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LITERATURE REVIEW OF ECOLOGICAL EFFECTS OF AQUACULTURE

Effects on Wild Fish

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

5.1.1 Overview of wild fish issues

Aquaculture in New Zealand involving the addition of feed is currently focused on finfish and, in particular, the farming of king salmon within coastal embayments along New Zealand's South Island. The effects of finfish farms on wild fish are expected to be generally similar across the other species likely to be farmed in New Zealand.

A potential immediate effect on wild fish populations from the development of a finfish farm is the degradation or loss of habitat beneath or in close proximity to new farm structures (e.g., spatial overlap with species' critical spawning grounds and/or migration routes). Proper site assessments and selection prior to development of finfish farms can avoid these direct impacts on wild fish populations. Besides the direct impact to existing wild fish habitats, the effects of finfish farms on wild fish can include the attraction of fish to artificial structures. The culture of finfish involves the use of three dimensional cage structures that are surrounded by predator exclusion nets and are attached to other structures (e.g., floating walkways and living quarters) used in managing the farm. By adding three-dimensional structures to the marine environment, finfish farms provide habitat for colonisation by fouling organisms and associated biota. These newly colonised structures and the habitat they create tend to attract wild fish species seeking foraging habitat, detrital food sources or refuge from predators (e.g., Dealteris et al. 2004). In addition to the structures themselves, submerged artificial lighting at night is frequently used on finfish farms to control maturation and increase productivity (e.g., Porter et al. 1999). The lighting can also enhance the attraction of wild fish to farm structures.

The main effects associated with the creation of artificial habitats, and the attraction of wild fish species to aquaculture structures, include the following:

- Aggregation of wild fish around the cage structures and entrapment of smaller fish that can enter the cage structures. This may lead to enhanced predation on wild fish by higher trophic level predators (e.g., seals) and predation by cultured fish on wild fish trapped within cage structures.
- Consumption of waste feed by wild fish.
- Changes in recreational fishing patterns and pressure, which could affect wild fish populations differently than in the absence of the structures.

In general, the effects of finfish farms on wild fish populations are likely to be small in comparison with the effects on other aspects of the marine ecosystem, such as effects on the seabed. Management options for minimising effects on wild fish include proper site selection, which requires assessments of potential impacts of farm developments on wild fish stocks. Assessments should identify proximity to critical, sensitive or protected habitats and species, with particular reference to potential impacts on spawning grounds or juvenile habitats, and should describe the potential impacts the farm might have on these habitats and/or species. Careful management of feed quality and feeding practices aimed at minimising waste feed inputs to the surrounding environment will assist in minimising the effects of an artificial feed source on wild fish populations.

The effects of finfish farms on wild fish populations in New Zealand are not well documented and some knowledge gaps exist, particularly with regard to the effects of finfish farms on fish movements and various reproductive stages (e.g., larval settlement).

5.1.2 Descriptions of main effects and their significance

Table 5.1: Effects of feed-added fish farm placement on existing wild fish habitat(s).

Description of effect(s)	The placement of a finfish farm directly above or adjacent to benthic habitats (e.g., spawning areas or rocky reefs) can impact wild fish populations through degradation of their habitat, particularly through biodeposition from fish faeces and waste feed (Chapter 3, 3.2.1 overview of seabed effects).
Spatial scale	*Local* to *bay*-wide – Depending on the location of the farm(s) with proximity to neighbouring habitats and the hydrodynamic environment, which influences the footprint.
Duration	*Medium* to *long term* – Degradation of benthic habitats associated with biodeposition can result in prolonged adverse effects (see Chapter 3, 3.2.1 overview of seabed effects).
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds, habitats and/or migration routes.
Knowledge gaps	Ongoing research into the possible effects of farms on neighbouring habitats important to wild fish, such as rocky reefs (see Chapter 3, 3.2.1 overview of seabed effects).

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

Summary

The effects of finfish farms on seabed habitats and associated organisms are primarily covered in Chapter 3, 3.2.1 overview of seabed effects. Briefly, the placement of farm structures above or near to important wild fish habitats will have direct effects on wild fish populations due to adverse effects on benthic habitats within the primary depositional footprint of finfish farms. Proper placement of farms and effect assessments prior to development should avoid and/or minimise any effects of feed-added aquaculture on wild fish habitats.

Table 5.2: Effects relating to attraction of wild fish to feed-added fish farm structures.

Description of effect(s)	Finfish farm structures create an artificial habitat that can attract wild fish species seeking refuge and food sources. As a result, wild fish species can aggregate in and around finfish farms, which can provide habitat and also food sources (both natural and waste feed).
Spatial scale	Site specific to *regional* – Depending on the location of the farm(s), proximity to neighbouring habitats and the types of wild fish coming in contact with the farm.
Duration	*Short* to *long term* – Fish may temporarily visit while migrating to other grounds or remain for the length of their lives and/or the farm. Small fish (e.g., baitfish) commonly enter finfish cages and can remain within them until harvest.
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds and/or migration routes. Attraction of local fish species should be considered in the management plans of farms.
Knowledge gaps	The effects of artificial structures on the settlement of juvenile fish. Possible effects of farms on fish movement to spawning or fishing grounds.

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

Summary

Marine farms and other artificial structures in marine environments provide a three-dimensional reef habitat suspended in the water column for colonisation by fouling organisms and associated biota. Based on research conducted overseas, artificial structures can support a considerably greater biomass and density of organisms than adjacent natural habitats (Glasby 1999; Connell 2000; Dealteris et al. 2004). Artificial structures are also known to provide shelter, habitat complexity and a food source for small fish, as indicated by overseas work (Relini et al. 2000; Caselle et al. 2002).

Many of the same types of fish, which include small planktivores, demersal fish and higher trophic level carnivores, are found around fish farms worldwide (Boyra et al. 2004; Dempster et al. 2002, 2009). Yet present evidence suggests that structure morphologies can be strongly species specific, with different fish benefiting from particular structure types (Caselle et al. 2002), and the size of fish aggregations may vary over time (Boyra et al. 2004; Valle et al. 2006).

Attraction of wild fish to waters surrounding finfish farms could be positive in that the habitat created by the artificial structures and increased food availability could enhance wild fish populations. Conversely, the effects could potentially be negative in that it could result in regional fish populations becoming displaced from other habitats or possibly more vulnerable to recreational harvest.

Little information is available on how fish farms, by providing an artificial habitat may affect the settlement of juvenile fish or the movement of adult fish to and away from other traditional habitats or reproductive grounds. Some species of larval and juvenile fish will be attracted to the structures (Dempster & Taquet 2004; Fernandez-Jover et al. 2009), however, the ecological implications of such settlements, when placed in context with existing recruitment patterns to natural substrates within the same region, is unknown. It is unclear whether fish farm structures provide additional or alternative settlement opportunities. Overseas, there are a few examples (e.g., Uglem et al. 2008, 2009) of tagged adult fish demonstrating regular movements between fish farms and traditional spawning or fishing grounds, the positive or negative consequences of which are yet to be determined.

The attraction of wild fish to farm structures will vary with the type of farm, its location and the local/regional populations that are present. While attraction and level of aggregation for a given wild fish species cannot be predicted for any particular farm, it is likely that larger farms, located in shallow waters closer to the coast, generally attract more wild fish species (Dempster et al. 2002, 2009). Waste feed and the use of submerged artificial lighting can contribute to the attraction of farm structures to wild fish (see Table 5.3 below).

Table 5.3: Effects from the use of submerged artificial lighting at night by feed-added aquaculture operations.

Description of effect(s)	Submerged artificial lighting is used at night in the farming of salmon in order to control maturation and increase farm production. Lighting can result in further attraction of wild fish species and enhance predation on organisms attracted to the lights. Small baitfish are known to enter cage structures and have been observed to be predated upon at some level by the salmon. The extent to which lights enhance attraction of baitfish into farm structures has not been quantified.
Spatial scale	Site specific submerged lighting used on finfish farms affects a small area within approximately 10m of the farm boundaries.
Duration	*Short* to *medium term* – Fish may temporarily visit once while migrating to other grounds or remain for the seasonal period in which lights are used. Baitfish able to enter the cage structures may remain within the farm until harvest, at which time they are released.
Management options	Attraction of local fish species at night should be considered in the management plans of farms. Minimise the use of lights both above and below the water line and use only the levels of submerged lighting required for beneficial outcomes. Inspection of gut contents during routine inspections of fish for disease and condition would assist in determining whether the salmons' diet is subsidised by wild prey.
Knowledge gaps	The extent to which submerged artificial lighting on finfish farms enhances the attraction of wild fish over and beyond the structures themselves has not been quantified. There is a lack of knowledge around the amount of predation by caged fish on wild species attracted by submerged artificial lighting.

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

Summary

The use of submerged lighting within salmon farms can greatly increase production and control maturation of the caged fish (Porter et al. 1999; Schulz et al. 2006) but also has the potential to attract a variety of phototaxic organisms, including wild fish to finfish cages at night (Cornelisen & Quarterman 2010). The "footprint" of submerged artificial lights is mainly confined to within the cage structures and to mid-water depths; hence wild fish along the bottom or further than about 10 metres from cage structures are unlikely to be affected. To date, only a few studies overseas and within New Zealand have focused on the attraction or aversion of wild fish species to submerged lights associated with finfish farms (SAD 2011).

A recent study of salmon farms in the Marlborough Sounds observed aggregations of schooling baitfish, such as yellow-eyed mullet, associated with lit areas in the cages (Cornelisen & Quarterman 2010). McConnell et al. (2010) also noted that certain species of wild pelagic fish (e.g., Pacific herring) occurred in greater abundance within lit waters than unlit waters in British Columbia, Canada. Night-time predation on baitfish by the salmon will also be likely to be higher due to an increase in prey visibility compared to an unlit cage. Additionally, the attraction and aggregation of baitfish adjacent to illuminated cage structures could enhance night-time predation by other wild fish and marine mammals, such as seals. For example, a study on feeding by harbour seals in a British Columbia river demonstrated that artificial lighting on bridges was partly responsible for enhanced night-time predation on salmon smolt (Yurk & Trites 2000).

Table 5.4: Consumption of food sources made available to wild fish by feed-added aquaculture operations.

Description of effect(s)	Waste feed pellets may provide an alternative food source for wild fish species.
Spatial scale	Site specific to *regional* – Due to the different fish species that may be present.
Duration	*Short* to *long term* – Fish may temporarily visit to feed while migrating to other grounds or remain for the length of their lives.
Management options	Application of best practices for maximising feed quality and minimising feed waste. Potential attraction of local fish species should be considered in the management plans of farms.
Knowledge gaps	Continue research into the best feeding products, practices and monitoring techniques to ensure minimal feed waste and to minimise effects on the environment and wild fish populations.

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

Summary

Feed loss has been identified as a primary driver of wild fish aggregation around fish farms overseas (Tuya et al. 2006). Wild fish on the outside of cages may feed on waste feed pellets that pass through the cage, while populations of small fish living inside the cages may be supported by the smaller feed particles, or "dust", that is a waste component of most feeds. By consuming waste feed and assimilating nutrients, wild fish aggregations have the potential to ameliorate seabed effects beneath fish farms (Felsing et al. 2004; Dempster et al. 2005). In studies from Western Australia (Felsing et al. 2004) and the Mediterranean (Vita et al. 2004), wild fish have been shown to reduce the amount of feed that reaches the seabed by as much as 60 percent to 80 percent. Additionally, any feed that does reach the seabed may be quickly consumed by bottom feeding fish (Thetmeyer et al. 2003).

Wild fish that aggregate around cages overseas have been shown to have altered body condition in terms of tissue fat content and fatty acid composition compared with their wild counterparts (summarised in Dempster & Sanchez-Jerez 2008). Increased lipid energy reserves are a good proxy for fecundity prior to spawning in fish and, as such, may suggest that wild fish supplementing their diet near fish farms will have increased reproductive success. However, farm feeds differ in their fatty acid composition to a natural diet and it is not yet known how a farm-supplemented diet may affect egg quality or larvae survival (Salze et al. 2005; Fernandez-Jover et al. 2011). In this context, international studies have suggested that finfish farming can increase regional fish biomass, even beyond the immediate vicinity of the cages (Dempster et al. 2004, 2006; Machias et al. 2004). At present, no specific information is available on how the existing finfish farms in New Zealand might modify the condition of wild fish (positively or negatively) in the vicinity of salmon farms due to waste feed products.

Table 5.5: Changes to fishing pressure due to the presence of feed-added aquaculture.

Description of effect(s)	The presence of finfish farms may increase or decrease fishing pressure on wild fish populations, depending on the extent of protection afforded to fish aggregating near farm structures.
Spatial scale	Site specific to *regional* – Dependent on the presence and extent of nearby farms to fishing regions.
Duration	*Short* to *long term* – Wild fish may aggregate around farm structures and, therefore, may be more susceptible to harvest.
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds and fishing regions. Attraction of local fish species should be considered in the management plans of farms, with attention given to the possible effects on commercial and recreational fish stocks in regard to current fisheries management.
Knowledge gaps	The effects of finfish farms on fishing pressure, and in turn on wild fish stocks, remain relatively unknown in New Zealand.

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

Summary

As finfish farms are known aggregators of certain wild fish species, farms have the potential to serve either as ecological traps or possible sources for wild fish stocks in relation to important fisheries species (Dempster et al. 2006, 2009, 2011). In some overseas commercial fisheries, farms are regularly relied upon for aiding in aggregating pelagic fishery species for capture (e.g., Buckley et al. 1989) making them more vulnerable to possible depletion. This is the same concept upon which fish attraction devices (FADs) are used to aggregate fish for commercial and recreational fishing purposes (Buckley et al. 1989; Relini et al. 2000; Dempster & Kingsford 2003). Alternatively, if fishing is not allowed in the vicinity of the farm, the additional protection and food sources may eventually lead to enhanced wild fish populations. Regardless of the possible outcome, fisheries management should be considered where finfish farms are concentrated as this aggregation effect may influence important fisheries species at a regional scale.

In New Zealand, restriction of commercial fishing within the vicinity of farms due to the presence of the farm structures leads to reduced exposure to commercial fishing; however, to what extent this reduction is mitigated by increased vulnerability to recreational fishing pressure around farms is unknown. There is also little information on the extent of recreational fishing pressure around aquaculture farms, including differences in fishing pressure between finfish and shellfish farms. These issues will need site-specific consideration as part of future finfish farm development in New Zealand.

5.2 Filter-feeders (green-lipped mussels and Pacific oysters)

5.2.1 Overview of wild fish issues

Unlike the literature for finfish farms, studies that describe how shellfish farms affect wild fish assemblages are hard to find. Nonetheless, some of the mechanisms by which fish are affected still apply and are discussed here.

Direct effects from the development of shellfish farms include alteration of essential fish habitats through the deposition of shell litter and biodeposition of particulate matter. These effects can be avoided or minimised through proper site selection and effects assessments prior to development (see Chapter 3 – Benthic effects). As in the case of finfish aquaculture, shellfish structures provide habitats for colonisation by fouling organisms and associated biota. These newly colonised structures tend to attract wild fish species seeking foraging habitats, detrital food sources and/or refuge from predators (e.g., Dealteris et al. 2004). The initial attraction of wild fish species to aquaculture structures (e.g., habitat creation) can lead to a variety of related effects including:

- Changes in the distribution and productivity of wild fish populations due to the addition of artificial structures that create new habitats used by wild fish.
- Changes in recreational fishing patterns and pressure, which in turn could affect wild fish populations differently than in the absence of the structures.
- Larval fish depletion by shellfish and/or potential trophic interactions (e.g., alteration of plankton composition and food availability).

In general, the effects of shellfish farms on wild fish populations are likely to be small in comparison with the effects on other aspects of the marine ecosystem, such as effects on the seabed. Management options for minimising effects on wild fish include proper site selection, which requires assessments of potential impacts of farm developments on wild fish stocks. Assessments should identify proximity to critical, sensitive or protected habitats and species and describe the potential impacts the farm might have on these habitats and/or species.

From a more positive perspective, marine farms and other artificial structures are recognised as providing shelter, habitat complexity and a food source for fish, and the aggregation of various fish species around such structures is well recognised (Relini et al. 2000; Morrisey et al. 2006). Conversely, the effects can, potentially, be negative in that they may result in regional fish populations becoming displaced from other habitats or possibly more vulnerable to recreational harvest.

The attraction of wild fish to farm structures will vary with the type of farm, its location and the local/regional populations that are present. As a result, an assessment of the farm's potential impact on wild fish stocks in a particular location will be important as well as considering regional fisheries management.

Summary

Shellfish farming involves introducing a complex structure within the water column above an otherwise featureless seabed (i.e., sand and/or mud) and the structures can be colonised by a diverse and productive fouling community. Studies from New Zealand (e.g. Ministry for Primary Industries (MPI) port baseline surveys) and overseas (Hughes et al. 2005; Braithwaite et al. 2007) indicate that the dominant biota on such structures includes macroalgae (seaweeds) and sessile (attached) filter-feeding invertebrates, such as sea squirts, bryozoans and mussels. Such alterations to the existing habitat may alter the environment's suitability for fish (Caselle et al. 2002; Dempster et al. 2006).

Artificial structures are recognised as providing novel foraging habitats, detrital food sources, breeding habitats, and refuge from predators for some species (Dealteris et al. 2004). This is the same concept upon which FADs are used to aggregate fish for commercial and recreational fishing purposes (Buckley et al. 1989; Relini et al. 2000; Dempster & Kingsford 2003). Hence, it is commonly believed that marine farms have the propensity to enhance fish abundances (Dealteris et al. 2004). Yet, some studies also warn against presuming that artificial structures constitute an effective fish habitat. One such study, which compared natural to artificial reefs (Clynick et al. 2008), found that, while they supported similar species, the overall assemblages were quite different.

Fish associations have been described in New Zealand studies relating to mussel farms (Gibbs 2004; Morrisey et al. 2006) but do not appear to have been considered for oysters. Hence, while the types of effects and interactions described for mussel farms may be possible in the case of oyster farms, virtually nothing is known of their significance. In particular, there is potential for oyster farms to affect shallow and intertidal habitats important to juvenile fish (Simenstad & Fresh 1995). Farming of Pacific oysters in New Zealand occurs primarily within shallow,

5.2.2 Descriptions of main effects and their significance

Table 5.6: Effects relating to attraction of wild fish to filter-feeder farm structures.

Description of effect(s)	The presence of shellfish farms may increase or decrease fishing pressure on wild fish populations, depending on the extent of protection afforded to fish aggregating near farm structures.
Spatial scale	Site specific to *regional* – Dependent on the presence and extent of nearby farms to fishing regions.
Duration	*Short* to *long term* – Wild fish may aggregate around farm structures and, therefore, may be more susceptible to harvest.
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds and fishing regions. Attraction of local fish species should be considered in the management plans of farms, with attention given to the possible effects on commercial and recreational fish stocks in regard to current fisheries management.
Knowledge gaps	The effects of shellfish farms on fishing pressure, and in turn on wild fish stocks, remain relatively unknown in New Zealand.

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intertidal waters and, therefore, is likely to have less of an effect on wild fish populations than the farming of mussels, which occurs throughout the water column and in subtidal waters.

Various studies of inshore mussel farms in New Zealand found that farms were associated with more and a greater variety of fish species (Grange 2002), but that assemblages consisted mainly of species characteristic of local demersal habitats (Morrisey et al. 2006). Although this may be the case in inshore areas, observations from around offshore farms in Hawke's Bay and Opotiki suggest that pelagic species are more common around structures than in open water (when they are present during summer, N. Keeley, pers. obs.). Other observations from around offshore aquaculture structures have identified small groups of juvenile fish seeking shelter within the lines. Hence any effects are likely to be site and region specific due to the different fish species that may be present, and each species may have unique responses to the type of artificial habitat (Morrisey et al. 2006). The precise effect on wild fish assemblages will therefore be difficult to predict without reference to a comparable scale operation within the proposed bay/region.

Table 5.7: Changes to fishing pressure due to filter-feeder aquaculture operations.

Description of effect(s)	The presence of shellfish farms may increase or decrease fishing pressure on wild fish populations, depending on the extent of protection afforded to fish aggregating near farm structures and the location of the farms. Effects are likely to be smaller for oyster farms in the intertidal zone than for mussel farms located further offshore.
Spatial scale	Site specific to *regional* – Dependent on the presence and extent of nearby farms to fishing regions.
Duration	*Short* to *long term* – Species may obtain short-term refuge from fishing pressure or remain on farms as a permanent protected area. Wild fish may aggregate around farm structures and, therefore, may be more susceptible to harvest.
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds and fishing regions. Attraction of local fish species should be considered in the management plans of farms, with attention given to the possible effects on commercial and recreational fish stocks in regard to current fisheries management.
Knowledge gaps	It remains unknown as to whether increased recreational pressure around shellfish farms has a negative effect on fish populations. Little, if anything, is known about the effects of oyster farms on wild fish assemblages and, in turn, their influence on fishing pressure.

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

Summary

Wild fish abundances around shellfish farms can also be affected by changes in the way the area is subjected to fishing pressure. Sites that have historically been part of a trawl fishery, for example, will no longer be accessible due to the presence of structures, essentially creating a commercial "no-take" area akin to a marine reserve (Dempster et al. 2006). The effect of removing commercial fishing pressure may, however, be somewhat offset by changes in the way the area is utilised by recreational fishers (N. Keeley, pers. obs.). In the Coromandel, for example, marine farms are generally viewed as good fishing locations, particularly when the crop is being harvested and the fouling organisms that are being cleaned from the mussels are being discharged back into the water. In addition, increased catches of species such as snapper (*Pagurus auratus*) are often reported in proximity to mussel farms, in part reflecting aggregation of snapper to feed on the mussel stock. Similarly, other popular recreational fish such as blue cod (*Parapercis colias*) can be caught beneath mussel lines in some regions (Gibbs 2004). It is presently unknown whether increased recreational pressure around marine farms has a negative effect on the wider fish population. If the farms are aggregating fish from a wider area, but not enhancing the populations, then the stocks may be reduced; or alternatively, if the farms are providing additional food and habitats then the population may be enhanced and sustain the increased recreational pressure.

Table 5.8: Larval grazing by shellfish in filter feeder aquaculture operations.

Description of effect(s)	The presence of high densities of filter feeders could reduce larval recruitment into fishery populations through consumption of fish eggs and larvae by farmed mussels and oysters.
Spatial scale	Site specific to *regional* – Dependent on location and spatial extent of farm, characteristics of eggs and larvae, and hydrodynamic regime (transport processes).
Duration	*Short* to *medium term* – Effects occur within the farm but may have longer-term consequences at the population level, depending on the species and population range.
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds.
Knowledge gaps	Further modelling (and validation) is required to improve estimates of larval mortality associated with mussel and oyster farming and, in turn, the effects of shellfish aquaculture on wild fish populations.

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

Summary

Gibbs (2004) noted that cultured shellfish populations have the potential to directly reduce recruitment into fishery populations through the consumption of eggs and larvae as observed by Davenport et al. (2000) and Lehane & Davenport (2002). Although no field research has been undertaken to assess the extent of this grazing mortality, blue cod recruitment in Admiralty Bay, where mussel culture occupied about 10 percent of the total bay area, was assessed (Gibbs 2004). The results suggested that the impact from the level of culture in 2004 is equivalent to an additional mortality (on top of variable natural mortality) of less than 10 percent. The study also noted that this reduction could be negated by allowing a further 1.1 percent of the female spawning stock to remain unfished. In a similar study, Broekhuizen et al. (2004) modelled the possible effects of a large farm development in the Firth of Thames on survival of snapper (*Chrysophrys auratus*) larvae. The authors concluded that the farm could reduce numbers of eggs surviving to age eight days by 2.5 percent to 15 percent when the farm was fully developed (greater than 2000 hectares), and by 2 percent to 6 percent with the existing level of farmings.

The sparse literature suggests that while the grazing influence of farms could have an impact on recruitment to fisheries; the scale of this effect will largely be governed by the extent of the culture, behaviour and characteristics of larvae and flow dynamics of the regions in question. Findings for the Firth of Thames are significant because the farm development concerned is situated near to where important snapper spawning grounds are thought to be. However, given that Admiralty Bay represents one of the most intensively farmed regions in New Zealand, impacts greater than the 10 percent determined by Gibbs (2004) seem unlikely under present culture pressures. It should also be noted that both of the desktop studies for depletion estimates potentially overestimate grazing for a number of reasons. First they assume perfect mixing within modelled "cells" of water and that there is no avoidance ability on behalf of the larvae, nor any size selection preference being exhibited by mussels. The proportion of eggs encountered is also out of the total released and needs to be put into context with anticipated natural mortality. Further research into the effects of shellfish aquaculture on larval stages of wild fish is required to confirm the extent to which increased aquaculture developments (including the effects of multiple farms) will impact wild fish populations.

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

5.3.1 Overview of wild fish issues

The effects of farming lower trophic level species such as sea cucumbers (*Australstichopus mollis*) and *Undaria* seaweed (*Undaria pinnatifida*) on wild fish populations has not been documented; however, the effects are likely to be less pronounced than those associated with both shellfish aquaculture, which can affect larval fish stages through filter feeding, and finfish aquaculture, which involves the addition of an external food source to the environment (e.g., Dempster et al. 2002, 2004). The only known effects to date will involve the creation of habitat through the addition of farm structures and the resulting effects these structures have on removing or increasing fishing pressure on local wild fish species. The effects of large offshore sites (e.g. greater than 1000 hectares) would warrant additional consideration given the scale of these developments compared with existing operations, especially as offshore developments tend to be situated within range of inshore commercial and recreational fish species.

5.3.2 Descriptions of main effects and their significance

Table 5.9: Effects relating to attraction of wild fish to lower trophic level aquaculture farm structures.

Description of effect(s)	Aquaculture farm structures create an artificial habitat that can attract wild fish species seeking refuge and food sources. As a result, wild fish species can aggregate in and around farms. The effects from farms designed for culturing seaweeds within the water column are likely to be greater than those for culturing sea cucumbers, which are benthic deposit feeders.
Spatial scale	Site specific to *regional* – Depending on the location of the farm(s), proximity to neighbouring habitats and the types of wild fish coming in contact with the farm.
Duration	*Short* to *long term* – Fish may temporarily visit while migrating to other grounds or remain for the length of their lives and/or the farm.
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds and/or migration routes. Attraction of local fish species should be considered in the management plans of farms.
Knowledge gaps	Very little is known about the effects of aquaculture involving the culture of seaweed and sea cucumbers on wild fish. It is presumed that the effects of the structures on attracting and aggregating fish will be similar to those for shellfish aquaculture.

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

Summary

Culture of sea cucumbers is likely to involve ranching on the seabed and beneath mussel farms; hence, any effects associated with their culture on attracting wild fish are likely be associated with the overlying structures. The culture of seaweeds such as *Undaria* would presumably involve long-line systems similar in structure to mussel farms; hence, any effects will be similar to those described for green-lipped mussels.

Table 5.10: Changes to fishing pressure due to the presence of lower trophic level aquaculture.

Description of effect(s)	The presence of lower trophic level aquaculture may increase or decrease fishing pressure on wild fish populations, depending on the extent of protection afforded to fish aggregating near farm structures and the location of the farms.
Spatial scale	Site specific to *regional* – Dependent on the presence and extent of nearby farms to fishing regions.
Duration	*Short* to *long term* – Species may seek short-term refuge from fishing pressure or rely on farms as a permanent protected area.
Management options	Site selection to minimise or avoid the likelihood of spatial overlap with species' critical spawning grounds and commercial fishing regions. Attraction of local fish species should be considered in the management plans of farms, with attention given to the possible effects on commercial fish stocks in regard to current fisheries management.
Knowledge gaps	It remains unknown as to whether increased recreational pressure around aquaculture farms in general leads to a negative effect on fish populations. Little, if anything, is known about the effects of aquaculture involving seaweeds or sea cucumbers on wild fish assemblages and, in turn, their influence on fishing pressure.

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

Summary

Wild fish abundances around aquaculture farms can also be affected by changes in the way the area is subjected to fishing pressure. Sites that have historically been part of a trawl fishery, for example, will no longer be accessible due to the presence of structures, essentially creating a commercial "no-take" area akin to a marine reserve (Dempster et al. 2006). Influences from removing commercial fishing pressure may, however, be somewhat offset by changes in the way the area is utilised by recreational fishers (N. Keeley, pers. obs.). In the Coromandel, for example, marine farms are generally viewed as good fishing locations, particularly when the crop is being harvested and the fouling organisms are being discharged back into the water. It is presently unknown whether this increased recreational pressure around marine farms has a negative effect on the wider fish population. If the farms are aggregating fish from a wider area, but not enhancing the populations, then the stocks may be reduced; or alternatively, if the farms are providing additional food and habitats then the population may be enhanced and the increased recreational pressure sustained.

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