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Potential Environmental Effects Associated with the Proposed Shift from Mussel to Finfish Farming in the Firth of Thames

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Executive summary

Local and international literature was reviewed to identify the potential environmental effects of fish farming in the Firth of Thames (FoT), and the results of FoT-specific studies were summarized. The key conclusions of this review were:

- Marine farms provide habitat for invasive species and the movement of farm stock and equipment provides a pathway for their transfer within and between regions. Nutrients released from fish farms are likely to exacerbate the growth of some invasives already in the Firth of Thames, such as the Asian kelp *Undaria pinifitada*, and potentially increase their spread. The potential consequences of invasive species could be very significant, and their scale of impact could extend well beyond the farm area.
- Interbreeding between farmed and wild stock has the potential to alter the genetic make-up of wild fish stocks, if: farmed fish are selectively bred; are grown to maturity; and/or have high escape rates. The potential for genetic effects is also influenced by the size of the wild population and natural immigration rates. Genetic impacts can be minimized by preventing fish escapes, using sterile fish or harvesting before maturity, avoiding selective breeding and maintaining large, natural populations of wild fish.
- Fish farming uses significant quantities of fishmeal, which is produced from fish obtained by wild capture. Rapid growth in the fish farm industry has increased the demand for fishmeal and led to global concern about the sustainability of fish stocks used in its production. Currently, all fishmeal used in New Zealand is sourced from overseas.
- There is a high probability that the deposition of waste food, faeces and chemical contaminants will led to degradation of the seabed directly beneath fish farms, and for a relatively small distance beyond (up to several hundred meters). Benthic ecosystems are likely to be heavily impacted within the immediate deposition zone, but the level of impact will reduce toward the margin of the depositional footprint.
- The Firth of Thames currently receives relatively high nutrient loads from its river systems. Nutrients released from fish food and metabolic wastes would add to the overall nitrogen budget of the Firth. The influence of this could range from insignificant to significant relative to Firth-wide nitrogen-ecosystem processes, depending on scale of fish production and to a lesser extent fish-food conversion rates. Local effects are likely to be greater than Firth-wide effects.
- Mussel culture has the potential to offset some nutrient effects. At full production, Areas A and B in Wilson Bay, plus other mussel farms in the Firth could theoretically offset nitrogen released from 2900 tonnes of fish production. In practice, the level of direct offsetting is likely to be less than this, because all of these mussels would have to be located in the area(s) directly influenced by farm nutrients.
- Infections of parasites and disease agents may be amplified within sea cages, but actual disease is only likely to occur in the cultured fishes. This is because the mobility of the wild fishes tends to prevent hyperinfections from occurring, eliminating a necessary prerequisite for disease. However, infection rates may increase slightly in wild fishes that have an association with the area surrounding sea cages. A high concentration of fish farms can act as a reservoir of parasites, such as sea lice and infect wild populations.
- The value of the southern Firth of Thames to waders is recognised through the designation of Ramsar status to intertidal areas. 135 bird species have been identified in the Ramsar site and around 35,000 waders use the southern Firth each

year. The only potential link between fish farms in Wilson Bay and waders in the Ramsar site appears to be via an indirect response to changes in food abundance or habitat modification, caused by nutrient enrichment. However, it is unlikely that such indirect effects will have a significant impact on the Ramsar site.

- Fish farms can positively affect seabirds through the provision of new roosting sites and by attracting fish. Conversely, they can negatively affect seabirds through entanglement, disturbance and loss of habitat. However, the footprint of fish farms on seabird habitat would be very small, so any effects are likely to be minor.

- Fish farms can affect marine mammals through entanglement, habitat exclusion, and disturbance by vessel strikes and underwater noise. However, available information suggests that the adoption of good farm management practices should minimize the risk of these impacts actually occurring.

- Wild fish can be attracted to fish farms and this may have a beneficial effect on wild fish stocks if the area is protected from intensive fishing, or improve the recreational fishing resource if the area is left unprotected.

- Fish farms can also alter waves and current flows, attract wild fish and promote the settlement and growth of non-resident native species. The (additional) impacts of these issues are considered to be relatively minor.

1 Background

Existing aquaculture rules in Environment Waikato's Regional Coastal Plan only provide for shellfish farming and associated research. This is an impediment to the aquaculture industry and is believed to be hampering development and new market opportunities. Environment Waikato is therefore considering a change to the Regional Coastal Plan, to include rules that would allow for other forms of aquaculture. The range of potential species suitable for marine culture could include sponges, seaweeds, crustaceans and fish.

Marine farming can only occur within Aquaculture Management Areas (AMA) identified in a Regional Coastal Plan. There is now 1500 hectares allocated to marine farming within the Waikato Region and nearly 900 hectares of this has already been developed for mussel and oyster farming. The largest AMA is in Wilson Bay, within the Firth of Thames, and this is the most likely area for large-scale aquaculture diversification.

The most likely form of "new" aquaculture to be implemented is finfish farming (subsequently referred to as fish farming), because of its potential to generate greater returns than shellfish farming. However, international experience has shown that the environmental effects of fish farming can be significant. A key reason for this is that fish farms are situated within and intimately linked to the surrounding receiving environment. While wastes from land-based aquaculture and agriculture can be contained or treated, prior to being discharged to the receiving environment, this is not practicable for fish farms in the marine environment. There is also a high level of interaction between fish farms and biological components of the surrounding ecosystem, which increases the potential for negative impacts on natural biota.

As part of the analysis of policy options for fish aquaculture, Environment Waikato is required to consider the potential environmental effects of fish farming. The purpose of this report is to identify and summarize the key environmental issues associated with fish farming and to summarize the findings of a number of investigations commissioned by Environment Waikato, which have assessed some of the issues identified. Note that a variety of management options are available to reduce, minimise or eliminate the risks posed by fish farming. These are not considered in detail here, but will be addressed in a companion report.

2 Key environmental issues

2.1 Interbreeding with wild fish

Hatchery produced fish are selectively bred to optimize specific traits such as rapid growth and disease resistance. Interbreeding with wild fish can occur through fish escapes and the release of gametes and fertilized eggs. Most information on the effects of interbreeding between farmed and wild fish comes from studies of escaped salmon. Selective breeding and limited brood stock has led to rapid genetic changes in farmed salmon (Naylor at al. 2005), and corresponding alterations to the genetic makeup of wild fish populations through interbreeding (Fleming 2000). One-way gene flow from farmed to wild populations can be a powerful evolutionary force. For instance, Fleming (2000) estimated that genetic differences between farmed and wild populations of salmon in the North Atlantic could halve every 10 generations (approximately). Consequently, interbreeding between farmed and wild fish can lead to the loss of genetic diversity, which may affect the ability of a species to adapt to environmental change.

Genetic differences between wild salmon and farm escapees, or the offspring of farm-wild hybrids, are expressed in the physiological and behavioural differences. For example, farmed salmon typically outgrow wild juveniles (which reflects selective breeding for growth), are more aggressive (which leads to the competitive displacement of wild fish) and less responsive to predator risk (Naylor et al 2005). However, the survival of farmed salmon in the wild tends to be much lower than wild salmon (McGinnity et al 2003). McGinnity et al (2003) warned that repeated escapes could reduce the fitness of the wild population through interbreeding and competition and potentially threaten the viability of vulnerable populations.

Species such as kingfish, which have relatively broad geographical ranges may be less prone to genetic effects, particularly if they are harvested prior to maturity. However, the combination of selective breeding (NIWA 2008), one-way gene flow and high numbers of farmed fish (relative to local populations) still pose a risk, if significant numbers of farmed fish and/or their gametes are allowed to escape. The risk of genetic impact is potentially greater for other fish species, with more limited distributions and movement patterns.

Youngson et al. (2001) provided the following recommendations for limiting the genetic effects of fish farming:

1. Total physical containment should be the principal target;

2. Measures for the recovery of escaped stock should be developed and applied;

3. The use of sterile fish is recommended;

4. Use local, unselected stocks (i.e. avoid selective breeding);

5. Maintain high numbers at all life stages in wild stocks.

These recommendations should be considered when establishing management systems, which aim to minimize the potential for genetic effects.

2.2 Invasive species

Marine farms are known to promote the spread of invasive through the movement of vessels, materials and stock (Dodgshun et al. 2007, Hewitt et al. 2004, Minchin 2007, Smith et al. 2007), and through the provision of habitat and conditions that are ideal for the growth of invasive species. They provide a hard, floating substrate that is maintained near the water surface in high light conditions, and with elevated nutrient levels. Such conditions promote the growth of species such as shallow-subtidal invertebrates and opportunistic seaweeds.

High dissolved inorganic nitrogen loads may be particularly problematic for fish farms, if they promote the productivity of unwanted algae such as the Asian kelp, *Undaria pinifitada*. This species has a strong association with mussel farms in the Hauraki Gulf, including Wilsons Bay, and has spread to many of the areas where mussel farms are located (Fig. 1).

The transmission of invasive species may also be promoted by service vessels which remain in contact with, or in close proximity to, infested farm structures for prolonged periods of time. This could assist in the transmission of invasive species between the fouled structures and vessel hulls, and conversely from the vessel hulls to uninfested structures. Spread can also be promoted by harvesting and cleaning operations, which detach viable fragments from farm structures, that are capable of drifting into new areas and reproducing.

Escaped exotic fish (or other taxa) could also have a significant environmental impact if they permitted to be grown, but the effects would have to be assessed on a case by case basis. Obviously, these impacts can be easily avoided by culturing only native species.

The long-term effects of invasive species on native marine species and habitats could be significant, and affect the broader Firth of Thames and beyond. Removal of marine farms infested by invasive species may eliminate a significant reservoir, but the broader effects of invasive species will probably be ongoing.

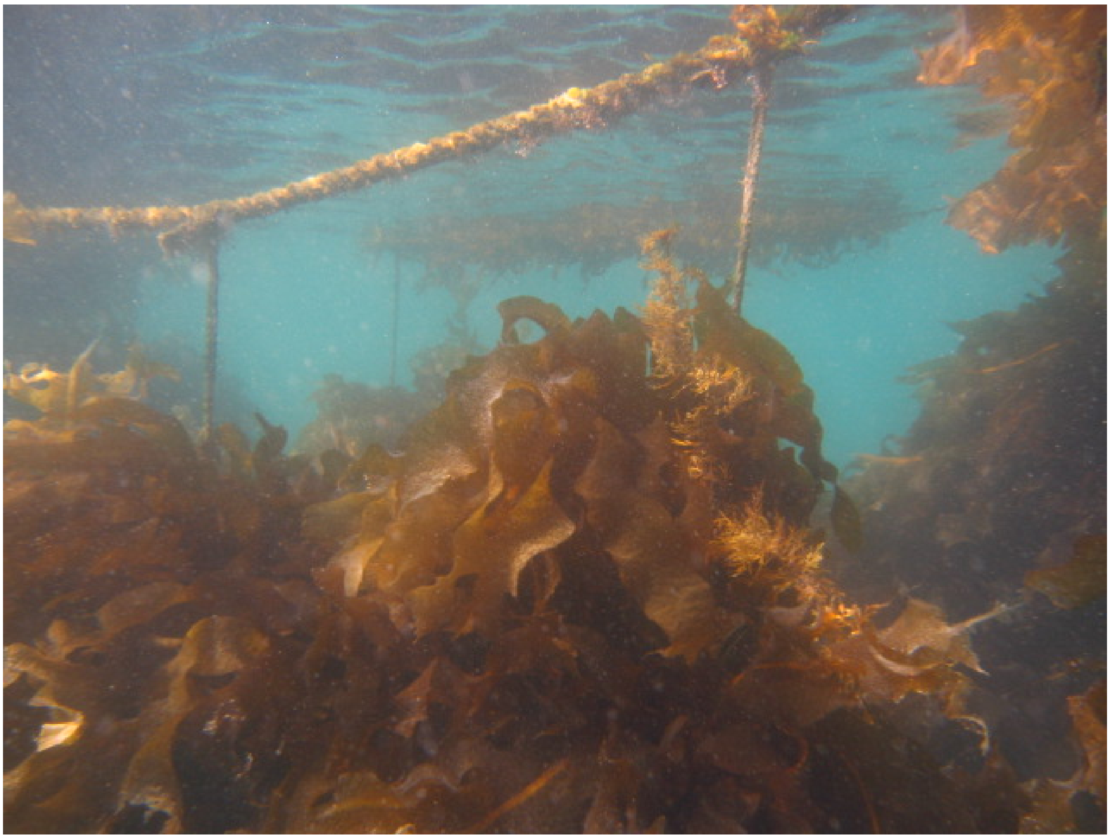

Figure 1: Growth of the invasive Asian kelp Undaria pinnatifida on mussel lines in Port Fitzroy, Great Barrier Island

2.3 Deposition of waste material

The intensive culture of caged fish invariably leads to the deposition of nutrient-rich organic matter waste feed and faecal matter on to the seabed. Nutrient-rich wastes alter the physical, chemical and ecological characteristics of the benthic environment. The microbial decay of waste material uses up oxygen, leading to reduced oxygen levels in sediments and in more severe cases the overlying water column. Nitrification[1] is inhibited in anoxic sediments, which also limits denitrification[2] and causes the release of ammonium from marine sediments (Holmer et al. 2003). This in turn, can stimulate algal growth and, in a positive feedback loop, further exacerbate organic enrichment. In cases of extreme organic loading to the seafloor, the sediments can become devoid of any life other than bacteria. Typically such sediments have an upper layer of sulphide oxidising bacteria. Under such conditions, ‘outgassing’ of highly toxic hydrogen sulphide or methane can occur from the sediments, with consequent adverse impacts on natural biota and the fish in the cages above (Gyllenhammar and Håkanson 2005, Islam 2005, Forrest et al 2007).

Waste deposition and subsequent changes in habitat quality affects the animals living on or in the sediments on the seabed. Extreme enrichment, leading to the seabed becoming devoid of sediment-dwelling infauna, has been described for most salmon farms in New Zealand (Forrest et al 2007). Typical changes that occur along an enrichment gradient include (adapted from Forrest et al 2007):

1. Complete loss of benthic macrofauna in the worst affected area directly beneath the farm.

[1] Nitrification converts ammonia to nitrates.
[2] Denitrification converts nitrate to nitrogen, which is harmlessly released to the atmosphere.

2. An impact zone where there is a peak in total animal abundance due to the proliferation of one or a few highly tolerant taxa such as the polychaete worm *Capitella capitata.*

3. A transitional zone away from the farm, where species richness increases, and total animal abundance declines down to “normal” background levels.

4. Background levels of species richness, animal abundance and community composition.

The extent and severity of the benthic footprint depends on the stocking densities, the type of feed and feeding systems, cage design, the settling velocities of wastes, the depth of the water, currents (Forrest et al. 2007, Giles 2007, Oldman 2008), and potentially, waste consumption by wild fish and other animals (Felsing 2005). The extent of depositional impact is often skewed in the direction of prevailing currents, but is typically limited to the area directly beneath fish farms and 10s – 100s of meters beyond (Forrest et al. 2007).

Management strategies have been developed that reduce the level of impact associated with salmon farming in New Zealand. These have involved reducing the amount of feed required by improving feed quality, and improving feed consumption by caged fish through improvements to food dispensing systems (e.g. automated feeders linked to underwater cameras that detect waste feed) (Forrest et al 2007). Feed is the main expense in fish farming, so strategies to reduce food wastage are actively sought by industry for both environmental and economic reasons.

Recovery of the seabed following the cessation of fish farming can take anything from months to years, and largely depends on the scale and magnitude of impact and the flushing characteristics of the site. Forrest et al. (2007) describe the best studied example from New Zealand, as a salmon farm in the Marlborough Sounds which was completely fallowed in 2001. Although habitat quality had improved significantly by 2007, the area was still recovering and full recovery was expected to take another three or more years. International studies show that even where the farm footprint is recolonised after fallowing, the new colonisers almost always differ from the original community, and complete recovery to initial community structure rarely occur within the timeframes of most studies (one to five years).

The potential impact of waste deposition in Wilsons Bay was addressed by Giles (2007) and Oldman (2008), which are summarized in Sections 3.1 and 3.2.

2.4 Parasites and disease

Fish farming is similar to other forms of intensive agriculture, in its susceptibility to infestation by parasites and diseases. Most of the published information on the broader effects of aquaculture-related parasites and diseases comes from salmon farming in the Northern Hemisphere, which has a long history of industrial fish production. In the Northern hemisphere sea lice infestation is a significant problem for farmed and wild salmon. Experiments have shown that 30 sea lice can cause osmoregulatory breakdown in post-smolt salmon, and on smaller smolts, as few as 11 can cause mortality (cited in Butler 2002). Consequently, farmers must implement effective parasite and disease control practices to maintain the economic viability of the industry.

However, salmon farms still act as the major reservoirs for sea-lice. For instance, Bulter (2002) estimated that in Scotland, sea lice hosted by farmed salmon produced between 78% and 97% of louse eggs, depending on the degree of infestation. In contrast, sea lice hosted by wild fish hosts produced <1% of eggs, with the remainder produced by lice hosted on escaped fish. Declines in the number of wild salmon have been linked to elevated louse infestation associated with salmon farms in Norway and Ireland (Butler 2002). In Canada, farm-induced lice infestation has depressed wild salmon populations to the point where local extinctions may occur (Krkosek et al. 2007). However, Krkosek et al. (2007) suggest that parasite outbreaks might not occur until farm fish abundance crosses a host-density threshold. Consequently, the threat may not exist at low farm abundances.

The implications for New Zealand are that fish farms are likely to be an incubator for disease and parasites that could affect wild fish stocks. Salmon aquaculture appears to be relatively disease and parasite free in New Zealand (Forrest et al. 2007). However, New Zealand species, such as kingfish, that have naturally occurring parasites, which may become problematic under intensive culture conditions. The potential impact of disease and parasite transfer in the Firth of Thames was addressed by Diggles (2008), which is summarized in Section 3.4.

2.5 Nutrients

The loads of dissolved nitrogen and phosphorus released from intensive fish culture can comprise a relatively large proportion of the overall nutrient mass balance for coastal systems (Islam 2005). Consequently, there is potential for the additional nutrient burden imposed by fish farming to have undesirable consequences in respect to enrichment, particularly in poorly flushed systems that are already subject to high nutrient loads (e.g. from agriculture or wastewater discharges). Nutrients promote the growth of algae, which in highly productive systems can reduce water clarity, physically smother biota or cause reductions in dissolved oxygen concentrations through microbial decay (Forrest et al 2007). Concern has also been raised about the potential for nutrient release to increase the occurrence of harmful algal blooms (Buschmann et al. 2006). However, a robust causal link for this does not appear to have been established.

The potential for adverse effects from dissolved nutrients from cage fish culture depends on existing levels of enrichment and the flushing and dilution of the dissolved wastes emanating from cages. Monitoring results from the Marlborough Sounds indicate that, although measurable increases in nitrogen concentration have been recorded in salmon cages, flushing and mixing are sufficient to prevent significant enrichment (Forrest et al 2007). This is consistent with studies from the NW Pacific, which have also found that nutrients were rapidly diluted to a level where adverse effects cannot be detected in well flushed areas (Brookes and Mahnken 2003).

Nutrient effects from fish farms in Wilsons Bay have been considered by Zeldis (2008), who developed a nutrient budget for the Firth of Thames, which included a number of farming scenarios. The findings of this study are summarized in Section 3.3.

2.6 Feedstock sustainability

Aquaculture has been promoted as a method of reducing pressure on wild fish stocks. Unfortunately, this potential benefit is yet to be realised, because predatory fish species are the mainstay of the marine fish farm industry, and wild fish stocks are the primary source of food used in their culture. The global effects of harvesting wild fish[3] to provide fish-meal for aquaculture has been identified as a growing international problem that potentially threatens wild fish stocks (Naylor et al. 2000, Pauly et al 2007). Fishing has a direct effect on target species, associated bycatch, and indirect effects on the broader marine ecosystem.

Fishmeal is the preferred protein source for most aquaculture feeds, and although the fishmeal can be replaced by vegetable protein (e.g. soya) or monocellular proteins, the economics of this practice are currently unattractive (FAO Fisheries and Aquaculture Department 2006). Recent estimates indicate that approximately 25% of the global harvest of wild-fish (estimated to be 104.1 million tonnes in 2004) is used for the production of fish meal (estimated to be 25.5 million tonnes in 2004) (FAO Fisheries

[3] Including finfish, crustaceans and other taxa.

and Aquaculture Department 2006). It has been estimated that in 2003, around 53% of global fishmeal and 87% of global fish oil was used by the aquaculture industry for the production of salmonids, marine fish and marine shrimp (FOA Fisheries Department 2006). The main raw materials used for producing fishmeal include: trimmings from fish processing plants, bycatch from fishing, and fish species, which occur in large volumes but do not have a demand as direct human food.

In 2004, farm production of salmonids, marine fish and marine shrimp was estimated to be approximately 3.6 million tonnes, with marine fish accounting for 1.3 million tonnes (FAO Fisheries and Aquaculture Department 2007). This contrasts with estimates of annual production for the Firth of Thames, which range from 1,000 – 10,000 tonnes, depending on the farming area (i.e. approximately equivalent to 10 – 100 Ha respectively). Accordingly, fish production from the Firth of Thames would equate to 0.07% - 0.7% of worldwide marine, farmed fish production in 2004, and based on a pro-rata estimates of fishmeal production and use, utilise approximately 3,700 to 37,000 tonnes of wild fish (or 0.004 to 0.036% of the annual global biomass of harvested wildfish) (Table 1).

Wet fish utilisation can also be estimated using wet fish to fishmeal conversion ratios and food conversion rates. Yields from landed fish (wet) to fish meal (dry) and fish oil average 26% (Hardy and Talcon 2002). Estimates based on food conversion ratios of 1.3 and 1.5, for the range of fish production scenarios used by Zeldis (2008), suggest that the wild fish biomass used by fish farms in Wilson Bay could range from 5,000 to 57,692 tonnes (Table 1). This equates to 0.005% to 0.06% of the 2004 global wild-fish harvest. The proportional contribution from individual fish stocks, such as anchovy, is likely to be greater than the proportional contribution from the total global harvest.

Note that industry aims to achieve food conversion ratios of around 1, which would reduce the biomass of wild fish required. Based on a food conversion ratio of 1, and 1000 to 10,000 tonnes of fish production, the estimated wild fish biomass required ranges from 3,800 to 38,000 tonnes (Table 1). This is more consistent with the pro-rata estimate obtained above.

Table 1: **Estimates of the wild fish biomass (tonnes) required for the production of farmed fish. Estimates are based on the production of fishmeal using a fish to fishmeal conversion rate of 26% (Hardy and Talcon 2002), and pro-rata estimates based on the utilisation of wild fish for the production of fish meal and fish oil (see text).**

Tonnes of farmed fish produced	Estimated tonnes of wild fish required			
	FCR 1.0	FCR 1.3	FCR 1.5	Pro rata estimate
1,000	3,846	5,000	5,769	3,743
2,000	7,692	10,000	11,538	7,486
3,000	11,538	15,000	17,308	11,230
5,000	19,231	25,000	28,846	18,716
10,000	38,462	50,000	57,692	37,432

2.7 Chemical use

A range of chemicals can be used on fish farms for the control of diseases and parasites, and to prevent marine fouling. At present, fish feeds used on New Zealand fish farms do not contain antibiotics, vaccines, steroids or other growth enhancers. However, therapeutant use may be required to control parasites and disease in the future (Forest et al. 2007). Internationally, a range of pharmaceuticals are used on fish farms, including: antibiotics; anaesthetics; ectoparasiticides; endoparasiticides; and, vaccines. These are used to control internal and external parasites and microbial infections. All of them may be discharged to the open water and accumulate in sediments (Costello 2001). Sea lice are the most significant parasite on Atlantic salmon farms, and a range of medicines are used in their control.

A smaller range of antibiotics are used to control microbial infections. Overseas, antibiotics are proactively used to prevent, as well as treat disease. Antibiotics build up in sediments beneath fish farms, where they are relatively persistent. For instance, the estimated half lives in marine sediments of commonly used treatments are around 300 days (Halling-Sorensen 1998). Development of microbial resistance is considered to be the most critical issue associated with the use of antibiotics (Lalumera 2004). This is a problem for ongoing disease control on fish farms, but there is also concern that it may also contribute to the development of resistance to drugs used in human medicine (Costello 2001). The development of vaccines and improved farm practices (e.g. rotation and fallowing) are reducing their application in European countries (Costello 2001), but it is unlikely that their use can be completely eliminated.

New Zealand salmon farms are reported to be largely free of parasite and disease problems, and pharmaceutical use has not been required (Forrest et al. 2007). This may not be the case for species, such as kingfish, which are known to naturally host a number of disease agents and parasites (Diggles 2002). Veterinary medicines may therefore be necessary for new fish species, but the extent to which they will be required is not yet known.

Heavy metals, used as dietary supplements and in antifoulants, can also accumulate to high concentrations in sediments beneath fish farms. Zinc is a common dietary supplement that is added to New Zealand salmon feeds. As a result, zinc has accumulated in sediments beneath some in Malborough salmon farms, to concentrations that are probably toxic to benthic organisms (Forrest et al. 2007). Copper concentrations can also exceed low-level sediment quality guideline values in sediments beneath existing salmon farms (Forrest et al. 2007). The source of the copper is antifoulant paints, which are used to prevent biofouling of farm structures and nets.

The impact of chemicals deposited onto the sea bed could be persistent, environmentally significant, and are likely to exacerbate the effects of organic wastes. However, their effects should be fairly localized (probably within the farm footprint).

Recovery from chemical contamination, following the cessation of fish farming, could take several years. In contrast, soluble chemicals are likely to disperse and break down readily (Forrest 2007).

2.8 Birds

A literature search using the research database Aquatic Sciences and Fisheries Abstracts, suggests that there has been relatively little research published on the impacts of fish farms on seabirds and waders. Furthermore, available research tends to be related to the economic cost of birds preying on farmed fish and the efficacy of exclusion methods, rather than on the effects of the farms on birds per se. Similar conclusions were reached by Nemtzov and Olsvig-Whittaker (2003) who examined the effects of fishpond netting to birds, and found no other studies that quantified this hazard. In light of this knowledge gap, the key sources of information on the potential impacts of fish farms on birds are primarily based on limited research and expert opinion.

Fish farms provide roosting sites and prey (i.e. farmed and wild fish that are attracted to the farms) for sea birds. Bird predation of farm stock is a significant economic issue in some locations, and netting or deterrence methods are commonly used to reduce or prevent its occurrence. Entrapment in predator netting is probably the major direct cause of bird mortality from fish farms. However, fish farms have the potential to directly affect the behaviour and ecology of birds through the placement of farm structures and activities in areas used by seabirds (i.e. exclusion and disturbance effects), or indirect or indirectly affect bird ecology by changing food availability and habitat quality. These impacts (if any) could be positive or negative, and are likely to be very species specific. The potential effects of fish farms in the Firth of Thames have been considered by Sagar (2008). The findings of that assessment are summarized in Section 3.6.

2.9 Marine mammals

Fish farming can affect marine mammals through: habitat exclusion, entanglement, disturbance, noise and collisions. In southern New Zealand, fur seals are the most prevalent mammal species around salmon farms, where they potentially benefit from the provision of food and haul out points (Forrest et al. 2007). As a consequence, salmon cages in the Marlborough Sounds are surrounded by predator nets, designed to prevent seal access. At present, seal numbers are very low in the Hauraki Gulf, so they are unlikely to be a problem for local fish farms. However, dolphins and whales are common and could potentially be affected.

Incidents of mammal entanglement in fish farm nets are relatively rare in New Zealand. Forrest et al (2007) indicate that during 25 years of salmon farming in New Zealand, there have only been 2 reports of seal, and 2 reports of dolphin entanglement. During that period, improvements have been made to net design and operational practices to further reduce the likelihood of entanglement.

Fish farms also occupy space that may be used by marine mammals. At present, exclusion is not considered to be a significant issue in New Zealand, due to the limited scale of fish farming, but international experience indicates that extensive fish farming can displace small cetaceans. For instance, in Chile, where fish farms are fairly extensive, some authors suggest that dolphins may now be excluded from bays and fiords they have previously used. Acoustic deterrent devices, which have been used to dissuade seals for feeding on farm stock, can extend the extent of exclusion (Forrest et al. 2007).

Conversely, research from Italy, suggests that dolphins may be attracted to fish farms, due to the presence of prey, and in doing so become susceptible to entanglement in nets (López and Shirai 2007, López and Shirai 2008). Over a 15 month period, López and Shirai (2007) observed the incidental capture of three bottlenose dolphins in large, loose predator nets, and questioned whether the local population could sustain losses of this magnitude. Note that the management practice of keeping nets taut, which has been adopted in New Zealand, should reduce this risk (Forrest et al. 2007).

Other effects, such as disturbance, collision and noise could also be significant, but need to be considered within the context of other human activities occurring in the coastal environment.

The specific impacts of fish farms in the Firth of Thames have been considered by De Fresne (2008). The findings of that assessment are summarized in Section 3.5.

2.10 Attraction of wild fish

The aggregation of fish around artificial structures is a well recognized phenomenon (Forrest et al. 2007). Feeding and/or the presence of farmed fish appears to magnify the aggregative effects of structures alone (Tuya et al. 2006), and has led to them being described as 'super-FADs' (fish attraction devices) (Fernandez-Jover et al. 2007). For example, in a study of nine fish farms in Spain and one farm in NSW Australia, the abundance and biomass of wild fish was estimated to 52 - 2837 times and 2.8 - 1126 times greater at the fish farms compared with nearby controls, respectively (Dempster et al. 2004).

The degree of attraction to fish farms varies among fish species. For instance, Tuya et al. (2006) observed strong aggregation responses for the sparids[4] *Pagellus* spp and *Sparus aurata* (which was one of the farmed species), particulate feeders, and large, benthic-feeding rays and sharks. In contrast, herbivorous fish, and other bentho-demersal carnivores were largely unaffected by the presence of farmed fish and/or feed, but did respond positively to the presence of the farm structure itself. Other sparids appeared to be negatively affected by the presence of farmed fish and/or feed, and increased in abundance when farm activity ceased.

Spatial aggregation of wild fish can have negative ecological effects (e.g. promotion of disease and parasite transmission, increased vulnerability to capture), but could also be beneficial, particularly if coupled with protection from fishing (Dempster et al. 2004). Feeding by wild fish may also decrease the amount of waste food that reaches the seabed, and thereby, reduce the associated benthic effects (Felsing et al. 2005). Consumption of food pellets has also been linked to high fat content and altered fatty acid composition in the tissues of wild fish that aggregate around fish cages (Fernandez-Jover et al. 2007). Fernandez-Jover et al. (2007) suggest that such changes could increase the spawning capacity of wild fish and thereby enhance their populations.

2.11 Alteration of waves and water flows

Fish farm nets and structures obstruct current flows and waves. Currents are deflected around and below farm structures, with flow through the farm depending on the “porocity” of the structures (Forrest et al 2007). Consequently, both the speed and orientation of water flows can be affected. Wave energy is also dissipated through the farm. Currents generated by episode wave events can be important in resuspending and dispersing material deposited to the seabed. Obstruction of currents and waves can therefore reduce the flushing of farm wastes and nutrients, which in turn, increases the potential for localized impacts. However, the actual impact is likely to be determined by the characteristics of the site, and farm design, configuration and scale.

2.12 Non-resident species

Fish farms provide hard physical structure which can be colonized by native species, which are not normally present in a particular area. Floating structures maintain fouling organisms at optimal depths, and elevated particulate organic matter and nutrient concentrations may promote their growth (Troell et al 2003).

The direct ecological consequences of fouling by native species is likely to be minimal or positive, due to the enhancement of local biodiversity and the provision of food and biogenic structure that can be utilized by other components of the marine community. However, fouling can be a significant problem for marine farmers, because of the additional weight and drag it creates. Antifoulants, are therefore used to prevent fouling, which can lead to indirect, contaminant effects (as discussed in Section 2.7 above).

3 Detailed assessments of issues

A number of technical reports have been prepared, which provide detailed, site specific assessments of the potential impacts of fish farming on in the Waikato Region. These reports had considered the effects of fish farming on: the seabed, nutrient loads, marine mammals and seabirds. The main findings of these reports are summarized below.

[4] NZ snapper come from the sparid family

3.1 Footprint estimates for finfish farms in Wilson Bay (Oldman 2008)

Hydrodynamic modeling was used to estimate the potential shape and extent of benthic footprints, associated with fish farms in Wilson Bay. The models took into account measured currents from Wilson Bay, a range of fall velocities for waste material, cage depths, and overall water depth. It did not take into account resuspension of settled wastes, which may be important in shallow water depths. Predictions are presented using a standardized waste load (1 kg/day). This allows the results to be scaled up to assess the effect of varying the amount of waste discharged from the farm.

Model results indicated that between:

- 1.7% and 10.9% of waste material (by mass) was deposited beneath a 5 m deep cage in 10 m of water;

- 1.0% and 9.3% of waste material (by mass) was deposited beneath a 10 m deep cage in 20 m of water; and,

- 0.6% and 6.6% of waste material (by mass) was deposited beneath a 15 m deep cage in 30 m of water.

Deposition directly beneath the farms was greatest for the fastest fall velocity and slowest current speed. The remaining waste material was dispersed and deposited beyond the cage margins. Fall velocity and cage depth had the greatest influence on the extent of the overall footprint. However, the affect of varying current speeds from their 25th to 75th percentiles was relatively minor.

Dispersal patterns reflected water flows, which predominantly occurred in a long shore direction, leading to an elliptical footprint. The maximum width of the depositional footprint was 75 m and the maximum length was between ca. 150 m and 700 m, depending on the configuration of the cages, water depth and the fall speed of waste material. Accordingly, for 15 m x 15 m cages, there could be some cumulative effects if farms were placed within 500 - 700 m of each other in a long shore direction. Maintaining farms 100 m apart in the cross shore direction, should limit the cumulative impacts in this direction. Oldman concludes that the longitudinal footprint for measureable effects is likely to be smaller than the predicted depositional footprint, and may range between 100 and 200 m.

3.2 Benthic carrying capacity for finfish farming (Giles 2007)

A Bayesian network analysis was carried out to determine the probability that waste deposition from fish farms in Wilsons Bay would have adverse effects on the seabed, within the farm footprint. The analysis was based on existing local and international information, and compared predictions for fish farms with three different free-water depths (5, 10 & 15 m) and three different stocking densities (10, 15 & 25 kg.m3) (free-water depth is the depth from the bottom of the fish cage to the sea floor). Predictions were obtained for a range of geo-chemical and ecological variables, including: sediment enrichment, acid volatile sulphide, denitrification, nitrification, pH, porewater sulphides, redox potential,sediment oxygen consumption, sediment to water ammonium flux, sulphate reduction, water content, macrofauna biomass, species diversity, and the presence of bacterial mats. Sediment enrichment was derived from combinations of organic matter, organic carbon, and nitrogen, and was ranked from low to very high.

Of the scenarios considered (i.e. the free-water depth beneath cages and stocking density), free-water depth had the greatest influence on the severity of impact.

Therefore, Giles (2007) suggested that a minimum of 10 metres of free water space should be provided beneath fish cages to reduce enrichment effects. In general, this led to only a small reduction in the probability of adverse effects, of a particular magnitude occurring, but the actual probability of significant adverse effects was relatively high for all of the scenarios examined. For instance, the probability of getting high levels of sediment enrichment ranged from ca. 20% to 30 % depending on the combination of stocking density and cage depth. The probability of getting "very high" levels of sediment enrichment (which is the worst case presented) ranged from ca. 10% to 35%.

3.3 Nutrient carrying capacity of the Firth of Thames (Zeldis 2008)

The potential contribution of fish farms to the overall nitrogen budget of the Firth of Thames was estimated using typical farm stocking densities, feed input, food composition and food conversion ratios. Nitrogen generation from five fish production scenarios (ranging from 1,000 to 10,000 $t.y^{-1}$) and using two food conversion ratios (1.3 & 1.5) were estimated[5]. These were compared with nitrogen mass balances from 'natural' ecosystem processes, including riverine and oceanic nutrient loadings, nutrient losses through hydrographic export, denitrification, and mussel harvesting. About 85% of nitrogen discharged from fish farms will be in dissolved forms (ammonium, urea, nitrate, the sum of which is called dissolved inorganic nitrogen (DIN) here), and the rest in particulate form. Dissolved inorganic nitrogen is the most available form of nitrogen for primary production.

Fish farm DIN production was estimated to range from:

- 2.1% to 23.3% of the annual load of dissolved inorganic nitrogen (DIN) from rivers draining into the Firth of Thames;
- 4.7% to 57.9% of the annual load of DIN from oceanic sources; and,
- 1.3 to 16.6 % of the annual DIN load from rivers plus oceanic sources.

In each case, these were calculated using FCR 1.3 & 1,000 t production, and FCR 1.5 & 10,000 t production respectively.

The relative contribution of fish farms to the total nitrogen budget of the Firth of Thames was substantially lower than it was for DIN, because a large proportion of riverine and oceanic nitrogen is in particulate form (e.g. contained in bacteria, phytoplankton and detritus) or, to a lesser extent, dissolved organic forms (i.e. a complex mix of organically derived molecules such as proteins). These have to be broken down to inorganic forms before they become available for primary production. The estimated proportion of total nitrogen from fish farms ranged from 0.6% to 7.1% of the sum of riverine and oceanic nitrogen, for FCR 1.3 & 1,000 t production, and FCR 1.5 & 10,000 t production respectively.

The potential for mussel production and harvesting to moderate the effects of nitrogen release was also examined. About 11.2 tonnes of mussel harvest will remove the nitrogen equivalent of one tonne of fish production at a FCR of 1.3. The 2006 mussel harvest was estimated to have removed slightly less nitrogen than would be released through the production of 2000 tonnes of fish.

Zeldis (2008) concluded that nitrogen release from fish farm production, ranging from 1,000 to 10,000 tonnes, would exert an influence that varied from insignificant to significant. He noted that water quality in the Firth of Thames was already significantly enriched, and questioned whether further nitrogen loading was desirable. He also

[5] 1000 $t.y^{-1}$ approximately equates to a farm size of 5 to 10 Ha, whereas 10,000 $t.y^{-1}$ equates to a farm size of 75 to 100 Ha.

highlighted that the local effects of nitrogen release are likely to be substantially greater than the Firth-wide effects, and warned of the potential for increased primary productivity to adversely affect valuable ecosystem services, such as assisting with denitrification processes. However, dynamic, bio-physical modelling of the local area would be required to determine the risk of these effects occurring.

Mussel co-culture could moderate some of the potential effects. Theoretically, at full production (i.e. Wilson Bay Areas A and B plus the other farms in the FoT) mussels could offset the nitrogen released by 2900 tonnes of fish production. However, the extent to which it is relevant depends on the location of mussel farms relative to the location of actual effects. For example, to moderate the effects of enrichment, mussels would have to be grown in the same area that enhanced algal growth occurred, which may extend beyond the current aquaculture management area boundaries.

3.4 Potential for the transfer of disease and parasites (Diggles 2008)

The potential for the transfer of diseases and parasites from cultured to wild fish in the Firth of Thames was considered by Diggles (2008). Cultured fingerlings transferred into sea cages should not harbour any disease agents if they originate from land based hatcheries that utilise standard biosecurity practices. However, disease agents already present in wild fish populations will probably be vectored onto cultured fish.

Disease transfer will be restricted to agents with direct lifecycles (i.e. that do not have intermediate hosts), which allow direct, horizontal transmission within the sea cage environment. This excludes parasites such as cestodes, nematodes, acanthocephalans, myxozoans and digeneans with complex multihost lifecycles. Parasites such as monogeneans, digenean blood flukes, some myxozoans and protozoans may infect cultured fish, but most have high host specificity and will only infect the cultured fish, if wild conspecifics occur adjacent to the sea cages.

Infection rates of conspecific wild fishes may increase slightly in the areas immediately surrounding the sea cages for some parasites (e.g. monogeneans, protozoans). However, disease tends to occur only in the cultured fishes, as the mobility of the wild fishes tends to prevent hyperinfections from occurring, eliminating a necessary prerequisite for disease. Potential negative impacts on wild fishes are therefore likely to be limited only to one very specific scenario. That is, where site attached species take up permanent residence in the areas immediately under or next to sea cages where diseased fishes (particularly conspecifics) are being cultured

3.5 Impacts on marine mammals (Du Fresne Ecology Ltd 2008)

The main marine mammal species that utilize the Firth of Thames are short-beaked common dolphins, bottlenose dolphins, killer whales, Bryde's whales and beaked whales. However, stranding data indicate that a variety of other marine mammals utilize the Firth on occasion.

The potential effects of fish farming on marine mammals include: entanglement in farm nets, habitat exclusion, and disturbance by vessel strikes and underwater noise. Small cetaceans and seals are at most risk from entanglement. There is evidence that dolphins and seals are attracted to fish farms, and they have been caught in predator exclusion nets in New Zealand and overseas. However, changes to net design (reduced mesh size) and operational practices have substantially reduced the risk of entanglement in New Zealand. There have been no known incidents of marine mammal entanglement in New Zealand since these changes were introduced; suggesting the risk of entanglement has been reduced to very small levels, if not eliminated entirely. Seals are relatively rare in the Hauraki Gulf, so the risk of seal entanglement is further reduced.

The small scale of fish farming proposed for the Firth of Thames relative to area of available habitat, means the effects of direct, physical exclusion are likely to be minor. However, the scale of impact could be increased through disturbance, particularly by underwater noise. Increases in the volume of boat traffic could also increase the incidence of vessel strikes. Large whales, which spend extended periods on the surface are most susceptible, but small cetaceans are also vulnerable. Whales struck by vessels travelling faster than 13-15 knots are more likely to be killed or suffer severe injury.

The report concluded that the New Zealand aquaculture industry has been proactive in reducing the risk of entanglement to marine mammals, and recommended adopting operational practices developed for the Marlborough Sounds in the Firth of Thames. Available information suggests that the impacts of habitat exclusion, underwater noise and vessel strikes are likely to be minor and/or similar to existing mussel farms, but more information is required to properly assess their effects.

3.6 Impacts on sea and coastal birds (Sagar 2008)

Intertidal areas of the southern Firth of Thames have been designated as a Ramsar site because of their importance to migratory waders. A total of 132 species of birds have been recorded from the Firth of Thames, primarily from the Kaiaua – Miranda area. The intertidal flats are particularly important feeding grounds and support around 35,000 waders each year. Current information suggests that the greatest threats to this biological system are related to terrestrial drivers including: sediments, contaminants, habitat loss, invasive species and nutrients. These stressors are most likely to have an indirect effect on birds, through habitat modification and their impact on prey items such as shellfish and polychaetes.

The main, potential pathway for fish farm impacts on the Ramsar site is through nutrient release, and its influence on benthic productivity. The impacts of nutrient release on waders could be:

- neutral if primary production within the Ramsar site is not significantly affected by increases in nutrient release;
- positive if secondary productivity (i.e. prey species) increases along with primary productivity (i.e. algae); or,
- negative if macroalgae blooms occurred in intertidal areas, or increased nutrients led to the expansion of mangrove forests.

However, Sagar (2008) concluded that increased productivity could affect habitat quality near the fish farms, but these effects are unlikely to extend to the Ramsar site.

Seabirds may be directly affected by entanglement, habitat exclusion, provision of roosting sites, disturbance, ingestion of foreign objects and increased prey availability. Some seabirds are likely to avoid foraging near fish farms, leading to localised displacement. These are likely to be species that forage over large distances (e.g. flesh-footed shearwaters and gannets), so the overall impact on them is likely to be insignificant. Species that forage close to fish farms, such as shags and cormorants, may actually benefit from the provision of roosting sites and increased prey availability, although they are likely to be more susceptible to entanglement. However, entanglement appears to be well managed in New Zealand, so the overall impact of fish farms on seabirds is likely to be minor.

4 Conclusions

Fish farming in the Firth of Thames is likely to have a range of effects on the local coastal environment and broader system. Large scale and potentially irreversible impacts could occur through promoting the growth and spread of invasive species.

Interbreeding between wild and selectively bred farmed fish has the potential to affect the genetics of wild fish stocks if substantial numbers of fish escape from sea cages and/or farmed fish mature and release gametes before harvest. Fish production in the Waikato Region will require fishmeal derived mainly from wild fish. The production of fishmeal is a globally significant issue, with approximately 25% of the global of fisheries biomass being used in the production of fishmeal. Detailed assessments of the impacts of the above issues have not been carried out for the Waikato Region.

There is a high probability that the deposition of waste material (Giles 2007), pharmaceuticals, and other chemical contaminants will lead to significant environmental degradation directly beneath fish farms in Wilson Bay and benthic impacts may extend for a small distance beyond (Oldman 2008). Seabed recovery within the farm footprint could take five or more years, if the farms are removed. At the Firth scale, nutrient loads released from fish farms in Wilson Bay could range from environmentally insignificant to significant, depending on the scale of production (Zeldis 2008). Localised nutrient effects are likely to be greater than far-field effects, but mussel harvests could offset some of these effects. The spread of diseases and parasites to wild fish is unlikely to occur in the Firth of Thames, unless site attached species take up residence near sea cages. In this case impacts should be fairly localised.

Available information suggests that fish farms in the Firth of Thames should not have a significant impact on marine mammals (Du Fresne Ecology Ltd 2008). Nor are they likely to have significant, or widespread, impacts on waves, currents or non-resident species, although specific assessments have not been carried out to confirm this. Overseas, fish farms are highly effective at attracting wild fish and similar responses may occur in New Zealand. This could have both positive and negative environmental consequences.

The environmental effects of fish farming can be reduced (but are unlikely to be eliminated) through a range of design and management measures. Options for reducing the effects of fish farms will be considered in a companion report.

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Appendix: Parasite and disease transfer

Transfer of parasites between wild and cultured fishes with respect to aquaculture development in the Firth of Thames, New Zealand

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Summary

Cultured fingerlings from land based hatcheries which utilise standard biosecurity practices should not harbour any disease agents when they are transferred into sea cages. In virtually all cases, diseases agents already present in wild fish populations will be vectored onto cultured fish, but disease interactions between wild and cultured fishes will be restricted only to those disease agents with direct lifecycles which allow horizontal transmission within the sea cage environment. This excludes parasites such as cestodes, nematodes, acanthocephalans, myxozoans and digeneans with complex multihost lifecycles. Several parasites such as monogeneans, digenean blood flukes, some myxozoans and protozoans may infect cultured fish, but most (monogeneans, digenean blood flukes, myxozoa) have high host specificity and hence will only infect the cultured fish species if conspecifics are present in the wild adjacent to the sea cages, where they act as reservoirs of infection. While infection rates of conspecific wild fishes may increase slightly in the areas immediately surrounding the sea cages for some parasites (e.g. monogeneans, protozoans), infections are amplified only in the sea cages and disease tends to occur only in the cultured fishes. The mobility of the wild fishes tends to prevent hyperinfections from occurring, eliminating a necessary prerequisite for disease. Potential negative impacts on wild fishes are therefore likely to be limited only to one very specific scenario where site attached species take up permanent residence in the areas immediately under/next to sea cages where diseased fishes (particularly conspecifics) are being cultured.

Introduction

This document addresses a specific question posed in relation to aquaculture development in the Firth of Thames, NZ, namely, "Are diseases and parasites transferred from one fish species to another, and could this be a significant issue with respect to their transfer between farmed fish and wild fish stocks? For comment on other issues related to ecological impacts of aquaculture development, the reader is referred to Forrest et al. (2007).

Here I will assume a scenario that the fish are being cultured in sea cages as this is the most likely situation and also the one most likely to facilitate transfer of disease agents between wild and cultured fish populations. As for the species of fish being cultured, I will assume these will include obligate marine species such as kingfish (*Seriola lalandi*), snapper (*Pagrus auratus*), and flatfish (*Rhombosolea* spp., *Colistium* spp.). Culture of salmon will not be discussed as the region is unlikely to be suitable for this activity. For the purposes of this discussion, I will also assume the fish stocked into the sea cages originate from land based hatcheries (i.e. they are not collected from the wild), as in NZ closure of the lifecycle is a standard practice for intensive aquaculture of all the species listed above. The hatchery reared fingerlings will therefore as a rule not harbour any disease agents when they are moved into sea cages due to the various routine biosecurity protocols used by land based hatcheries (e.g. filtration of water to exclude infective stages, screening of broodstock for viruses etc.). We will also assume they are fed artificial diets, again standard aquaculture practice in NZ.

Parasite and disease checklists for these various hosts in NZ were outlined in Hine et al. (2000), and Diggles et al. (2002). For kingfish in particular, several more recent studies have examined the parasites and disease agents present in both wild and cultured populations in Australia and NZ, including Diggles (2002), Sharp et al. (2003), Diggles and Hutson (2005), Chambers and Ernst (2005), Hutson and Whittington

(2006), and Hutson et al. (2007a, 2007b). These studies reveal the existence of the following disease agents: viruses, bacteria, copepods, monogeneans, digeneans, cestodes, acanthocephalans, myxozoans, nematodes, and protozoans. These groups of disease agents will be discussed below in relation to the subject in question.

Bacterial and viral disease agents

Opportunistic bacterial disease agents such as *Vibrio* sp. have been recorded from all of the host species mentioned above (Diggles et al. 2002), however these bacteria are ubiquitous in the marine environment and are naturally present in seawater in New Zealand at up to 1 x 10^6 cells/ml (one million *Vibrio* per millilitre of seawater). Because these bacteria are ubiquitous, their presence in cultured fish species is of little consequence to wild fish populations. This is because these bacteria always act as opportunistic disease agents and therefore only adversely affect fish which are stressed by poor water quality and/or damaged by farming practices. Wild fish and shellfish which are not stressed or injured are simply not affected by ubiquitous opportunistic bacterial pathogens such as *Vibrio* sp.

Viral diseases may infect several different host species. Viruses have been reported in cultured flatfish in New Zealand (Hine and Diggles, unpublished) and wild and cultured kingfish in Australia (Diggles and Hutson 2005). However in both cases the viruses (aquatic birnavirus in Turbot *Colistium* sp., and betanodavirus in kingfish) were most likely vertically transmitted to cultured juvenile fish via eggs or milt obtained from infected broodstock sourced from the wild. We do know for certain that at least one of these viruses (aquatic birnavirus) is naturally present in New Zealands marine environment (Tisdall and Phipps 1987). Betanodavirus, however, has not been recorded from New Zealand to date, though both kingfish and silver trevally (*Pseudocaranx dentex*) are native to New Zealand and wild populations of both species are known to carry the virus in other countries (Gagne et al. 2004, Diggles and Hutson 2005). Expression of disease with both types of virus is usually only observed in juvenile fishes in hatcheries, and because of this, routine screening of fingerlings for these viruses is undertaken by hatcheries as part of their quality management process, with any batches of fish testing positive for virus usually being destroyed. It is highly unlikely, therefore, that fingerlings large enough to be transferred into sea cages for growout will be carrying these viruses. Furthermore, there are no confirmed reports of these viruses being transmitted from sea cage cultured fish into wild fish populations and subsequently causing disease, however there are many instances where wild fish have acted as reservoirs for these viruses resulting in disease and mortalities of cultured fish (Gagne et al. 2004).

Copepods

Some copepods show relatively low host specificity and can "jump" between hosts. These include *Naricolax chrysophryenus*, which was originally described from snapper in Australia and New Zealand, but which has recently been found in both wild and cultured kingfish in Australia (Hutson and Tang 2007). It is evident that *Naricolax* species does not exhibit a high degree of host-specificity as it infests seven host fish families (Ariidae, Carangidae, Hexagrammidae, Lateolabracidae, Leiognathidae, Sparidae and Stromateidae) (Hutson and Tang 2007). Similarly, *Caligus epidemicus*, which has been described from flounder (*Rhombosolea leporina*) in Manukau Harbour (Diggles 2000, Hine et al. 2000), has low host specificity as it has also been recorded from wild kingfish in Australia (Hutson et al. 2007a) and was originally described in Australia from yellowfin bream (*Acanthopagrus australis*) (see Hewitt 1971). Hence it appears very likely that hatchery reared fish grown out in sea cages will be exposed to infective stages of copepods vectored by wild fishes, and that some of these copepods may be able to jump hosts and infect the cultured fish. Whether infection of cultured fish will in turn result in increased intensity of reinfection of wild fish populations is a moot point. There is some evidence of this occurring in the culture of salmonids (Heuch and Mo 2001, Orr 2007), but no evidence for any of the obligate marine fish species discussed here, despite the fact that kingfish, flatfish and snapper have been cultured in Japan for over 50 years..

Monogeneans

Monogeneans can be problematic in the culture of virtually every species of marine fish, including kingfish, snapper and flatfishes (Ernst et al. 2002, Diggles et al. 2002, Diggles and Hutson 2005, Chambers and Ernst 2005). The fact that wild fishes are the source of monogenean infections of marine fish cultured in sea cages is beyond doubt (Ernst et al. 2002, Diggles et al. 2002) as monogeneans can be quite common on wild fishes (Sharp et al. 2003, Hutson et al. 2007b). Monogenean infections can cause disease in cultured fishes due to the latters' higher rearing density, their inability to escape the sea cage and other stressors related to culture situations. However monogeneans have high host specificity and transmission back from cultured to wild fish will occur only to conspecifics. Recent research from Australia (Chambers and Ernst 2005) suggests that infection rates of wild kingfish could be significantly higher if they frequent areas up to 1 km immediately downcurrent from sea cages holding cultured kingfish, and slightly higher than background levels up to 8 km from a farm site. This suggests that wild conspecifics immediately adjacent to sea cages may experience transient increases in monogenean infection rates if cultured fish become infected. However the mobility of wild fishes tends to prevent monogenean hyperinfections from occurring, eliminating a necessary prerequisite for disease. The possibility of wild fishes being adversely effected by monogenean hyperinfections will therefore apply only to a specific scenario whereby a site attached species takes up permanent residence in areas immediately under/next to sea cages where diseased conspecifics are being cultured.

Digeneans, cestodes, nematodes, acanthocephalans and myxozoans

A risk assessment which considered the likelihood of parasites from these groups infecting cultured kingfish (Hutson et al. 2007a) found that the chances of cultured kingfish becoming infected by cestodes, nematodes and acanthocephalans and some myxozoans vectored by wild fish is low to negligible. This is because of the low likelihood that the multi-host lifecycles of these parasites would be completed in the confines of sea cages, especially in fish which are fed artificial feeds. This suggests that failure to complete the multihost lifecycle will preclude any parasite interactions between cultured and wild fish for these parasite groups. However, Hutson et al (2007a) found that certain digeneans, namely blood flukes, and myxozoans present in wild kingfishes, were likely to infect cultured kingfish and represented a threat to the health of the cultured kingfish. These parasites tend to have high host specificity, however, and therefore it would appear unlikely that they would jump hosts into other species which may occur near sea cages. The possibility of wild fishes experiencing increased infection by blood flukes or myxozoans again would apply only to one specific scenario whereby a site attached species takes up permanent residence in areas immediately under/next to sea cages where diseased conspecifics are being cultured.

Protozoans

Protozoan disease agents (e.g. *Brooklynella*, *Uronema* and related scuticociliates, *Trichodina* sp and *Cryptocaryon irritans*) have low host specificity, direct lifecycles and tend to be problematic in cultured fishes mainly in hatchery situations when large numbers of juvenile fishes are present, rearing conditions are suboptimal and biosecurity protocols are inadequate. In all cases infection is horizontal and direct, and the parasites originate from wild fishes which act as reservoirs of infection for the cultured fishes. Protozoa seldom cause disease in wild fish populations. Indeed, wild yellowbelly flounder (*Rhombosolea leporina*) in Manukau Harbour can have extremely heavy natural infections with *Trichodina* spp. with no apparent adverse effects (Diggles 2000). However protozoan infections can cause disease in cultured fishes due to the higher density of cultured fishes, their inability to escape the sea cage and other stressors related to culture situations. The fact that virtually all protozoan parasites of fishes have low host specificity means that various species of wild fish immediately adjacent to sea cages may experience transient increases in infection rates if the cultured fish become infected. However the mobility of wild fishes tends to prevent protozoan hyperinfections from occurring, eliminating a necessary prerequisite for disease. Wild fishes could theoretically experience infection with protozoan parasites at intensities which could cause disease only in one specific scenario whereby a site attached species takes up permanent residence in areas immediately under/next to sea cages containing cultured fishes which are also suffering from disease caused by protozoans.

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