leading to HABs, although causal links have not been made in overseas studies (La Rosa et al. 2002; Tett & Edwards 2002);
- high dissolved inorganic nitrogen loads may promote the productivity of benthic macroalgal species, such as *Undaria* as discussed in relation to finfish culture development in the Firth of Thames and southern Hauraki Gulf (Kelly 2008);
- seabed organic enrichment leading to the proliferation of introduced bivalves like *Theora lubrica,* which proliferate at intermediate levels of enrichment, or disturbance from finfish and oyster culture (Forrest & Creese 2006; Keeley et al. 2011).

For kingfish aquaculture, a broad range of parasites and pathogens[3] are described in cultured finfish belonging to the *Seriola* genus globally, 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. 2007). Kingfish in Australasia have a range of known pathogens and parasites (Forrest et al. 2011), but it is apparent that the monogenean[4] (flatworm) ecto parasites are the most problematic in Australian kingfish culture. This situation arises because monogeneans have direct, single-host lifecycles (i.e. do not require an intermediate host; see Forrest et al. 2011) 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 reinfection rates of cultured fish (Ernst et al. 2005). A risk assessment for multi-cellular parasites of *Seriola lalandi* in South Australia sea-cage culture identified the monogeneans *Benedenia seriolae* and *Zeuxapta seriolae* as "extremely likely to establish and proliferate" at new farm sites (Hutson et al. 2007). *Benedenia seriolae* (skin fluke) inhabits the skin and fins of kingfish 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. 2007) and potentially New Zealand (Leef & Lee 2009), with estimates of 20 percent of total production costs to control these parasites cited in the literature (e.g. Ernst et al. 2005).

Further, studies of the dispersal of the skin fluke *B. seriolae* suggest that considerable distances (greater than 8 km) may be required for effective management units (Chambers & Ernst 2005), which also suggests that there is a real risk of hyper-transmission to and from wild conspecifics, with unknown ecological effects. Tagging of wild fish associated with salmon farms in Norway has revealed that fish farms should be considered as connected, not only through ocean currents but also through wild fish movements. If wild fish share pathogens with farmed salmonids, their behaviour implies that they have the potential to act as vectors for diseases and parasites between salmon farms (Uglem et al. 2009).

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. 2007). Smith et al. (2009) identify the ciliate *Miamiensis avidus*, a single-celled 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 of Forrest et al. 2011). Many known disease groups in *Seriola* spp. (including viruses, opportunistic bacterial pathogens, obligate parasites, myxozoan[5] groups and sanguinicolid digeneans (blood flukes) are unde-rrepresented in New Zealand (Diggles 2002), with Forrest et al. (2011) 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 of diseases that occur at such low prevalence in wild populations that they are undetected (Weaver 2001; Diggles 2002).

For hapuku, only limited grow-out trials have been undertaken in New Zealand, and thus there remains considerable uncertainty regarding which pathogens or parasites will become persistent commercially significant diseases (Zeldis et al. 2011a). During preliminary trials, the only mortality event identified was a protozoan parasite infection resulting from handling stress (Heath pers. comm; Zeldis et al. 2011a). 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 of Forrest et al. 2011).

[3] Defined here as an agent of disease, for example a bacterium or virus.
[4] That is, Ectoparasitic trematodes.
[5] Members of the phylum Myxozoa.
[6] Any of various parasitic flatworms of the class Cestoda.

Although likely to be of lesser importance, the following organisms may also be significant, and hence could be considered as part of routine surveillance (see Section 7.4.3 of Forrest et al. 2011):

- 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 which have not yet been described;

B. Specific risks relating to pest, parasite and pathogen interactions

i. Fouling necessitates antifoulant applications, increases drag on sea-cage infrastructure, deforming cages and posing risks from gear failure and escapes, posing threats such as genetic transfer or disease/parasite transmission

Fouling pests impact on farm structures and associated equipment by creating drag (Beveridge 2004), for example, *Undaria* fouling on seacages and associated mooring lines. This fouling can create stress on these structures, adding risk during, for example, adverse weather events, leading to damage and stock escaping from the farm, as has occurred in Tory Channel. The loss of stock could potentially lead to genetic transfer of artificially enhanced traits to wild conspecifics (Jensen et al 2010). Similarly, escapees could aid in the transmission of disease or parasites.

ii. Fouling clogs nets and slows water exchange inside cages, resulting in poor oxygen exchange (especially in summer) and waste cleaning/removal, increasing the likelihood of fragmentation or spread

Fouling pests also have the ability to slow water exchange through associated drag and clogging of net cages, resulting in poor oxygen exchange which may become critical at sites with low oxygen levels during summer months, when oxygen demand and fish metabolism is greatest (Beveridge 2004). The process of cleaning of farm structures, however, could potentially lead to increased likelihood of fragmentation and spread of some fouling species that could subsequently reproduce or reattach, recolonising the farm structures or natural substrata (e.g. Hopkins et al. 2011).

iii. Pests can act as potential intermediate hosts for pathogens and parasites

Fouling pests on farm structures have the additional potential to be intermediate hosts of pathogens and parasites that are problematic for finfish, or other forms of aquaculture. For example, fouling of farm structures by bivalves like the Pacific oyster means they could potentially become hosts for parasitic mudworms or predatory flatworms, that may lead to either problems for neighbouring shellfish farms or wild shellfish populations (Meyers 1984). Overseas studies show that mussels can act as intermediate hosts harbouring pathogens that are transferable to fish (Keeley et al. 2009). The aquabirnavirus infectious pancreatic necrosis virus has been detected in *Mytilus edulis* (VPS 2000). It is a common virus of salmonids and is also a suspected clam pathogen in Taiwan. *Mytilus galloprovincialis* was identified as a reservoir host for infections of the aquatic birnavirus in the Japanese flounder *Paralichthys olivaceou* (Kitamura et al. 2007). This internationally significant disease of world-wide distribution has been reported in healthy king salmon returning from the sea on the east coast of the South Island in New Zealand (Diggles et al. 2002). Although not detected in New Zealand mussels, the possibility of *P. canaliculus* harbouring this virus, at least temporarily, finds support in the reports by Lewis et al. (1986) and Greening et al. (2001) where polioviruses and enteroviruses have been shown to persist in *P. canaliculus* after experimental exposure. Caution is clearly required in Integrated Multi-Trophic aquaculture (IMTA), as mytilids might harbour viruses with consequent threat to susceptible fish (Keeley et al. 2009). However, Skår & Mortensen (2007) found that blue mussels fouling fish cages did not act as a reservoir for infectious salmon anaemia virus.

iv. Fouling attracts wild fish species that could become parasite/pathogen vectors or intermediate hosts

Farm structures can act as fish aggregation devices (FADs) (Dempster et al 2009). Fouling pests provide increased habitat complexity that may enhance the attractiveness of structures, potentially enhancing the FAD effect. Fish attracted to farm structures, especially if conspecific to those species already farmed, for example kingfish becoming attracted to prey fish associated with the farm, may be at risk of disease or parasite transmission. Flat fish feeding on cod-farm wastes can be intermediate hosts for the *Lernaeocera* parasite, transferring it to nearby cod farms (Hemmingsen & MacKenzie, 2001).

7.2.3. Pest, parasite and pathogen management options

A. Consenting and infrastructure considerations

Within New Zealand, new aquaculture developments must go through a consenting process. Currently, this is managed in an ad-hoc fashion by regional councils. The Tasman District Council for instance, has discretion in its plan to consider "management of biosecurity risk organisms, such as *Undaria*". New rules controlling filter feeding bivalves and additive species, including finfish, require the council to

[7] A group of parasitic nematodes that can cause anisakiasis in humans.

consider “managing risks of incursion, disease, biosecurity risk organisms, and genetic risk to wild stocks” (R. Squires, Tasman District Council, pers. comm.).

However, best practice internationally suggests that a more structured approach considering factors such as farm spacing, zoning, staged development and epidemiological units should be considered as part of RMA consent requirements to minimise biosecurity risks from pathogens and pests on a case-by-case basis.

Site selection is clearly important for reasons outlined in Section 7.1.2. OIE’s online aquatic animal health code (OIE 2011) suggests establishing zones and using compartmentalisation (through geographical separation) of epidemiological units to manage biosecurity risks. They describe the concept of an epidemiological unit as “a group of animals that share approximately the same risk of exposure to a pathogenic agent”. Creating defined areas based upon the concept of the epidemiological unit will underpin biosecurity activities in response and readiness work, which stakeholders both agree with and understand the benefits of having (Morrisey et al. 2011).

Regional councils therefore have 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 other countries where finfish cage separation requirements are specified, minimum distances vary widely; for example, ranging from 300 metres 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 differences in required spacing’s highlight that a robust assessment of farm spacing requires considerable site-specific information (Forrest et al. 2011). Results of the Phase II aquaculture readiness modelling concluded that dispersion of pathogens and pests by water movements occurs over relatively small spatial scales and long-distance dispersion (for example, from the top of the North Island to the South Island) and is unlikely over the period during which the pathogen remains infectious. Human-mediated movements of aquaculture stock and equipment, in contrast, are capable of transmitting pathogens over much larger distances and in shorter time frames (Morrisey et al. 2011).

Within the consenting process, on going management options should be established. Recommended methods include staged development coupled with surveillance programmes to detect incursions or exacerbation of existing pests, parasites and pathogens.

MPI has recognised that there is a need for proactive systems to limit the likelihood of entry and subsequent spread of pests and diseases (Morrisey et al. 2011). Currently, New Zealand has strict import controls in place to limit the potential for pest or disease introductions. However, such systems are not infallible, and preparation is required to ensure (1) early detection of any incursion and (2) that there are widely understood response actions that can be implemented quickly when an incursion is detected. MPI, in recognising the biosecurity needs of the aquaculture industry, has commissioned research (the Aquaculture Readiness Data project) to support the development of a readiness system for aquaculture. Phase I of this research was designed to obtain fundamental information on New Zealand’s aquaculture and fisheries enhancement industries. Phase I produced (1) a geodatabase of aquaculture facilities (land, marine and freshwater based) from publicly available information, (2) information on the movement of stock and equipment between facilities based on a survey of the industry and (3) a report on the current spatial knowledge of New Zealand’s aquaculture operations. Phase II was designed to develop, in consultation with stakeholders, defined areas based upon the concept of an epidemiological unit. Aquacultured organisms in each defined area have a similar likelihood of exposure to a pest or disease. In the context of disease and pest management, these areas may serve as surveillance zones for the early detection of incursions, act as predefined movement control areas, or serve as zones to re-establish trade during or after an outbreak, in addition to providing spatial information about farmed or enhanced species for general animal health management.

Whereas, the salmon industry in New Zealand has, to date, been largely free of problems with parasites and pathogens, the fact that successful commercial cultivation of kingfish and hapuku has not yet occurred in this country introduces uncertainty regarding the full suite of problematic species that will emerge in culture (Forrest et al. 2011). It is likely that a developing industry may face unexpected issues in relation to biosecurity risks, especially for hapuku, which has never been grown commercially anywhere. Overseas, the large scale seed production and culture of groupers (Epinephelinae) continue to encounter increasing difficulties, especially with a host of infectious diseases, including different viral, bacterial and parasitic pathogens. Little is known about the impact of major diseases that may go beyond direct mortalities and loss in production (Harikrishnan et al. 2011). Recent work by Stephens & Savage (2010) described greater than 70 percent 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 (e.g. Katagiri et al. 2007; Egusa 1985), highlight that biosecurity risk in the context of diseases in finfish culture can be highly unpredictable, and have unforeseen implications for culture operations and the wider environment.

Farming fish at high densities can also result in the concentration and emergence[6] 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), with increasing outbreaks of disease by an ever increasing range of pathogens (Austin & Austin 1999; Robertson et al. 2000). The risks associated with parasite and pathogens are therefore likely to increase as finfish farming intensifies in New Zealand.

Techniques for addressing uncertainty and helping safeguard against the potential for catastrophic unforeseeable events or exacerbation resulting from intensification 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 (Forrest et al. 2011). Not only does staging provide a means of reducing environmental risk, it helps to ensure that the infrastructure, expertise and institutional arrangements are available to support the pace of development.

B. International: Import health standards

International border protection for pest, parasites and pathogens are controlled through import health standards, for example, the import health standard for importing juvenile yellowtail kingfish specifies stringent biosecurity procedures for fish stock (and transportation water) sourced from Australia (MAFBNZ 2010a). This standard includes requirements for receiving facilities to be of specific standards, specified modes of transport to be used, transport to occur in UV sterilised water, a four week quarantine period for stock and veterinary inspections (MAFBNZ 2010a).

C. Domestic: Development of industry codes of practice to address:

i. Management of pathways to reduce the risk of infection of culture sites and/or the subsequent spread of marine pests, parasites and pathogens

For domestic biosecurity pathway management, development of codes of practice will not necessarily ensure environmental sustainability given the potential plethora of uncontrolled vector pathways, such as wild animal and fish movements and public and commercial boating activities, but they are a step in the right direction. The New Zealand salmon industry has developed a code of practice that includes prevention and precautionary principles pertinent to managing biosecurity risks and incursions (NZSFA 2007).

To specifically address biosecurity risks, New Zealand King Salmon Ltd is currently in the process of developing a biosecurity management plan for marine pests, pathogens and parasites (Grant Lovell pers. comm.). This plan is likely to include specific requirements regarding management of risk pathways and on-farm activities, such as surveillance for risk organisms. In the past, New Zealand King Salmon Ltd has also developed codes of practice or been part of implementing risk reduction practices for specific species, such as for the tunicate *Didemnum vexillum* during a regional management programme in the Marlborough Sounds over 2006–2008.

ii. On-farm management to reduce risk to the wider environment

The New Zealand Salmon Farming Association (2007) code of practice does not specifically emphasise biosecurity risks and their management outright. Rather it outlines expected management practices that have a precautionary approach that should help to prevent and mitigate effects to the wider environment. For example, these include:

i. Farm site and structures:

   a. Site – complying with the RMA, following approved management practices and site survey prior to expansion.

   b. Structure – installed and constructed fit for purpose, capable of dealing with weather and environmental conditions to minimise interference with the natural environment and prevent escapes.

ii. Operations: fish stocks – the source should not cause an unacceptable biosecurity risk.

iii. Husbandry/fish resource – nets in sea cages should be inspected regularly for holes or fouling; remedial action should be taken immediately to rectify any unsatisfactory situation.

[6] 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 and Peeler 2005)

iv. Fish health and management of disease and mortalities – A preventative approach to disease in salmon uses management techniques[7] and routine monitoring of fish health and mortality by personnel trained in the recognition of disease.

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

i. defouling nets to maintain water flow, maintain water quality, reduce parasite reservoirs and reduce stress on farmed fish;

ii. defouling sea-cage pontoons, nets and anchor warps to reduce drag (Forrest et al. 2011).

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). 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 (Morrisey et al. 2000). 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 (Forrest et al. 2011).

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 non-indigenous species are present.

7.2.4 Knowledge gaps

i. Ecological effects and significance

There is a clear lack of knowledge of the ecological effects and the implications for natural habitats of many of the pest parasites and pathogenic organisms that could be associated with finfish aquaculture in New Zealand. There is limited information on disease transmission to wild conspecifics and the potential for disease transmission to shorebirds, seabirds and other wildlife (Forrest et al. 2011). For the finfish industry itself, it is envisaged that biosecurity-related knowledge gaps will arise from growing new species in new systems or at new sites as the industry expands and strives for better efficiency and higher production levels.

Only limited grow-out trials have been undertaken in New Zealand for hapuku, and, thus, there remains considerable uncertainty regarding identification of which pathogens or parasites will become persistent commercially significant diseases (Zeldis et al. 2011a). When new areas are developed, associated risk species may become more abundant locally and more widespread regionally. While such effects represent an increased biosecurity risk, their ecological significance is poorly understood (Forrest et al. 2011).

In terms of pest, disease and parasite risks to the wider environment, uncertainty regarding potential effects arises from the fact that the suite of organisms associated with culture will not be clearly understood until commercial operations are under way. 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 seldom known (Forrest et al. 2011). 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, for example, the pilchard herpes virus seabird cascade (see Section 7.1.3.2).

ii. Exacerbation risks

Similarly, research effort may be required to elucidate links between finfish farm effluent discharge, eutrophication and HABs, which, in the long-term, may need to be accompanied by regional-scale monitoring of target HAB species. It is difficult to establish causal linkages between increased fish farming and exacerbation risks such as increased nutrient inputs associated with finfish farm waste and HABs, with the assumptions being that continued inputs of dissolved nutrients from farming activities usually result in environmental changes that significantly alter planktonic and benthic communities (see review by Skejić et al. 2011). This is likely to create uncertainty for authorities as to how to manage cumulative effects, especially where multiple anthropogenic stressors (including land-based) have already heavily modified marine environments. For instance, it has been estimated that about 90 percent of Waikato nutrient load to the Firth of Thames comes down the Waihou and Piako Rivers from terrestrial farming and significant benthic mussel populations have already been removed from the system (Kelly 2011).

iii. Environmentally friendly therapeutants and mitigation methods

A range of methods can be applied to effectively treat fouling on vessels and equipment, such as application of biocidal

[7] Management techniques include: yearly disease status inspections, stocks routinely monitored for stress and disease, mortalities recorded, and the use of veterinary medicines on farms is not current company practice.

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). However, until the fouling pest species are known, whether a practical or eco-friendly eradication method is available is also unknown. Screening of eradication methods therefore may be required on a species or taxonomic group level for example, the evaluation of eradication methods for *Eudistoma elongatum* (Morrisey et al. 2009; Page et al. 2011).

iv. Waste capture and/or recycling

The process of net cleaning may also create significant but yet to be quantified ecological effects (Handley pers. obs.). Research overseas has trialled the capture and removal of solid wastes below salmon farms (Buryniuk et al. 2006), but as the maintenance and removal of fouling organisms may be most cost-effectively achieved in situ, there appears to be research opportunities to contain, recycle and utilise the nutrients sequestered by fouling species (e.g. Cattaneo-Vietti et al. 2003).

v. Dispersal and/or infection mechanisms

Fragmentation of organisms during cleaning or as an innate organism dispersal mechanism could potentially contribute to the spread of pest species and pathogens (if they are intermediate hosts) from farm structures. The ability of organisms to disperse, reattach or survive following fragmentation has been assessed in a limited way in New Zealand (e.g. Hopkins et al. 2011) and is currently being reviewed as part of in-water cleaning of recreational and commercial vessels by MPI (Page and Morrisey, NIWA pers. comm.).

7.3 Filter feeders (Green-lipped mussels and Pacific oysters)

Please read this section in association with Section 7.1, which outlines factors relevant to all aquaculture operations.

The Pacific oyster (*Crassostrea gigas*) is an exotic species in New Zealand and is considered by some to be a pest in its own right (e.g. www.waikatoregion.govt.nz/Environment/Natural-resources/coast/Coastal-pressures/Coastal-pests/), as is the case in many countries worldwide (Ruesink et al. 2005). Pacific oysters have become well established in most North Island harbours and in the Nelson/Marlborough region (Jenkins & Meredyth-Young 1979; Handley 1992; Handley S, pers. obs.). *C. gigas* is not registered as an Unwanted Organism by MPI and is farmed commercially in North Island harbours, from Kawhia Harbour north, and in the Marlborough Sounds and Golden Bay. The spread of Pacific oysters south of the Marlborough Sounds is limited by water temperatures that are too cool for successful reproduction (Forrest et al. 2009).

The New Zealand green-lipped mussel, (*Perna canaliculus*), is endemic to New Zealand and has been farmed under the trademark name Greenshell mussels since the 1970s. Mussels are farmed subtidally on ropes suspended beneath floatation buoys attached to anchors on/in the seafloor. Mussel spat are collected attached to wild, beach-cast seaweed at Kaitaia and also on hairy ropes suspended at spat catching sites in the Nelson, Marlborough and West Coast regions. About 80 percent of industry seed-stock needs are met by transfers of "Kaitaia spat", with movements of spat from other regions (especially Tasman and Golden Bays) and "seed mussels" (20–60mm length) between growing regions (Keeley et al. 2009). Spat are transported to growing sites, where they are seeded in cotton stockinette on culture lines, or spat holding sites. Spat can then be grown at optimum densities or re-seeded as they grown to avoid overcrowding and achieve uniform and rapid growth.

7.3.1 Biosecurity risk pathways specific to shellfish aquaculture

Internationally, the role of shellfish industry pathways in the spread of exotic species is well documented, linking them to the spread of biofouling pests, toxic or noxious microalgae (associated with biotoxin production and shellfish poisoning), parasites and disease (Perez et al. 1981; Boudouresque et al. 1985; Grizel & Héral 1991; Wasson et al. 2001; Leppäkoski et al. 2002; Hewitt et al. 2004; Ruesink et al 2005; Keeley et al. 2009). This is especially true in the case of macroscopic biofouling (Boudouresque et al. 1985; Minchin 2007; Mineur et al. 2007; McKindsey et al. 2007) and associated organisms (e.g. Duggan 1979; Utting & Spencer 1992). A number of studies have also documented survival of toxic and nuisance microalgae as a result of aquaculture transfers (McKindsey et al. 2007), with overseas studies also highlighting the potential importance of oyster transfers (Grizel & Héral 1991; Ruesink et al 2005; McKindsey et al. 2007). In fact, the introduction of *Crassostrea gigas* for aquaculture is regarded as one of the most important pathways for the global spread of non-indigenous species (Verlaque 2001; McKindsey et al. 2007). Ruesink et al. (2005) estimated that more than 40 percent of exotic marine species in Europe, the western United States and North Sea may have been introduced through oyster aquaculture. Consequently, international transfers of shellfish for aquaculture are now subject to rigorous risk assessment procedures.

Domestic pathways in New Zealand that pose biosecurity risks involve industry vessel movements and the movement of reproductive material, spat or seed shellfish and associated growing equipment. The propensity for shellfish aquaculture activities to spread risk organisms stems from the fact that intertidal and subtidal cultivation methods, and their associated structures and materials (e.g. racks, ropes, floats, pontoons, baskets and trays), provide habitats that allow such organisms to proliferate at high densities (Clapin & Evans 1995; Floc'h et al. 1996; Handley 1997a, 2002; Carver et al. 2003; Lane & Willemsen 2004; Coutts & Forrest 2007). From a biosecurity perspective, and for subtidal farming in particular, ecological risks arise because the farm may become infested and/or farm structures act as "reservoirs" for the further spread of pests. While a number of farm-related mechanisms have been described (Forrest & Blakemore 2002), transfers of green-lipped mussel (*Perna canaliculus*) seed stock within and between farming regions are of particular significance, and have already resulted in the spread of a number of high profile pests in New Zealand (e.g. the kelp *Undaria pinnatifida* and tunicate *Didemnum vexillum*) (Keeley et al. 2009). Alfaro et al. (2011) provides an up-to-date description of the mussel spat industry.

Between-region transfers of unwanted pests, parasites or diseases can occur via movement of aquaculture vessels, stock or equipment (Keeley et al. 2009). Transfer may also occur through the movement of recreational vessels that become infected after mooring in the vicinity of marine farms or marine farm equipment (Floerl et al 2009). Based on studies of pests associated with mussel culture in New Zealand (Forrest & Blakemore 2006; Forrest et al. 2007a) and oyster culture here and overseas (Handley 2002; Mineur et al. 2007), there is a high likelihood that associated fouling organisms will survive if such transfers occur without the application of antifouling treatments.

At **local** scales, the spread from reservoirs can take place via microscopic life stages (e.g. seaweed spores or animal larvae) that are released into the water column (Forrest et al. 2008). Alternatively, dispersal can occur via fragmentation and drift of viable fragments of the pest (Forrest et al. 2000; Bullard et al. 2007). Marine farms, jetties and vessel moorings can then act as "stepping stones" enhancing spread even if the source was not from aquaculture operations (Bulleri & Airoldi 2005, Forrest et al. 2008). The shellfish farm may not be the source, but may exacerbate the risk of spread from another source. Intensification of farming operations could lead to increased risk of the spread of parasites, pests or pathogens at a local scale. If farm space is limiting, options to intensify can include increasing stock levels or utilising unsuitable sites. For example, growing Pacific oysters on subtidal mussel farms can increase fouling and mudworm infestation levels (Handley 1997a, 1997b).

Poor farm management practices can amplify fouling and pest populations leading to marketing issues, stress and potential disease issues (Handley & Jeffs 2002; Handley & Bergquist 2007; Handley 1997b, 2002).

7.3.2 Descriptions of main effects and their significance

7.3.2.1 Effects from marine pests

Table 7.7: Ecological effects from marine pests due to filter-feeder aquaculture.

Description of effect(s)	**A. General biosecurity risks from marine pests** i. Shellfish culture pathways lead to infection of farm sites by marine pests. ii. Infected farm acts as a reservoir for pest spread to wider environment. iii. Shellfish farms alter environmental conditions and facilitate establishment of marine pests. For example, organic enrichment on seabed may favour non-indigenous soft-sediment species. Removing fouling waste in situ adds to the latter process. iv. Spat transfers may spread pest from spat catching sites or hatcheries. **B. Specific risks relating to pest and disease interactions** i. Fouling increases drag on farm infrastructure, posing risks from gear failure and/or drop-offs, posing threats from disease transmission and fragmentation/spread. ii. Fouling smothers stocks or clogs baskets/trays, and slows water exchange resulting in poor oxygen exchange (especially in summer) and waste removal, increasing the likelihood of disease outbreak/transmission. iii. Pests pose biosecurity risks as potential intermediate hosts for pathogens and parasites. iv. Fouling attracts wild fish species that could become parasite/pathogen vectors or intermediate hosts. v. Farming Pacific oysters increases their propensity to proliferate and colonise hard and soft substratum with potential for adverse ecological effects.
Spatial scale	*Local* to *national* scale.
Duration	Irreversible if pest establishes a viable population and eradication is not feasible.
Management options	**A. Consenting and infrastructure considerations** • Farm spacing, zoning, staged development, identification of epidemiological units and so on. **B. International: Import health standards** • Import health standards, for example, for juvenile yellowtail kingfish from Australia **C. Domestic: Development of industry Codes of Practice to address** i. Management of pathways to reduce the risk of infection of culture sites and/or the subsequent spread of marine pests, including: • risk reduction procedures for domestic stock transfers (including associated transfer water) that are consistent with MPI border standards; • procedures for vessels and/or the transfer of equipment to minimise the risk of marine pest transport with shellfish culture pathways (e.g. vessel antifouling, cleaning, inspections). ii. On-farm management to reduce risk to the wider environment, including: • education and surveillance to facilitate early detection of pest species; • routine farm management procedures for cleaning of oyster racks or mussel floats and backbone ropes on longlines between crops; • application of pest response and containment procedures where feasible; • farm site selection and management practices that maximise growth and condition but minimise risks of pest infestations.

Table 7.7: Ecological effects from marine pests (continued)

Knowledge gaps	• Implications for natural habitats of the development of marine pest populations on aquaculture structures. • The direct and indirect ecological effects of marine pests in the wider New Zealand environment. • Effective and environmentally friendly mitigation methods for anthropogenic pathways, and established pest populations on shellfish farms and in natural habitats. • Intermediate host status of fouling organisms for parasites and pathogens and interactions/links with other aquaculture species. • Fouling waste recycling technologies. • Links between benthic effects/nutrient loadings and exacerbation/facilitation of marine pests and HABs. • Fragment or larval dispersal distances of some fouling species. • Subtidal oyster culture techniques that minimise pest infestations. • Environmentally friendly antifoulants for ropes/cages that can prevent settlement of fouling species. • Remote setting methods to control oyster spat density to prevent overcrowding.

* Italicised text in this table is defined in chapter 1 – Introduction.

7.3.2.2 Ecological effects from pathogens and parasites

Table 7.8: Ecological effects from parasites and pathogens due to filter-feeder aquaculture.

Description of effect(s)	**A. General biosecurity risks from marine pathogens and parasites** i. Shellfish culture pathways lead to infection of farm sites by pathogens or parasites. ii. Infected farm acts as a reservoir for pathogen or parasite spread to wider environment. iii. Shellfish farms alter environmental conditions and facilitate establishment of pathogens or parasites. **B. Specific risks relating to shellfish aquaculture** i. Pathogens and parasite infestations reduce growth, condition and health of stocks, increasing likelihood of spread to wider environment. ii. Increased handling associated with parasite/disease intervention may lead to heightened risk of stock loss/drop-offs or increased stress on stock, both enhancing risk to the wider environment. iii. Therapeutants and other interventions could affect non-target species in the wider environment. iv. Increased waste production (mortalities), leading to land disposal and associated environmental effects, including disease transfer risk.
Spatial scale	*Local* to *national* scale.
Duration	Irreversible if pest establishes a viable population and eradication is not feasible.
Management options	**A. Consenting and infrastructure considerations** • Farm spacing, zoning, staged development, identification of epidemiological units and so on. **B. International: Import health standards** • Import health standards used to control equipment transfers. **C. Domestic: Development of industry codes of practice to address:** i. Management of pathways to reduce the risk of infection of culture sites, and/or the subsequent spread of pathogens or parasites, including: • risk reduction procedures for domestic stock transfers (including associated transfer water) that are consistent with MPI border standards. Quarantine procedures.

Table 7.8: Ecological effects from parasites and pathogens (continued)

Management options	• procedures for vessels and/or the transfer of equipment to minimise the risk of pathogens or parasites with finfish culture pathways (e.g. vessel antifouling, cleaning, inspections). ii. On-farm management to reduce risk to the wider environment, including: • education and surveillance to facilitate early detection of stock infected by pathogens or parasites; • application of parasite or pest response, including therapeutant treatment, isolation/ quarantine/culling of infected stocks; • farm site selection and management practices that maximise growth and condition but minimise risks of disease and parasites.
Knowledge gaps	• Identification of potential pathogens and parasites that could become problematical to cultured bivalves. • The direct and indirect ecological effects of parasites and pathogens to non-cultured species in the wider environment. • Natural prevalence and distribution of disease agents in the New Zealand marine environment. • The natural transmission mechanisms and farm-to-farm dispersal potential of many disease agents. • Links between pest infestations and susceptibility to disease. • Links between hatchery-produced shellfish spat and disease spread (e.g. ostreid herpes virus). • Breeding for disease resistance. • Rapid assessment tools for diseases like the ostreid herpes virus.

* Italicised text in this table is defined in chapter 1 – Introduction.

7.3.2.3 Description of effect/s

A. General biosecurity risks from marine pests, parasites and pathogens

In the New Zealand summer of 2010/11 an invasive ostreid herpes virus-1 (OsHV-1) was identified to cause 50–80 percent of oyster spat in most North Island harbours (MAFBNZ 2010a; http://web.oie.int). It appears that this virus may have been present in New Zealand waters since at least 1991 where it caused mass mortality of oysters in a hatchery in the Mahurangi Harbour (Hine et al. 1992, Forrest et al. 2009), but then did not manifest in farmed or wild stocks until 2010, possibly mediated by stress related to unusually high summer water temperatures (MAFBNZ 2010a). Until that time, there had been no documented (OIE listed, OIE 2011) serious parasites or pathogens of Pacific oysters for the approximately 30-year culture history of this species in New Zealand (Diggles et al. 2002).

Several less serious diseases and parasites associated with New Zealand Pacific oysters have also been reported, most of which are also globally ubiquitous and pose some commercial threat to oyster production. These include various species of predatory flatworm and commensal mudworm species that can elicit parasitic effects (Handley 2002; Handley & Bergquist 1997). The wider ecological effects of these risk organisms are unknown but could be potentially positive in locations where amenity values are compromised by Pacific oysters.

New Zealand farmed Pacific oysters have not suffered significant or unexpected affects from indigenous pathogens such as Apicomplexan X (APX), *Bonamia exitiosa Rickettsia* and digestive epithelial virosis. The Pacific oyster has, however, been shown to be a potential reservoir and carrier of the protistan *Bonamia ostreae* contracted from *Ostrea edulis* but does not express the pathogen (Lynch et al. 2010). This supports findings reported elsewhere that Pacific oysters appear more resilient to some diseases (Elston 1993) suffered by other oysters. Previous to the herpes virus outbreak in 2010, and in the light of extensive pathology surveys on New Zealand Pacific oysters (with negative results) it was inferred that culture of pre-existing Pacific oysters in New Zealand is unlikely to pose a pathological threat (Keeley et al. 2009). However, any new importation of Pacific oyster stock should be subject to examination and be sourced from a documented disease-free area governed by a specific import health standard, for which there is currently none available. This is suggested because observations from overseas indicate that there is a risk of spreading disease via introduction of oysters for culture, particularly from Pacific oysters (Keeley et al. 2009).

Although New Zealand may lack some of the Pacific oyster diseases and parasites identified overseas, congeneric diseases of shellfish and others of close taxonomic affiliation do occur in New Zealand waters and could affect Pacific oysters. It follows that, should New Zealand Pacific oysters suffer an incursion by an exotic disease or parasite, it is possible that oyster farms could assist in the spread of disease to other mollusc species. However, the effect of non-native species can be unpredictable. For example, Thieltges et al. (2008) reported that the presence of introduced Pacific oysters and American slipper limpets (*Crepidula fornicata*) mitigated the effects of a trematode parasite on blue mussels (*Mytilus edulis*). It appears that the introduced oysters diverted the trematodes from their usual native hosts, thus reducing infection levels. Other less significant diseases are discussed by Keeley et al. (2009). The apparent advantage to aquaculture of Pacific oysters being relatively disease resistant also presents a liability in that this species potentially provides an asymptomatic reservoir of pathogens that could be more damaging to other oysters and bivalves (Forrest et al. 2009).

Green-lipped mussels are not highly prone to disease (Keeley et al. 2009). New Zealand mussels have not been reported with any pathogens appearing on the OIE list of important diseases (Webb 2007). The risk of transmission of pathogens or parasites from cultured to wild *P. canaliculus* and then to other species can be considered minimal or unknown at present. With the exception of the protozoan parasite APX, all other diseases reported in cultured mussels usually have lower prevalence and intensities than in wild mussels (S Webb, Cawthron Institute pers. obs.). Previous studies have not found disease associated mortalities in *P. canaliculus* (Hine 1989) or the presence of potentially serious pathogens within the mussels (Hine 1996).

A recent review on mytilids with particular emphasis on *P. canaliculus* (Webb 2007) indicates that there have been no particularly destructive diseases of mussel species identified in New Zealand, with the exception of a digestive viral disease. Digestive viral disease (digestive epithelial virosis) was first noted by Jones et al. (1996) who reported mortalities in cultured green-lipped mussels in the outer Marlborough Sounds, of which the majority were associated with virus-like particles and digestive tubule damage. Other less significant diseases are discussed by Keeley et al. (2009).

i. Filter feeder culture pathways lead to infection of farm sites by pests, pathogens or parasites

Effects from naturalised populations of Pacific oysters throughout their New Zealand distribution can arise where high densities occur in natural and artificial habitats of estuaries, ports and harbours. While Pacific oysters may be invasive, primarily in rocky habitats and artificial structures, there is also evidence that they can invade soft-sediment estuarine habitats both overseas (Cognie et al. 2006) and within their distributional range in New Zealand (Jenkins 1997; Forrest B pers. obs.; Handley S pers. obs.). Pacific oyster reefs in New Zealand can accumulate mud, and sharp oyster shell can degrade coastal recreational values (Hayward 1997). Naturalised Pacific oyster populations may also displace native species in New Zealand (Dromgoole & Foster 1983). Based on these studies, it can be expected that dense aggregations of naturalised oysters have the potential to lead to significant ecological changes, including displacement of indigenous oyster species in habitats where they establish (Escapa et al. 2004; Sousa et al. 2009; Melo et al. 2010).

Awareness of biosecurity issues related to mussel farming in New Zealand was largely precipitated in the late 1990s by concerns regarding the human-mediated spread and ecological effects of the Asian kelp *Undaria pinnatifida* (Sinner et al. 2000; Keeley et al. 2009). Around this time, fouling also became recognised as a significant threat to the mussel industry when a population explosion of the sea squirt *Ciona intestinalis* resulted in mussel crop losses in parts of the Marlborough Sounds. Subsequently, other fouling pests have emerged whose potential for adverse effects on the mussel industry and the wider ecosystem have been recognised, such as the sea squirts *Styela clava* and *Didemnum vexillum* (Coutts & Forrest 2007; Gust et al. 2007; Keeley et al. 2011). While many of these pest organisms have reached problematical densities only on mussel farms and other artificial structures in New Zealand, overseas evidence also reveals their potential to be highly invasive in natural habitats (e.g. *Didemnum*; Bullard et al. 2007; Lengyel et al. 2009; Mercer et al. 2009; Smith et al. 2010; Cohen et al. 2011). While a number of farm-related vector mechanisms have been described (Forrest & Blakemore 2002), transfers of mussel seed stock within and between mussel farming regions are of particular significance, and although aquaculture is not linked to the importation of pests in New Zealand, aquaculture practices have been linked to the spread of *Undaria* and *Didemnum*.

ii. Infected farm acts as a reservoir for pest, pathogen or parasite spread to wider environment

Internationally, a number of pest algal species, such as *Codium fragile* sp. *tomentosoides, Sargassum muticum* and *Undaria pinnatifida*, have been associated with oyster cultivation (Trowbridge 1999; Verlaque 2001; Mineur et al. 2007). In New Zealand, the translocation of tunicates *Styela clava* and *Eudistoma elongatum* has been associated with oyster culture (Coutts & Forrest 2005; Smith et al. 2007; Morrisey et al. 2009). The firm substratum offered by racks, oysters, ropes and the various containers that growers use to protect their crop from predators, provides an ideal habitat for fouling organisms that may include seaweeds, shellfish, barnacles and many species of tunicates and bryozoans (Handley pers. obs. Inglis & Gust 2003). This fouling, as for green-lipped mussels, has the ability to slow water transfer rates and, hence, feed supply, increasing the risk of predators, pests, and further fouling (Handley 1997b; Ross et al. 2001). In contrast, traditional wooden-stick culture techniques used in New Zealand are open to the water column and less prone to fouling. Intertidal and subtidal structures (and associated shellfish crops) provide ideal habitats for some fouling species to proliferate at high densities (Carver et al. 2003; Lane & Willemsen 2004; Coutts & Forrest 2007), potentially acting as reservoirs for the subsequent spread of pest organisms as described for mudworms and flatworms (see “Mussels” section below).

iii. Exacerbation; shellfish farms alter environmental conditions and facilitate establishment of marine pests, parasites or pathogens

In the summer of 2004–05 an elongate tunicate infested oyster racks in the Houhora Harbour, Northland, and was later identified as *Eudistoma elongatum* originating from Queensland (Handley 2005; Smith et al. 2007; Morrisey et al. 2009). While the ecological effects of intertidal and subtidal populations of *Eudistoma* are unknown, *Eudistoma* is well established in intertidal and subtidal areas and is particularly prominent in summer, dying back in winter to small buds. Recently, populations of this ascidian have rapidly expanded, creating conspicuous fouling on oyster racks, marina infrastructure, rocky shores and soft subtidal benthic habitats. All of the locations in which *Eudistoma elongatum* has appeared contain oyster farms, and it seems likely that its spread, if not its introduction, may be associated with movement of aquaculture equipment or stock (Morrisey et al. 2009). There is, consequently, potential for transfer of *Eudistoma* with oyster stocks or equipment moved to other oyster-growing areas in northern New Zealand that are currently uninfected, including Mahurangi, Whangaroa, Whangarei and Kaipara Harbours. Forrest & Blakemore (2002) cite an example of oyster stock being moved to Kaipara, Mahurangi and Parengarenga Harbours in response to degraded water quality in the Bay of Islands. In the case of *Eudistoma* in Northland, spread via natural dispersal between harbours is unlikely since *Eudistoma* does not appear to occur on exposed coasts and the dispersal capability of its larvae is probably small (M Page, NIWA pers. comm.).

Spionid polychaete worms, commonly referred to as “mudworms” are another example of risk organisms that can proliferate and potentially spread to and from aquacultured shellfish, (Handley 1997b). Mudworms infest a range of shellfish by boring through their shells, and if they are numerous or penetrate the host shell-cavity, they can cause parasitic effects including stress-induced poor growth and condition, potentially contributing to mortality (Handley 1997a; 1998; Diggles et al. 2002). Mudworms occasionally infest green-lipped mussels in New Zealand, with outbreaks recorded in Coromandel and the Marlborough Sounds (Handley unpub. data; Read & Handley 2004). Overseas, mudworms have been described infesting *Mytilus* species in the United Kingdom (Kent 1979; 1981), in Australia (Skeel 1979; Pregenzer 1983), and in the USSR (Murina & Solonchenko 1991). Compression tests showed that high levels of *Polydora ciliata* infestation tended to weaken the shells of *Mytilus edulis* in the United Kingdom (Kent 1981). Green-lipped mussels in New Zealand have been infested by both *Polydora* and *Boccardia* species, with up to 20–30 percent of crop unsuitable for sale in the half shell (Handley unpub. data; Read 2010). Mudworms can spread to cultured shellfish from infested wild shellfish populations including cockles, dredge oysters, scallops, paua and horse mussels (Diggles et al. 2002), but links between increased infestation of wild shellfish and shellfish, farming are unknown and difficult to quantify.

Predation by flatworms can also affect wild and farmed shellfish, including juvenile and adult mussels. Outbreaks appear to occur in mussels when they are seeded at very high densities that allow flatworms to settle and avoid being eaten by fish, for example, at the top of droppers where they are tied off to the back-bone and looped over, creating a mass of mussels (Handley 1999a, b and 2000, Handley pers. obs.). Again, the exacerbation risks stemming from reservoir effects of flatworm-infested shellfish aquaculture stocks to the wider environment are unknown.

Deposition of fouling biota may also contribute to seabed enrichment beneath mussel farms when fouling organisms reach high densities on farm structures and fall to the seabed either naturally or during defouling by farm operators (Keeley et al. 2009). The fouling biomass may intermittently be a substantial component of the organic material deposited to the seafloor, as appears to be the case for the recent spread of the invasive sea squirt *Didemnum vexillum* at mussel farms in the Marlborough Sounds. In such situations, the deposited fouling biomass may exacerbate enrichment effects (Keeley et al. 2009). Limited research has been undertaken by the mussel industry to collect and market fouling species, including blue mussels, *Mytilus edulis* (e.g. by the Marlborough Mussel Co), *Undaria* (see Section 7.3.4.2) and other seaweeds (S Handley and M Kelly, NIWA, unpub. data) that could reduce the potential spread of pest species and reduce benthic effects.

iv. Spat transfers may spread pest from spat catching sites or hatcheries

When the mussel spat reaches an appropriate size, it is seeded onto grow-out longlines. Spat and seed mussels (spat seeded onto growing ropes) are susceptible to fouling from tunicates, especially *Didemnum vexillum,* that smother and restrict water flow (A Pannell, pers comm). The floating subtidal culture methods used for mussels appear particularly prone to fouling. There is considerable interest in spat supply from mussel hatcheries, to take advantage of selective breeding technologies and to overcome threats associated with biosecurity risks stemming from wild spat collection. Pathway treatment options have been developed and tested for the control of *Undaria* on mussels and for spat transfers using freshwater, heat and a range of other treatments (Forrest & Blakemore 2006; Forrest et al. 2007a). Efforts to develop robust and reliable secondary treatment tools to eliminate pest transfer risks that are also operationally feasible and affordable have been elusive (Forrest & Blakemore 2006; Denny & Hopkins 2007; Forrest et al. 2007a; Keeley et al. 2009). Hence, at times, voluntary bans on aquaculture transfers have been implemented by the industry to reduce the risk of spreading target pest species. For example, in May 2000, a bloom of the paralytic shellfish poison producing *Gynodinium catenatum* led to a voluntary halt to transfers of Kaitaia spat (MacKenzie & Beauchamp 2000) until treatments were developed.

B. Specific risks relating to pest, parasite and pathogen interactions

Pests, parasites and pathogens are commonly overlooked or under-appreciated as key drivers shaping local community structure and biodiversity (NRC 2010). Internationally, the introduction or transfer of marine molluscs has resulted in the inadvertent introduction of several pathogens (e.g., Elston et al, 1986; Burreson et al, 2000; Naylor et al, 2001; Friedman & Finley, 2003; Wetchateng, 2008), however, ecological effects to the wider environment of such outbreaks are poorly described.

A detailed description of diseases known to affect non-finfish aquaculture species both in New Zealand and overseas is provided in Appendix 2 of Keeley et al. (2009).

i. Fouling increases drag on farm infrastructure, posing risks from gear failure and/or drop-offs, posing threats from disease transmission and fragmentation/spread

Fouling pests have the ability to slow water exchange through associated drag and clogging of trays or baskets, resulting in poor oxygen exchange, which may become critical at sites with low oxygen levels during summer months, when oxygen demand and shellfish metabolism is greatest (Beveridge 2004). The process of cleaning of farm structures, however, could potentially lead to increased likelihood of fragmentation and spread of some fouling species that could subsequently reproduce and/or reattach, re-colonising the farm structures or natural substrata (e.g. Hopkins et al. 2011). For example, the in-situ removal of the seasquirts *Didemnum vexillum* in mussel lines or *Eudistoma elongatum* on intertidal oyster racks could lead to the fragmentation and spread of these species (Handley pers. obs).

ii. Fouling smothers stocks or clogs baskets/trays, and slows water exchange, resulting in poor oxygen exchange (especially in summer) and waste removal, increasing the likelihood of disease outbreak/transmission

The clogging of baskets or growing trays for oysters, or overgrowth of fouling organisms, impairing oxygen exchange in mussels may result in undue stress (Beveridge 2004), which may increase susceptibility to disease and subsequent potential transmission to conspecifics and the wider environment.

iii. Pests pose biosecurity risks as potential intermediate hosts for pathogens and parasites

There is limited evidence that shellfish predators, such as flatworms, may be intermediate hosts for pathogens (Jennings 1997). Farmed stocks often exhibit lower infection levels than wild mussels or other bivalves, so the risk of them acting as reservoirs for transfer of disease therefore appears low, unless farmed mussels become vehicles for the spread of introduced exotic diseases (see Keeley et al. 2009).

iv. Fouling attracts wild fish species that could become parasite/pathogen vectors or intermediate hosts

As farm structures can act as fish aggregation devices (FADs) (Dempster et al 2009), fouling pests by providing increased habitat complexity, can also lead to fish recruitment and enhance the attractiveness of structures, potentially enhancing the FAD effect. These fish could predate shellfish, become parasite/pathogen vectors or intermediate hosts of disease or parasite transmission.

v. Farming Pacific oysters increases their propensity to proliferate and colonise hard and soft substratum with potential for adverse ecological effects

The farming of Pacific oysters could potentially exacerbate the spread of Pacific oysters as a pest fouling species and competitor on native substrata and assemblages. While the Pacific oyster proliferates on hard substrata in the intertidal zone, it can also colonise muddy substrata and alter shoreline characteristics if the larvae settle on exposed shells or stones and, then on conspecifics (Jenkins 1997). This can lead to extensive oyster reefs forming on soft sediments, altering sediment characteristics and hydrodynamics in shallow estuarine areas (Handley pers. obs).

7.3.3 Pest, parasite and pathogen management options

The choice of site-appropriate growing methods for shellfish can strongly affect susceptibility to risk organisms, pest reservoir risk and, hence, associated ecological effects (see Section 7.1.2). This section should be read in association with Section 7.1.5, which outlines management strategies relevant to all aquaculture operations.

A. Consenting and infrastructure considerations

Within New Zealand, new aquaculture developments must go through a consenting process. Currently, this is managed in an ad-hoc fashion by regional councils. For example, the Tasman District Council has discretion in its plan to consider "management of biosecurity risk organisms, such as *Undaria*", and the new rules controlling filter feeding bivalves and additive species, including finfish, require the council to consider "managing risks of incursion, disease, biosecurity risk organisms, and genetic risk to wild stocks" (R. Squires, Tasman District Council, pers. comm.).

However, best practice internationally suggests that a more structured approach considering factors such as farm spacing, zoning, staged development and epidemiological units could be considered as part of RMA consent requirements to minimise biosecurity risks from pathogens and pests on a case-by-case basis.

Site selection is clearly important for reasons outlined in Section 7.1.2. The OIE's online aquatic animal health code suggests establishing zones and using compartmentalisation (through geographical separation) of epidemiological units to manage biosecurity risks (OIE 2011). They described the concept of an epidemiological unit as "a group of animals that share approximately the same risk of exposure to a pathogenic agent". Creating defined areas based upon the concept of the epidemiological unit will underpin biosecurity activities in response and readiness work, which stakeholders both agree with and understand the benefits of having (Morrisey et al. 2011).

Regional councils therefore have a particular interest in whether farm spacing can be used as a management strategy to contain marine pest populations and pathogen or parasite outbreaks (see below).

In other countries, where finfish cage separation requirements are specified, minimum distances vary widely; for example, ranging from 300 metres 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 may be of little use in a regional context, except to highlight that a robust assessment of farm spacing requires considerable site-specific information (Forrest et al. 2011).

Results of the Phase II aquaculture readiness modelling concluded that dispersion of pathogens and pests by water movement occurs over relatively small spatial scales, and long-distance dispersion (for example, from the top of the North Island to the South Island) is unlikely over the period during which the pathogen remains infectious. Human-mediated movements of aquaculture stock and equipment, in contrast, are capable of transmitting pathogens over much larger distances and shorter time frames (Morrisey et al. 2011).

Within the consenting process, ongoing management options should be established. Methods include staged development coupled with surveillance programmes to detect incursions or exacerbation of existing pests, parasites and pathogens.

MPI has recognised that there is a need for proactive systems to limit the likelihood of entry and subsequent spread of pests or diseases (Morrisey et al. 2011). Currently, New Zealand has strict import controls in place to limit the potential for pest or disease introductions. However, such systems are not infallible and preparation is required to ensure (1) early detection of any incursion and (2) that there are widely understood response actions that can be implemented quickly when an incursion is detected. MPI, in recognising the biosecurity needs of the aquaculture industry, has commissioned research (the Aquaculture Readiness Data project) to support developing a readiness system for aquaculture. Phase I of this research was designed to obtain fundamental information on New Zealand's aquaculture and fisheries enhancement industries. Phase I produced (1) a geodatabase of aquaculture facilities (land, marine and freshwater based) from publicly available information, (2) information on the movement of stock and equipment between facilities, based on a survey of the industry and, (3) a report on the current spatial knowledge of New Zealand's aquaculture operations. Phase II was designed to develop, in consultation with stakeholders, defined areas based upon the concept of an epidemiological unit. Aquacultured organisms in each defined area have a similar likelihood of exposure to a pest or disease. In the context of disease and pest management, these areas may serve as surveillance zones for the early detection of incursions, act as predefined movement control areas, or serve as zones to re-establish trade during or after an outbreak, in addition to providing spatial information about farmed or enhanced species for general animal health management.

B. International: Import health standards

International border protection for pest, parasites and pathogens is controlled through import health standards. To date, there are have not been any standards developed for importation of shellfish seed, but the standard for kingfish fingerling import may act as a useful reference (MAFBNZ 2010a).

C. Domestic: Development of industry Codes of Practice to address:

i. Management of pathways to reduce the risk of infection of culture sites and/or the subsequent spread of marine pests, parasites and pathogens

For domestic biosecurity pathway management, development of codes of practice will not necessarily ensure environmental sustainability given the potential plethora of uncontrolled vector pathways like wild animal and fish movements and public and commercial boating activities, but they are a step in the right direction. International border protection for pests, parasites and pathogens is controlled through import health standards. Such standards can include requirements for receiving facilities to be of a specific standard, specified modes of transport to be used, transport to occur in UV sterilised water, quarantine periods and veterinary inspections (e.g. MAFBNZ 2010a). The New Zealand Oyster Industry Code of Practice (NZOIA 2007) has specific sections on biosecurity management including:

i. provisions to uphold the New Zealand *Styela clava* Code of Practice and Biosecurity Code of Practice;

ii. notifying Ministry for Primary Industries of the finding of any notifiable organism or organism not normally seen or detected in New Zealand;

This code specifies that "biosecurity threats should be seen in context, including other vectors, for example; equipment, vessels, biota, currents, also that the key New Zealand Biosecurity measures against undesirable aquatic organisms are to keep them out of New Zealand and for early detection (most probably at ports)". Emergency biosecurity provisions are also stipulated, including:

i. If the farmer is advised in writing of the requirement by Aquaculture New Zealand, the farmer shall comply with a biosecurity monitoring (and/or management) plan or protocol regarding transfers/pests/diseases, or other biosecurity considerations to the satisfaction of Aquaculture New Zealand.

ii. Supervisors should be familiar with the list and with the reporting procedures for new organism incidents as required by Ministry for Primary Industries.

The New Zealand Mussel Industry Code of Practice (NZMIC 1999) advocates the onsite cleaning of floats and backbone ropes (and turning cleaned floats over) to ensure that encrusting biota and sediment are released within the permitted area to help prevent the transfer of species between different farming areas.

ii. On-farm management to reduce risk to the wider environment

Oyster farmers are advised to be alert to any unusual or extreme mortality, parasites and predators or fouling of oysters on the farm, which should be reported to MPI (NZOIA 2007). If possible, equipment with risk organisms attached should be removed from the environment and transported ashore to an area where it cannot contaminate the marine environment. Equipment should not be moved between sites where risk organisms occur, and the appropriate authorities should be informed and advice sought on further action.

The transfer of wild and hatchery spat also provides pathways for the spread of risk organisms that can be monitored or controlled. For example, because of the recent herpes virus outbreak, it would appear prudent for any new importation of Pacific oyster stock to be subjected to examination and be sourced from a documented disease-free area or hatchery. This is suggested because observations from overseas indicate that there is a risk of spreading disease via the introduction of oysters for culture – particularly from Pacific oysters (see Keeley et al. 2009).

Other threat-specific treatments may exist. For example, to prevent the spread of tunicates like *Eudistoma, Didemnum* *vexillum* and other fouling on green-lipped mussel spat and stocks treatment of stock and equipment with acetic acid has been trialled (Morrisey et al. 2009, Denny & Hopkins 2007; Forrest et al. 2007a; Denny 2008). Further trials would be required to determine effective concentrations and durations of treatment that do not adversely affect the stock. Handley (2005) noted that fouling by *Eudistoma* could possibly be avoided by raising oyster racks to or above extreme low water neap as the tunicate did not appear to survive well in the intertidal zone, only on the undersides of the rails and on the vertical posts.

A heat treatment procedure for oyster spat was developed in an attempt to export pest-free live oysters to Australia to satisfy stringent biosecurity import requirements (J Dollimore, Biomarine Ltd pers. comm.). This treatment method was later adapted by the oyster industry in response to the presence of the toxic phytoplankton species *Gymnodinium catenatum* in the Kaipara in 2000, but has not been used since and would apparently be invoked only if a similar incident recurred in a spat collecting area (Taylor et al. 2005). Trials involving dipping oyster spat-catching bundles in freshwater or brine and spraying with vinegar were unsuccessful in achieving complete control of predatory flatworm infestations; and management techniques for avoidance were recommended instead (Handley 2002). Likewise, direct control of mudworm infestations is not recommended, rather, culture methods should be designed to avoid infestations by growing oysters at or above extreme low water neap tidal level at appropriate densities, or at sites free of mudworms in the subtidal (Handley 1995, 1997b, 2002). Adjustable intertidal longline systems have been developed in South Australia to hold stocks lower in the water column during periods when king tides coincide with hot weather (e.g. www.bstoysters.com/). These systems can also be adjusted to control mudworm infestations (Handley pers. obs.), but it is unknown whether this has been tested for New Zealand conditions.

Intertidal height can strongly influence oyster growth, condition, fouling and susceptibility to mudworm infestations. Subtidally cultivated oysters can suffer from fouling, mudworm and flatworm infestations, and aesthetic smell issues (Handley & Bergquist 1997; Handley 2002, 2005; NZOIA 2007; Morrisey et al. 2009). In the past decade, intertidal longline and basket systems developed in Australia have become popular for growing “single-seed” (individual de-clumped or hatchery-produced spat) product. Some of these systems have the ability to adjust the intertidal level to lower growing levels in hot weather or elevate oyster baskets to kill fouling, unlike the wooden rack and rails, which have a fixed level. A small amount of subtidal cultivation occurs as single-seed oysters grown in baskets, trays and “ren” culture in Auckland, Coromandel and the Marlborough Sounds (Handley pers. obs.). To increase returns and marketability, subtidally grown Pacific oysters are typically “finished-off” in the intertidal zone before sale as half-shell product rather than shucked for lower value meat-only product (Handley & Jeffs 2002; Handley pers. obs.). However, maximising intertidal exposure is likely to reduce biosecurity and ecological risks.

Tasmania undertakes annual monitoring of oyster parasites and disease as part of the Tasmanian Pacific Oyster Health Surveillance Program run by the Department of Primary Industries, Parks, Water and Environment (www.dpipwe.tas.gov.au). Oyster spat suppliers must participate in the surveillance programme. As all spat for the South Australian oyster industry is supplied from Tasmanian hatcheries and, given that a number of aquatic pests inhabit Tasmania, the potential exists for these pests to be transferred with spat to South Australian waters. Three exotic species of particular relevance to oyster spat importation include: mudworm (*Boccardia knoxii*), seastar (*Asterias amurensis*), and Asian kelp (*Undaria pinnatifida*) (EPA 2005).

Mussel farmers are also encouraged to minimise the settlement of encrusting organisms and their transfer among farms and to report any unusual or exotic species to the local marine farming organisation. The New Zealand Mussel Industry Council also developed a voluntary code of practice for the transfer of mussel seed to minimise risk associated with mussel seed transfers targeted at the pests: *Mytilus galloprovincialis*, *Ciona intestinalis* and *Undaria pinnatifida* (NZMIC 1999; NZMIC 2001). When the *Gymnodinium catenatum* blooms occurred on the west coast of the North Island in 2000 (see above), methods of washing mussel spat were developed to minimise cyst densities within infected spat so that inter-regional spat transfers could resume (Taylor 2000). The mussel industry has also previously been active in regional pest management programmes for *Undaria* in Big Glory Bay (Stewart Island) and in the Nelson region, and led a multi-stakeholder working group that was formed to assist in a Top of the South management programme for *Didemnum vexillum*. These management programmes demonstrated the considerable difficulties of effectively managing marine pests once established on mussel farms, pointing to the important need to focus on prevention of spread.

7.3.4 Knowledge gaps

Please read this section in conjunction with Section 7.1.4.

i. Ecological effects and significance

The considerable growth in the aquaculture industry anticipated over the next 15 years (NZAS 2006) will require a better understanding of the wider ecosystem effects of shellfish aquaculture. These include the cumulative effects including biosecurity effects of additional aquaculture and aquaculture development (combined with other anthropogenic stressors, e.g. Kelly 2011), within the context of ecological carrying capacity (Keeley et al. 2009). For example, outbreaks, host specificity and transmission from cultured shellfish of diseases, such as the oyster herpes virus, pose high levels of potential risk, but also many unknowns. Hence, there is a need to understand more about how intensification and diversification of aquaculture may increase risk to the New Zealand environment. A useful step would be to gauge the susceptibility of cultured species by assessing novel disease loads in the same organism growing in foreign waters. Other important information that would allow better assessment of disease risk includes identification of the parasite APX (see Keeley et al. 2009) to species level and differentiating it (or otherwise) from the APX in flat oysters. Also, life-cycle studies on *Marteilia* are needed to ascertain the stringency of intermediate host specificity.

Exotic pathogen threats to green-lipped mussels can only be speculated upon (Keeley et al. 2009). In this category, *Marteilia* spp. and disseminated haemic neoplasia (a molluscan leukemia) were identified by Webb (2007) as the most likely non-native threats. Other threats to mussels appear to be posed by parasites introduced by invading species of blue mussel (e.g. *Mytilus edulis*). These common ship-borne fouling organisms are a likely source of overseas pathogens. Hybridisation of invasive indigenous blue mussels (*M. galloprovincialis*) presents a further potential pathology hazard by the production of a more susceptible reservoir host for these pathogens. The physical coincidence of hybridising mussels and pathogens in New Zealand waters is possible but unknown.

There is a clear lack of knowledge about the ecological effects of many of the risk organisms that could be associated with shellfish aquaculture in New Zealand. For example, there is limited information on disease transmission to wild shellfish and host specificity. Overseas, the aquabirnavirus infectious pancreatic necrosis virus has also been detected in *Mytilus edulis* (VPS 2000). It is a common virus of salmonids and is also a suspected clam pathogen in Taiwan. Although not detected in New Zealand mussels (Keeley et al. 2009), the possibility of green-lipped mussels harbouring this virus, at least temporarily, is suggested by the fact that polioviruses and enteroviruses have been shown to persist in *P. canaliculus* after experimental exposure (Lewis et al. 1986; Greening et al. 2001). Caution is clearly required in polyculture, as mytilids might harbour viruses with consequent threat to susceptible fish.

In the absence of space for expansion of the oyster industry in Northland, Handley & Jeffs (2002) recommended that industry should develop subtidal methods for culturing Pacific oysters so that future expansion could take place in coastal or offshore waters. However, subtidal cultivation poses more risks and biological challenges that need to be addressed by research to minimise fouling pests and disease. Similarly, with increasing pressure on mussel culture space, there have been efforts to farm offshore in more wave-prone locations, which may also pose biosecurity risks in unpredictable ways. For example, wave action damaging mussel shells in the Firth of Thames appeared to facilitate mudworm infestations of mussels grown there (Handley 2003). When new aquaculture areas are developed, associated risk species may become more abundant locally, and more widespread regionally. While such effects represent an increased biosecurity risk, their ecological significance is poorly understood (Keeley et al. 2009; Forrest et al. 2011). Quantifying and monitoring such regional- scale changes can be difficult and beyond the scope of the aquaculture industry alone.

ii. Environmentally friendly therapeutants and mitigation methods

There is 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). However, until the fouling pest species are known, whether a practical or eco-friendly eradication method is available is also unknown. Screening of eradication methods therefore may be required on a species or taxonomic group level, for example the evaluation of eradication methods for *Eudistoma elongatum* associated with oyster culture (Morrisey et al. 2009; Page et al. 2011).

iii. Exacerbation risks

Similarly, research effort may be required to elucidate links between aquaculture-related eutrophication and HABs, which in the long-term may need to be accompanied by regional-scale monitoring of target HAB species (Forrest et al. 2011). In terms of pest, disease and parasite risks to the wider environment, uncertainty regarding potential effects arises from the fact that the suite of organisms associated with culture may not be clearly understood until sites or regions are fully developed. 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 seldom known (Forrest et al. 2011).

iv. Waste capture and/or recycling

Whilst research here and overseas has trialled in situ cleaning devices for mussel culture, the process of cleaning farm equipment and removing fouling organisms in-situ could also create significant but yet to be quantified ecological effects (Keeley et. al. 2009; Handley pers. obs.). As the maintenance and removal of fouling organisms may be most cost-effectively achieved in situ, there appear to be research opportunities on ways to contain, recycle and utilise the fouling organisms for pharmaceutical or nutriceutical purposes, or for the nutrients sequestered by fouling species.

v. Dispersal and/or infection mechanisms

Fragmentation of organisms during cleaning, or as an innate organism dispersal mechanism, could potentially contribute to the spread of pest species and pathogens (if they are intermediate hosts) from farm structures. The ability of organisms to disperse, reattach or survive following fragmentation is currently being reviewed as part of in-water cleaning of recreational and commercial vessels by MPI (Page and Morrisey, NIWA pers. comm.).

7.4 Lower trophic level species (*Undaria* and sea cucumbers)

7.4.1 Descriptions of main effects and their significance

7.4.1.1 Sea cucumbers

Table 7.9: Ecological effects from marine pests, pathogens and parasites due to sea cucumber aquaculture.

Description of effect(s)	**A. General biosecurity risks from marine pests** i. Sea cucumber culture pathways lead to infection of farm sites by marine pests, pathogens and parasites. ii. Infected farm acts as a reservoir for pest, pathogen and parasite spread to wider environment. iii. Sea cucumber farms alter environmental conditions and facilitate the establishment of marine pests. For example, farm structures facilitate fouling, and removing fouling in-situ may add to organic enrichment on the seabed, favouring non-indigenous soft-sediment species. **B. Specific risks relating to pest and disease interactions** iv. Fouling increases drag on farm infrastructure, posing risks from gear failure and/or escapes, posing threats from disease transmission. v. Fouling clogs baskets/trays, and slows water exchange, resulting in poor oxygen exchange (especially in summer), and waste removal, increasing the likelihood of parasite and disease outbreak and transmission. vi. Pests pose biosecurity risks as potential intermediate hosts for pathogens and parasites. vii. Intensive land-based culture leads to outbreaks of parasites/disease, leading to risk of transmission and adverse ecological effects.
Spatial scale	*Local* to *national* scale.
Duration	Irreversible if pest establishes a viable population and eradication is not feasible.

Table 7.9: Ecological effects from marine pests, pathogens and parasites (continued)

Management options	**A. Consenting and infrastructure considerations** • Farm spacing, zoning, staged development, identification of epidemiological units and so on. **B. International: Import health standards** • Import health standards used to control feed or equipment transfers. **C. Domestic: Development of industry codes of practice to address:** i. Management of pathways to reduce the risk of infection of culture sites and/or the subsequent spread of marine pests, including: • risk reduction procedures for domestic stock transfers (including associated transfer water), that are consistent with MPI border standards; • procedures for vessels and/or transfer equipment to minimise the risk of marine pest transport with culture pathways (e.g. vessel antifouling, cleaning, inspections). ii. On-farm management to reduce risk to the wider environment, including: • education and surveillance to facilitate early detection of risk species; • routine farm management procedures for cleaning of culture cages or floats and backbone ropes on longlines between crops; • application of response and containment procedures where feasible; • farm site selection and management practices that maximise growth and condition but minimise risks from pests, parasites or disease.
Knowledge gaps	• Lack of knowledge of sea cucumber risk organisms and their significance in culture – unknown farming methods hampers this assessment. • Implications for natural habitat of the development of reservoir populations of risk species. • Direct/indirect ecological effects of risk species in the wider environment. • Effective and environmentally friendly mitigation methods for established pest populations on farms and in natural habitats. • Intermediate host status of fouling organisms for parasites and pathogens and interactions/links with other aquaculture species. • Fouling waste recycling technologies. • Fragment or larval dispersal distances of fouling species, parasites and pathogens.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Sea cucumbers (*Australostichopus mollis*) are not cultured commercially in New Zealand at present, but *A. mollis* is being investigated as a potential co-culture species with green-lipped mussels (Slater & Carton 2007; Slater 2009). Culture techniques could take a variety of forms including land based, seabed ranching, IMTA or co-culture or more natural reseeding. Some methods require the addition of feed, whereas some could mitigate impacts of other forms of aquaculture. Land-based culture systems for sea cucumber may be conceptually less prone to biosecurity risk as they could be isolated from wild stocks and transport vectors associated with marine farms (e.g. vessels, equipment transfers).

A. Pathways

Biosecurity risk pathways will be dependent on the culture methods used, but some methods (e.g. off-bottom subtidal culture) will be conceptually similar to other types of subtidal culture for mussels and oysters, described elsewhere in this report (see Section 7.3.1). Many of the risk species of pests and pathogens associated with off-bottom culture also have the potential to be similar to those described for other types of subtidal culture operation. Ecological effects stemming from pests, parasites and pathogens associated with sea cucumber aquaculture in New Zealand are unknown as the industry is currently undeveloped. However, as sea cucumbers are deposit feeders and have been suggested as an ideal co-culture species (Stenton-Dozey, NIWA pers. comm.), they may play a role in mitigating some benthic effects of aquaculture (see Chapter 3 Benthic Effects).

B. Pests and diseases

The little that is known about sea cucumber pests relevant to New Zealand is listed here. In New Zealand, a commensal isopod was reported in *A. mollis* by Menzies & Miller (1954). The new isopod superficially resembled a small louse. However, lack of lesions and the fact that the mouth-parts of the isopod were not modified suggest that the animal is a commensal of the sea cucumber and not a parasite. The isopods were quite common on the host. The only other ectocommensals on holothurians, to our knowledge, are scale-worms, such as *Arctonoe pulchra,* which live on the sea cucumber, and *Stichopus californicus*, which cling to the host by hook-like parapodial setae. Several endocommensals that live in the cloacal chamber of various holothurians have been reported, including a pea crab, *Opisthopus transversus*, often found in *Stichopus*, and a small fish occurring in large West Indian sea cucumbers (Menzies & Miller 1954). In a review of parasites and diseases of cultivated sea cucumbers, of about 150 parasites identified in holothuroids, few caused signs of disease, with bacterial diseases considered most pathogenic (Eeckhaut et al. 2004).

Overseas disease issues appear especially prevalent in China where the intensity of sea-cucumber culture is greatest (Ito & Kitamura 1997; Chen 2003; Becker et al. 2004). The expansion and intensification of sea cucumber culture in China has led to the occurrence of various diseases, which is limiting the sustainable development of this industry. New (or not previously reported) diseases have been discovered, such as syndromes of rotting edges, ulceration of the stomach in auricularia stages and autolysis of young juveniles caused by bacterial agents. Skin ulceration, erosion of epidermis and body oedema was triggered by various pathogens including bacteria (*Vibrio* and *Pseudomonas*; FAO 1991), fungi and parasites during outdoor cultivation. Pathogens induced up to 80 percent mortality. In more recent research in New Zealand, Archer (1996) encountered bacterial infection problems in his culture of *A. mollis* whereas Slater (2009) did not. However, Slater considered that disease outbreaks were likely when culture is further intensified, and this appears to be a reasonable assertion given overseas experience.

For parasites and pathogens, the broad processes that could lead to adverse ecological effects from sea cucumber aquaculture are likely to be comparable with those for other aquaculture species. However, the specific parasites and disease agents are largely unknown. In fact, the species that may be problematic in culture, or for the wider environment, are unlikely to be clearly understood until the New Zealand sea cucumber is farmed, either by itself or as part of co-culture systems (e.g. with shellfish farming).

C. Consenting and infrastructure

The methods for culture of sea cucumbers are currently unclear but are likely to involve either pond structures onshore, seabed ranching or seabed/suspended structures.

If sea cucumbers are cultured in land-based systems, potential models for biosecurity management, developed by the Australian Department of Primary Industries for abalone aquaculture include:

i. the Victorian Abalone Aquaculture Translocation Protocol;

ii. the Abalone Aquaculture biosecurity protocol audit guidelines;

iii. the Victorian Protocol for the Translocation of Aquatic Animals to Recirculating Aquaculture Systems.

For further information see: www.dpi.vic.gov.au/fisheries/about-fisheries/Moving-and-stocking-live-aquatic-organisms

Seabed ranching is currently not a commercial option for farmers without sea cucumber quota, but if this culture technique is employed, it is likely to have the greatest potential for interaction between wild stock and farm stocks. Potential adverse effects of such interactions (genetic dilution and disease transfer) must be fully considered before proceeding with permitting this type of activity. Evaluation of existing restocking/ranching programmes for paua and interactions between farmed and wild mussels may assist in addressing the potential issues raised here.

D. International import health standards

International border protection for pests, parasites and pathogens is controlled through import health standards (www.biosecurity.govt.nz/ihs/search). Such standards can include requirements for aquatic equipment to be visibly clean of contaminants, and if any biological material is to be imported, receiving facilities to be of a specific standard, specified modes of transport to be used, transport to occur in UV sterilised water, quarantine periods and veterinary inspections (e.g. MAFBNZ 2010a). Once these industries are developed, industry codes of practice may be developed to address such issues as pathway risk management and wider environmental issues (as for shellfish Section 7.3). As the aquaculture of sea cucumber is in its infancy in New Zealand, and the resulting biosecurity and ecological risks are poorly understood, staged development accompanied by monitoring and research would be advisable. This would appear especially prudent given overseas disease experience in intensive culture situations for sea cucumbers.

In the case of disease outbreaks, therapeutant interventions include antibiotics such as terramycin, acheomycin and sulphanilamides (FAO 1991). Given that the use of therapeutants in New Zealand is now governed by the EPA (formerly the Environmental Risk Management Authority (ERMA), see Additives chapter), the use of such interventions, inside and outside hatcheries is expected to be strictly controlled. Ericksson et al. (2011) recommend that, in developing aquaculture of the tropical sea cucumber (*Holothuria scabra*), in the absences of any standards and protocols for responsible sea cucumber farming, the operators and legislators should use standards developed for other aquaculture organisms as a benchmark for sustainable management. For example, standards for inspection and equipment to detect early signs of pathogens or disease, issuing health certificates and quarantine measures that are outlined by WWF (2010) and the OIE 2011 for the abalone shellfish, should be applied to sea cucumber farming.

Overseas, preventive measures used in China to limit sea cucumber disease include:

i. good hatchery management operation;

ii. disinfection of tanks, plates and tools before use;

iii. removal of excess food, faeces and other organic matter;

iv. provision of high quality water (Yin-Geng et al. 2004).

Knowledge gaps

As a fledgling industry, the farming of sea cucumbers presents many knowledge gaps in terms of biosecurity risks, especially related to disease and pests, which are unlikely to be addressed until preliminary culture trials using wild derived stock have been undertaken. However, the knowledge gaps for sea cucumbers are expected to be similar to other subtidally cultured species (see Section 7.3) but confounded by the lack of information on what systems may be economically and ecologically viable in New Zealand for the culture of *Australostichopus mollis*.

Key issues will include an analysis of the potential for wild and/or farmed interactions and identification of the diseases and pests associated with sea cucumbers.

7.4.1.2 *Undaria*

Table 7.10: Ecological effects from marine pests, pathogens and parasites due to *Undaria* aquaculture.

Description of effect(s)	**A. General biosecurity risks from marine pests** *i.* *Undaria* culture pathways lead to infection of farm sites by marine pests (including Undaria itself). ii. Infected farm acts as a reservoir for pest spread to wider environment. *iii.* *Undaria* farms alter environmental conditions and facilitate the establishment of marine pests. For example, organic enrichment on the seabed favours non-indigenous soft-sediment species. Removing fouling in situ adds to this process. **B. Specific risks relating to pests, parasites and disease interactions** *iv.* *Undaria* is a highly successful invader to a range of habitats and capable of forming extensive dense stands. v. Fouling increases drag on farm infrastructure, posing risks from gear failure, crop loss and fragmentation, posing threats from disease transmission. vi. Pests pose biosecurity risks as potential intermediate hosts for pathogens and parasites. vii. Fouling attracts wild fish species that may graze on *Undaria* or could become parasite/ pathogen vectors or intermediate hosts.
Spatial scale	*Local* to *national* scale.
Duration	Irreversible if pest establishes a viable population and eradication is not feasible.
Management options	**A. Consenting and infrastructure considerations** • Farm spacing, zoning, staged development, identification of epidemiological units etc. **B. International: Import health standards** • Import health standards used to control equipment transfers. **C. Domestic: Development of industry codes of practice to address:** i. Management of pathways to reduce the risk of infection of culture sites and/or the subsequent spread of marine pests, including: • risk reduction procedures for domestic stock transfers (including associated transfer water), that are consistent with MPI border standards; • procedures for vessels and/or the transfer of equipment to minimise the risk of marine pest transport with culture pathways (e.g. vessel antifouling, cleaning, inspections). ii. On-farm management to reduce risk to the wider environment, including: • education and surveillance to facilitate early detection of pest species; • routine farm management procedures for cleaning of culture floats and backbone ropes on longlines between crops; • application of pest response and containment procedures where feasible; • farm site selection and management practices that maximise growth and condition but minimise risks of pest infestations; • *Undaria* eradication: Heat treatment of infected structures (Chathams), physical removal of sporophytes (Big Glory Bay).

Table 7.10: Ecological effects from marine pests, pathogens and parasites (continued)

Knowledge gaps	• Lack of knowledge of *Undaria* risk organisms and likely significance of effects in culture. • Field validation of treatments for *Undaria* of aquaculture equipment and stock. • Development and refinement of response protocols, including eradication methods. • Implications for natural habitats of the development of marine pest populations on aquaculture structures. • The direct and indirect ecological effects of marine pests in the wider environment. • Effective and environmentally friendly vector management tools, and mitigation methods for established pest populations on marine farms and in natural habitats. • Intermediate host status of fouling organisms for parasites and pathogens and interactions/links with other aquaculture species.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Ecological effects of *Undaria* (as an introduced organism)

Undaria is a non-indigenous kelp regarded both as a fouling nuisance on marine farms and a threat to the ecology of high value coastal areas around New Zealand (Sinner et al. 2000), and is classified as an Unwanted Organism under the Biosecurity Act 1993. In April 2010, MPI introduced policy that allows for commercial harvesting of *Undaria* from artificial surfaces and farming of *Undaria* in areas already heavily infested. By retaining *Undaria's* status as an Unwanted Organism under the Biosecurity Act 1993, MPI maintains control over permitting for the commercial use of *Undaria*. Aquaculture of *Undaria* is common in Asia. Aquaculture research in New Zealand conducted in the late 1990s established "proof of concept" for *Undaria* farming, based on laboratory investigations and field grow-out trials in the Marlborough Sounds. The research was discontinued as the public profile of *Undaria* as a pest species increased; however, the interest in this species as an aquaculture candidate remained. The exact cultivation methods for this species are unknown; however, based on grow-out trials in New Zealand, and overseas culture methods, it is likely that floating subtidal cultivation methods will be used.

A. Pathways

The spread of *Undaria* between countries and regions has mostly been attributed to vessel movements and transfer of marine farming equipment and seed stock (e.g., Perez et al. 1981; Hay 1990; Brown 1999). Natural spread occurs predominantly at the scale of metres to hundreds of metres annually (Brown 1999; Forrest et al. 2000; Russell et al. 2008).

The biosecurity risk arising from *Undaria* itself as a culture species will be reduced to some extent by the fact that culture will be restricted to localities where the kelp is already well established. Nonetheless, in such locations, it is possible that the widespread or intensive cultivation of *Undaria* (e.g. to a level of biomass that by far exceeds naturalised population levels) may exacerbate risks to adjacent natural habitats within the limited dispersal range of the species. The basis of this assertion is that increased "propagule pressure" (i.e. more spores in the case of *Undaria*) could lead to increased invasion success by *Undaria* (B. Forrest, unpubl. data), which is a phenomenon well recognised in invasive species research (e.g. Sylvester et al. 2011). Moreover, the greater the propagule pressure the more likely it is that invasive species will overcome factors (e.g. seabed predation) that might otherwise limit establishment in rocky habitats in places like the Marlborough Sounds (Forrest et al. 2011). A final consideration is that, if *Undaria* culture takes place, additional thought may also need to be given to whether any new *Undaria* risk pathways arise that do not already occur as part of aquaculture operations generally, and which are considered regionally or nationally significant.

New Zealand studies have drawn varied conclusions about the impacts of the establishment of *Undaria*, although the majority of studies suggest that effects on native communities are relatively minor. High densities of juvenile spotties (*Notolabrus celidotus*) have been noted amongst dense stands of *Undaria* (e.g., Battershill et al. 1998; Brown 1999). Battershill et al. (1998) concluded that *Undaria* may displace multi-species macroalgal communities, but Hay & Villouta (1993) suggested that *Undaria* colonised bare areas outside beds of native brown seaweeds, rather than the beds themselves. Hay & Sanderson (1999) considered that there was very little evidence that *Undaria* displaced native brown seaweeds in several New Zealand harbours where it had been established for many years, and a three-year study in Lyttelton Harbour found little evidence of any impact on the low shore community structure from colonisation by *Undaria* (Forrest & Taylor 2002). Russell et al. (2008) highlighted *Undaria's* ability to establish in a wide range of environments and to form dense monospecific stands as a potential threat to native reef communities. The ecological effects of *Undaria* in New Zealand have been reviewed by Sinner et al. (2000).

Internationally, studies of the impact of *Undaria* on indigenous biotic communities are limited. Studies in Argentina found increased species diversity and abundance associated with its presence (Irigoyen et al. 2011b), but also identified transitory habitat loss for reef fishes due to exclusion from the reef surface by the dense stands of *Undaria* (Irigoyen et al. 2011a).

Interactions between *Undaria* and grazer populations have been studied most extensively in Tasmania, where *Undaria* successfully colonised areas of urchin barrens after grazers first removed native macroalgae (e.g. Johnson 2001; Valentine & Johnson 2003; Edgar et al. 2004; Valentine & Johnson 2004, 2005a, 2005b). In Argentina, high densities of urchin and gastropod grazers were noted on *Undaria* in summer (Valeria Teso et al. 2009).

B. Pests and pathogens

Ecological effects from pest species associated with *Undaria* farming are likely to be generally similar to those of mussel or subtidal oyster culture, given that the pathways, marine pests (e.g. fouling species) and other processes are likely to be generally comparable. However, as with the scant literature regarding the ecological effects of *Undaria*, there is even less known of the ecological effects of diseases associated with this species. A range of potential diseases, pathogens and parasites of *Undaria* are detailed by Neill et al. (2008) and Park et al. (2008) and these may be considered as potential biosecurity threats both to native seaweeds and also to the commercial utilisation of *Undaria* in New Zealand. The pigmented endophytic[13] brown alga *Laminariocolax aecidioides* infects *Undaria* in Spain and in Argentina (Neill et al. 2008). This endophyte has been implicated in influencing the depth range of thalli of *Saccharina latissima*, where increased infection severity prevents host thalli surviving in water depths of 2m, in contrast to deeper water, where growth of the endophyte is light limited (Schaffelke et al. 1996). Although a related species infects New Zealand kelps, it is unknown whether *L. aecidioides* could infect New Zealand kelps (Neill et al. 2008). In contrast with *Undaria* overseas, no known pathogens have so far been observed in/on *Undaria* in New Zealand, although populations here have not been well screened for the presence of such organisms. New Zealand *Undaria* hosts the endophyte, *Microspongium tenuissimum*, but, this endophyte is also found in the native *Ecklonia radiata* and various red algae. The infection of *Undaria* with *M. tenuissimum* was not associated with macroscopic signs (Heesch 2005).

[13] An organism, especially a fungus or micro-organism, that lives inside a plant, in a parasitic or mutualistic relationship.

7.4.2 Management options

A. Consenting and infrastructure considerations

The choice of site-appropriate growing methods for sea cucumbers and *Undaria* is expected to strongly affect susceptibility to risk organisms, pest reservoir risk and, hence associated ecological effects (see Section 7.1.2). This section should be read in association with Section 7.1.5, which outlines management strategies relevant to all aquaculture operations.

Management options of biosecurity risks are first indirectly handled in an ad-hoc fashion by regional councils during the marine farm consenting process. For example, the Tasman District Council has discretion in its plan to consider "management of biosecurity risk organisms, such as *Undaria*", and new rules controlling filter feeding bivalves and additive species including fin fish, require the council to consider "managing risks of incursion, disease, biosecurity risk organisms, and genetic risk to wild stocks" (R. Squire pers. comm., Tasman District Council). Such considerations as farm spacing, zoning, staged development and epidemiological units should be considered as part of RMA consent requirements on a case-by-case basis.

B. International import health standards

International border protection for pests, parasites and pathogens are controlled through import health standards (www.biosecurity.govt.nz/ihs/search). Such standards can include requirements for aquatic equipment to be visibly clean of contaminants, and, if any biological material is to be imported, receiving facilities to be of a specific standard, specified modes of transport to be used, transport to occur in UV sterilised water, quarantine periods and veterinary inspections (e.g. MAFBNZ 2010a).

Once these industries are developed, industry codes of practice may be developed to address such issues as pathway risk management and wider environmental issues (as for shellfish Section 7.3). As the aquaculture of *Undaria* is in its infancy in New Zealand, and the resulting biosecurity and ecological risks are poorly understood, staged development, accompanied by monitoring and research would be advisable. This would appear especially prudent given overseas disease experience in intensive culture situations for *Undaria*.

As an Unwanted Organism under the Biosecurity Act 1993, MPI maintains control over permitting for the commercial use of *Undaria*. Strategies to minimise the spread of *Undaria* have been investigated, and an overall strategy for managing *Undaria* in New Zealand has been discussed (Sinner et al. 2000).

However, national level management strategies for *Undaria* are not envisaged, as the kelp is widespread in New Zealand. Management options as part of farming *Undaria* may include a range of generic conditions, for example (MAFBNZ 2010c):

- where *Undaria* is sourced and how it is transferred to the farm site to prevent inadvertent spread;
- how and where ropes are seeded to ensure that no viable *Undaria* is returned to the marine environment;
- how *Undaria* is to be collected/harvested from the farm to reduce the biosecurity risk of the activity;
- how any equipment (including vessels) used in the farming or processing of *Undaria* is to be treated to prevent the inadvertent spread of *Undaria*;
- how to transfer collected *Undaria* to prevent the inadvertent transfer of *Undaria*;
- how the *Undaria* is to be disposed of, processed or used to ensure that no viable *Undaria* is returned to the marine environment; and
- that it is the applicant's responsibility to seek permission under any other relevant legislation.

Further work is under way by MPI to identify selected heavily infested areas where it would be appropriate to allow *Undaria* farming, and to develop a standardised risk management plan template to assist applicants with identifying potential biosecurity risks associated with their farming operation and how these risks might be mitigated (MAFBNZ 2010d). In terms of *Undaria's* pest status, there is still stakeholder interest in managing the spread of *Undaria* to a few high value areas in New Zealand, and in developing associated plans to manage potential vectors of spread (e.g. vessels) or control/eradicate established populations. One example is Fiordland, for which a range of vector management measures have been investigated for *Undaria* and other species (e.g. Sinner et al. 2009), including vessel surveillance and plastic wrapping areas of Bluff Port, and a population eradication attempt is under way for *Undaria* in a small bay in Breaksea Sound, jointly funded by MPI, Department of Conservation and Environment Southland. This eradication attempt has included hand picking and biological control with kina (*Evechinus chloroticus*).

As with any new aquaculture venture, it would be advisable to develop appropriate management strategies for *Undaria* and any associated risk organisms as the industry develops. To address pathway risks, for example, a range of methods for *Undaria* and other species has already been developed (Wotton et al. 2004; Forrest & Blakemore 2006: Forrest et al. 2007a; Piola et al. 2009). This industry has been slow to develop, and industry standards or codes of practice have yet to be developed (T. Haggit, pers comm. Seaweed Association of New Zealand).

Overseas, there are three commercial carrageenan-bearing seaweeds that have a long history as the preferred species for farming: *Kappaphycus alvarezii* and *Kappaphycus striatum*, both commercially known as "Cottonii", and *Eucheuma denticulatum,* commercially known as "Spinosum" (www.marinalg.org). A position paper developed by Marinalg International on the protocol for introducing non-native seaweeds for culture, states that these three species and their varieties have different habitat requirements and consequently require separate risk assessments. They suggest feasibility studies, baseline inventories, appropriate risk assessments and developing contingencies for mitigation prior to introductions taking place. They note that, in the last 40 years there have been two reported cases where *Kappaphycus* plants have spread from introduction sites and adversely impacted on native habitats. It is unlikely that non-native macroalgal species will be deliberately imported for culture in New Zealand

Knowledge gaps

Please read this section in conjunction with Section 7.1.4.

There is a need for basic underpinning surveys and research to document the biodiversity and distribution of pests, pathogens and parasites of algae in New Zealand to provide information to managers about the risks of their spread (Neill et al. 2008). Likewise, there needs to be assessment of risks like that for introducing a significant algal disease agent associated with reintroduction of *Undaria* via international shipping. There is generally a need for better information on the ecological effects of *Undaria* (including issues of propagule pressure in farm areas) and associated species. There is also the need for better mitigation tools for established pest populations, and refinement and testing of treatment and novel eradication protocols (Sinner et al. 2000; Forrest & Blakemore 2006; Forrest et al. 2007a).

References

Acosta, H.; Forrest, B.M. (2009). The spread of marine non-indigenous species via recreational boating: A conceptual model for risk assessment based on fault tree analysis. *Ecological Modelling 220*: 1586–1598.

Aguilar-Manjarrez, J.; Kapetsky, J.M.; Soto, D. (2010). *The potential of spatial planning tools to support the ecosystem approach to aquaculture.* Expert Workshop, 19–21 November 2008, Rome, Italy. FAO Fisheries and Aquaculture Proceedings 17. Food and Agriculture Organization, Rome, Italy.

Alfaro, A.; Jeffs, A.G.; Gardner, J.P.; Breen, B.; Wilkin, J. (2011). Green-lipped mussels in GLM9. New Zealand Fisheries assessment report 2011/48. 77p.

Amemiya, I. (1928). Ecological studies of Japanese oysters with special reference to the salinity of their habitat. *Journal of the College of Agriculture Imperial University of Tokyo 9(5)*: 333–382.

Anderson, S.A.; Hulston, D.A.; McVeagh, S.M.; Webb, V.L.; Smith, P.J. (2009). In vitro culture and cryopreservation of *Uronema marinum* isolated from farmed New Zealand groper (*Polyprion oxygeneios*). *Journal of Microbiological Methods 79*: 62–66.

Anderson, R.M.; May, R.M. (1981). The population dynamics of microparasites and their invertebrate hosts. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 291(1054)*: 451–524.

Anderson, S.; Salinas, I.; Tubbs, L.A.; Lumsden, J.S.; Diggles, B.; Webb, V.; Gublin, Y.; Pether, S.; Irvine, G.; Walker, S. (2010). The importance of hygiene for live feed management: Lessons learned from New Zealand groper (*Polyprion oxygeneios*) juveniles. Husbandry and Nutrition Sixth International Symposium on Aquatic animal Health: Global Strategies for a Changing Environment, 5–9 September, Tampa, Florida, United States of America.

ANZECC (1997). Code of practice for antifouling and in-water hull cleaning and maintenance. Canberra, Australian and New Zealand Environment and Conservation Council: 12 p.

Aquatic Animal Health Code (2011). Section 2. Risk Analysis. World Organisation for Animal Health (OIE). http://www.oie.int/ [accessed 27 October 2011].

Archer, J.E. (1996). Aspects of the Reproductive and Larval Biology and Ecology of the Temperate *Holothurian Stichopus mollis (Hutton)*, Ph.D. thesis. School of Biological Sciences, University of Auckland, Auckland. 178 p.

Askew, C.G. (1972). The growth of the oysters *Ostrea edulis* and *Crossostrea gigas* in Emsworth Harbour. *Aquaculture 1(2)*: 237–259.

Austin, B.; Austin, D.A. (1999). *Bacterial fish pathogens: Disease of farmed and wild fish* (3rd (revised) edn.). Springer-Praxis, Chichester, United Kingdom.

Battershill, C.; Miller, K.; Cole, R. (1998). The understorey of marine invasions. *Seafood New Zealand 6(2):* 31–33.

Becker, P.; Gillan, D.; Lanterbecq, D.; Jangoux, M.; Rasolofonirina, R.; Rakotovao, J.; Eeckhaut, I. (2004). The skin ulceration disease in cultivated juveniles of *Holothuria scabra* (Holothuroidea, Echinodermata). *Aquaculture 242*: 13–30.

Beveridge, M.C.M. (2004) Cage Aquaculture. Fishing News Books, Surrey, England.

Biosecurity Council. (2003). *Tiakina Aotearoa Protect New Zealand: The Biosecurity Strategy for New Zealand.* Biosecurity Council, Wellington, New Zealand. www.biosecurity.govt.nz/files/biosec/sys/strategy/biosecurity-strategy.pdf. Accessed March 2012.

Bjørn, P.A.; Finstad, B. (2002). Salmon lice, *Lepeophtherius salmonis* (Krøyer), infestation in sympatric populations of Arctic char, *Salvelinus alpinus (L.)* and sea trout, *Salmo trutta (L.),* in areas near and distant from salmon farms. *ICES Journal of Marine Science 59:* 131–139.

Bondad-Reantaso, M.G.; Subasinghe, R.P.; Arthur, J.R.; Ogawa, K.; Chinabut, S.; Adlard, R.; Tan, Z.; Shariff, M. (2005). Disease and health management in Asian aquaculture. *Veterinary Parasitology 132*: 249–272.

Boudouresque, C.F.; Gerbal, M.; Knoepffler-Peguy, M. (1985). L'algue japonaise *Undaria pinnatifida* (Phaeophyceae, Laminariales) en Méditerranée. *Phycologia 24*: 364–366.

Brown, S.N. (1999). Dispersal characteristics of the adventive seaweed *Undaria pinnatifida* in New Zealand. MSc thesis, University of Otago, Dunedin, New Zealand.

Bullard, S.G.; Lambert, G.; Carman, M.R.; Byrnes, J.; Whitlatch, R.B.; Ruiz, G.M.; Miller, R.J.; Harris, L.G.; Valentine, P.C.; Collie, J.S.; Pederson, J.; McNaught, D.C.; Cohen, A.N.; Asch, R.G.; Dijkstra, J. (2007). The colonial ascidian *Didemnum* sp. A: Current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. *Journal of Experimental Marine Biology and Ecology 342*: 99–108.

Bulleri, F.; Airoldi, L. (2005). Artificial marine structures facilitate the spread of a non-indigenous green alga, *Codium* *fragile* ssp. *tomentosoides*, in the North Adriatic Sea. *Journal of Applied Ecology 42*: 1063–1072.

Bunce, A.; Norman, F.I. (2000). Changes in the diet of the Australasian gannet (*Morus serrator*) in response to the 1998 mortality of pilchards (*Sardinops sagax*). *Marine and Freshwater Research 51*: 349–353.

Burreson, E.M.; Stokes, N.A.; Friedman, C.S. (2000). Increased virulence in an introduced pathogen: *Haplosporidium nelsoni* (MSX) in the Eastern oyster, *Crassostrea virginica*. *Journal of Aquatic Animal Health 12*: 1–8.

Buryniuk, M.; Petrell, R.J.; Baldwin, S.; Lo, K.V. (2006). Accumulation and natural disintegration of solid wastes caught on a screen suspended below a fish farm cage. *Aquacultural Engineering 35(1)*: 78–90.

Buschmann, A.; Riquelme, V.; Hernandez-Gonzalez, M.; Varela, D.; Jimenez, J.; Henriquez, L.; Vergara, P.; Guinez, R.; Filun, L. (2006). A review of the impacts of salmonid farming on marine coastal ecosystems in the southeast Pacific. *ICES Journal of Marine Science 63(7)*: 1338–1345.

Butt, D.; Raftos, D. (2007). Immunosuppression in Sydney rock oysters (*Saccostrea glomerata*) and QX disease in the Hawkesbury River, Sydney. *Marine and Freshwater Research 58*: 213–221.

Butt, D.; Shaddick, K.; Raftos, D. (2006). The effect of low salinity on phenoloxidase activity in the Sydney rock oyster *Saccostrea glomerata*. *Aquaculture 251*: 159–166.

Cabello, F.C. (2004). Antibiotics and aquaculture in Chile: Implications for human and animal health. *Revista Médica de Chile 132(8)*: 1001–1006.

Cabello, F.C. (2006). Heavy use of prophylactic antibiotics in aquaculture: A growing problem for human and animal health and for the environment. *Environmental Microbiology 8(7)*: 1137–1144.

Carver, C.E.; Chisholm, A.; Mallet, A.L. (2003). Strategies to mitigate the impact of *Ciona intestinalis* (L.) biofouling on shellfish production. *Journal of Shellfish Research 22*: 621–631.

Cattaneo-Vietti, R.; Cerrano, C.; Benatti, U.; Giovine, M.; Tazioli, S.; Bavestrello, G. (2003). A marine biological underwater depuration system (MUDS) to process waste waters. *Biomolecular Engineering 20(4–6)*: 291–298.

Chambers, C.B.; Ernst, I. (2005). Dispersal of the skin fluke *Benedenia seriolae* (Monogenea: Capsalidae) by tidal currents and implications for sea-cage farming of *Seriola* spp. *Aquaculture 250*: 60–69.

Chen, J. (2003). Overview of sea cucumber farming and sea ranching practices in China. *SPC beche-de-mer Information Bulletin 18*: 19–23.

Cigarria, J.; Fernandez, J.; Magadan, L.P. (1998). Feasibility of biological control of algal fouling in intertidal oyster culture using periwinkles. *Journal of Shellfish Research 17(4)*: 1167–1169.

Clapin, G.; Evans, D.R. (1995). *The status of the introduced marine fanworm* Sabella spalanzanii *in Western Australia: A preliminary investigation.* Centre for Research on Introduced Marine Pests Technical Report 2. CSIRO Marine Research, Hobart, Tasmania.

Cognie, B.; Haure, J.; Barillé, L. (2006). Spatial distribution in a temperate coastal ecosystem of the wild stock of the farmed Pacific oyster *Crassostrea gigas* (Thunberg). *Aquaculture 259*: 249–259.

Cohen, C.S.; McCann, L.; Davis, T.; Shaw, L.; Ruiz, G. (2011). Discovery and significance of the colonial tunicate *Didemnum vexillum* in Alaska. *Aquatic Invasions 6(3)*: 363–371.

Coleman, N. (1996). *Potential for the establishment of wild populations and biological risk assessment of the introduction of Pacific Oysters into Victoria*. Marine and Freshwater Resource Institute, Queenscliff, Victoria, Australia.

Costello, M.J. (2009). How sea lice from salmon farms may cause wild salmonid declines in Europe and North America and be a threat to fishes elsewhere. *Proceedings of the Royal Society of London. Series B: Biological Sciences 276*: 3385–3394.

Coutts, A.D.M.; Forrest, B.M. (2005). *Evaluation of eradication tools for the clubbed tunicate* Styela clava. Cawthron Report 1110. Cawthron Institute, Nelson, New Zealand.

Coutts, A.D.M.; Forrest, B.M. (2007). Development and application of tools for incursion response: Lessons learned from the management of a potential marine pest. *Journal of Experimental Marine Biology and Ecology 352*: 154–162.

Coutts, A.D.M.; Piola, R.F.; Hewitt, C.L.; Connell, S.; Gardner, J.P.A. (2010). Effect of vessel voyage speed on the survival and translocation of biofouling organisms. *Biofouling 26*: 1–13.

Cranfield, H.J.; Gordon, D.P.; Willan, R.C.; Marshall, B.A.; Battershill, C.N.; Francis, M.P.; Nelson, W.A.; Glasby, C.J.; Read, G.B. (1998). *Adventive marine species in New Zealand*. NIWA Technical Report 34.

Curtin, L. (1986). Mudworm menace in oyster farms. *"Catch" Shellfisheries Newsletter 31*: 10–11.

Dann, P.; Norman, F.I.; Cullen, J.M.; Neira, F.J.; Chiaradia, A. (2000). Mortality and breeding failure of little penguins, *Eudyptual minor*, in Victoria, 1995–96, following a widespread mortality of pilchard, *Sarinops sagax*. *Marine Freshwater Research 51*: 355–362.

Darbyson, E.; Locke, A.; Hanson, J.M.; Willison, J.H.M. (2009). Marine boating habits and the potential for spread of invasive species in the Gulf of St. Lawrence. *Aquatic Invasions 4*: 87–94.

de Jong, S.; Tanner, J. (2004). Environmental risk assessment of marine finfish aquaculture in South Australia. SARDI Research Report Series 130. South Australian Research and Development.

Dempster, T.; Uglem, I.; Sanchez-Jerez, P.; Fernandez-Jover, D.; Bayle-Sempere, J.; Nilsen, R.; Bjørn, P.A. (2009). Coastal salmon farms attract large and persistent aggregations of wild fish: An ecosystem approach. *Marine Ecology Progress Series 385*: 1–14.

Denny, C.M. (2008). Development of a method to reduce the spread of the ascidian *Didemnum vexillum* with aquaculture transfers. *ICES Journal of Marine Science 65*: 805–810.

Denny, C.M.; Hopkins, G.A. (2007). *Development of a method to reduce the spread of the ascidian* Didemnum vexillum *with aquaculture transfers.* Cawthron Report 1333. Cawthron Institute, Nelson, New Zealand.

de Nys, R.; J.; Uriz, M. J. (2010) *Natural Control of Fouling,* in Biofouling (eds S. Dürr and J. C. Thomason), Wiley-Blackwell, Oxford, UK. Ch.8. pp 109–120.

Diggles, B.; Hutson, K. (2005). Finfish: Diseases of kingfish (*Seriola lalandi*) in Australasia. *Aquaculture Health International 3*: 12–14.

Diggles, B.K. (2002). *Import risk assessment: Juvenile yellowtail kingfish (*Seriola lalandi*) from Spencer Gulf Aquaculture, South Australia.* Prepared for Island Aquafarms Ltd. NIWA Client Report WLG 2002/03.

Diggles, B.K. (2008). Transfer of parasites between wild and cultured fishes with respect to aquaculture development in the Firth of Thames, New Zealand. DigsFish Services Pty Ltd. In: *Potential environmental effects associated with the proposed shift from mussel to finfish farming in the Firth of Thames*, appendix 2. Kelly, S. Environment Waikato Technical Report 2008/38.

Diggles, B.K.; Hine, P.M.; Handley, S.; Boustead, N.C. (2002). *A handbook of diseases of importance to aquaculture in New Zealand.* NIWA Science and Technology Series 49.

Diggles, B.; Hutson, K. (2005). Finfish: Disease of kingfish (*Seriola lalandi*) in Australasia. *Aquaculture Health International 3:* 12–14.

Dinamani, P. (1974). Pacific oyster may pose threat to rock oyster. *Catch '74*: 5–9.

Dromgoole, F.I.; Foster, B.A. (1983). Changes to the marine biota of the Auckland Harbour. *Tane 29*: 79–95.

Duggan, C.B. (1979). Man's role in the spreading of oyster pests and diseases. In: *Proceedings of a symposium on the introduction of exotic species advantages and problems,* pp. 51–56. Kernan, R.P.; Mooney, O.V.; Went, A.E.J. (eds.). Royal Irish Academy, Dublin, Ireland.

Dworjanin, S.A.; De Nys, R.; Steinberg, P. (2006). Chemically mediated antifouling in the red alga *Delisea pulchra*. *Marine Ecology Progressive Series 318*: 153–163.

Edgar, G.J.; Barrett, N.S.; Morton, A.J.; Samson, C.R. (2004). Effects of algal canopy clearance on plant, fish and macroinvertebrate communities on eastern Tasmanian reefs. *Journal of Experimental Marine Biology and Ecology 312*: 67–87.

Eeckhaut, I.; Parmentier, E.; Becker, P.; da Silva, S.G.; Jangoux, M. (2004). Parasites and biotic diseases in field and cultivated sea cucumbers. In: *Advances in sea cucumber aquaculture and management*, pp. 311–326. FAO Fisheries Technical Paper 463. Food and Agriculture Organization, Rome, Italy.

Egusa, S. (1983). Disease problems in cultured yellowtail, *Seriola quinqueradiata*, culture: A review. *Rapports et process-verbaux des reunions Conseil International Pour l'Exploration de la Mer 182*: 10–18.

Egusa, S. (1985). *Myxobolus buri* sp. n. (Myxosporea: Bivalvulida) parasitic in the brain of *Seriola quinqueradiata* Temminck et Schlegel. *Fish Pathology 19*: 239–244.

Elston, R.A. (1993). Infectious diseases of the Pacific oyster, *Crassostrea gigas*. *Annual Review of Fish Disease* 3: 259–276.

Elston, R.A.; Farley, C.A.; Kent, M.L. (1986). Occurrence and significance of Bonamiasis in European flat oysters *Ostrea edulis* in North America. *Diseases of Aquatic Organisms 2(1)*: 49–54.

Enright, C.T.; Elner, R.W.; Griswold, A.; Borgese, E.M. (1993). Evaluation of crabs as control agents for biofouling in suspended culture of European oysters. *World Aquaculture 24*: 49–51.

Enright, C.; Krailo, D.; Staples, L.; Smith, M.; Vaughan, C.; Ward, D.; Gaul, P.; Borgese, E. (1983). Biological control of fouling algae in oyster aquaculture. *Journal of Shellfish Research 3*: 41–44.

EPA (2005). *Code of practice for the environmental management of the South Australian oyster farming industry.* EPA Adelaide, South Australia.

Eriksson, H.; Robinson, G.; Slater, M.J.; Troell, M. (2011). Sea cucumber aquaculture in the Western Indian Ocean: Challenges for sustainable livelihood and stock improvement. *Ambio* DOI 10.1007/s13280–011–0195–8.

Ernst, I.; Whittington, I.D.; Corneillie, S.; Talbot, C. (2005). Effects of temperature, salinity, desiccation and chemical treatments on egg embryonation and hatching success of *Benedenia seriolae* (Monogenea: Capsalidae), a parasite of farmed *Seriola* spp. *Journal of Fish Diseases 28*: 157–164.

Escapa, M.; Isacch, J.P.; Daleo, P.; Alberti, J.; Iribarne, O.; Borges, M.; dos Santos, E.P.; Gagliardini, D.A.; Lasta, M. (2004). The distribution and ecological effects of the introduced Pacific oyster, *Crassostrea gigas* (Thunberg, 1793) in northern Patagonia. *Journal of Shellfish Research 23*: 765–772.

FAO (1991). *Training manual on breeding and culture of scallop and sea cucumber in China. Part II: Sea cucumber (*Stichopus japonicus*) culture in China.* Food and Agriculture Organization, Rome, Italy. www.fao.org/docrep/field/003/AB729E/AB729E00.htm#TOC accessed 26/8/2011.

Floc'h, J.; Pajot, R.; Mouret, .V (1996). *Undaria pinnatifida* (Laminariales, Phaeophyta) 12 years after its introduction into the Atlantic Ocean. *Hydrobiologia 326/327*: 217–222.

Floerl, O.; Inglis G. J.; Dey, K.; Smith A (2009). The importance of transport hubs in stepping stone invasions. *Journal of Applied Ecology 46(1)*: 37–45.

Forrest, B.; Hopkins, G.; Webb, S.; Tremblay, L. (2011). *Overview of marine biosecurity risks from finfish aquaculture development in the Waikato region.* Prepared for Waikato Regional Council. Cawthron Report 1871. Cawthron Institute, Nelson, New Zealand.

Forrest, B.M.; Blakemore, K. (2002). *Inter-regional marine farming pathways for the Asian kelp* Undaria pinnatifida. Cawthron Report 726. Cawthron Institute, Nelson, New Zealand.

Forrest, B.M.; Blakemore, K.A. (2006). Evaluation of treatments to reduce the spread of a marine plant pest with aquaculture transfers. *Aquaculture 257*: 333–345.

Forrest, B.M.; Brown, S.N.; Taylor, M.D.; Hurd, C.L.; Hay, C.H. (2000). The role of natural dispersal mechanisms in the spread of *Undaria pinnatifida* (Laminariales, Phaeophyceae). *Phycologia 39*: 547–553.

Forrest, B.M.; Creese, R.G. (2006). Benthic impacts of intertidal oyster culture, with consideration of taxonomic sufficiency. *Environmental Monitoring and Assessment 112*: 159–176.

Forrest, B.M.; Gardner, J.P.A.; Taylor, M.D. (2008). Internal borders for managing invasive marine species. *Journal of Applied Ecology 46*: 46–54.

Forrest, B.M.; Hopkins, G.A.; Dodgshun, T.J.; Gardner, J.P.A. (2007a). Efficacy of acetic acid treatments in the management of marine biofouling. *Aquaculture 262*: 319–332.

Forrest, B.M; Keeley, N.; Gillespie, P.; Hopkins, G.; Knight, B.; Govier, D. (2007b). *Review of the ecological effects of marine finfish aquaculture.* Prepared for Ministry of Fisheries. Cawthron Report 1285, Cawthron Institute, Nelson, New Zealand.

Forrest, B.M.; Keeley, N.B.; Hopkins, G.A.; Webb, S.C.; Clement, D.M. (2009). Bivalve aquaculture in estuaries: Review and synthesis of oyster cultivation effects. *Aquaculture 298*: 1–15.

Forrest, B. M.; Taylor, M. D. (2002). Assessing Invasion Impact: Survey Design Considerations and Implications for Management of An Invasive Marine Plant. *Biological Invasions 4:* 375–386.

Friedman, C.S.; Finley, C.A. (2003). Anthropogenic introductions of the etiological agent of withering syndrome into northern California abalone populations via conservation efforts. *Canadian Journal of Fisheries and Aquatic Sciences 60(11)*: 1424–1431.

Glasby, T.M.; Connell, S.; Holloway, M.G.; Hewitt, C.L. (2007). Nonindigenous biota on artificial structures: Could habitat creation facilitate biological invasions? *Marine Biology 151*: 887–895.

Greening, G.E.; Dawson, J.; Lewis, G. (2001). Survival of poliovirus in New Zealand green-lipped mussels, *Perna canaliculus*, on refrigerated and frozen storage. *Journal of Food Protection 64(6):* 881–884.

Grizel, H.; Héral, M. (1991). Introduction into France of the Japanese oyster *Crassostrea gigas. Journal du Conseil permanent International pour l' Exploration de la Mer 47*: 399.

Gust, N.; Inglis, G.J.; Floerl, O.; Peacock, L.; Denny, C.; Forrest, B. (2007). *Assessment of population management trial options for* Styela clava *at three locations.* Prepared for Biosecurity New Zealand Post-clearance Directorate for Project BSP21705. NIWA Client Report CHC2007–094.

Handley, S. (1999a). Flatworms: Horrific predators of oysters or merely scavengers? *Seafood New Zealand* 48–49.

Handley, S. (1999b). Shellfish fleecing by flighty flatworms. Presentation at New Zealand Marine Sciences Society Conference, Wellington, 1 September.

Handley, S. (2000). Flatworms: Oyster predators or mere scavengers? *NIWA Aquaculture Update 24*: 4–5.

Handley, S.; Jeffs, A. (2002). *Assessment for future expansion of Pacific oyster farming in Northland.* Prepared for Enterprise Northland – Aquaculture Development Group. NIWA Client Report AL2003-027*.*

Handley, S.J. (1992). The dynamics of *spionid polychaete* (mudworm) infestations of the Pacific oyster *Crassostrea gigas* (Thunberg) in northern New Zealand. MSc thesis, University of Auckland, Auckland, New Zealand.

Handley, S.J. (1995). Spionid polychaetes in Pacific oysters, *Crassostrea gigas* (Thunberg) from Admiralty Bay, Marlborough Sounds, New Zealand. *New Zealand Journal of Marine and Freshwater Research 29*: 305–309.

Handley, S.J. (1997a). Optimizing subtidal oyster production, Marlborough Sounds, New Zealand: Spionid polychaete infestations, water depth and spat stunting. *Journal of Shellfish Research 16*: 143–150.

Handley, S.J. (1997b). Spionid polychaete worm infestations of the Pacific oyster *Crassostrea gigas* in New Zealand. PhD thesis. Auckland University, Auckland, New Zealand.

Handley, S.J. (1998). Power to the oyster: Do spionid-induced blisters affect condition in subtidal oysters? *Journal of Shellfish Research 17*: 1093–1099.

Handley, S.J. (2002). Optimizing intertidal Pacific oyster (Thunberg) culture, Houhora Harbour, northern New Zealand. *Aquaculture Research 33*: 1019–1030.

Handley, S.J. (2003). *Mudworm infestations of* Perna canalicuus*, Wilson's Bay, Coromandel.* NIWA Client Report TEC04401 NEL2003–016.

Handley, S.J. (2005). *Assessment of mudworm and sea-squirt infestations, Houhora Harbour, Northland.* NIWA Client Report NEL2005–022.

Handley, S.J.; Bergquist, P.R. (1997). Spionid polychaete infestations of intertidal pacific oysters *Crassostrea gigas* (Thunberg), Mahurangi Harbour, northern New Zealand. *Aquaculture 153*: 191–205.

Harikrishnan, R.; Balasundaram, C.; Heo, M.-S. (2011). Fish health aspects in grouper aquaculture. *Aquaculture 320(1–2)*: 1–21.

Hay, C.H. (1990). The dispersal of sporophytes of *Undaria pinnatifida* by coastal shipping in New Zealand, and implications for further dispersal of *Undaria* in France. *British Phycological Journal 25(4)*: 301–313.

Hay, C.H.; Sanderson, J.C. (1999). Dispersal of the Asian kelp *Undaria* in Australasia. In: *Islands in the Pacific century.* Pacific Science Inter-Congress, 13–19 July 1998. University of the South Pacific, Suva, Fiji Islands.

Hay, C.H.; Villouta, E. (1993). Seasonality of the Adventive Asian Kelp *Undaria pinnatifida* in New Zealand. *Botanica Marina 36*: 461–476.

Hayward, B. (1997). Introduced marine organisms in New Zealand and their impact in the Waitemata Harbour, Auckland. *Tane 36*: 197–223.

Heesch, S. (2005). Endophytic Phaeophyceae from New Zealand. PhD thesis, University of Otago, Dunedin, New Zealand.

Hemmingsen, W.; MacKenzie, K. (2001). The parasite fauna of the Atlantic cod, *Gadus morhua* L. *Advances in Marine Biology 40*: 3–80.

Hewitt, C.L.; Willing, J.; Bauckham, A.; Cassidy, A.M.; Cox, C.M.S.; Jones, L.; Wotton, D.M. (2004). New Zealand marine biosecurity: Delivering outcomes in a fluid environment. *New Zealand Journal of Marine and Freshwater Research 38*: 429–438.

Hewitt, G.C.; Hine, P.M. (1972). Checklist of parasites of New Zealand fishes and of their hosts. *New Zealand Journal of Marine and Freshwater Research 6*: 69–114.

Hidu, H.; Conary, C.; Chapman, S.R. (1981). Suspended culture of oysters: Biological fouling control. *Aquaculture 22*: 189–192.

Hine, P.M. (1989). Parasites and diseases of commercially important molluscs in New Zealand. In: *Advances in Tropical Aquaculture*, pp. 199–206. Tahiti, 20 February – 4 March. AQUACOP IFREMER Actes Colloque 9.

Hine, P.M. (1996). Southern hemisphere mollusc diseases and an overview of associated risk assessment problems. *Scientific and Technical Review of the Office International des Epizooties 15(2)*: 563–577.

Hine, P.M.; Wesney, B.; Hay, B.E. (1992). Herpes virus associated with mortalities among hatchery-reared larval Pacific oysters *Crassostrea gigas*. *Diseases of Aquatic Organisms 12*: 135–142. www.oysterssa.com.au/media/files/720.pdf. Accessed March 2012.

Hopkins, G.A.; Forrest, B.M.; Piola, R.F.; Gardner, J.P.A. (2011). Factors affecting survivorship of defouled communities and the effect of fragmentation on establishment success. *Journal of Experimental Marine Biology and Ecology 396*: 233–243.

Hughes, D.J.; Cook, E.J.; Sayer, M.D.J. (2005). Biofiltration and biofouling on artificial structures in Europe: The potential for mitigating organic impacts. *Oceanography and Marine Biology: An annual review 43*: 123–172.

Hunt, L.; Chadderton, L.; Stuart, M.; Cooper, S.; Carruthers, M. (2009). Results of an attempt to control and eradicate *Undaria pinnatifida* in Southland, New Zealand, April 1997 – November 2004. Prepared for Department of Conservation, Invercargill, New Zealand.

Hutson, K.S.; Ernst, I.; Whittington, I.D. (2007). Risk assessment for metazoan parasites of yellowtail kingfish *Seriola lalandi* (Perciformes: Carangidae) in South Australian sea-cage aquaculture. *Aquaculture 271*: 85–99.

Inglis, G.J.; Floerl, O.; Ahyon, S.; Cox, S.; Unwin, M.; Ponder-Sutton, A.; Seaward, K.; Kospartov, M.; Read, G.; Gordon, D.; Hosie, A.; Nelson, W.; d'Archino, R.; Bell, A.; Kluza, D. (2010). *The biosecurity risks associated with biofouling on international vessels arriving in New Zealand: Summary of the patterns and predictors of fouling.* MAF Biosecurity New Zealand Technical Paper.

Inglis, G.J.; Gust, N. (2003). Potential indirect effects of shellfish culture on the reproductive success of benthic predators. *Journal of Applied Ecology 40(61)*: 1077–1089.

Irigoyen, A.; Eyras, C.; Parma, A. (2011a). Alien algae *Undaria pinnatifida* causes habitat loss for rocky reef fishes in north Patagonia. *Biological Invasions 13*: 17–24.

Irigoyen, A.; Trobbiani, G.; Sgarlatta, M.; Raffo, M. (2011b). Effects of the alien algae *Undaria pinnatifida* (Phaeophyceae, Laminariales) on the diversity and abundance of benthic macrofauna in Golfo Nuevo (Patagonia, Argentina): Potential implications for local food webs. *Biological Invasions 13*: 1521–1532..

Ito, S.; Kitamura, H. (1997). Induction of larval metamorphosis in the sea cucumber *Stichopus japonicus* by periphitic diatoms. *Hydrobiologia 358*: 281–284.

Jenkins, R.J. (1997). Studies on the dynamics of colonisation of the Pacific oyster *Crassostrea gigas* (Thunberg), in the Marlborough Sounds, New Zealand. Unpublished MSc thesis, University of Otago.

Jenkins, R.J.; Meredyth-Young, J.L. (1979). Occurrence of the Pacific oyster, *Crassostrea gigas*, off the South Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research 13*: 173–174.

Jennings, K.A. (1997). The reproductive biology of *Imogene mcgrathi* (Platyhelminthes: Polycladida) associated with oysters from Moreton Bay. Unpublished MSc. Thesis. University of Queensland, Queensland.

Jensen, Ø.; Dempster, T.; Thorstad, E.B.; Uglem, I.; Fredheim, A. (2010). Escapes of fishes from Norwegian sea-cageaquaculture: Causes, consequences and prevention. *Aquaculture and Environmental Interactions. 1*: 71–83.

Johnson, C. (2001). Relationship between occurrence of dense stands of the introduced Japanese kelp *Undaria pinnatifida* and abundance of sea urchins (*Heliocidaris erythrogramma*) on the east coast of Tasmania. Echinoderms 2000: Proceedings of the 10th International Conference, Dunedin, 31 January – 4 February 2000.

Jones, J.B.; Scotti, P.D.; Dearing, S.C.; Wesney, B. (1996). Virus-like particles associated with marine mussel mortalities in New Zealand. *Diseases of Aquatic Organisms 25*: 143–149.

Katagiri, T.; Hosokawa, A.; Maita, M. (2007). A new disease in cultured yellowtail Seriola quinqueradiata characterized by encephalomyelitis. *Fish Pathology 42*: 223–224.

Keeley, N.; Forrest, B.; Hopkins, G.; Gillespie, P.; Knight, B.; Webb, S.; Clement, D.; Gardner, J. (2009). *Sustainable aquaculture in New Zealand: Review of the ecological effects of farming shellfish and other non-finfish species*. Prepared for Ministry of Fisheries. Cawthron Report 1476. Cawthron Institute, Nelson, New Zealand.

Keeley, N.B.; Macleod, C.K.; Forrest, B.M. (2011). Combining best professional judgement (BPJ) and quantile regression splines to improve characterisation of macrofaunal responses to enrichment. *Ecological Indicators 12(1)*: 154–166.

Kelly, S. (2008). *Potential environmental effects associated with the proposed shift from mussel to finfish farming in the Firth of Thames.* Environment Waikato Technical Report 2008/38.

Kelly, S. (2011). State of our gulf seminar: Findings from the 2011 Tikapa Moana–Hauraki Gulf state of the environment report, Auckland Museum, August 9.

Kent, R.M.L. (1979). The influence of heavy infestations of *Polydora ciliata* on the flesh content of *Mytilus edulis*. *Journal of the Marine Biological Association of the United Kingdom 59*: 289–297.

Kent, R.M.L. (1981). The effect of *Polydora ciliata* on the shell strength of *Mytilus edulis*. *Journal du Conseil permanent International pour l' Exploration de la Mer 39*: 252–255.

King, M.G. (1977). Cultivation of the Pacific oysters (*Crassostrea gigas*) in a nontidal hypersaline pond. *Aquaculture 11(2)*: 123–236.

Kitamura, S.I.; Ko, J-Y.; Lee, W-L.; Kim, S-R.; Song, J-Y.; Kim, D-K.; Jung, S-J.; Oh, M-J. (2007). Seasonal prevalence of lymphocystis disease virus and aquabirnavirus in Japanese flounder, *Paralichthys olivaceus* and blue mussel, *Mytilus galloprovincialis*. *Aquaculture 266(1–4)*: 26–31.

Kospartov, K.; Inglis, G.; Seaward, K.; van den Brink, A.; D'Archino, R.; Ahyong, S. (2008). *Non-indigenous and cryptogenic marine species in New Zealand.* MAF Biosecurity New Zealand report.

Krkošek, M. (2010). Sea lice and salmon in Pacific Canada: Ecology and policy. *Frontiers in Ecology and the Environment 8*: 201–209.

Kutty, M.N. (1987). *Site selection for aquaculture: Introduction, technical and non-technical considerations in site selection.* Food and Agriculture Organization, Rome, Italy. www.fao.org/docrep/field/003/AC170E/AC170E00.htm. Accessed December 2011.

La Rosa, T.; Mirto, S.; Favaloro, E.; Savona, B.; Sara, G.; Danovaro, R.; Mazzola, A. (2002). Impact on the water column biogeochemistry of a Mediterranean mussel and fish farm. *Water Research 36*: 713–721.

Lafferty, K.D.; Porter, J.W.; Ford, S.E. (2004). Are diseases increasing in the ocean? *Annual Review of Ecology Evolution and Systematics 35*: 31–54.

Lane, A.; Willemsen, P. (2004). Collaborative effort looks into biofouling. *Fish Farming International, September 2004*: 34–35.

Leef, M.J.; Lee, P.S. (2009). Preliminary investigation into the killing effect of kingfish (*Seriola lalandi*) serum and mucus against the monogenean parasites *Benedenia seriolae* and *Zeuxapta seriolae*. *Aquaculture International 17*: 607–614.

Lengyel, N.L.; Collie, J.S.; Valentine, P.C. (2009). The invasive colonial ascidian *Didemnum vexillum* on Georges Bank: Ecological effects and genetic identification. *Aquatic Invasions 4*: 143–152.

Leppäkoski, E.; Gollasch, S.; Olenin, S. (2002). *Invasive aquatic species of Europe: Distribution, impacts and management*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Lewis, G.; Loutit, M.W.; Austin, F.J. (1986). Enteroviruses in mussels and marine sediments and depuration of naturally accumulated viruses by green lipped mussels (*Perna canaliculus*). *New Zealand Journal of Marine and Freshwater Research 20*: 431–437.

Li, Y.; Qin, J.G.; Abbot, C.A.; Li, X.; Benkendorff, K. (2007). Synergistic impacts of heat shock and spawning on the physiology and immune health of *Crassostrea gigas*: An explanation for summer mortality in Pacific oysters. *American Journal of Physiology: Regulatory, integrative and comparative physiology 293*: 2353–2362.

Locke, A.; Doe, K.G.; Fairchild, W.L.; Jackman, P.M.; Reese, E.J. (2009a). Preliminary evaluation of effects of invasive tunicate management with acetic acid and calcium hydroxide on non-target marine organisms in Prince Edward Island, Canada. *Aquatic Invasions 4(1)*: 221–236.

Locke, A.; Hanson, J.M.; MacNair, N.G.; Smith, A.H. (2009b) Rapid response to non-indigenous species. 2. Case studies of non-indigenous tunicates in Prince Edward Island. *Aquatic Invasions 4*: 249–258.

Lynch, S.A.; Abollo, E.; Ramilo, A.; Cao, A.; Culloty, S.C.; Villalba, A. (2010). Observations raise the question if the Pacific oyster, *Crassostrea gigas*, can act as either a carrier or a reservoir for *Bonamia ostreae* or *Bonamia exitiosa*. *Parasitology 137(10)*: 1515–1526.

MacKenzie, L.; Beauchamp, T (2000). Gymnodinium catenatum *in New Zealand: A new problem for public health and the shellfish industry.* Cawthron Report 210. Cawthron Institute, Nelson, New Zealand.

MAFBNZ (2010a). Range of factors at play in oyster deaths. Ministry of Agriculture and Fisheries Biosecurity New Zealand press release, 8 December.

MAFBNZ (Ministry of Agriculture and Fisheries Biosecurity New Zealand). (2010b). *Import health standard for juvenile yellowtail kingfish (*Seriola lalandi*) from Australia.* www.biosecurity.govt.nz/files/ihs/kngfisic.aus.pdf. Accessed August 2011.

MAFBNZ (Ministry of Agriculture and Fisheries Biosecurity New Zealand). (2010c) Import health standard for fish food and fish bait from all countries. www.biosecurity.govt.nz/imports/animals/standards/fisfooic.all.htm.

MAFBNZ (Ministry of Agriculture and Fisheries Biosecurity New Zealand). (2010d). *The commercial use of* Undaria pinnatifida*: An exotic Asian seaweed. MAF Biosecurity* New Zealand Information Paper 2010/02.

Mansell, B.; Powell, M.D.; Ernst, I.; Nowak, B.F. (2005). Effects of the gill monogenean *Zeuxapta seriolae* (Meserve, 1938) and treatment with hydrogen peroxide on pathophysiology of kingfish, *Seriola lalandi* Valenciennes, 1833. *Journal of Fish Diseases 28*: 253–262.

McKindsey, C.W.; Landry, T.; O'Beirn, F.X.; Davies, I.M. (2007). Bivalve aquaculture and exotic species: A review of ecological and management issues. *Journal of Shellfish Research 26*: 281–294.

Melo, C.M.R.; Silva, F.C.; Gomes, C.; Sole-Cava, A.M.; Lazoski, C. (2010). *Crassostrea gigas* in natural oyster banks in southern Brazil. *Biological Invasions 12(3)*: 441–449.

Menzies, R.J.; Miller, M.A. (1954). Marine asellote isopods of the genus Antias with the description of a new species from New Zealand. *Transactions of the Royal Society of New Zealand 83*: 383–389.

Mercer, J.M.; Whitlach, R.B.; Osman, R.W. (2009). Potential effects of the invasive colonial ascidian (*Didemnum vexillum* Kott, 2002) on pebble-cobble bottom habitats in Long Island Sound, USA. *Aquatic Invasions 4*: 133–142.

Meyers, T.R. (1984). Marine bivalve mollusks as reservoirs of viral finfish pathogens: Significance to marine and anadromous finfish aquaculture. *Marine Fisheries Review 46*: 14–17.

Minchin, D. (2007). Aquaculture and transport in a changing environment: Overlap and links in the spread of alien biota. *Marine Pollution Bulletin 55*: 302–313.

Mineur, F.; Belsher, T.; Johnson, M.P.; Maggs, C.A.; Verlaque, M. (2007). Experimental assessment of oyster transfers as a vector for macroalgal introductions. *Biological Conservation 137*: 237–247.

Molnar, J.L.; Gamboa, R.L.; Revenga, C.; Spalding, M.D. (2008). Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and the Environment 6(9)*: 485–492.

Morrisey, D.; Page, M.; Handley, S.; Middleton, C.; Schick, R. (2009). *Biology and ecology of the introduced ascidian Eudistoma elongatum, and trials of potential control options.* MAF Biosecurity New Zealand Technical Paper 2009/21. Prepared for MAF Biosecurity New Zealand. NIWA, Nelson, New Zealand.

Morrisey, D.; Plew, D.; Seaward, K. (2011). *Aquaculture readiness data Phase II.* MAF Technical Paper 2011/68. Prepared for MAF Biosecurity Operational Research. NIWA, Nelson, New Zealand.

Morrisey, D.J.; Gibbs, M.M.; Pickmere, S.E.; Cole, R.G. (2000). Predicting impacts and recovery of marine-farm sites in Stewart Island, New Zealand from the Findlay-Watling model. *Aquaculture 185*: 257–272.

Moyle, P.B.; Li, H.W.; Barton, B. (1987). The Frankenstein effect: Impact of introduced fishes on native fishes of North America. In: *Fish culture in fisheries management*, pp. 415–426. Stroud, R.H. (ed.). American Fisheries Society, Bethesda, Maryland, United States of America.

Murina, G-V.; Solonchenko, A.I. (1991). Commensals of *Mytilus galloprovincialis* in the Black Sea: Urastoma cyprinae (Turbellaria) and *Polydora ciliata* (Polychaeta). *Hydrobiologia*: 385–387.

Murray, A.G. (2008). Existing and potential use of models in the control and prevention of disease emergencies affecting aquatic animals. *Revue Scientifique et Technique de l'Office International Des Epizooties 27*: 211–228.

Murray, A.G.; Peeler, E.J. (2005). A framework for understanding the potential for emerging diseases in aquaculture. *Preventive Veterinary Medicine 67*: 223–235.

Naylor, R.L.; Williams, S.L.; Strong, D.R. (2001). Aquaculture: A gateway for exotic species. *Science 294*: 1655–1656.

Neill, K.; Heesch, S.; Nelson, W. (2008). *Diseases, pathogens and parasites of* Undaria pinnatifida*.* MAF Biosecurity New Zealand Technical Paper 2009/44.

NRC (2010). *Ecosystem concepts for sustainable bivalve mariculture.* By Committee on Best Practices for Shellfish Mariculture and the Effects of Commercial Activities in Drakes Estero, Pt. Reyes National Seashore, California.

Numata, M.; Davis, L.S.; Renner, M. (2000). Prolonged foraging trips and egg desertion in little penguins (*Eudyptula minor*). *New Zealand Journal of Zoology 27*: 277–289.

NZAS (2006). *The New Zealand aquaculture strategy*. Commissioned by the New Zealand Aquaculture Council with the assistance of the New Zealand Seafood Industry Council and the Ministry of Economic Development.

NZMIC (New Zealand Mussel Industry Council). (1999). *The New Zealand mussel industry code of practice.* Aquaculture New Zealand.

NZMIC (New Zealand Mussel Industry Council). (2001). *Code of practice for transfer of mussel seed.* Aquaculture New Zealand.

NZOI (New Zealand Oyster Industry). (2007). *New Zealand oyster industry code of practice.* Aquaculture New Zealand.

NZSFA (New Zealand Salmon Farmers Association). (2007). *Finfish aquaculture code of practice*. Aquaculture New Zealand.

OIE (2011). *Aquatic animal health code*. World Organisation for Animal Health. http://www.oie.int/en/international-standard-setting/aquatic-code/access-online/. Accessed August 2011.

Okamura, B.; Feist, S.W. (2011). Emerging diseases in freshwater systems. *Freshwater Ecosystem* 56: 627–637.

Page, M.J.; Morrisey, D.J.; Handley, S.J; Middleton, C. (2011). Biology, ecology and trials of potential methods for control of the introduced ascidian *Eudistoma elongatum* (Herdman, 1886) in Northland, New Zealand. *Aquatic Invasions* 6(4): 515–517.

Pannell, A.; Coutts, A.D.M. (2007). Treatment methods used to manage *Didemnum vexillum* in New Zealand. Report prepared for Biosecurity New Zealand. New Zealand Marine Farming Association.

Park, C.S.; Park, K.Y.; Baek, J.M.; Hwang, E.K. (2008). The occurrence of pinhole disease in relation to developmental stage in cultivated Undaria pinnatifida (Harvey) Suringar (Phaeophyta) in Korea. *Journal of Applied Phycology 20(5*): 485–490.

Peeler, E.J.; Taylor, N.G. (2011). The application of epidemiology in aquatic animal health - opportunities and challenges. *Veterinary Research*. 42(1): 94.

Perez, R.; Lee, J.Y.; Juge, C. (1981). Observations sur la biologie de l'algue japonaise *Undaria pinnatifida* (Harvey) Suringar introduite accidentellement dans l'Etang de Thau. *Science et Peche 315:* 1–12.

Piola, R.F.; Denny, C.M.; Forrest, B.M.; Taylor, M.D. (2009). Marine biosecurity: Management options and response tools. In: *Invasive species management: A handbook of principles and techniques*, pp. 205–231. Williams, P.A.; Clout, M.N. (eds.). Oxford University Press, United Kingdom.

Pregenzer, C. (1983). Survey of metazoan symbionts of *Mytilus edulis* (Mollusca: Pelecypoda) in Southern Australia. *Australian Journal of Marine and Freshwater Research 34*: 387–396.

Price, M.H.H.; Proboszcz, S.L.; Routledge, R.D.; Gottesfeld, A.S.; Orr, C. (2011). Sea louse infection of juvenile sockeye salmon in relation to marine salmon farms on Canada's west coast. *PLoS ONE 6(2):* e16851.

Quale, D.B. (1969). Pacific oyster culture in British Columbia. *Fisheries Research Board of Canada Bulletin 169*.

Read, G.; Handley, S. (2004). New alien mudworm now becoming a pest in longline mussels. *Water and Atmosphere 12(3)*: 30–31.

Read, G.A. (2010). Comparison and history of *Polydora websteri* and P*. haswelli* (Polychaeta: Spionidae) as mud-blister worms in New Zealand shellfish. *New Zealand Journal of Marine and Freshwater Research 44(2)*: 83–100.

Rhodes, L.L.; Mackenzie, A.L.; Kaspar, H.F.; Todd, K.E. (2001). Harmful algae and mariculture in New Zealand. *ICES Journal of Marine Science: Journal du Conseil 58*: 398–403.

Rigos, G.; Pavlidis, M.; Divanach, P. (2001). Host susceptibility to *Cryptocaryon* sp. infection of Mediterranean marine broodfish held under intensive culture conditions: A case report. *Bulletin of the European Association of Fish Pathologists 21*: 33–36.

Robertson, P.A.W.; O'Dowd, C.; Burrells, C.; Williams, P.; Austin, B. (2000). Use of *Carnobacterium* sp. as a probiotic for Atlantic salmon (*Salmo salar* L.) and rainbow trout (*Oncorhynchus mykiss*, Walbaum). *Aquaculture 185(3–4)*: 235–243.

Ross, P.G.; O'Beirn, F.X.; Luckenbach, M.W. (2001). Comparison of oyster *Crassostrea virginica* culture nursery and grow-out techniques. World Aquaculture Society, conference.

143 J.M. Parker Coliseum, Louisiana State University, Baton Rouge, LA, United States of America.

Ruesink, J.L.; Lenihan, H.S.; Trimble, A.C.; Heiman, K.W.; Micheli, F.; Byers, J.E.; Kay, M.C. (2005). Introduction of non-native oysters: Ecosystem effects and restoration implications. *Annual Review of Ecology Evolution and Systematics 36*: 643–689.

Ruiz, G.M.; Freestone, A,L,; Fofonoff, P.W.; Simkanin, C. (2009). Habitat distribution and heterogeneity in marine invasion dynamics: The importance of hard substrate and artificial structure. In: *Biological invasions in marine ecosystems: Ecological, management, and geographic perspectives,* pp. 321–332. Rilov, G.; Crooks, J.A. (eds.). Springer-Verlag Berlin Heidelberg.

Russell, L.; Hepburn, C.; Hurd, C.; Stuart, M. (2008). The expanding range of *Undaria pinnatifida* in southern New Zealand: Distribution, dispersal mechanisms and the invasion of wave exposed environments. *Biological Invasions 10*: 103–115.

Rutter Hinz Inc (2009). *Marine infrastructure study for the salmonid aquaculture industry Bay D'Espoir/Connaigre Peninsula/Fortune Bay region.* Report prepared for Department of Fisheries and Aquaculture, New Foundland.

Scavia, D.; Field, J.; Boesch, D.; Buddemeier, R.; Burkett, V.; Cayan, D.; Fogarty, M.; Harwell, M.; Howarth, R.; Mason, C.; Reed, D.; Royer, T.; Sallenger, A.; Titus, J. (2002). Climate change impacts on U.S. Coastal and Marine Ecosystems. *Estuaries and Coasts 25(2)*: 149–164.

Schaffelke, B.; Peters, A.F.; Reusch, T.B.H. (1996). Factors influencing depth distribution of soft bottom inhabiting Laminaria *saccharina* (L.) Lamour. in Kiel Bay, Western Baltic. *Hydrobiologia 326/327*: 117–123.

Silva, C.; Ferreira, J.G.; Bricker, S.B.; DelValls, T.A.; Martín-Díaz, M.L.; Yáñez, E. (2011). Site selection for shellfish aquaculture by means of GIS and farm-scale models, with an emphasis on data-poor environments. *Aquaculture 318(3–4)*: 444–457.

Sinner, J.; Forrest, B.; Taylor, M. (2000). *A strategy for managing the Asian kelp Undaria: Final report.* Cawthron Report 578. Cawthron Institute, Nelson, New Zealand.

Sinner, J.; Forrest, B.M.; O'Brien, M.; Piola, R.F.; Roberts, B. (2009). *Fiordland marine biosecurity risk management: Operational plan recommendations 2009–2013.* Prepared for MAF Biosecurity New Zealand and Fiordland Marine Guardians. Cawthron Report 1621. Cawthron Institute, Nelson, New Zealand.

Skår, C.K.; Mortensen, S. (2007). Fate of infectious salmon anaemia virus (ISAV) in experimentally challenged blue mussels *Mytilus edulis. Diseases of Aquatic Organisms. 74*: 1–6.

Skeel, M.E. (1979). Shell boring worms (*Spionidae: Polychaeta*) infecting cultivated bivalve molluscs in Australia. *Proceedings of the World Mariculture Society 10*: 529–533.

Skejić, S.; Marasović, I.; Vidjak, O.; Kušpilić, G.; Ninčević Gladan, Ž.; Šestanović, S.; Bojanić, N. (2011). Effects of cage fish farming on phytoplankton community structure, biomass and primary production in an aquaculture area in the middle Adriatic Sea. *Aquaculture Research 42*: 1393–1405.

Slater, M.J. (2009). The sea cucumber *Australostichopus mollis*: Juvenile feeding ecology and habitat. PhD thesis, University of Auckland, Auckland, New Zealand.

Slater, M.J.; Carton, A.G. (2007). Survivorship and growth of the sea cucumber *Australostichopus (Stichopus) mollis* (Hutton 1872) in polyculture trials with green-lipped mussel farms. *Aquaculture 272*: 389–398.

Smith, B.; Collie, J.; Lengyel, N. (2010). *Invasive species impacts marine life, alters feeding habits of bottomdwelling fish on Georges Bank.* State News Service, Northeast Fisheries Science Center, National Marine Fisheries Service, Woods Hole, Massachusetts, United States of America.

Smith, P.J.; Holdsworth, J.; Anderson, C.; Hine, P.M.; Allen, D.; Gibbs, W.; McKenzie, L.; Taylor, P.; Blackwell, R.H.; Williamson, S.H. (1996). Pilchard deaths in New Zealand, 1995. *New Zealand Fisheries Data Report 70*.

Smith, P.J.; McVeagh, S.M.; Hulston, D.; Anderson, S.A.; Gublin, Y. (2009). DNA identification of ciliates associated with disease outbreaks in a New Zealand marine fish hatchery. *Diseases of Aquatic Organisms 86*: 163–167.

Smith, P.J.; Page, M.; Handley, S.J.; McVeagh, S.M.; Ekins, M. (2007). First record of the Australian ascidian *Eudistoma elongatum*, an invasive species in northern New Zealand.

New Zealand Journal of Marine and Freshwater Research 41: 347–355.

Soto, D.; Aguilar-Manjarrez, J.; Brugère, C.; Angel, D.; Bailey, C.; Black, K.; Edwards, P.; Costa-Pierce, B.; Chopin, T.; Deudero, S.; Freeman, S.; Hambrey, J.; Hishamunda, N.; Knowler, D.; Silvert, W.; Marba, N.; Mathe, S.; Norambuena, R.; Simard, F.; Tett, P.; Troell, M.; Wainberg, A. (2008). Applying an ecosystem based approach to aquaculture: Principles, scales and some management measures. In: *Building an ecosystem approach to aquaculture,* pp. 15–35. Soto, D.; Aguilar-Manjarrez, J.; Hishamunda, N. (eds.). FAO/Universitat de les Illes Balears Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. FAO Fisheries and Aquaculture Proceedings 14. Food and Agriculture Organization, Rome, Italy.

Soto, D.; Jara, F.; Moreno, C. (2001). Escaped salmon in the inner seas, southern Chile: Facing ecological and social conflicts. *Ecological Applications 11*: 1750–1762.

Soto, D.; Norambuena, F. (2004). Evaluation of salmon farming effects on marine systems in the inner seas of southern Chile: A large-scale mensurative experiment. *Journal of Applied Ichthyology 20*: 493–501.

Sousa, R.; Gutierrez, J.L.; Aldridge, D.C. (2009). Non-indigenous invasive bivalves as ecosystem engineers. *Biological Invasions 11(10)*: 2367–2385.

Stephens, F.J.; Savage, A. (2010). Two mortality events in sea-caged yellowtail kingfish *Seriola lalandi* Valenciennes, 1833 (Nannopercidae) from Western Australia. *Australian Veterinary Journal 88*: 414–416.

Stickney, R.R., (2009). Diseases of aquaculture species. In: *Aquaculture: An introductory text* (2nd edn), chapter 5. CAB International, Oxfordshire, United Kingdom.

Stiven, A.E. (1964). Experimental studies on the host parasite system hydra and *Hydramoeba hydroxena* (Entz). II. The components of a single epidemic. *Ecological Monographs 34*: 119–142.

Sylvester, F.; Kalaci, O.; Leung, B.; Lacoursiere-Roussel, A.; Murray, C.C.; Choi, F.M.; Bravo, M.A.; Therriault, T.W.; MacIsaac, H.J. (2011). Hull fouling as an invasion vector: Can simple models explain a complex problem? *Journal of Applied Ecology 48(2)*: 415–423.

Taylor, G.A. (1997). Seabirds found dead on New Zealand beaches in 1995. *Notornis 44*: 201–12.

Taylor, M.D. (2000). *Sampling programme for lot testing of* Gymnodinium catenatum *cyst contamination in "Kaitaia spat".* Cawthron Report 606. Cawthron Institute, Nelson, New Zealand.

Taylor, M.D.; Dodgshun, T.J.; de Zwart, E. (2005). *Biosecurity management plan for a proposed south Kaipara oyster farm.* Cawthron Report 1123. Cawthron Institute, Nelson, New Zealand.

Tett, P.; Edwards, V. (2002). *Review of harmful algal blooms in Scottish coastal waters*. School of Life Sciences, Napier University, Edinburgh, Scotland.

Thieltges, D.W.; Reise, K.; Prinz, K.; Jensen, K.T. (2008). Invaders interfere with native parasite–host interactions. *Biological Invasions*. *11(6)*: 1421–1429.

Trowbridge, C.D. (1999). *An assessment of the potential spread and options for control of the introduced green macroalga* Codium fragile ssp. tomentosoides on Australian shores. Centre for Research on Introduced Marine Pests, CSIRO Marine Research, Hobart, Australia.

Tubbs, L.A.; Poortenaar, C.W.; Sewell, M.A.; Diggles, B.K. (2005). Effects of temperature on fecundity in vitro, egg hatching and reproductive development of Benedenia seriolae and Zeuxapta seriolae (Monogenea) parasitic on yellowtail kingfish Seriola *lalandi. International Journal for Parasitology 35*: 315–327.

Uglem, I.; Dempster, T.; Bjorn, P.-A.; Sanchez-Jerez, P.; Okland, F. (2009). High connectivity of salmon farms revealed by aggregation, residence and repeated movements of wild fish among farms. *Marine Ecology Progress Series 384*: 251–260.

Utting, S.D.; Spencer, B.E. (1992). Introduction of marine bivalve molluscs into the United Kingdom for commercial culture: Case histories. *ICES Marine Science Symposia 194*: 84–91.

Valentine, J.P.; Johnson, C.R. (2003). Establishment of the introduced kelp *Undaria pinnatifida* in Tasmania depends on disturbance to native algal assemblages. *Journal of Experimental Marine Biology and Ecology 295*: 63–90.

Valentine, J.P.; Johnson, C.R. (2004). Establishment of the introduced kelp *Undaria pinnatifida* following dieback of the native macroalga Phyllospora comosa in Tasmania, Australia. *Marine and Freshwater Research 55*: 223–230.

Valentine, J.P.; Johnson, C.R. (2005a). Persistence of sea urchin (*Heliocidaris erythrogramma*) barrens on the east coast of Tasmania: Inhibition of macroalgal recovery in the absence of high densities of sea urchins. *Botanica Marina 48:* 106–115.

Valentine, J.P.; Johnson, C.R. (2005b). Persistence of the exotic kelp *Undaria pinnatifida* does not depend on sea urchin grazing. *Marine Ecology Progress Series 285*: 43–55.

Valeria Teso, S.; Bigatti, G.; Casas, G.N.; Luz Piriz, M.; Penchaszadeh, P.E. (2009). Do native grazers from Patagonia, Argentina, consume the invasive kelp *Undaria pinnatifida? Revista del Museo Argentino de Ciencias Naturales 11*: 7–14.

Verlaque, M. (2001). Checklist of the macroalgae of Thau Lagoon (Hérault, France): A hot spot of marine species introduction in Europe. *Oceanologica Acta 24*: 29–49.

VPS (2000). *Scientific review of diseases of quarantine significance carried by bivalve molluscs.* Prepared for the Australian Quarantine and Inspection Service. www.daff.gov.au/_data/assets/word_doc/0012/12081/vps_report.doc.

Ward, T.M.; Hoedt, F.; McLeay, L.; Dimmlich, W.F.; Kinloch, M.; Jackson, G.; McGarvey, R.; Rogers, P.J.; Jones, K. (2001). Effects of the 1995 and 1998 mass mortality events on the spawning biomass of sardine, *Sardinops sagax*, in South Australian waters. *ICES Journal of Marine Science 58*: 865–875.

Wasson, K.; Zabin, C.J.; Bedinger, L.; Diaz, M.C.; Pearse, J.S. (2001). Biological invasions of estuaries without international shipping: The importance of intraregional transport. *Biological Conservation 102*: 143–153.

Waterman, P.B.; Sin, F.Y.T. (1991). Occurrence of the marine tapeworms, *Hepatoxylon trichiuri* and *Hepatoxylon megacephalum*, in fishes from Kaikoura, New Zealand. *New Zealand Natural Sciences 18*: 71–73.

Weaver, J. (2001). South Australia: Quarterly report – Neurological disease in yellowtail kingfish. *Animal Health Surveillance 6*: 12.

Webb, S. (2007). *Pathogens and parasites of the mussels* Mytilus galloprovincialis *and* Perna canaliculus*: Assessment of the threats faced by New Zealand aquaculture.* Cawthron Report 1334. Cawthron Institute, Nelson, New Zealand.

Wetchateng, T. (2008). Rickettsia-like organism (RLO) infection in the abalone, *Haliotis diversicolor supertexta:* Histopathology, diagnosis and treatment. PhD dissertation, Mahidol University, Bangkok, Thailand.

Whittington, R.J.; Jones, J.B.; Hine, P.M.; Hyatt, A.D. (1997). Epizootic mortality in the pilchard *Sardinops sagax neopilchardus* in Australia and New Zealand in 1995 I: Pathology and epizootiology. *Diseases of Aquatic Organisms 28*: 1–15.

Whittington, R.J.; Jones, J.B.; Hyatt, A.D. (2005). Pilchard herpesvirus in Australia 1995–1999. In: *Diseases in Asian aquaculture V*, pp. 137–140. Walker, P.; Lester, R.; Bondad-Reantaso, M.G. (eds.). Fish Health Section, Asian Fisheries Society, Manila, Philippines.

Wotton, D.M.; O'Brien, C.; Stuart, M.D.; Fergus, D.J. (2004). Eradication success down under: Heat treatment of a sunken trawler to kill the invasive seaweed *Undaria pinnatifida*. *Marine Pollution Bulletin 49*: 844–849.

Wurts, W.A. (1992). Basics of aquaculture site selection. *World Aquaculture 23(3)*: 42–43.

WWF (2010). *Bivalve Aquaculture Dialogue standards: Environmental and social standards for bivalve aquaculture*. World Wildlife Fund. www.worldwildlife.org/what/globalmarkets/aquaculture/WWFBinaryitem13945.pdf.

Yin-Geng, W.; Chun-Yun, Z.; Xiao-Jun, R.; Jie-Jun, C.; Cheng-Yin, S. (2004). Diseases of cultured sea cucumber, *Apostichopus japonicus*, in China. In: *Advances in sea cucumber aquaculture management*, pp. 297–310. FAO Fisheries Technical Paper 463. Food and Agriculture Organization, Rome, Italy.

Zeldis, J.; Broekhuizen, N.; Forsythe, A.; Morrissey, D.; Stenton-Dozey, J. (2011a). *Waikato marine finfish farming: Production and ecological guidance.* NIWA Client Report CHC2010-147.

Zeldis, J.; Felsing, M.; Wilson, J. (2006). Limits of acceptable change: A framework for managing marine farming. *Water and Atmosphere 14(2)*: 16–17.

Zeldis, J.; Hadfield, M.; Morrisey, D.; Broekhuizen, N.; Stenton-Dozey, J. (2011b). *Tasman aquaculture: Guidance on farming additive species – Stage 1.* Prepared for Ministry of Fisheries Aquaculture Unit. NIWA Client Report CHC2011-005, NIWA Project PRM201022.

Zuccollo, J.; (2010). *Value of kingfish and hapuku farming: Preliminary analysis*. Report to Ministry of Fisheries by NZIER, 17 December 2010.