APPENDIX G: Marine Mammals Report

REPORT NO. 3316

MARINE MAMMAL ASSESSMENT FOR A PROPOSED SALMON FARM OFFSHORE OF THE MARLBOROUGH SOUNDS

MARINE MAMMAL ASSESSMENT FOR A PROPOSED SALMON FARM OFFSHORE OF THE MARLBOROUGH SOUNDS

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Prepared for the New Zealand King Salmon Co. Ltd

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EXECUTIVE SUMMARY

The New Zealand King Salmon Company Limited (NZ King Salmon) want to develop a site for salmon farming in the deeper, high energy waters offshore of the Marlborough Sounds. The proposal area is located offshore of the Marlborough Sounds, due north of Cape Lambert, and east of the Chetwode Islands. The exact details of the number of pens and pen types are still to be confirmed. Cawthron Institute has been contracted to provide an assessment of the potential effects on marine mammals arising from the development of this proposed marine farm area.

The greater Cook Strait and South Taranaki Bight region, in association with Marlborough Sounds waters, is considered an important area for a large number of New Zealand's cetacean and pinniped species as well as a vital migration corridor for several whale species. The species that occur in the vicinity of the proposal are common, bottlenose and dusky dolphins, NZ fur seals, orca, southern right and humpback whales. While the proposed farm area represents a very small fraction of the total habitat available to support these marine mammal species, it potentially constitutes important winter habitat for southern right whales and forms part of humpback whales' northern migration corridor. Marlborough Sound waters also support sub-populations of nationally threatened bottlenose dolphins, Hector's dolphin and orca, which need to be considered.

Impacts on marine mammals from aquaculture result from an overlap between the activity and the habitat use and / or migration routes of the species. The main effects of the current proposal are possible habitat displacement or avoidance and entanglement risk. Other impacts considered include underwater noise, artificial submerged lighting and trophic flow-on effects. While the overall likelihood of any adverse effects is considered low, the consequences of a rare event such as the fatal entanglement of threatened species warrants appropriate mitigation actions. To ensure that the most appropriate measures are in place, an update of the current Marine Mammal Management Plan (MMMP) prior to commencing operations is recommended along with several suggested best management practices regarding the set-up and operation of open ocean marine farms that can help further reduce the risks of entanglement and other adverse effects.

It is acknowledged that there are still knowledge gaps and uncertainty around how marine mammals will perceive open ocean farm structures visually and acoustically, and importantly, the results of their reactions to farms. Recommended mitigation actions are aimed at addressing some of these gaps, including documenting how marine mammals respond to the proposed farms, while assessing the effectiveness of any mitigation measures put in place.

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1.1. Description of proposal

NZ King Salmon want to install salmon farms in open ocean areas due to improved environmental conditions for farming and reduced biosecurity risk. The proposal area is 1,800 ha, northeast of the Marlborough Sounds, due north of Cape Lambert, and east of the Chetwode Islands (Figure 1). With a total water space of about 1,800 ha, the proposed site could potentially support a large-scale salmon farm development. The total area occupied by surface structures at any one time would be considerably less than the total proposal area (1,800 ha), and NZ King Salmon want flexibility to move the farm structures within the site.

There are physical operational constraints at sites with high water currents and wave action that must be considered when selecting pen technology. In addition, pen technologies for such exposed environments are relatively new, and the details of the pen structures and mooring design used in the proposal are yet to be confirmed. Options include multiple polar-circle style pens serviced by an onsite barge system (see Figure 2), and pens that can be submersed to afford protection from unfavourable oceanic conditions. Screw anchor systems are likely to be used to fix the structures to the seabed.

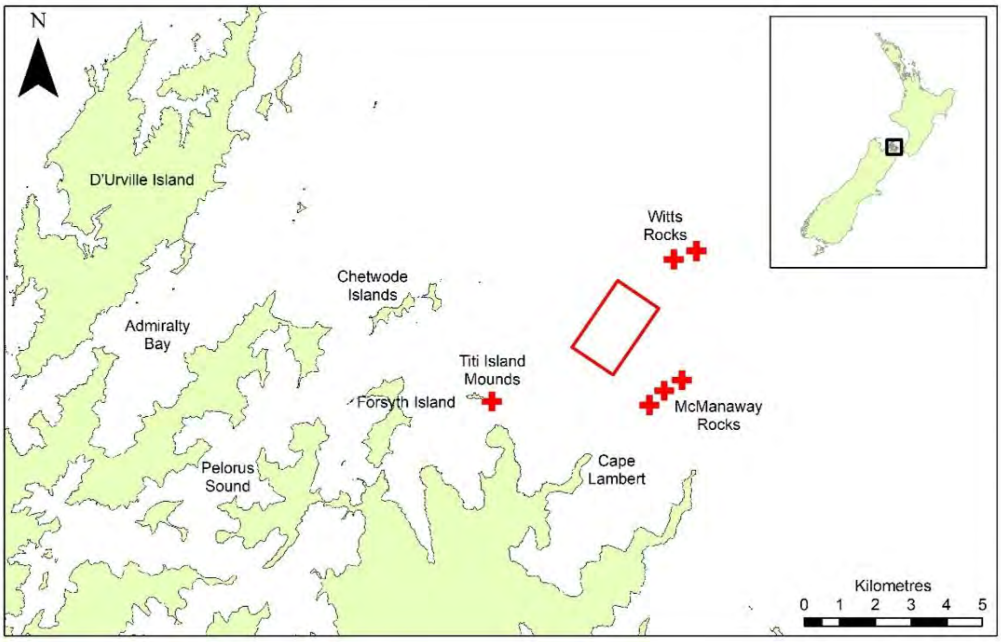


Figure 1. Proposed location of the open ocean farm development (~1,800 ha; red box). Areas recognised as ecologically significant marine sites (red crosses; from Davidson et al. 2011) are also indicated.

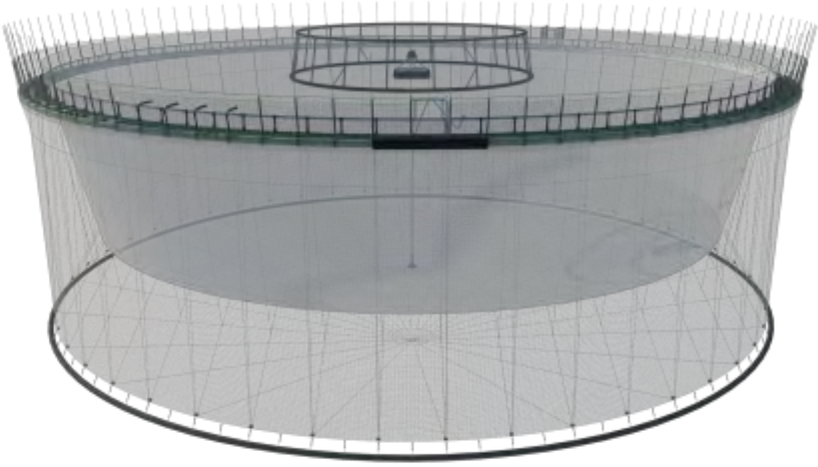


Figure 2. An example schematic drawing of a ‘Fortress’ pens by Huon aquaculture, similar to those that may be considered in this proposal. Note the depiction does not include mooring lines. https://www.huonaqua.com.au/huons-fortress-pens/

1.2. Scope of assessment

The Cawthron Institute (Cawthron) has been contracted to provide a comprehensive assessment of the potential effects on marine mammals that might arise from the activities of the proposed farm application offshore of the Marlborough Sounds. The specific scope of this assessment consists of the following components:

1. A review of the existing environment in relation to the known residency, migratory and seasonal patterns of marine mammals from the greater Marlborough Sounds, South Taranaki Bight and Cook Strait coastal and offshore regions.
2. An assessment of potential and known effects from the proposal (including installation) on any resident and transient marine mammal species by considering the types of effects, their spatial scales and durations, likelihood, and potential consequences.
3. Where applicable, recommendations for mitigation and/or monitoring are suggested.

2. DESCRIPTION OF EXISTING ENVIRONMENT

When determining the potential implications of open ocean developments on marine mammals, the appropriate scale of consideration is not at the site level but rather at the temporal and spatial scales relevant to the marine mammal species involved. This is because the normal home range of most marine mammals varies between hundreds to thousands of kilometres. For instance, while humpback whales may be considered only seasonal migrants through Cook Strait waters, this particular stretch of water represents an important corridor that this species uses in order to reach key habitats elsewhere. As a result, the importance of the proposal area is placed in context of the species' regional (i.e. Cook Strait and associated waters) and New Zealand-wide distributions.

In the absence of any long-term and spatially-explicit baseline research on marine mammals in the greater Cook Strait region, species information and sighting data were collated from existing short-term or localised studies undertaken within the region by various organisations (i.e. Department of Conservation—DOC, Cawthron, NIWA, University of Auckland, University of Massey, Orca Research Trust; for more details see Appendix 1). In addition, opportunistic sightings reported to DOC (including the public, tourism vessels, seismic surveys, etc.) and strandings (previously collated through Te Papa National Museum and now DOC) were reviewed. Collectively, this information is used to determine what is currently known about the relevant species' occurrence, behaviour, and distribution within the area of interest and to evaluate those species most likely to be affected by the proposed project (Figure 3).

We note that detailed information on abundance, distribution and critical habitats is available for only a limited number of New Zealand's species, despite New Zealand's prominence as a marine mammal global hotspot. Even in the absence of adequate population information, the potential risks to marine mammal species associated with various anthropogenic activities can still be assessed based on the species' life history dynamics (e.g. species-specific sensitivities, conservation listing, life span, main prey sources) summarised from New Zealand and international data sources (e.g. peer-reviewed journals, New Zealand Threat Classification System-NZTCS, NABIS, IUCN Red List of Threatened Species).

The outer Marlborough Sounds, in association with Cook Strait, is considered an important area for a large majority of New Zealand's cetacean (whales, dolphins and porpoises) and pinniped (seals and sea lions) species (see Figure 3; Slooten et al. 2002; Davidson et al. 2011; Douglas et al. 2017). Out of the more than 50 species of marine mammals known to live and / or migrate through New Zealand waters, at least 28 cetacean and four pinniped species have been recorded within Cook Strait and associated coastal waters (including the Marlborough Sounds).

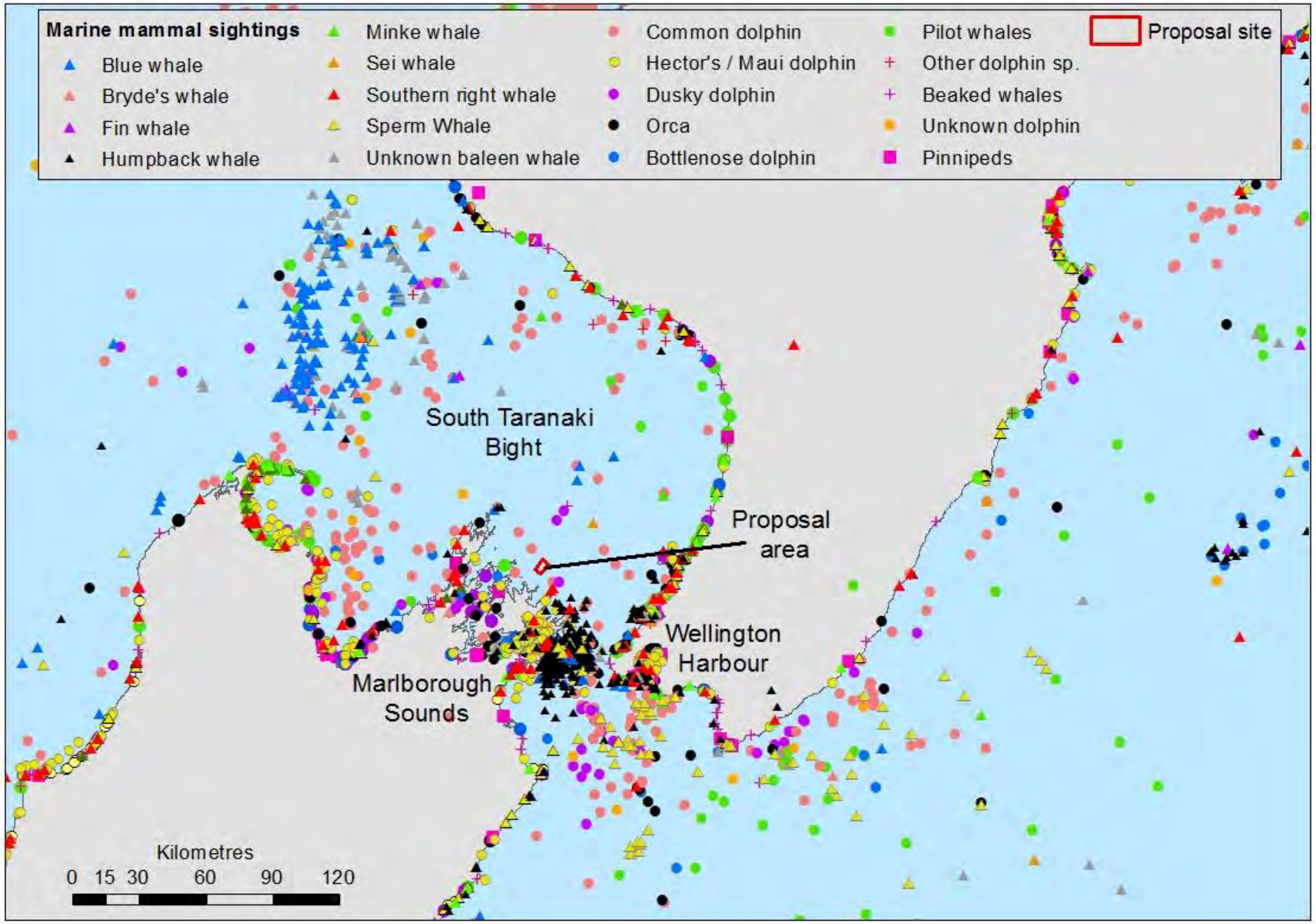


Figure 3. The spatial locations of systemic and opportunistic marine mammal sightings (whales, dolphins and pinnipeds) and strandings reported within the general Cook Strait region and associated waters of both the North and South Island, including the South Taranaki Bight and Marlborough Sounds. The proposal area is highlighted in a red rectangle.

Figure 3 and 4 highlight the various marine mammal species recorded passing through Cook Strait and therefore, potentially in association with the proposal area. It is important to note that a large majority of these sighting are opportunistic rather than systematic. Consequently, the number of sightings in these figures do not necessarily represent unique animals (i.e. the same animal may be reported by multiple members of public or on two separate days). As effort is not considered for these sighting records, ports, favourite fishing spots and tour boat tracks are likely to be over-represented in places where these operations normally occur and during periods of more favourable conditions (e.g. summer, daylight). Therefore, the apparent distribution from these data is unlikely to accurately reflect the species' actual distribution patterns.

Most sightings were reported within and between Queen Charlotte Sound (Marlborough Sounds) and Wellington Harbour (North Island). The large number of reported sightings in this area is most likely a reflection of the number of marine ferries and commercial tour and fishing trips undertaken between these locations. In addition, the large number of humpback and blue whale sightings reported off Tory Channel and within the middle of the south Taranaki Bight (respectively) represent localised, multi-year research studies specifically undertaken to observe those species within these areas.

Other 'hotspots' for opportunistic records include coastal regions known as tourist destinations including Abel Tasman National Park in Tasman Bay and Kapiti Island off the southwestern corner of the North Island. Clumps of more offshore sightings likely represent either commercial fishing destinations or seismic survey locations, as both activities are required to carry marine mammal and / or fisheries observers on-board in New Zealand waters. There are sparse sightings reported offshore of the Marlborough Sounds towards D'Urville Island and across inner South Taranaki Bight water towards the Whanganui coastline.

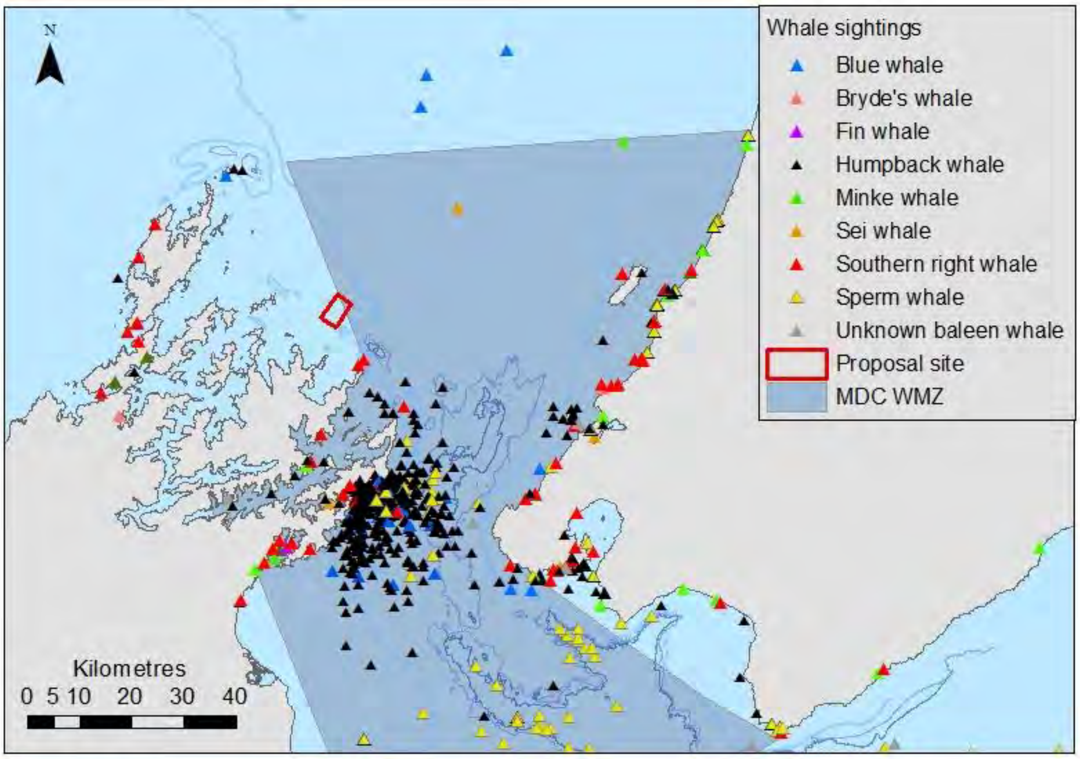
For this assessment, less emphasis is placed on the location of sightings with more importance stressed on the presence of the identified species in the wider region and timing of the sightings. A list of the more prevalent and commonly reported species within the Cook Strait region is presented in Table 1 and divided into three general categories that describe the current knowledge about their distribution patterns:

- Resident—a species that lives (either remains to feed and / or breed) within Cook Strait and surrounding waters either permanently (year-round) or for regular time periods.
- Migrant—a species that periodically migrates through part(s) of Cook Strait but remain only for temporary time periods that may be predictable seasonally.
- Visitor—a species that visits Cook Strait or surrounding waters intermittently. Depending on the region's proximity to the species' normal distribution range, visits may occur seasonally, infrequently or rarely.

Table 1. The residency patterns of the more commonly reported marine mammal species known to frequent Cook Strait and associated waters relevant to the current proposal. Species conservation threat status is listed for the New Zealand system (NZTCS; Baker et al. 2019) and international IUCN system (ver 3.1).

Common Name	Species Name	NZ Threat Classification (NZTCS)	IUCN Red Listing	Residency Category in Cook Strait and associated waters	Patterns of Seasonality (relative to proposal area)
RESIDENTS					
Common dolphin	*Delphinus delphis*	Not Threatened	Least Concern	Seasonal to Year-Round Resident	Most commonly-seen cetacean in South Taranaki Bight / Cook Strait area; individuals and groups are regularly seen offshore of the Marlborough Sounds (Sounds), as well as inshore, travelling past the proposal area. Generally, more common in offshore waters between spring and autumn and inshore regions over winter.
Bottlenose dolphin	*Tursiops truncatus*	Nationally Endangered	Least Concern	Year-round Resident	Small population across the top of the South Island that utilise the Sounds and are part of a larger Cook Strait coastal population. Animals regularly travelling back and forth between Queen Charlotte Sound (QCS) / east coast and western areas of the Sounds would pass by Port Gore near the proposal area.
NZ fur seal	*Arctocephalus forsteri*	Not Threatened	Least Concern	Year-Round Resident	Documented breeding colonies in outer Sounds (Stephens Island, Trio Islands). There are haul-out sites scattered within the mid- and outer-Marlborough Sounds. Seasonality is unknown but likely winter/spring when pups are leaving rookeries.
Hector's dolphin	*Cephalorhynchus hectori*	Nationally Vulnerable	Endangered	Year-round Resident	While there are resident groups year-round in Golden Bay, QCS and Clifford/Cloudy Bay, they are rarely encountered west of Cape Jackson.
MIGRANTS					
Southern right whale	*Eubalaena australis*	At Risk - Recovering	Least Concern	Seasonal Migrant	Periodically found within coastal regions of the Sounds and associated coastal area of Cook Strait during migration periods, suggesting they would pass near and potentially inshore of the general proposal area. Most often seen in winter and spring.
Humpback whale (oceanic pop. only)	*Megaptera novaeangliae*	Migrant	Endangered	Seasonal Migrant	North migration path through Cook Strait, and offshore of the Sounds (mainly May-August). Recovery of this population from whaling days may see more humpback whales encountered in offshore Sounds waters in years to come.
Blue whale	*Balaenoptera musculus (sub-spp. brevicauda & intermedia)*	Data Deficient	Critically Endangered to Data Deficient	Seasonal to Year-Round Migrant	Recognised foraging area off Farewell Spit in the middle of the South Taranaki Bight, with distribution extending down toward Cook Strait. More common in warmer months with fewer sightings over winter months. Unlikely to occur within proposal area.

Common Name	Species Name	NZ Threat Classification (NZTCS)	IUCN Red Listing	Residency Category in Cook Strait and associated waters	Patterns of Seasonality (relative to proposal area)
Minke whale	*Balaenotpera bonarensis*	Data Deficient	Near threatened	Seasonal Migrant	May be attracted to region to feed in productive waters of South Taranaki Bight; tend to enter shallower, more coastal areas (e.g. estuaries, bays and harbours) than other whales, observed mainly late winter – spring in this region.
VISITORS					
Dusky dolphin	*Lagenorhynchus obscurus*	Not Threatened	Data Deficient	Seasonal to Year-Round Visitor	Seasonal movements between the Sounds (particularly Admiralty Bay) and Kaikoura over the colder months of autumn to spring, as well as other regions around the South Island. Animals travelling between areas of the Sounds would pass by Port Gore near the proposal area.
Long-finned pilot whale	*Globicephala melas*	Not Threatened	Data Deficient	Seasonal to Year-Round Offshore Visitor	Known to migrate through Cook Strait with a high chance of at least one group stranding in Golden Bay each year. Stranding records suggest they follow the coastline at least in Tasman and Golden Bay. They may also pass by Port Gore near the proposal area. More common over summer and autumn.
Orca (killer whale)	*Orcinus orca*	Nationally Critical	Data Deficient	Seasonal to Infrequent Visitor	Two of three NZ subpopulations of orca travel between / or around the South Island and in particular Cook Strait. These animals travel long distances and have been sighted throughout the Sounds and Cook Strait coastal waters. Can be encountered any time of year but tend to occur more between spring and autumn months.
Sperm whale	*Physeter macrocephalus*	Data Deficient	Vulnerable	Seasonal to Infrequent Offshore Visitor	Fewer sightings west of Tory Channel, sighted mainly over late summer and autumn. Unlikely to pass through proposal area.
Beaked whales	Ziphiidae species (9 species)	Data Deficient	Data Deficient to Least Concern	Potential Rare Offshore Visitors	Little to no information on these cryptic and generally solitary offshore species. Known to forage in deep offshore waters. The stranding and few sighting records suggest they are more common over later summer and autumn in these waters.



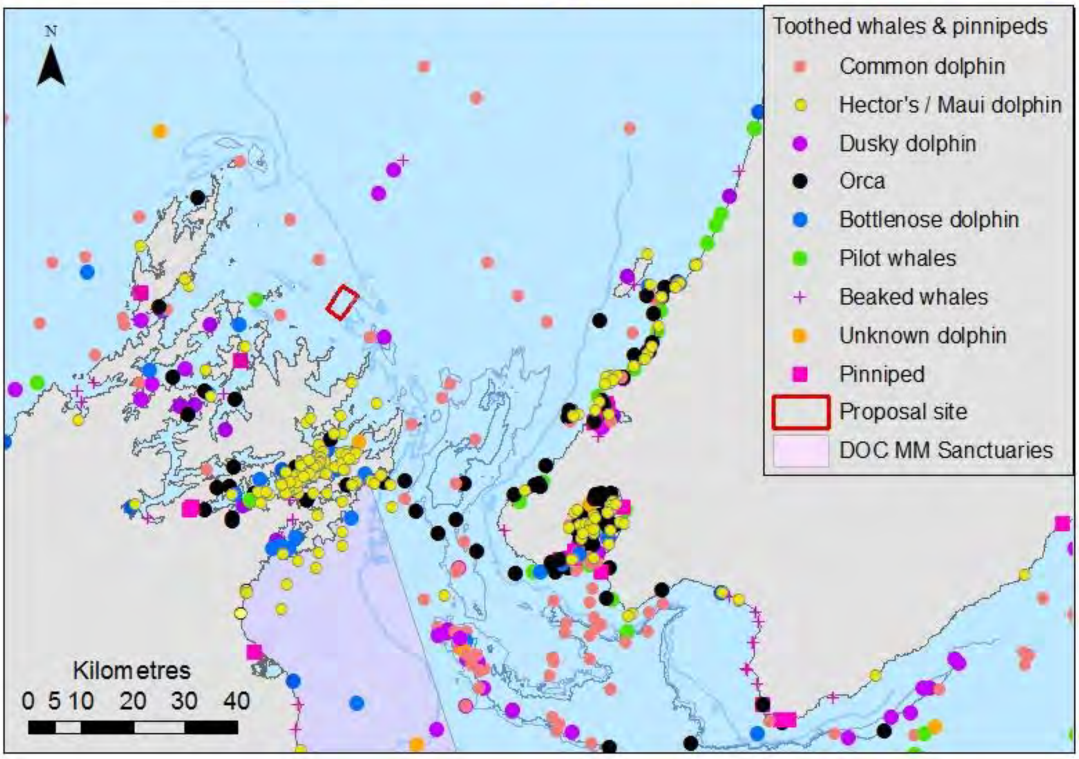


Figure 4. The distribution of Department of Conservation (DOC) reported strandings (1912–2015) and opportunistic sightings (1977–2018) within the greater Cook Strait region. The spatial extent of these maps is more detailed than Figure 3 to help distinguish those species reported near the proposal area. Migrating baleen whale species (plus sperm whale) are shown in the top image and toothed whales, dolphins and pinnipeds (seals) are shown in the bottom image. The proposal area is the red rectangle. The increasingly blue lines represent the 100 m, 200 m and 300 m depth contours, respectively. MDC WMZ – Marlborough District Council's Whale Migration Zone.

2.1. Species of concern

The more frequently occurring species within the Cook Strait region, and those therefore most likely to be affected by the proposed project, include common, bottlenose and dusky dolphins, New Zealand fur seals, orca, and southern right and humpback whales. A short summary of these and other relevant species listed in Table 1 is given below. These species are listed in decreasing order from those that are more likely to be affected by the proposed site to the least likely.

Common dolphins are the most frequently observed species within the wider Cook Strait region with more than 300 opportunistic sightings made year-round (Figure 4). Groups range from 1 up to 1000 dolphins with larger groups (e.g.100 to 1000 animals) generally found in more offshore, open waters from spring to autumn while smaller groups occurring in more inshore regions such as the Marlborough Sounds. A review by Meakin (2014) of common dolphin sightings in the inner Marlborough Sounds found this species appears to gradually move into the Sounds mainly from the east over late summer and autumn, moving towards the west to over-winter in both Pelorus Sound and Admiralty Bay. Animals appear to move between these areas throughout winter followed by a gradual migration back towards the east, first from Admiralty Bay and then from Pelorus Sound during the spring months. These data suggest that this species will likely regularly be passing through the general proposal area.

Bottlenose dolphins also regularly and systematically move from one end of the Sounds to the other, as well as through nearby regions such as Golden/Tasman Bay and Cloudy / Clifford Bay (Figure 4). Merriman et al. (2009) found these animals made up an open, yet semi-resident population of approximately 385 dolphins observed generally in groups of 30–40 animals. Bottlenose dolphins are foraging generalists and can be quite adaptive in their feeding styles. For instance, this species has been known to opportunistically pull salmon out through the bottom of pens in the Marlborough Sounds. Bottlenose dolphins in New Zealand are current listed as *nationally endangered* by the NZTCS due to their restricted ranges and ongoing population declines in at least 1 and possibly 2 of the 3 regional sub-populations (Baker et al*.* 2019).

The main species of pinnipeds found around the Marlborough Sounds is the **NZ fur seal**. This species is regularly observed year-round within breeding colonies and haul-out sites across the Marlborough Sounds region, with the closest breeding colonies to the proposal area approximately 20 km away off the Trio Islands and nearby Stephens Island (Bentley et al. 2014). Fur seals are considered non-migratory but are known to easily and repeatedly cover large distances to find food. Some adults will travel out to open waters over winter while younger animals focus over shallower continental shelf waters. Fur seals are regularly observed around salmon farms in the Marlborough Sounds, hauling out on structures where possible and raiding pens for food (see Entanglement, Section 3.2 for more details). Sighting of fur seals around salmon farms in the Marlborough Sounds seem to peak soon after pups depart from colonies around late winter / spring months (M. Gillard, NZ King Salmon, pers. comm.).

A large local population of **Hector's dolphin** (c. 600-1,000 dolphins) inhabits the coastal waters of Clifford/Cloudy Bay, just to the east of the Marlborough Sounds (MacKenzie & Clement 2014), while small numbers of animals are regularly observed year-round within Queen Charlotte Sound (QCS; ~20 dolphins; Cawthorn 1988, Clement et al. 2001) and Golden Bay / Abel Tasman waters (~100-200 animals, MacKenzie & Clement 2014). Within QCS, animals appear to be highly localised to more central regions of QCS and the entrance to Cook Strait (Cross – unpubl. data). While their occurrence in the proposal area is likely to be extremely low, they may occasionally move through the area. The status of this species as *nationally vulnerable* (Baker et al. 2019) means that any potential impacts, no matter how remote, warrant mention and consideration more due to its status and the public's awareness of its plight.

Dusky dolphins are more of a seasonal visitor to this region as they are sighted mainly over colder months when a variable population of at least 220 individuals (~2-4% of the New Zealand-wide population) is known to seasonally inhabit the Admiralty Bay region (Markowitz et al. 2004). Admiralty Bay is now recognised as an important wintering and feeding area for dusky dolphins migrating from Kaikoura and other regions around New Zealand (Davidson et al. 2011); a route which takes them through the general region of the proposal. Inshore group sizes are generally small (less than 10 animals) but tend to be much larger offshore (i.e. 100 to 1000 dolphins). Nationally, dusky dolphins are categorised as *not threatened*, but the absolute size of the New Zealand population is currently unknown (Baker et al. 2019).

Orca, as transients through Marlborough Sound waters, can be observed year-round but are more common during late spring and throughout summer months (Visser 2000; Slooten et al. 2002). At least three sub-populations of orca are thought to exist; a regional North Island population, a regional South Island population, and a population that travels back and forth between the two islands. Visser (2007) suggests that the tendency by orca to forage in and around enclosed harbours or bays targeting rays for food makes this species more susceptible to coastal developments. Orca are currently listed as *nationally critical* by the New Zealand Threat Classification System (Baker et al. 2019) based on low abundance.

The general migrations of several baleen whale species from Antarctic and sub-Antarctic feeding to tropical calving grounds pass through Cook Strait and associated regions, commencing in early winter (May) and ceasing again with their return to Antarctic waters by late spring (November / December). Of the species identified in Figure 4, humpback and southern right whales are the baleen whales that have more coastal tendencies and have been regularly observed in waters near the proposal area.

Humpback whales are the most commonly seen baleen whale on their migration through Cook Strait and offshore of the Marlborough Sounds, Kapiti and south Taranaki coastlines (Figure 4). Northern migrating whales are thought to pass through Cook Strait as early as May and as late as September (Dawbin 1956; Gibbs et al. 2017; Goetz & Hupman 2017). Only the occasional sighting of a south-bound whale is observed in October or November within these waters.

Based on the sighting rates reported between 2004 and 2015 in Gibbs et al. (2017), it is likely that at least 600 whales pass through Cook Strait each year during the northern migration. Gibbs et al. (2017) also assessed the approximate distance humpback whales travelled offshore during their northward migration. Data indicate that most whales pass between 2 and 6 km offshore of Tory Channel headlands (the narrowest point in Cook Strait), although some whales have been recorded more than 10 km offshore. However once past this area, there are few data on the actual migratory routes of humpbacks (or other whales) migrating through Cook Strait to South Taranaki Bight.

Regular sightings of **southern right whales** occur within the wider Cook Strait region but are found generally closer to coastal shorelines and inshore regions rather than offshore waters. Historically, the eastern side of the Marlborough Sounds and Clifford/Cloudy Bay were important whaling sites for this species (Dawbin 1986) as whales migrated back to their traditional wintering and calving grounds around New Zealand. Current sightings indicate that southern right whales are observed across the Cook Strait region from April to December but generally peak around August (Carroll et al. 2014; DOC database). Whales can be observed with newborn calves from August onwards, with Clifford/Cloudy Bay recognised as a historical calving area (Patenaude 2003).

Due to their recently documented recovery around mainland New Zealand (Carroll et al. 2014), southern right whales have been down-listed from *nationally endangered* to *nationally vulnerable* and now *at risk – recovering* by the New Zealand Threat Classification System (Baker et al. 2016; Baker et al. 2019). However, right whales' tendency to remain within shallow, protected bays and coastal waters (particularly for calving), and their natural curiosity, places them more at risk of interacting with anthropogenic activities in New Zealand's waters than most other whale species.

Five other species of baleen whales are also thought to seasonally or occasionally migrate through the Cook Strait region; **blue, minke, sei, fin,** and **Bryde's whales**. Most whales are observed further offshore on shelf waters within the South Taranaki Bight or within Strait waters. A cluster of **blue whale** sightings within the South Taranaki Bight is mainly due to seismic survey monitoring; but further research has suggested that this region is an important summer foraging habitat for this species (Torres 2013). Similar to blue whales, the few observed sightings of the other whale species generally occur within the wider Cook Strait region during the warmer months from spring, summer and late autumn.

More offshore visitors to Cook Strait waters include **pilot whales**, **sperm whales,** and a few species of **beaked whales** (DOC databases; Baker 2001; Brabyn 1990). Medium-sized groups (e.g. 50 animals) of **pilot whales** were regularly observed throughout the year but tend to be more offshore as this species lives near and / or along the edge of the continental shelf. However, this species is known for its occasional large mass strandings (hundreds of animals) in Golden Bay (Brabyn 1991) over warmer summer and autumn months when they tend to wander into shallower waters, following the coastline (DOC databases). Despite regular sightings of pilot whales, little is known about their abundance or seasonal distribution patterns around New Zealand.

S**perm whale**s were mainly sighted to the east of Tory Channel, found often in association with the Cook Strait Canyon with only the occasional inshore sightings over warmer periods. There are very few live sightings of **beaked whales**; a fairly cryptic and solitary species. However, the stranding records in this area suggest that these deeper water species may also occasionally visit the wider Cook Strait regions with warmer waters.

2.1.1.Species summary

All animals travelling from eastern to western (and vice versa) parts of the Marlborough Sounds would travel past Cape Jackson and thus near the proposal area. However, it is unclear how far from the coast most species might travel as there has been no systematic survey effort in the area and, there is relatively little opportunity for incidental sightings in this region compared to the other parts of the Marlborough Sounds. Based on the available data, and in reference to both Section 6(c) of the Resource Management Act (RMA) and Policy 11(b) of the New Zealand Coastal Policy Statement (NZCPS), there is no evidence indicating that any of these species have home ranges restricted solely to the waters offshore of the Marlborough Sounds, nor that these waters are considered ecologically more significant in terms of feeding, resting or breeding habitats for any particular species relative to other areas of the outer Sounds or the greater Cook Strait region. Instead, the proposed farm area represents a small fraction of offshore habitats available to support those marine mammal species utilising this wider coastal region.

The possible exceptions are the recovering southern right whales, given their use of coastal waters as potential winter habitats, and the humpback whales' northern migration corridor. The general significance of Cook Strait waters to several migratory whale species is well known (Davidson et al. 2011). The proposed farm sites lie just across the boundaries of the proposed Cook Strait whale migration zone identified in Map 17 of the proposed Marlborough Environmental Plan (MEP—Map 17; 2017). There are currently no limits or legislation to be avoided or applied within this zone, but it must be considered by any consents or developments. However, little information is available on where the majority of whales tend to pass through this corridor once past the Tory Channel headlands to assess what effect(s) this overlap might have on the species of concern.

As discussed throughout this section, these waters also support potential sub-populations of endangered species, such as Hector’s and bottlenose dolphins and orca. These species are particularly relevant in regard to Policy 11(a) of the NZCPS, which refers to avoiding any adverse effects on nationally and / or internationally recognised threatened species.

3. ASSESSMENT OF EFFECTS

Most consequential interactions between marine mammals and aquaculture result from a direct overlap between the spatial location of the facilities and important habitats (i.e. feeding or nursing) and / or migration routes of the species (MPI 2013). However, a recent global review of aquaculture and marine mammals by the United States' National Oceanic and Atmospheric Administration (NOAA; Price et al. 2017) acknowledges that there are still very few empirical data on marine mammal responses to aquaculture or the results of their reactions to and with the farms (if any), despite aquaculture's presence in nearshore regions world-wide for more than 20 years.

The situation is complicated by the fact that the individual species involved is likely to influence the nature of the interaction as well as the probability of an interaction occurring. Particular species of whales or dolphins will be highly sensitive to any disturbance, while other cetacean species may even be attracted to the structures (e.g. Clement & Halliday 2014). In addition, some individuals within a given population (such as juveniles, old, diseased, or disoriented individuals) may be more prone to becoming involved in direct interactions, such as entanglements or collisions with certain gear types (e.g. Wilson et al. 2006; Kemper et al. 2003).

To date, documented effects of aquaculture on marine mammals relate mainly to habitat exclusion / displacement issues and entanglement in structures (e.g. Würsig & Gailey 2002; Kemper et al. 2003; Markowitz et al. 2004; Heinrich & Hammond 2006; Pearson et al. 2012). Depending on the size of the farm and nature of operations, other issues such as underwater noise, submerged lighting and possible flow-on effects due to alterations in trophic pathways may also apply (MPI 2013). These effects are reviewed in more detail below.

3.1. Habitat exclusion or displacement

The proposed farms, located within more open waters off the Marlborough Sounds, may be perceived by marine mammals as a new physical, visual or acoustic obstruction along a once previously open coastline that they may choose to ignore, investigate or avoid. As noted in a recent global review by Price et al. (2017), there is currently very little information on how marine mammals might perceive farm structures within the open ocean environment, and even fewer data that can adequately inform the possible consequences of their responses.

Existing management strategies have recommended avoidance of marine mammal interactions by siting new farms in areas that minimise the likelihood of overlap with migration routes or critical habitats (e.g. MPI 2013). This has been possible to date as most farms have been located within more protected, inshore waters in regions with few resident populations of marine mammals. However, the expansion of aquaculture into open ocean waters means that this primary avoidance option may no longer be feasible. The movement of aquaculture to more open ocean waters now means that interactions with baleen whales and larger (e.g. greater than 100 animals) pods of dolphins are likely, where previously such occurrences were rare to non-existent within inshore locations.

3.1.1. Baleen whales

Baleen whales, such as southern right whales or humpback whales, do not echolocate. Instead, they use visual and normal audio cues to inform themselves about their environment. In terms of humpback whales, their migratory routes are assumed to be socially and culturally driven (e.g. calves learn migratory paths from their mothers) rather than environmentally driven (e.g. water temperatures). Consequently, some individuals have been recorded swimming through finfish farms in Australia destroying structures and / or entangling themselves, seemingly unaware of the farms while following their traditional migration routes (e.g. Pemberton et al. 1991; Kemper et al. 2003).

Conversely, too much activity near sensitive habitats and / or migration corridors may result in active avoidance by whales from historical habitats, particularly mother and calf pairs (e.g. Herman 1979; Glockner-Ferrari & Ferrari 1990), and potentially displacement into sub-optimal or unfavorable habitats. Based on historical whaling station data and recent sighting data collected near Tory Channel, the location of the proposed farm off Cape Lambert may lie near the traditional migration paths of at least humpback and southern right whales, and even possible blue whale feeding grounds within the South Taranaki Bight (Dawbin 1956; Gibbs et al. 2017; DOC sighting and stranding database). These are the species, along with minke whales, that are most vulnerable to entanglements in marine gear worldwide (see more in Entanglement Section 3.2). Other baleen species (e.g. fin, sei) and sperm whales are generally thought to migrate through deeper, more open ocean routes, only occasionally passing closer to shore to rest (see Figure 3).

In a similar situation in Australia, an experimental open ocean farm for kingfish in New South Wales was assessed during its resource consenting process as representing a 'moderate' risk due to the uncertainty [1] of any migratory disruption / displacement of whales based on spatial overlap with the farm (NSW DPI 2012). As a result of the ranking, mitigation actions associated with the small scale (20 ha) research phase of

[1] The overall risk was considered to be 'moderate' given that there is uncertainty about whale (as well as great white shark) critical habitat, migratory pathways, potential behavioural changes and predatory interactions. Hence, the resulting ranking ensured adequate management attention was provided for these issues until the research activities could further validate the assessment.

the farm included monitoring all marine mammal interactions with the farm[2], as well as daily maintenance procedures and frequent structural integrity monitoring, to establish baseline expectations and to document the outcomes of any interactions.

While the active avoidance of farm structures by a few individual whales would not be considered a significant disruption, the displacement of the migration pathway further offshore or complete avoidance of vital resting or nursing habitats could have larger scale repercussions on the population if these responses led to a reduction in fitness (i.e. extra travel time causes reduced reproduction rates in pregnant females). A related issue to consider is that while one site of open ocean farms may pose little or low risk to migrating whales, the cumulative risk from several sites along the length a migratory route may increase the overall risk. However, as is the case globally (Price et al. 2017), there are not enough data on whale populations within New Zealand to know how the various species might respond to the proposed farms or the longer-term consequences of these responses.

3.1.2. Odontocetes and pinnipeds

More information is available on how odontocetes or echolocating species (e.g. orca and bottlenose dolphins) may respond to farm structures in their habitats as these species generally occur year-round and utilise more inshore habitats where aquaculture development has historically taken place. Yet, the longer-term, biological consequences of their responses are still unclear and expert opinions can be conflicting (e.g. Admiralty Bay and dusky dolphins).

Multi-year studies undertaken in Admiralty Bay (located to the west of the proposal site) have demonstrated that dusky dolphins appear unable to cooperatively herd small schooling fish (e.g. pilchards) when adjacent to or within mussel farm structures (Pearson et al. 2012). Clement and Halliday (2014) also noted the reluctance of common dolphins to enter or feed near farm structures within the same region. Collectively the evidence suggests that while these dolphin species are not displaced from Admiralty Bay, they do not appear to be utilising habitats occupied by marine farms in the same manner as they do unoccupied habitats. Yet, the significance of such 'disruptions' to their foraging and feeding success is currently unknown, and may range from less than minor (i.e. discernible effect but too small to affect more than a few individual animals) to more than minor implications (i.e. the loss of a primary food source begins to have population-level effects, such as reduced reproduction rates).

Alternatively, other marine mammal species may be attracted to the proposed farms. NZ fur seals are strongly attracted to salmon farms within the Marlborough Sounds with individuals regularly found resting on structures and/or attempting to feed on fish

[2] A Marine Fauna Interaction Management Plan described the approach for recording and monitoring of all marine fauna interactions during the operational stage, including interactions with the sea cages, vessels or humans, as well as any behavioural changes such as in movement corridors and foraging / socialising patterns.

in the pens (M. Gillard, NZ King Salmon, pers. comm.). Finfish stock in the farms can also attract dolphins, such as bottlenose and dusky dolphins, due to these species' curious natures and the associated wild fish aggregations under and near farms. This attraction can have its own repercussions in the form of damaged nets/structures, stock loss and / or entanglement (see Entanglement, Section 3.2).

Based on the limited evidence available, the likelihood for habitat displacement or avoidance behaviours associated with the proposed farm is considered *low* due to the limited contact species will have with the area and farms themselves. However, species' responses are uncertain at this stage, particularly for whale species, due to lack of adequate data, hence the recommendations for additional data collection are provided (see Table 2). This assessment is based on the relevant factors summarised below and listed in Table 2.

Spatial and temporal factors

- Several established breeding colonies for NZ fur seals occur relatively close (within 20 km) to the proposed farm sites. While the option of submerged farms does not offer obvious haul-out or resting sites for individual seals, any options with floating structure would likely be used for hauling out given a lack of alternative resting locations nearby.
- Bottlenose, dusky and common dolphins travel through Cook Strait and utilise nearby coastal waters. Bottlenose and common dolphins are observed year-round while the dusky dolphins are mainly sighted over colder months.
- Most migratory whales occur in the area for a limited period each year; mainly in the winter and spring months, and most only remain for a day or less (the exception being southern right whales who may remain for several days to weeks).
- Migration pathways of whales in western Cook Strait waters are not well-known but increasing numbers of humpback, southern right and blue whales have been documented in and around Cook Strait waters as populations continue to recover from whaling impacts.
- The current scale of historical aquaculture farms in Cook Strait and outer Sound waters (included the proposed farms) is considered small relative to the overall home ranges of resident and / or visiting species, which are large and overlap with similar types of habitats in other parts of Cook Strait and associated regions.
- Cook Strait waters are not considered to be particularly rare and or unique in terms of feeding, resting or breeding habitats. Exceptions might include more inshore waters for southern right whale cow / calf pairs.
- The farm site currently lies just across the boundary of a 'whale migration zone' identified in the proposed Marlborough Environment Plan (pMEP), although noting that the anecdotal data upon which the boundary of the zone was based are limited.

Known displacement / avoidance factors

- Current exposure to existing salmon farms within inner or sheltered regions of the Marlborough Sounds has resulted in periodic attraction of bottlenose dolphin, dusky dolphin and fur seals to farm sites.
- Physical farming structures for salmon do not appear to exclude any particular species from moving past them but are likely to affect the efficiency of certain feeding strategies (e.g. cooperative group foraging) near them locally. Note the scale and layout of multiple farms are likely important factors in such cases.
- Finfish aquaculture is not known to generate intense or consistently loud underwater sounds nor involve large volumes of vessel traffic that may result in habitat displacement relative to other anthropogenic coastal activities in the more general area (e.g. commercial shipping and fishing).

3.2. Entanglement

The process of assessing entanglement risk follows the RMA and EEZ Act, which essentially combines the likelihood of the occurrence (e.g. the number of whales / dolphins likely to adversely interact with a farm) versus the magnitude of effect (e.g. interactions could lead to death, injury, avoidance or have no negative effect at all). As discussed in the previous sections, we lack sufficient data on most marine mammal species within one or both of these categories (see Price et al. 2017).

Within New Zealand, marine mammal entanglement in aquaculture structures has been a relatively minor issue to date (MPI 2013), despite over 30 years of sea-cage salmon farming and several decades of oyster and mussel farming. This is thought to be mainly due to the limited overlap within more inshore and sheltered locations. However, it is unclear how this record relates to the frequency of interactions taking place between species and the industry. Without records of the absence of species near farms and / or the absence of adverse interactions with farms when present (also known as negative data), we cannot quantify the real level of risk or place it in context (i.e. paucity of entanglements because farms are relatively benign or density of farms and reporting is too low to detect potentially injurious interactions; Price et al. 2017).

Additionally, as aquaculture within a region increases in scale, the risk of physical interactions between the structures and marine mammals may as well, given the larger portion of the water column that these more open ocean farms can occupy. But this risk is also highly dependent on the species (e.g. threatened vs non-threatened), the types of cages / pens and equipment employed (e.g. rigid vs loose lines or nets), as well as operational procedures around farm activities, as these aspects influence the probability and possible outcome (i.e. injury vs mortality) of any such interactions (MPI 2013). Previous New Zealand entanglements along with oversea data (particularly from Australia) can help inform which New Zealand marine mammal species may be more vulnerable to entanglement risk as well as which farm configurations or gear may increase or reduce the risk.

3.2.1. Baleen whales

Generally, larger whales are considered more susceptible to entanglement in marine gear from fisheries and aquaculture (e.g. ropes, buoys) than other marine mammals, with three species most commonly reported worldwide: humpback, minke and right whales (Benjamins et al. 2012; Young 2015). Regarding the present proposal, the extent to which the proposed farm sites overlap with potential winter migration corridors for southern right and humpback whales, as well as their known vulnerability towards entanglement, make these species the primary whales of concern.

However, there are currently fewer than ten whales recorded worldwide as being entangled and/or damaging finfish farms within inshore regions, most of which were humpback whales: Australia (n = 2 released alive; Kemper et al. 2008), British Columbia (n = 3 fatal entanglement; n = 2 released alive, FOC database 2018), Scotland (n = 1 fatal calf entanglement; Ryan et al. 2016) and Chile (n = 1 fatal calf entanglement; Hucke-Gaetea et al. 2013). To date, there are no reported entanglements of whales within any New Zealand salmon or other finfish farms, although there are two records of whales being fatally entangled in mussel farm lines. Yet, as the marine farming industry and populations of humpback and southern right whales continue to increase in New Zealand, the probability of interactions is also expected to increase along with the associated risk of entanglement.

The exact mechanism of entanglement is still under debate; whether the whales cannot detect the gear, or a curious whale deliberately interacts with gear because the structures are not recognised as a potential threat (Benjamins et al. 2014; Price et al. 2017). As mentioned in the previous section, a whale (suspected to be a southern right whale) in Australia collided with and damaged a salmon cage in Tasmania (Pemberton et al. 1991) while a humpback broke through a net and swam into a tuna feedlot in Port Lincoln (South Australia, Kemper & Gibbs 2001). Global reviews have also noted that younger, less experienced animals (calves and juveniles) were found to be more at risk of entanglement compared to adult whales, perhaps due to inexperience or a more inquisitive nature (e.g. Benjamins et al. 2014; Knowlton et al. 2012). Individuals engaged in feeding, mating or resting may also have an increased risk of entanglement as they are distracted and less focused on the possible presence of unfamiliar structures in the water column.

3.2.2. Odontocetes and pinnipeds

Odontocetes, or toothed whales and dolphins, use sonar clicks to explore their environment and hunt for prey. Their echolocation capability means that they can detect structures and objects in the water column three-dimensionally, unlike baleen whales (e.g. Madsen et al. 2006; Markowitz et al. 2004). However, despite this ability, odontocetes still entangle with finfish farms, and are often more at risk of entanglement than whales due to their attraction to the caged fish as an easy food source or to the associated aggregations of wild fish around farms.

Fatal entanglements of dolphins in finfish farms have been reported from Australia (Kemper & Gibbs 2001; Kemper et al. 2003), British Columbia (Figure 5 – FOC 2015), Scotland (Ryan et al. 2016), and Italy (Díaz López & Bernal-Shirai 2007) as well as New Zealand (MPI 2013, Cawthorn 2011). There have been 10 dolphin entanglements reported in New Zealand salmon farms between 1987 and 2018 (A. Baxter, DOC Nelson, DOC stranding database). Entangled species include dusky dolphin (n = 7), Hector's dolphin (n = 2), and bottlenose dolphin (n = 1; Appendix 2). Almost all animals were found or believed drowned in predator nets or during operational changes (i.e. switching out predator nets) when nets were no longer under tension.

To date, the marine mammals most at risk of entanglement with finfish farms are pinnipeds, and within New Zealand, NZ fur seals. Pinnipeds are thought to be strongly attracted to the farmed fish as a food source, and as current farms are mostly located within embayments and sheltered inshore areas, they also serve as convenient haul-out sites for the animals. An increased pinniped presence can cause major problems for farmers through direct predation, destruction of gear, fish escapements through damaged nets and reduced fish growth and performance (Kemper et al. 2003; M. Gillard, NZ King Salmon, pers. comm.). Consequently, salmon cages in the Marlborough Sounds, for example, are surrounded by predator nets and above-water fences that are designed to prevent predator access to the fish stock and the farm structures.

Despite their strong attraction to farms, there have been only six reported fatal entanglements of NZ fur seals in salmon farms within the Marlborough Sounds (and numerous live releases). As with the dolphin incidences, almost all involved entanglement in predator nets or between predator nets and the salmon cage, and most of the events involved juvenile seals. Existing salmon farms in Big Glory Bay (Stewart Island) have regular visits and interactions with bottlenose dolphin, NZ fur seals and NZ sea lions. However, these current farms, which use a SeaFarm System, do not use predator nets outside the fish pens. This factor may account for the zero marine mammal entanglement record in this bay to date (A. Undorf-Lay, Sanford, pers. comm.).

New Zealand's entanglement rates are significantly lower than other countries such as British Columbia or Australia (see Figure 5). However, we have no data to place these rates in context as most aquaculture farms (here or overseas) are not required to monitor or report marine mammal presence (absence) or interactions with their structures and/or vessels. Based on the above evidence, it is highly likely that dolphin and pinniped species will visit and interact with the proposed farms from time to time.

However, unlike baleen whales, it is thought that most entanglements of these species occur when farms, or more likely predator nets, are not properly installed or maintained (e.g. Tanner 2007). Evidence from overseas reports demonstrate that entanglement risk can increase if farms are poorly designed, installed or maintained (e.g. Kemper & Gibbs 2001; Allen & Bejder 2003; Kemper et al. 2003; Grooms & Coughran 2005; Díaz López & Bernal- Shirai 2007). Thus, appropriate management and mitigation actions can help reduce the chances of entanglement significantly.

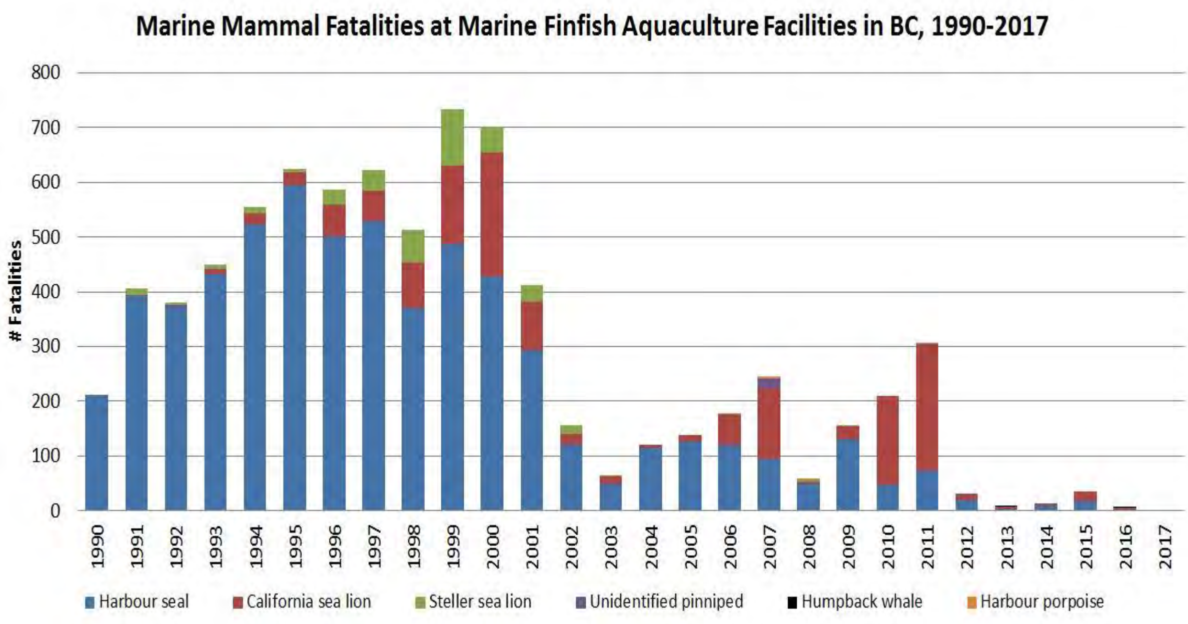


Figure 5. Marine mammal interactions with marine finfish aquaculture sites in British Columbia listed by species and year as reported through Fisheries and Oceans Canada (http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar-mam/index-eng.html).

Overall, the likelihood for entanglement is considered *low* for all species. However, the consequence of such a rare event is highly dependent on the animal(s) involved as several of the above species are considered threatened or endangered, and a fatal entanglement could have potentially serious regional or population level repercussions. While NZ fur seals and dolphins (mainly dusky and bottlenose) are considered the species most at risk regarding this proposal, evidence suggests that the risk may be reduced through appropriate farm design and strict operational procedures. The entanglement of baleen whales, particularly southern right and humpback whales, has also been considered due to the more open ocean location and scale of the proposal. This assessment is based on the relevant factors summarised below and listed in Table 2.

Spatial and temporal factors

- Several established breeding colonies for NZ fur seals occur relatively close (within 20 km) to the proposed farm sites.
- Bottlenose, dusky and common dolphins travel through Cook Strait and utilise nearby coastal waters. Bottlenose and common dolphins are observed year-round while the dusky dolphins are mainly sighted over colder months.
- Most migratory whales occur in the area for a limited period each year; mainly in the winter months and spring months, and most only remain for a day or less (the exception being southern right whales who might remain for several days to weeks).
- Most baleen whale species (with the possible exception of southern right whales and south-bound humpback whales) do not feed while migrating, hence individuals are less likely to be 'distracted' and vulnerable to entanglement.
- Migration pathways of whales are not well-known but increasing numbers of humpback, southern right and blue whales have been documented in recent years as populations continue to recover from whaling impacts.
- Farm spacing in relation to existing (and potential future) farms are likely to be important spatial factors in determining entanglement risk; particularly overlapping warps lines that may cross each other at depth and the width of lanes or corridors between and among farms.

Entanglement factors

- Possibility of entanglement for NZ fur seals, humpback and southern right whales, and dusky and bottlenose dolphins within New Zealand farms based on previous entanglement incidences overseas.
- Higher entanglement possibility during construction or decommission periods, but risk reduced with recommended mitigation actions (see Section 4).
- Current exposure of relevant dolphin and pinniped species to similar types of aquaculture activity within the Marlborough Sounds and other NZ regions have resulted in only a few reported entanglements in finfish farming gear (Appendix 2). However, there are no data to assess risk due to the lack of context data (e.g. absences and effort).
- Most entanglements in New Zealand salmon farms have occurred in or associated with predator nets. Final pen types and configurations have not yet been confirmed.
- Evidence from overseas and within New Zealand demonstrates that entanglement risk can be reduced through proper siting, appropriate design and maintenance features, and strict operational procedures and protocols.

3.3. Underwater noise disturbance

Associated closely with habitat exclusion is habitat degradation in the form of underwater noise disturbance as increasing underwater noise levels are always a concern regarding marine mammals. Noise has the potential to negatively affect cetacean species since they rely heavily on underwater sounds for communication, orientation, predator avoidance and foraging. Depending on the overlap in the hearing range of a species, anthropogenic noise can mask important intra-species communication noises as well as interfere with other acoustic cues such as predators or nearby vessels (e.g. Lammers et al. 2013; Erbe 2002; Gerstein & Blue 2006).

Potential effects associated with increases in underwater noise include auditory damage, behavioural changes such as avoidance (and / or attraction) of the area, and acoustic masking (e.g. Southall et al. 2007; Weilgart 2007; Wright et al. 2007). For example, Chilean dolphins (*Cephalorhynchus eutropia*) in an area of intensive mussel farming in Chile were found to respond to vessel noise by bunching, increasing speed, and increasing reorientation rate (Ribeiro et al. 2007). Too much noise disturbance or masking could theoretically affect reproductive success if the noise is generated near an important breeding ground and is ongoing for an extended period (Todd et al. 2015).

MPI (2013) noted that the level and persistence of any underwater noises associated with a finfish farm itself are expected to be minimal relative to other underwater noise sources. In this case, the levels of underwater noise generated by nearby commercial shipping and fishing vessel traffic in Cook Strait and outer Sound waters plus seasonal seismic survey in the South Taranaki Bight region are likely to exceed any noise produced by the farms. However, it should be emphasised that no research has assessed the types and level of noise associated with ongoing farm activities (including maintenance and harvesting) or the possible effects of other noise-producing activities near salmon farms.

The direct effect of anthropogenic noise from the proposed salmon farm and associated operations is expected to have a *nil to negligible* effect on local marine mammal species (Table 2). Noise generated from farm operations and vessels will likely attract species such as NZ fur seals and bottlenose dolphins to the farms; the greater risk from any attraction to farm structures is potential entanglement issues (see previous section). Southern right whales may also be attracted, given their curious nature, or may avoid the area depending on the scale of operations and their group dynamics (i.e. lone animal versus mother / calf pair).

3.4. Artificial lighting

To date, overseas studies and those within New Zealand that have focused on the effects of submerged lights associated with finfish farms suggest it can attract aggregations of schooling baitfish to the pens that in turn may increase night-time predation by marine mammals and other species (e.g. SAD 2010; McConnell et al. 2010; Cornelisen & Quarterman 2010; Cornelisen 2011; Cornelisen et al. 2013). However, Cornelisen et al. (2013) found the footprint of submerged artificial lights is mainly confined within the cage structures themselves and mid-waters depths, and any associated effects are small and highly localised to the farms.

As a result, marine mammals will more likely be attracted to any increase in noise and activity of caged or wild fish in response to the lights rather than the lights themselves. The effect of this attraction then becomes more of an entanglement issue (Table 2). Cornelisen (2016) suggests minimising any lighting effects by ensuring only the minimum of lighting necessary to achieve the farms' outcomes is used.

3.5. Possible flow-on effects due to alterations in trophic pathways

There is the potential for wider, more indirect ecosystem effects on marine mammals due to finfish aquaculture in the form of food-web alterations (Black 2001; Kaiser 2001; Würsig & Gailey 2002; Kemper et al. 2003). There are numerous studies quantifying the impacts that salmon farms can have on the benthos and water quality in New Zealand coastal and enclosed waters (e.g. Keeley et al. 2009; MPI 2013). If situated in suitable conditions, this impact is likely to be localised to within several hundred metres of the farms. If the farm is in too low of current flow or near sensitive habitats, the result may be significant for the local ecosystem. However, there is currently no documented research on how the indirect effects of finfish farming on local ecosystems may affect New Zealand marine mammals and / or their prey.

In general, the large-scale home ranges and generalist feeding-strategy of most marine mammals ensures that any localised impacts to potential prey resources do not often have any substantial flow-on effects to the population. The only marine mammals found near the proposal area with any regularity are possibly NZ fur seals. However, this species is likely foraging along the entire coastline and off the nearby continental shelf edge out to Cook Strait (e.g. Chilvers & Goldsworthy 2015). The lack of any marine mammal species foraging exclusively around the proposal region means that even if there are some localised effects on prey resources, they are likely to have a *nil to negligible* effect on the relevant marine mammal species (Table 2).

3.6. Cumulative impacts

The likelihood of most of the above effects occurring is dependent on the scale and intensity of the finfish farms within the proposed area relative to the amount and types of habitats needed for the various functional requirements of the different marine mammal species, as discussed throughout this report. Other anthropogenic activities also affect the environment in which Cook Strait / Marlborough Sounds marine mammals live including large-scale commercial shipping and recreational boating, bycatch in fisheries; bottom disturbance (e.g. fishing dredges and trawls); underwater noise; land-based sedimentation; and contaminant and nutrient enrichment.

Few studies to date have researched the potential cumulative effect of multiple anthropogenic activities on marine mammals. As a result, attempts to regulate any of these issues, individually or cumulatively, are currently extremely difficult as little is known about their biological significance for any species of marine mammal. One of the main research recommendations by Price et al. (2017) is the need for a formal risk analysis of potential aquaculture interactions in comparison to other marine activities such as fishing, shipping, boating, development/construction operations, etc. Additional work is also needed to assess whether overseas modelling frameworks being developed to address cumulative effects, such as Interim Population Consequences of Disturbance Model (IPOD; Donovan et al. 2016), could be expanded to include other sources of disturbance and to be applicable for different marine mammal species.

Table 2. Summary of potential effects on marine mammal species from the proposal.

Potential environmental effects	Spatial scale of effect on marine mammals	Persistence / duration of effect for marine mammals	Consequence(s) for marine mammals	Likelihood of effect	Avoidance Factors / Mitigation Options (see Section 4 and Table 2)	Significance level of residual effect
Habitat / prey disturbance from farm structures and associated activities	**Medium to Large** Limited to immediate area and habitats within and adjacent to the farm(s)	**Persistent** Farm structures will be permanent for the length of consent; most species only present in area for hours to days	**Individual to Regional Level** Local avoidance by foraging dolphins; avoidance by more sensitive species or age groups (e.g. mother / calves) **Individual Level:** Pinnipeds / dolphins may approach site	**Low** **Moderate**	• Acoustic baseline monitoring to characterise occurrence in waters near farm • Record and report any visual sightings, noting the type and frequency of marine mammal interactions (including absences) to build a local / regional picture	**Less than Minor** **Negligible**
Entanglement in farm structure and / or debris	**Medium to Large** Limited to immediate area and habitats within and adjacent to the farm(s)	**Persistent** Farm nets and ropes will be permanent for the length of its consent; most species only present in area for hours to days	**Regional to Population Level** Death or injury of endangered or threatened species **Individual Level** Death or injury of non-threatened pinniped or dolphin	**Low** **Low**	• Avoid or minimise operational changes (i.e. predator nets) during critical periods • Avoid loose nets, keep all lines under some degree of tension • Make lines easily detectable and investigate methods to stiffen • Avoid overlap or crossing of warp lines between farms.	**Less than Minor** **Negligible**
Increase in underwater sound from farm structures and associated vessels	**Small to Large** Dependent on types of noise produced and frequencies	**Short or Persistent** Farm will be permanent; but noise sporadic and potentially more seasonal	**Individual to Regional Level** Individual avoidance by whales or certain age groups; local attraction of pinnipeds and some dolphins	**Low** - Avoidance to **Moderate** - Attraction	• Minimise above-water and underwater noise to reduce the exclusion (or attraction) of wildlife	**Nil to Negligible**
Attraction to artificial submerged lighting	**Small to Medium** Dependent on types of lights and location within the farm	**Short and Persistent** Farms permanent; seasonal lighting at night-time only	**Individual** Local attraction of pinnipeds and some dolphins	**Low to Moderate**	• Minimum amounts of lighting and proper positioning to reduce the attraction of wildlife	**Nil to Negligible**
Flow-on effects to marine mammals	**Medium to Large** Limited to immediate waters and habitats adjacent to the farm	**Short to Persistent** Dependent on trophic effect; potential seasonality	**Individual Level** Local avoidance; individuals may approach for foraging opportunities	**Not Applicable to Low**	• Ensure proper site placement	**Nil to Negligible**

Definition of terms used in table:

- Spatial scale of effect: Small (tens of metres), Medium (hundreds of metres), Large (> 1 km)
- Persistence of effect: Short (days to weeks), Moderate (weeks to months), Persistent (years or more)
- Consequence: Individual, Regional, Population level
- Likelihood of effect: Not Applicable (NA), Low (< 25%), Moderate (25–75%), High (> 75%)
- Significance level: Nil (no effects at all), Negligible (effect too small to be discernible or of concern), Less than Minor (discernible effect but too small to affect others), Minor (noticeable but will not cause any significant adverse effects), More than Minor (noticeable that may cause adverse impact but could be mitigated), Significant (noticeable and will have serious adverse impact but could be potential for mitigation

4. MITIGATION

Overall, the likelihood of any potential adverse impacts from aquaculture activities affecting local and visiting marine mammals is assessed as *low* (Table 2). This assessment is based on the consideration of the types of effects, their spatial scales and durations, and relevant species' information. However, given that some of the possible consequences of rare events (i.e. entanglement) could have regional and / or population level effects (i.e. injury or death of an endangered or threatened animal), mitigation is warranted and several recommended actions are listed in Table 3 to help reduce these risks to as close to zero as possible.

NZ King Salmon currently have a marine mammal and protected shark management plan in operation for their inshore Marlborough Sounds salmon farms. To ensure that the most appropriate measures are in place, this plan needs to be updated to address any further issues raised in this report that apply to operating in open ocean waters in consultation with DOC and an experienced marine mammal expert. This plan should at least outline in detail: (i) a dis-entanglement protocol for whales in the unlikely event that there is an entanglement, (ii) any implemented open ocean mitigation procedures that will need to be reviewed for effectiveness during operations and (iii) determine timelines for any subsequent reporting requirements (if warranted; Table 3).

If the farm is consented, there are a range of best management practices (BMPs) regarding the set up and operation of marine farms that can help reduce risks of entanglement and other adverse effects (Table 3). Note that BMPs are suggested even where effects are expected to be negligible. For example, it is suggested that the industry encourages or supports specific research into potential effects of underwater noise (MPI 2013). Many of these suggested practices are already reflected in the Finfish Aquaculture Environmental Code of Practice (ECOP) developed by the New Zealand Salmon Farmers Association (NZSFA 2007) and their more recent Sustainable Management Framework for New Zealand Salmon (ANZ 2015). In addition, if NZ King Salmon are intending to comply with the Aquaculture Stewardship Council's (ASC) certification standards, several of the above recommendations and BMPs are aligned with ASC indicators and requirements as highlighted in Table 3 (e.g. ASC 2019).

The Price et al. (2017) review emphasises that there is a …[global] la*ck of scientific reporting on entanglement frequency, severity of resulting injuries and mortality rates associated with interactions, effective deterrent methods, and technological innovation to reduce interactions and decrease harm if contact occurs*. In order to quantify the current level of marine mammal interactions with finfish farms, New Zealand aquaculture companies should be taking the approach of farmers in British Columbia (FOC database 2018) and some Australia companies (NSW 2018; see Appendix 3) in which they monitor and report all visual sightings and interactions with marine mammals (including absences) seen near to the farm or while travelling to and from the farm in a transparent and open web-based database. This includes fatal entanglements, injuries, and all other interactions. (e.g. rubbing ropes, bumping against structures).

A complementary approach to visual observations would be to use passive acoustic underwater monitoring, an established technique internationally for the monitoring of vocalising marine mammals. Passive acoustic recorders (i.e. moored underwater acoustic recorders) automatically listen and record any underwater sound at frequencies likely to be from marine mammal vocalisations. These recordings (also known as detections) are downloaded at a later date and used to assess whether marine mammals may have been present in a particular area. A pilot study to test the efficacy of underwater acoustic recorders at the proposal site was undertaken in August 2018 (Childerhouse & Pine 2019). The acoustic recorders performed well in the deep-water environment and detected a total of 499 marine mammal events over the short 43-day deployment period, including 136 dolphin events and 363 whale events. These preliminary results suggest a low number of dolphins passing through the area on a regular basis. Along with humpbacks, vocalisations of several baleen whales were recorded all of which are known to take advantage of the productive South Taranaki Bight waters during this time of year. No unexpected species were detected based on a cursory analysis of the data.

Acoustic recorders, however, are limited in range for some mid- and high-frequency species (e.g. several hundred metres to kilometres), and cannot assess if marine mammals are truly absent (i.e. versus present but not vocalising or echo-locating). Yet, the advantage of using passive acoustic moorings is that they can 'listen' for the presence of any marine mammals both day and night and when sea conditions are not favourable for visual sightings. In addition, acoustic recorders can provide data on any underwater noise generated from the farms themselves and associated operations (e.g. feeding, vessels).

The recommended monitoring approach means that if future interactions with a species changes (e.g. increased entanglement risk), industry can evaluate the significance of the change, pinpoint possible reasons and develop potential solutions more effectively and efficiently with an information baseline. In addition, record keeping around sightings of marine mammals (either visual, acoustic or both) in proximity to the structures, as well as when travelling to and from the proposed farms, would provide an important context for any future development stages and / or decisions around site selection in nearby areas. For example, the fatal entanglement of a single animal after daily sightings of the species over 10 years demonstrates effective operational measures are in place. Being able to benchmark the expected levels of interaction with marine mammals based on local records will provide a more realistic picture of species-specific risk of these farms for any current or future development stages or consent applications.

Table 3. Proposed best management goals and practices (BMP) to minimise the risk of any adverse effects of the proposed farms on marine mammals in Cook Strait waters. DOC = Department of Conservation, MDC = Marlborough District Council).

Management goal	BMP	Reporting
1. Minimise the exclusion of marine wildlife from their critical habitat, or modification of such habitat	1a. Record marine mammal interactions (either visually, acoustically or both) during high risk periods, such as structure construction and net retrieval, in addition to building a baseline occurrence in waters near farms.	• Record and report the type and frequency of marine wildlife interactions (including absences and effort), in a standardised format (ASC 2.4.1). Records provided to DOC and MDC and made publicly available (e.g. web).
	1b. Minimise above-water and underwater noise to reduce the exclusion (or attraction) of marine mammals.	• Keep records of the extent to which any reduction techniques were successful or unsuccessful (ASC 2.5.1); encourage research into effects.
2. Minimise the attraction of marine wildlife to farms	2a. Minimise wastage during feeding to reduce associated attraction of fish.	• Nothing required, encourage or support specific research into effects.
	2b. Collect and appropriately store and dispose of fish mortalities to reduce marine mammal attraction.	• Continue to record / report the type and frequency of fish mortalities and / or subsequent predation interactions in a standardised format.
	2c. Minimise artificial lighting to reduce attraction of prey fish and predators.	• Nothing required, encourage or support specific research into effects.
3. Aim to minimise entanglement with a goal of zero mortality in line with Aquaculture Stewardship Council (ASC) standards	3a. Avoid loose rope / nets. Keep all nets / lines weighted and under some degree of tension. Investigate methods to stiffen lines / nets with rigid or semi-rigid cores.	• Self-checking as per MMMP, records provided to DOC and MDC.
	3b. Investigate methods to make lines / nets more easily detectable in the water column; type, colour, texture, reflectivity.	• Self-checking as per MMMP, records provided to DOC and MDC.
	3c. Avoid the overlap or crossing of warp lines between farms, particularly at depth.	• Self-checking as per MMMP, records provided to DOC and MDC.
	3d. Implement regime for net inspection (semi-rigid or well-tensioned net material, no billowing), maintenance (e.g. repair holes), and replacement to minimise the potential for adverse effects.	• Self-checking as per MMMP, records provided to DOC and MDC.
	3e. Avoid predator exclusion nets if possible. If used, ensure appropriate design, enclosed at the bottom (base of net), and use net mesh sizes < 6 cm.	• Self-checking as per MMMP, records provided to DOC and MDC.
	3f. Minimise potential for loss of rubbish or debris from farms, recover lost material.	• Self-checking as per MMMP, records provided to DOC and MDC.
	3g. Record all entanglement incidents regardless of outcome (*e.g.* injury or mortality) and made publicly available soon after (ASC 2.5.5. and 2.5.6).	• In case of a fatal incident, carcass(es) recovered, given to DOC, and steps taken in consultation with DOC to reduce the risk of future incidences (ASC 2.5.2). Records provided to DOC and MDC.

5. CONCLUSIONS

This report describes the local and visiting marine mammals that utilise and / or are influenced by the outer Marlborough Sounds waters and the associated Cook Strait / South Taranaki Bight ecosystem. In particular, information on the various species was reviewed for any life-history dynamics that could make them more vulnerable to salmon farming activities or where the proposed NZKS sites may overlap with any ecologically significant feeding, resting or breeding habitats. This, in turn, enabled the potential effects associated with the proposal on marine mammals to be assessed.

The marine mammals most likely to be affected by the proposed project include those species that frequent the outer Marlborough Sounds region year-round or on a semi-regular basis. These species are common, bottlenose and dusky dolphins, NZ fur seals, orca, southern right whales and humpback whales. Other species including Hector's dolphins, several species of baleen whale, pilot whales, sperm whales and beaked whales were also considered in this assessment because of their records of occurrence in the general area, their known species-specific sensitivities (e.g. underwater noise); and / or potential public and iwi concerns.

The offshore waters of the Marlborough Sounds are not currently considered significant habitats for any marine mammal species, with the possible exception of southern right whales as part of their potential winter habitats and humpback whales' northern migration corridor. Instead, these waters represent a small fraction of similar habitats available to these marine mammals utilising the Marlborough Sounds and wider Cook Strait region. However, it is important to note that several of the above listed species are nationally and / or internationally recognised as threatened species that live in semi-isolated sub-populations or recovering colonies, and thus need to be considered in regard to Policy 11(a) of the NZCPS.

Based on the direct and indirect potential effects highlighted in this report, the overall effects of the salmon farms on marine mammal species within outer Marlborough Sound waters are assessed as less than minor when considered with the recommended mitigation actions. This conclusion is based in part on site-specific information from other consultant reports as well as relevant information from overseas practices (e.g. Kemper et al. 2003; Tanner 2007; Price et al. 2017). However, it is acknowledged that there are still considerable knowledge gaps and uncertainty around how marine mammals will perceive more open ocean farm structures visually and acoustically, and importantly, the results of their reactions to farms.

As such, recommended mitigation actions are aimed at addressing some of these gaps through the collection of data to improve our understanding of how marine mammals respond to the proposed farms, rather than testing of specific predictions of effect. Such a programme will serve the dual purpose of collating the information necessary to assess the actual level of interaction risk between salmon farms in this area and the relevant New Zealand marine mammals while assessing the effectiveness of any mitigation measures put in place. These measures can then be amended, if necessary, while operations are underway, and for later development stages.

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7. APPENDICES

Appendix 1. Data sources for this assessment.

Several areas within central New Zealand coastal waters have had more targeted mammal data collection undertaken (although not all of these were systematic data collection methods). These are summarised below:

- Wider Cook Strait region (various boat and aerial surveys);
  - Cook Strait Whale Project (Gibbs et al. 2018)
  - Passive acoustic monitoring for the wider Cook Strait region (Goetz & Hupman 2017)
  - South Taranaki Bight blue whale research (e.g. Torres 2013; Barlow et al. 2018; Goetz et al. 2018).
  - Hector's surveys (Clement et al. 2001; MacKenzie & Clement 2014)
- Queen Charlotte Sound
  - Research through Massey-Albany (e.g. Cross 2013; Merriman 2007, 2009)
  - Multibeam survey sightings (Goetz & Hupman 2017)
- Admiralty Bay
  - Research program through Texas A&M (e.g. Markowitz et al. 2004, Würsig papers, Vaughn et al. 2007, Pearson et al. 2012B).
  - Other institutes (DOC—Lloyd unpubl. data, U of Auckland/Cawthron - Clement & Halliday 2014).
- Other databases
  - Department of Conservation opportunistic database and stranding record database (formerly maintained by Te Papa National Museum)
  - National Aquatic Biodiversity Information System (NABIS)
  - Scientific research through Department of Conservations:
    - L Boren - several projects with NZ fur seals around the South Island
  - Scientific research through University of Auckland:
    - EL Carroll – several projects on southern right whales around New Zealand mainland and offshore, sub-Antarctic islands
  - Orca Research Trust - various Visser publications and sighting database
  - Berkenbusch K, Abraham ER, Torres L 2013. New Zealand marine mammals and commercial fisheries. New Zealand Aquatic Environment and Biodiversity Report No. 119. 110 p.

Appendix 2. Records of known marine mammal entanglements in marine farms within New Zealand.

DOC ID	Common name	#	Date	Location	Type	NZ Region	Description	Refer
1021	Hector's dolphin	1	26/12/1987	Akaroa Harbour	salmon	Canterbury	Found freshly dead with distinctive net marks near the salmon farm.	
11	Dusky dolphin	1	1999	NZKS - Ruakaka	salmon	Marlborough	Dead, animals trapped between adjoining nets, current designs avoid this problem	M. Cawthorn (NZKS evidence)
12	Dusky dolphin	1	1999	NZKS - Ruakaka	salmon	Marlborough	Dead	M. Cawthorn (NZKS evidence)
1309	Hector's dolphin	1	17/02/2005	NZKS - Ruakaka	salmon	Marlborough	Found in the bottom of farm, carcass not recovered. Good certainty around species ID - Salmon farm worker identified from a selection of dolphin species photos	DOC-Marlborough (M. Avis)
13	Bottlenose dolphin?	1	2010	Crail Bay farm	salmon	Marlborough	Dead, caught in loose predator net being removed for cleaning , prior to NZKS owning this farm	M. Cawthorn (NZKS evidence)
3167	Dusky dolphin ??	1	24/08/2011	NZKS - Crail Bay	salmon	Marlborough	Second dolphin in a week that had been caught in predator net. Cause of death was likely drowning/asphyxia due to net entanglement	DOC- Nelson (A. Baxter)
	Dusky dolphin	1	29/08/2011	NZKS - Crail Bay	salmon	Marlborough	Dead in net with circumpolar technology	DOC- Nelson (A. Baxter)
3277	Dusky dolphin	1	14/06/2012	NZKS - Waihinau Bay	salmon	Marlborough	Thought to be 3 days old before noticed and divers managed to remove it. Brought in by staff	DOC-Marlborough (M. Avis)
16	Dusky dolphin	1	21/09/2018	NZKS - Richmond	salmon	Marlborough	Divers were conducting routine checks of the net. On the base of the net they found a dead dolphin trapped in the net.	DOC- Nelson (A. Baxter)
17	Dusky dolphin	1	1/11/2018	NZKS - Kopaua	salmon	Marlborough	Dead in net	DOC- Nelson (A. Baxter)

Appendix 3. An example of marine mammal sightings collected from Australian experimental finfish farm off New South Wales (NSW 2018; https://www.huonaqua.com.au/wildlife-interactions/).

Report period		Observations while travelling (to and from Lease)				
Start	**Finish**	**Humpback**	**Calf**	**Dolphin**	**Seal**	**Observations**
4/12/2017	17/12/2017			pod		
18/12/2017	31/12/2017					
01/01/2018	14/01/2018					
15/01/2018	28/01/2018					
29/01/2018	11/02/2018			pod		
12/02/2018	25/02/2018			pod		
26/02/2018	11/03/2018			pod		
12/03/2018	18/03/2018			26		
19/03/2018	25/03/2018				1	Seal on empty pen
26/03/2018	08/04/2018			Pods of 50		
09/04/2018	22/04/2018			29		
23/04/2018	06/05/2018			235		
07/05/2018	20/05/2018	1				East of lease
21/05/2018	03/06/2018	4	1	20		Whales breached east of lease
04/06/2018	17/06/2018	9	1	150		East of lease
18/06/2018	01/07/2018	22		40		East of lease travelling north
02/07/2018	15/07/2018	15		70		On way to lease
16/07/2018	30/07/2018	3				On way to lease
31/07/2018	12/08/2018			2		In Providence Bay

Report period		Observations around Marine Aquaculture Research Lease (in and around Lease area)							
Start	**Finish**	**Humpback**	**Calf**	**Dolphin**	**Seal**	**Observations**	**Nature of interactions**	**Entanglements**	**Comments/Tasks carried out**
4/12/2017	17/12/2017							Nil	Feeding and Pen Maintenance
18/12/2017	31/12/2017							Nil	Feeding and Pen Maintenance
01/01/2018	14/01/2018			1	3	5 x Grey Nurse Sharks	Seal on walkway. Sharks between nets	Nil	Feeding and Pen Maintenance
15/01/2018	28/01/2018			2	2	2 x Whaler Sharks	Seals feeding on fish. Sharks inside net	Nil	Pen repairs/feeding after storm event
29/01/2018	11/02/2018					1 x Great White Shark	Shark around Pen 1603	Nil	Feeding and Pen Maintenance
12/02/2018	25/02/2018		10		2		Seal on walkway Pen 1603	Nil	Feeding and Pen Maintenance
26/02/2018	11/03/2018					2 x Whaler Sharks	Removed from Pen 1601	Nil	Feeding and Pen Maintenance
12/03/2018	18/03/2018			15		1 x Bull Shark	Diver observation on outside of pen	Nil	Feeding and Pen Maintenance
19/03/2018	25/03/2018							Nil	Feeding, Bathing and Pen Maintenance
26/03/2018	08/04/2018			60	4		1 seal around pen	Nil	Feeding and Pen Maintenance
09/04/2018	22/04/2018				1		1 seal around pen	Nil	Feeding and Pen Maintenance
23/04/2018	06/05/2018				8	1 (observed on lease)	1 seal around pen	Nil	Feeding, Pen Maintenance and bathing
07/05/2018	20/05/2018							Nil	Feeding, pen maintenance and moorings
21/05/2018	03/06/2018	1			5		1 seal around pen	Nil	Feeding, bathing and pen maintenance
04/06/2018	17/06/2018	9	2	20	13	Whales 100m off pens	1 seal around pen	Nil	Feeding, bathing and pen maintenance
18/06/2018	01/07/2018				4		1 seal around pen	Nil	Harvest
02/07/2018	15/07/2018	1			1	Whale near NW special mark	1 seal around pen	Nil	Pen maintenance
16/07/2018	30/07/2018							Nil	Site maintenance
31/07/2018	12/08/2018							Nil	Site maintenance

APPENDIX H: Seabirds Report

POTENTIAL EFFECTS ON SEABIRDS OF OPEN OCEAN FISH FARMING, COOK STRAIT

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POTENTIAL EFFECTS ON SEABIRDS OF OPEN OCEAN FISH FARMING, COOK STRAIT

Contract Report No. 4594

June 2019

Project Team:
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CONTENTS

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1. INTRODUCTION

New Zealand King Salmon intends to make an application to establish an open ocean salmon farming operation in the Marlborough Sounds. The site of interest is approximately five kilometres north of Cape Lambert (refer to Appendix 1 maps for site location). Water depth at the site varies from 70 metres to 120 metres. New Zealand King Salmon have installed monitoring equipment to refine wave height models, and propose to later install trial structures without fish. Fish will then be farmed on a pilot basis before scaling up to commercial quantities. The company envisages that open ocean farming at a commercial scale may be possible within the next 10 years.

Overseas, various types of open ocean farming methods are in commercial use, and a number of prototype and conceptual open ocean farming technologies are being trialled. At this stage, the specific farming technology that will be used at the site has not been determined. Within this context, New Zealand King Salmon would like an assessment of the potential effects of open ocean fish farming on seabirds at this location as part of feasibility studies in preparation for lodging a resource consent application.

This report provides the results of a review of the bird species that are likely to use the general location of the proposed marine farm site and evaluates the importance of the site to those species. The report also assesses the potential effects and risks of the proposed farm on these bird species in the absence of constraints. The report reviews the possible mitigation measures that could be implemented to reduce seabird interactions. Finally, the report sets out the standards required for a Seabird Management Plan to address monitoring and management of seabirds.

The draft report was externally peer reviewed by Mike Bell, Director, Wildlife Management International Ltd. This review resulted in some amendments to the report.

2. TYPES OF OPEN OCEAN FISH FARMING

This section does not aim to provide a full synthesis of potentially suitable open ocean marine farming methods. Most developments are Norwegian in origin. This is because the Norwegian government is encouraging development in open ocean salmon farming by providing access to cheaper water space. Information on structures and effects on birds is not readily available. The three types of open ocean marine farming technology described briefly below illustrate the range of farms already in use or being developed. Photographs and details are from company websites.

Huon Aquaculture (Australia) operates in Tasmania, South Australia and New South Wales using Fortress Pens (Figure 1). This is presently the only fully operational open ocean fish farming operation globally. The pens are built from extremely strong, flexible fully-enclosed nets which employ a predator net to exclude seals. The pens have also been built to minimise interactions with birds by using a small mesh size, and providing limited opportunities to roost. Bird mortality is reported as part of requirements of Aquaculture Stewardship Certification.

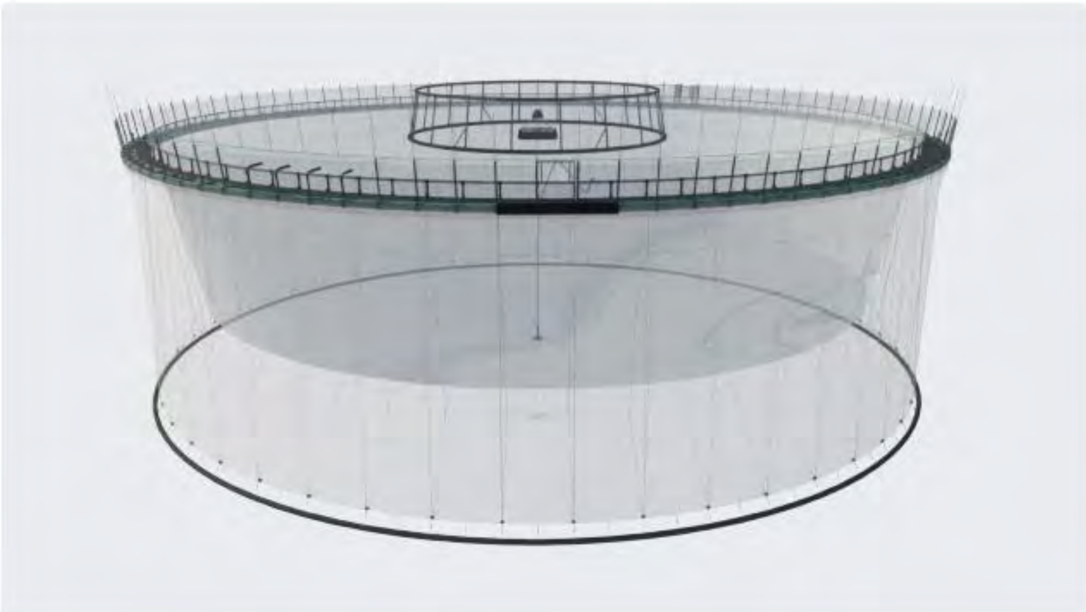

Figure 1: Fortress Pen *in situ* (top), and diagrammatic representation showing external weighted predator net (below). Huon Aquaculture, Australia.

Figure 2: Havfarm One, 430 metres in length and 54 metres wide, anchored to the seafloor. Nordlaks Oppdrett, Norway.

Numerous Norwegian proposals have been put forward, including the Havfarms (Nordlaks Oppdrett; Figure 2), and Ocean Farm 1 (SalMar; Figure 3). Licences have been granted for Havfarm 1.

Figure 3: Ocean Farm 1. Height 68 m, diameter 110 m, volume 250,000 m^3. Can operate in waters between 100 and 300 meters deep. SalMar, Norway.

3. SEABIRDS OF THE MARLBOROUGH SOUNDS AND COOK STRAIT

3.1 Overview

The Marlborough Sounds and Cook Strait support a high diversity and abundance of seabirds, including many seabird breeding colonies. Both the Marlborough Sounds and wider Cook Strait have been identified as 'Important Bird Areas', as the sites are considered to support globally threatened seabird species, greater than 1% of the global population of one or more seabird species, and greater than 10,000 pairs of seabirds (Forest and Bird 2014)[1].

Seabirds of the Marlborough Sounds and Cook Strait regions are summarised in the following sections, using information derived from multiple sources. Breeding locations of seabirds in the Marlborough Sounds are mostly from published accounts. In contrast, no 'at-sea' surveys of seabirds have been undertaken in Cook Strait, and only one has been undertaken in the Marlborough Sounds (see discussion in Fisher and Boren 2012). However, large data sets are available through the citizen science global web-based database 'eBird', and fisheries observer seabird observations, and relevant

1 BirdLife International's Important Bird and Biodiversity Area concept has been applied for over 30 years. More than 12,000 Important Bird Areas in over 200 countries and territories have been identified to date. Note that Important Bird Areas are contiguous from Cook Strait, down the eastern coast of the South Island, around Stewart Island, and along the southern coast of Fiordland.

records have been summarised. Unpublished data, particularly on breeding locations of seabird species, have not been included. As such, it is likely that breeding locations have been omitted. This is not considered to have a bearing on the overall conclusion that the Marlborough Sounds-Cook Strait area supports numerous breeding colonies for multiple seabird species.

Key species or groups of species are described in the following sections. Maps showing breeding locations are provided for key species in Appendix 1, and tabular summaries of data, including published reference sources are provided in Appendix 2.

3.2 eBird data set

'eBird' is a citizen science, global, on-line checklist database programme. Observations of single birds through to checklists of all birds seen at a location are submitted to the website. The database now holds tens of millions of records from around the world. Results are freely available through searches by species or specific areas. The website has become a valuable source of information to assist with the development of lists of bird species present in particular locations. Wildland Consultants requested a download of all New Zealand records in March 2018 and the results summarised in this report are therefore current (Sullivan *et al*. 2009; eBird 2018)[2]. Conditions of use have been met.

Three polygons were created in a GIS and overlaid with the bird observation locations in order to select relevant records; Marlborough Sounds and coastal region, the Cook Strait, and Wellington Harbour and coastal region (Figure 4). Wellington Harbour was included to capture the entire route of the Interislander/Bluebridge passenger ferries and to maximise the potential observations of infrequently-observed pelagic species and allow for incorrect georeferenced locations. It should be noted that the vast majority of eBird records within this wider area come from observations on the Cook Strait ferry route. Other areas have little or no coverage. Observations from the Cook Strait ferry route are assumed to be generally representative of birds present in the wider area.

Records were filtered further to exclude observations recorded on land, and any land-based or coastal species, e.g. swans, ducks, and kingfishers. Many observations only recorded the presence of a species rather than a count. In such cases, the observation was included as a single bird. As a consequence, actual numbers will be underestimates.

In total, 3,037 species observations were extracted for the Marlborough Sounds and coastal region, 3632 species observations for the Cook Strait region, and 5,463 species observations for the Wellington Harbour and coastal region. In total, a minimum of 208,624 individual birds were recorded (Table 1).

Use of this data set requires an understanding of its limitations. Anyone can submit data to the website. In New Zealand, submissions come from a range of people, who are generally either keen bird watchers (who vary from not-so-skilled to highly experienced), or people working in environmental fields submitting data collected during field trips (such as Department of Conservation staff). Of all New Zealand's birds, seabird identification presents the greatest challenge to bird watchers, with a great

2 eBird Basic Dataset. Version: EBD_relMarch-2018. Cornell Lab of Ornithology, Ithaca, New York. March 2018.

diversity of species, many of which look very similar from a distance. Records submitted to eBird may include misidentifications. Also, eBird taxonomy and common names are often different to those used in New Zealand, meaning people may potentially select the wrong species when entering data.

Albatross taxonomy is a particular issue. eBird albatross taxonomy recognises less taxa than are recognised in the threat classification lists in New Zealand. As such, some taxa that are likely present in Cook Strait do not appear in Tables 1 and 2, like Gibson's albatross (subsumed under wandering albatross) and northern and southern royal albatross (combined as royal albatross). As a result, more taxa are likely present than are shown in Tables 1 and 2. For other species, observers often only identify an individual to species level, rather than subspecies level. The implications of this are discussed in Section 7.2.

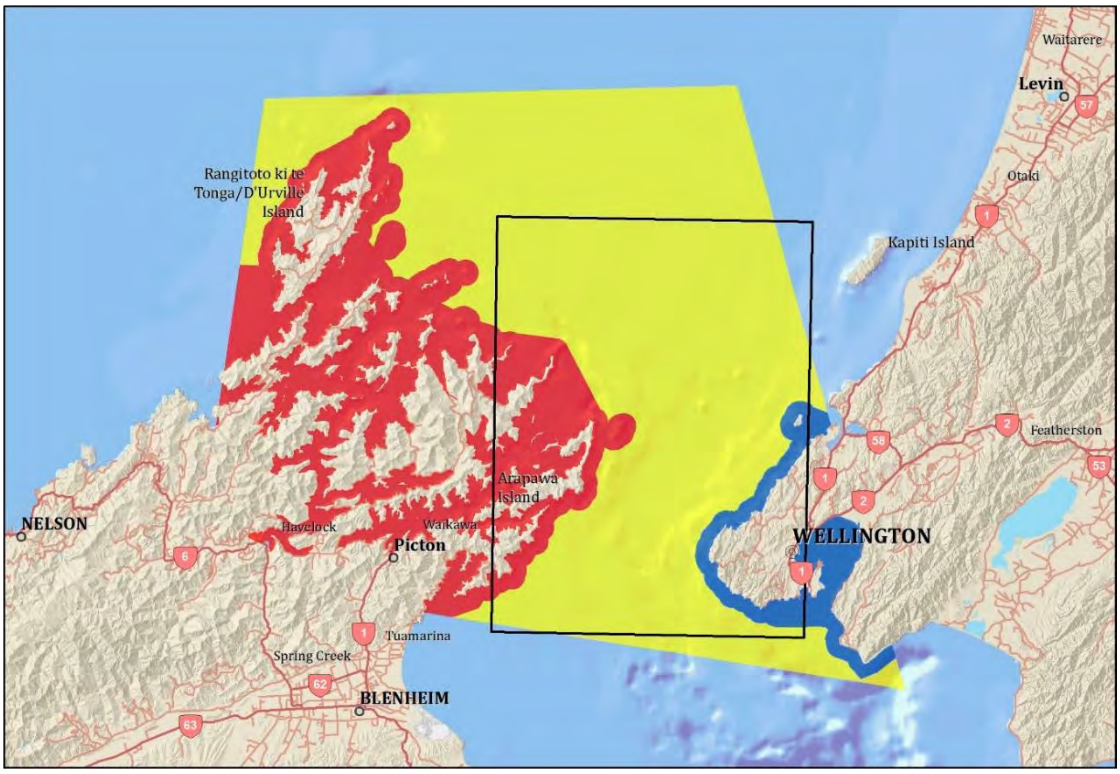

Figure 4: eBird analysis polygons showing Marlborough Sounds and coast (red), Cook Strait (yellow), and Wellington Harbour and coast (blue).

Furthermore, when someone submits the results of a day-long trip, for example, significant distances may have been travelled, and several habitats may have been surveyed. However, often, only one location point for that data set is submitted. For example, in the case of a bird watcher submitting the results from a trip on the Cook Strait ferry, the entire journey's bird list may be associated with a single point, potentially anywhere on the general route. eBird has a 'Hot Spot' facility, where observers can record birds seen at well-known birding hotspots and one of those hotspots is 'Cook Strait Ferry (Open Ocean Section)'. However, close examination of Cook Strait records for king shag indicates that at least some of the 16 individuals seen in the 'open ocean' (Table 1) were in fact seen in Queen Charlotte Sound, as shown by notes submitted by observers.

Table 1: eBird records of seabird species within the Marlborough Sounds, Cook Strait, and Wellington Harbour (data downloaded in March 2018).

Common Name	Marlborough Sounds and Coast		Cook Strait		Wellington Harbour and Coast		Total Reports	Total Birds
	Number of Reports	Number of Birds	Number of Reports	Number of Birds	Number of Reports	Number of Birds		
Penguins								
Blue penguin	139	613	66	262	115	249	320	1,124
Erect-crested penguin					2	2	2	2
Fiordland crested penguin					1	1	1	1
Moseley's rockhopper penguin					1	1	1	1
Albatrosses								
Black-browed mollymawk	6	15	70	509	10	35	86	559
Buller's mollymawk	1	5	62	179	5	19	68	203
Grey-headed mollymawk			2	2	0	0	2	2
Light-mantled sooty albatross	1	1	9	9	0	0	10	10
Royal albatross	6	6	99	258	12	21	117	285
Salvin's mollymawk			90	290	6	18	96	308
Snowy (wandering) albatross	2	2	68	99	6	6	76	107
White-capped mollymawk	16	58	272	1,895	26	81	314	2,034
White-capped/Salvin's/Chatham Island mollymawk			7	47	2	34	9	81
Shearwaters and petrels								
Buller's shearwater	4	39	78	573	6	9	88	621
Flesh-footed shearwater	13	314	83	567	4	8	100	889
Fluttering shearwater	259	20,806	291	18,360	445	26,692	995	65,858
Great shearwater			1	1	0	0	1	1
Hutton's shearwater	10	21	59	777	2	6	71	804
Little shearwater*	2	2	14	23	1	1	17	26
Short-tailed shearwater	1	70	12	42	0	0	13	112
Sooty Shearwater	14	54	166	1,885	11	58	191	1,997
Black-winged petrel			1	1	0	0	1	1
Cape petrel*	12	84	185	2,533	18	140	215	2,757
Cook's petrel			9	9	0	0	9	9
Grey petrel			1	1	0	0	1	1
Grey-faced petrel			26	31	1	1	27	32
Mottled petrel			2	3	1	10	3	13
Black petrel			4	19	0	0	4	19
Soft-plumaged petrel			1	1	0	0	1	1
Westland petrel	12	105	136	689	11	77	159	871
White-chinned petrel			36	112	1	1	37	113

Common Name	Marlborough Sounds and Coast		Cook Strait		Wellington Harbour and Coast		Total Reports	Total Birds
	Number of Reports	Number of Birds	Number of Reports	Number of Birds	Number of Reports	Number of Birds		
Broad-billed prion	1	1	6	12	0	0	7	13
Fairy prion	15	366	273	19,382	10	275	298	20,023
Antarctic fulmar			2	2	2	2	4	4
Diving petrel*	17	154	96	729	7	20	120	903
Grey-backed storm petrel			2	2	1	1	3	3
White-faced storm petrel	1	1	13	84	0	0	14	85
Wilson's storm petrel	1	4			0	0	1	4
Northern giant petrel	17	38	144	323	25	45	186	406
Southern giant petrel			14	28	5	6	19	34
Northern/Southern giant petrel			24	34	18	136	42	170
Gannets and shags								
Australasian gannet	274	2,360	209	983	364	572	847	3,915
King shag	168	1,753	13	16	2	2	183	1,771
Black shag	50	173	41	105	113	170	204	448
Little black shag	36	226	10	14	236	1,897	282	2,137
Little shag	137	382	38	76	653	1,875	828	2,333
Pied shag	261	1,162	74	237	238	421	573	1,820
Spotted shag	247	2,412	97	424	492	3,665	836	6,501
Southern black-backed gull	416	4,695	219	3,155	1,137	18,473	1,772	26,323
Skuas, gulls and terns								
Brown skua			4	4	0	0	4	4
Long-tailed skua	1	1			0	0	1	1
Parasitic skua	59	140	39	60	40	74	138	274
Pomarine skua	8	8	9	10	1	1	18	19
Skua species (one of above)	2	2	3	3	3	3	8	8
Black-billed gull	62	610	24	273	26	77	112	960
Red-billed gull	322	17,236	178	10,790	733	9,723	1,233	37,749
Arctic tern	1	1			0	0	1	1
Black-fronted tern	38	217	44	103	20	77	102	397
Caspian tern	157	447	20	47	74	119	251	613
White-fronted tern	248	2,483	186	2,866	574	17,512	1,008	22,861
White-winged black tern					2	2	2	2
Grand Total	**3,037**	**57,067**	**3,632**	**68,939**	**5,463**	**82,618**	**12,132**	**208,624**

* Little shearwaters could be North Island, Kermadec or Subantarctic subspecies. All are classified as At Risk in Robertson *et al*. (2017). Cape petrels could be migrants, or Snares cape petrels. Common diving petrel could be the northern or southern subspecies (both At Risk-Relict). The northern subspecies breeds in Cook Strait (Robertson *et al*. 2017).

Nevertheless, the results in Table 1 indicate fairly accurate reporting, with pelagic seabirds such as albatross and petrels being observed far more commonly in the Cook Strait region than elsewhere on the Cook Strait route.

Lastly, observers can submit reports of single birds or, alternatively, a checklist of every species seen. They can also choose to simply submit a report of a species, with no indication of numbers seen (appearing as an 'X' in eBird records). When people submit reports of single species, that species tends to be of particular interest (for example, rare or threatened), meaning that results can sometimes be biased towards such species. This is clearly a significant issue with the fisheries observer data set (Section 3.3). However, experience with eBird data sets indicates that submissions are generally of checklists of every bird seen.

In summary, the eBird data set in Table 1 is an extremely valuable source of information on the diversity and relative abundance of seabird species present in Cook Strait, and likely to be present in the area of the proposed marine farm site. The results in Table 1 are discussed in more detail in the following sections.

3.3 Fisheries observer data set

The Ministry for Primary Industries places observers on selected commercial fishing boats. The primary role of observers is to collect information on aspects of the quota management system such as catch effort and bycatch data. Observers began collecting seabird abundance data for the Department of Conservation in 2004. Numbers and species of birds observed in the proximity of fishing vessels are recorded using a unique three- or four-letter code. Observations are generally made during the first fishing event of the day, and sometimes more frequently depending on the other duties of the observer (Yvan *et al.* 2011).

These observer data have been analysed by Yvan *et al*. (2011) for the Department of Conservation. The data are freely available for use with appropriate acknowledgment. The authors state that species identifications should be treated with caution. The authors also note that "All the data were collected from fishing vessels and the counts will depend on the distribution of the seabird taxa, how attracted they are to fishing vessels, the visibility of the birds, how readily they may be identified, and the distribution of observed fishing effort. In general, inshore species will be underrepresented as observer coverage on inshore fishing vessels has been relatively low…Seabirds were identified to the most accurate taxonomic level possible. Because of the inherent difficulties of counting seabirds around vessels, the variation in the experience of observers, and changes in the protocol with time, the counts should be regarded as indicative only. The data will inevitably contain misidentified birds, and errors in transcribing the raw counts."

The seabird data set was constrained to a region of potential impact around the proposed development site. The resulting bird counts were collated from 506 trawl events, 65 set net events, and two bottom longline events. Total counts by species are shown in Table 2.

Table 2: Seabird records made by fisheries observers, Cook Strait (Department of Conservation data).

Common Name	Frequency of Species Observations	Number of Birds
Salvin's albatross	65	43,276
White-capped mollymawk	64	10,478
Albatrosses	30	6,544
Southern Buller's albatross	39	1,468
Black-browed albatrosses	38	1,533
Tasmanian mollymawk	3	1,100
Great albatrosses	24	209
Campbell black-browed albatross	4	151
Wandering albatrosses	8	86
Smaller albatrosses	5	64
Grey-headed albatross	1	50
Southern royal albatross	7	45
Chatham island albatross	4	4
Gibson's albatross	1	2
Cape petrel*	83	15,006
Giant petrel*	65	1,497
White-chinned petrel	5	540
Seabird - small	5	500
Westland petrel	17	334
Sooty shearwater	9	53
Prions	9	54
Storm petrels	3	23
Petrels	3	41
Fairy prion	3	4
Northern giant petrel	2	48
Black petrel	2	60
Petrels, prions, and shearwaters	2	6
Australasian gannet	1	1
Grey petrel	1	20
Southern black-backed gull	36	124
Seagulls	9	56
Red-billed gull	1	5

Taxonomical differences exist between the eBird and fisheries datasets which are difficult to resolve. The implications of taxonomy and misidentification are discussed in Section 7.2.

Diversity and abundance of seabird species in the eBird data versus the fisheries data are entirely different. For example, the thousands, sometimes tens of thousands, of fairy prions, fluttering shearwaters, white-fronted terns, shags, and gulls seen in Cook Strait waters by eBird recorders are largely absent from around commercial fishing boats operating in Cook Strait waters off the Marlborough Sounds. In contrast, the fisheries data set is dominated by albatross species, giant petrels, and cape petrels, attracted to the vessels by the fish being brought up on to deck, and the discards of offal and bycatch. Together, the data sets show the presence and relative abundance of seabirds in the area of the proposed marine farm.

3.4 Blue penguin

Blue penguins, often also referred to as little blue penguin or little penguin, breed throughout New Zealand, Stewart/Rakiura Island, and the Chatham Islands. The species is also found in Australia, where birds are referred to as fairy penguins. The taxonomy of blue penguin has been debated for decades. The checklist of the Birds of New Zealand (Gill *et al.* 2014) only recognises a single species, *Eudyptula minor*. However, the Department of Conservation currently recognises several subspecies, including northern blue penguin (*Eudyptula minor iredalei*) and southern blue penguin (*Eudyptula minor minor*). Both are classified as At Risk-Declining (Robertson *et al.* 2017).

Blue penguin breed throughout the Marlborough Sounds. Extensive surveys undertaken for the purpose of documenting ecologically important marine, freshwater and terrestrial sites in the Marlborough Region recorded numerous breeding populations of blue penguins, on both the mainland and on islands (Davidson *et al.* 1995). Reporting of relative abundance has, however, been very limited. Identified breeding locations are: Croisilles Bluffs, D'Urville Island, Bird Island (Forsyth Bay), Cape Jackson (Port Gore), Arapawa Island, Motuara Island, Motungarara Island, Moutapu Island, Pickersgill Island, and Amerikiwhati Island (all in Queen Charlotte Sound), and the Southern Sounds cliffs (north of Port Underwood to the entrance of Tory Channel; Davidson *et al*. 1995). Further breeding locations are present on the Trio Islands, Maud Island, Chetwode Islands, and Long Island (Mike Bell, Wildlife Management International, in lit. June 2019) Blue penguins are likely to breed at many more locations.

Blue penguins can travel significant distances from the colony when foraging, for example more than 45 kilometres (Hoskins *et al.* 2008; Preston *et al.* 2007). Most recently, individual blue penguins with GPS loggers from Motuara Island in the Marlborough Sounds were found to travel distances of up to 214 kilometres from their burrows during foraging trips, whereas some individuals remained in local waters (Poupart *et al.* 2017; Figures 5 and 6).

Blue penguins are typically demersal divers - feeding just above or on the sea bottom - and are thought to use the sea bed to trap their prey (Chiaradia *et al.* 2007). They have been shown to dive to depths of 55 metres, but are thought to generally feed in shallower waters (e.g. Chiaradia *et al.* 2007; Hoskins *et al.* 2008). Dietary studies indicate that blue penguins take a variety of inshore small fish species, squid, krill, and jellyfish (e.g. Chiaradia *et al.* 2016; Flemming *et al.* 2013; Fraser and Lalas 2004; Sutton *et al.* 2015; van Heezik 1990).

In contrast, Poupart *et al.* (2017) study took blood samples from penguins at Motuara Island, Marlborough Sounds, and examined the stable isotope ratios of carbon and nitrogen at different stages of the breeding cycle. This allows the determination of the relative trophic levels of prey and prey consumption from inshore versus offshore waters. Results indicated that the birds sampled during the incubation period fed on a broader range of offshore-dominated prey from lower trophic levels, including squid. In contrast, birds sampled while feeding chicks fed on a narrower range of prey from higher trophic levels, such as fish, from inshore areas of the Marlborough Sounds.

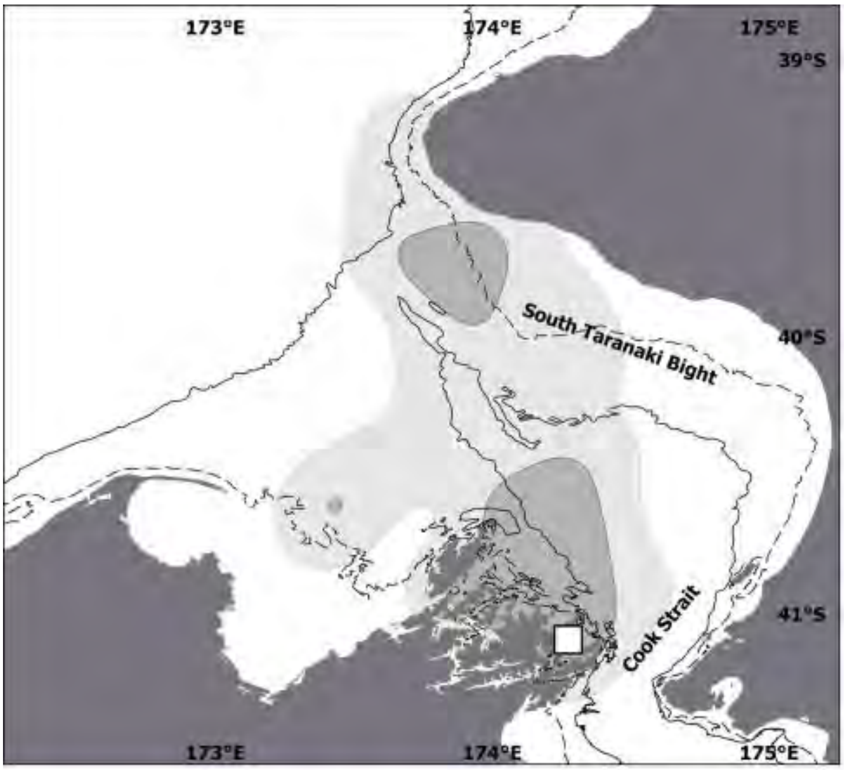

Figure 5: Foraging of Motuara Island blue penguins during incubation stage in 2015. The light grey area represents the home range (95% utilisation distribution or UD), the dark grey the focal area (50% UD). The location of the study colony is shown by the white square. The dashed line is the 50 metre bathymetric contour; the solid line is the 100 metre bathymetric contour (taken from Poupart *et al.* 2017).

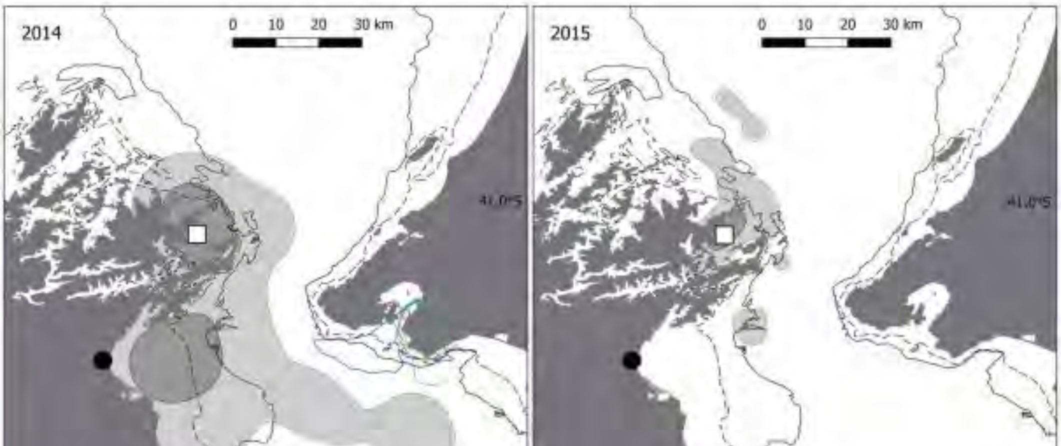

Figure 6: Inter-annual variability of Marlborough blue penguin foraging areas between 2014 and 2015. The light grey area represents the home range (95% utilisation distribution or UD), the dark grey the focal area (50% UD). The location of the study colony is shown by the white square; the black circle shows the Wairau River mouth. The dashed line is the 50 metre bathymetric contour; the solid line is the 100 metre bathymetric contour (taken from Poupart *et al.* 2017).

3.5 Albatrosses

The fisheries observer data set clearly demonstrates the presence of very high numbers of a range of albatross and mollymawk species, despite the issues inherent with non-expert identification and the different taxonomical systems used. Eleven taxa have been recorded in the combined eBird and fisheries observer data sets, and more are likely to be present, given issues with taxonomy and identification. All albatross breed well away from Cook Strait, with the closest breeding colonies being at Otago Peninsula and the Chatham Islands. All albatross species are capable of travelling hundreds to thousands of kilometres to forage and have vast feeding ranges. Most undertake extensive migrations after breeding to forage in areas distant from their breeding colonies. Albatross are not adapted to dive, and take a variety of food, mostly from the sea surface, often scavenging dead animals. Species differ in their diets, which range from large fish through to zooplankton.

Salvin's mollymawk (Threatened-Nationally Critical) is the species most commonly observed attending Cook Strait fishing vessels, and is one of the albatross species most at risk of fisheries bycatch mortality. It is mostly found from the Cook Strait south during the breeding season and migrates to seas off Peru and Chile after the breeding season. The species breeds at the Bounty Islands and Snares Island, where recent counts found *c.*41,000 pairs (Sagar 2017). Rapid declines of the species observed at Bounty Islands have been recently reported, which has resulted in the species' threat classification being upgraded from Nationally Vulnerable to Nationally Critical. The exact reason(s) for the decline are not known, but could be a combination of expanding seal populations on the Bounty Islands causing disturbance or loss of breeding habitat, commercial fishing operations that kill albatross, and/or climate change affecting food availability and distribution (Sagar *et al.* 2015). Salvin's mollymawk feeds on fish, squid, frill, salps, and offal from fishing boats, all taken from the surface.

3.6 Petrels and shearwaters

A total of 29 taxa of shearwaters, petrels, fulmars, diving petrels, and storm petrels have been observed within Cook Strait waters (eBird and fisheries observer data sets combined). Unlike albatross, at least six species breed at locations within the Marlborough Sounds (Map 2, Appendix 1). Two species - fluttering shearwater and fairy prion - are particularly common in Cook Strait according to eBird observations, with almost 20,000 records apiece. Other abundant species include sooty shearwater and Cape petrel, the latter being the most commonly recorded petrel/shearwater attending commercial fishing vessels, by an order of magnitude (Table 2). Both are caught in high numbers as fisheries bycatch.

Buller's shearwater (At Risk-Naturally Uncommon), flesh-footed shearwater (Threatened-Nationally Vulnerable), Hutton's shearwater (Threatened-Nationally Vulnerable), Westland petrel (At Risk-Naturally Uncommon), diving petrel (At Risk-Relict), white-chinned petrel (Not Threatened), and northern giant petrel (At Risk-Recovering) have also been recorded in the hundreds in Cook Strait (eBird and fisheries observer records). Populations of flesh-footed shearwater and Hutton's shearwater are in decline.

3.6.1 Fluttering shearwater

Fluttering shearwaters (At Risk-Relict) breed on several islands within the Marlborough Sounds but numbers have not been reported (Map 2). They are a regular sight in inshore waters, often seen in massive flocks while foraging. The species commonly remains within New Zealand coastal waters during the non-breeding season. The size of the population is poorly known; in the 1980s, the population was estimated at between 100,000 and one million birds (Gaskin 2013).

3.6.2 Hutton's shearwater

Hutton's shearwater (Threatened-Nationally Vulnerable) only breeds in the alpine zone of the seaward Kaikoura ranges. An introduced population has been established in farmland on the Kaikoura peninsula, within a predator-proof fence. The population is estimated to number over 100,000 pairs. Hutton's shearwater is primarily threatened by predation by stoats (*Mustela erminea*) and feral pigs (*Sus scrofa*), and the trampling of burrows by ungulates. The Waiau earthquakes of 2016 appear to have destroyed 10-15% of the colonies in landslides, as estimated from aerial photographs. The species mostly consumes crustaceans and small fish (Gaze 2017).

3.6.3 Sooty shearwater

Sooty shearwater (At Risk-Declining) is the most abundant seabird species within New Zealand, occurring in at least 180 breeding sites, and has been estimated at *c.*4.4-5.0 million pairs or up to 30 million birds; Waugh *et al.* 2013). The species breeds at several locations within the Marlborough Sounds but numbers are not known (Map 2). Several hundred thousand chicks are harvested annually as part of a customary take on islands around Stewart Island. The species feeds over inshore and offshore waters and undertakes non-breeding season migrations to the northern Pacific.

3.6.4 Flesh-footed shearwater

The population of flesh-footed shearwater (Threatened-Nationally Vulnerable) in New Zealand is estimated to number less than 12,000 breeding pairs (Taylor 2013a). Most of the global population is found in Australia. Both populations are in decline, probably due to interactions with fisheries vessels, and possibly ingestion of plastics. One colony is known from the Marlborough Sounds, on Titi Island, where a recent study estimated 157 breeding pairs (Waugh *et al*. 2014). This colony is approximately eight kilometres from the proposed open ocean farm site. During the non-breeding season, flesh-footed shearwaters migrate to the North Pacific Ocean. During the breeding season (approximately September to May), the species forages up to 400 kilometres from its breeding site but can be found over the continental shelf and shelf break (Kirk *et al.* 2017; Waugh *et al*. 2014). Five at-sea tracks were obtained from birds on Titi Island during the breeding season, showing that individuals foraged through Cook Strait, as far north as northern Taranaki, south down the West Coast, and out onto the Chatham Rise (Waugh *et al*. 2014). The species feeds on small fish and squid, usually taken in shallow dives.

3.6.5 Cape petrel

The New Zealand subspecies of Cape petrel (At Risk-Naturally Uncommon) breeds on the Snares, Bounty, Antipodes, Auckland, and Chatham Islands, and is commonly seen foraging from the Cook Strait south. The second subspecies breeds outside of New Zealand waters, but foraging distributions overlap. Cape petrels eat krill, amphipods, small fish and squid, and offal from fishing vessels. They take food from the surface, and rarely dive (Sagar 2013).

3.6.6 Fairy prion

Fairy prions (At Risk-Relict) are one of the most abundant and widespread seabird species in New Zealand, with a population numbering in the millions of pairs (Jamieson *et al.* 2016). Breeding populations are distributed from the Poor Knights Islands in the north to the Subantarctic, and several colonies are known from the Marlborough Sounds (Map 2). The largest colony in New Zealand is on Takapourewa/Stephens Island, estimated at 1.4 million pairs (Jamieson *et al.* 2016). Fairy prion is considered to be largely non-migratory, staying in New Zealand waters year-round, and feeding on or near the surface on krill, small fish and squid (Miskelly 2013). However, little research has been undertaken on foraging habits and at-sea distribution. This species is observed regularly in inshore waters.

3.6.7 Common diving petrel

The northern subspecies of common diving petrel breeds at several locations in the outer Marlborough Sounds including a large colony on the Trio Islands. The population may exceed more than a million pairs within New Zealand. Numbers in the Marlborough Sounds are poorly known. Despite being a very small seabird (weighing around 130 grams), individuals are able to dive relatively deeply; one study recorded mean maximum dives of 10.9 ± 6.1 metres, and up to 22.2 metres (Taylor 2009). The species primarily feeds on krill and copepods, obtained by pursuit diving (Miskelly 2013).

3.7 Australasian gannet

Australasian gannets (Not Threatened) breed at various sites around the New Zealand coast, and in Tasmania and south east Australia. Around 87% of the population occurs in New Zealand (Frost 2017). Aerial surveys have been undertaken of gannet colonies since the 1940s. The New Zealand population was estimated to be 46,004 breeding pairs in 1980-81, having increased from 37,774 pairs in 1960-61, and 21,033 pairs in 1946-47 (Wodzicki *et al.* 1984). Aerial surveys in 2000 have not been analysed but have been estimated to represent 55,000 pairs (Stephenson 2005), which would represent another increase. Ismar (2013) has suggested that the population is increasing at a rate of approximately 2% per year.

Gannets breed at two locations in the Marlborough Sounds, and at Cape Farewell, having only established in the northern South Island in recent decades. Birds were first reported breeding at Forsyth Island in 1969, but the colony was abandoned the following year. Birds shifted to the nearby mainland, but this colony also failed (Wodzicki *et al.* 1984). Gannets established a colony on a small peninsula forming the western coast of Waimaru Bay in 1975. Over 180 nests were counted in 2001 (Brown and Wilson 2004). A third colony established in the Marlborough Sounds in 1999 at Onario Point on Arapawa Island, shifting shortly after to Papakura Point. In 2002, 45 nests were reported at this colony (Brown and Wilson 2004).

Plate 1: Australasian gannet colony at Waimaru, Pelorus Sound.

Foraging ranges of Australasian gannets have been studied by several authors. For example, 21 gannets at the Cape Kidnappers colony travelled a mean distance from the colony of 55.6 ± 23.3 kilometres, with birds flying an average of 267.9 ± 120.6 kilometres during each foraging trip (Machovsky-Capuska *et al.* 2014). Australasian gannets have also been shown to undertake extensive non-breeding seasonal migrations. Geolocators attached to gannets at the Cape Kidnappers colony demonstrated that individual gannets flew to coastal waters of South Australia and Tasmania to overwinter, travelling up to 13,000 kilometres (Ismar *et al.* 2011).

The species regularly attends 'boil-ups' of dense fish schools brought to the surface by dolphins and predatory fish. It feeds on a variety of fish and squid, usually diving to less than six metres deep, although occasionally diving deeper (Machovsky-Capuska *et al*. 2011).

3.8 Shags

Six shag species are resident in the Marlborough Sounds. All species breed in the Marlborough Sounds and all feed in marine waters, king shag and spotted shag exclusively so. The distribution of colonies within the Marlborough Sounds is relatively well described due to regular surveys of king shag colonies, and an extensive survey of the entire Marlborough Sounds coastline (*c.*1,500 kilometres) in 2006 (Bell 2012). The 2006 survey data may not be entirely applicable to 2018, as all shag species abandon old colonies and establish new colonies over periods of time. However, these data still provide important information about the general distribution and relative abundance of shag species in the Sounds. Individual species accounts are provided below.

3.8.1 King shag

King shag (Threatened-Nationally Endangered) is the most threatened of the shag species found in the Marlborough Sounds. It is now entirely restricted to the Marlborough Sounds, but was once found more widely around the northern coast of the South Island, and around the southern coast of the North Island, probably experiencing range contraction after Polynesian arrival (Rawlence *et al.* 2017). The potential for recolonisation of former parts of its range exists; single king shags have been recorded in Wellington Harbour (July 2002) and Kaikoura (October 2011), and in 2015 and 2016, seven individual king shags, mostly first and second year birds, were recorded at Abel Tasman National Park (Schuckard 2017).

The species' threatened status is entirely due to its small population size (Robertson *et al.* 2017). The population is generally considered to be stable (e.g. Schuckard 2006a; Robertson *et al.* 2017), although survey data have not been collected using consistent methods, and so must be treated with caution. The first aerial census of all known colonies in February 2015 recorded 839 individuals at nine locations within the Marlborough Sounds (Schuckard *et al.* 2015). The following census in February 2018 indicated 24% fewer birds than in 2015 (Schuckard 2018). Preliminary analysis of a third aerial count in 2019 showed an apparent increase of 20% compared with the 2018 count (M. Bell unpublished data).

Plate 2: King shag colony at Duffers Reef, Pelorus Sound.

King shags are generally considered to forage within the Marlborough Sounds almost exclusively, and not out to sea. Two foraging studies indicate king shag will forage a maximum of 24 kilometres from the colony (Schuckard 1994, Schuckard 2006b).

Almost all the *c.*1,000 foraging records of king shag are from within the Marlborough Sounds (R. Schuckard unpublished data, compiled from numerous sources). However, it is likely that little effort has been spent searching for the species out to sea. Sixteen eBird records are of king shag in the Cook Strait area (although these could potentially be misidentifications or inaccuracies with sighting localities).

King shags are generally considered to be benthic foragers, taking mostly fish from the sea floor, as inferred from the results of two dietary studies. However, studies using geolocator tags have shown that several other species of *Leucocarbo* shags undertake pelagic dives as well as benthic dives.

3.8.2 Pied shag

In 2012, pied shag (At Risk-Recovering) was considered to be in decline, numbering between 1,000-5,000 mature individuals, and was classified as Threatened-Nationally Vulnerable (Robertson *et al*. 2012). The status of the species has been recently revised based on an in-depth population review (Bell 2013), and is now considered to be At Risk-Recovering, and numbering 5,000-20,000 mature individuals (Robertson *et al*. 2017). Examination of counts indicates numbers are increasing, at least within two of the three disjunct populations, in northern North island and central New Zealand (Bell 2013). Large numbers of pied shags have been recorded in Cook Strait (eBird records). The extensive 2006 survey of the Marlborough Sounds located many small colonies throughout the region (Map 6), suggesting that the population likely exceeds 1,000 mature individuals.

Pied shags used the Rena wreck, salvage vessels and buoys as roosts during the salvage operations (Riddell and Kessels 2014), indicating the distance the species will feed from shore (approximately 20 kilometres). The species' diet is poorly documented, but Powlesland (2017) notes that pied shag take fish from 6-12 cm in length including flounder, mullet, eel, goldfish, perch, goatfish, kahawai, wrasse, and common trevally. A Queensland study showed that the species took prey ranging from 2-45 cm in length, and was largely dependent on fisheries discards of bycatch (Blaber and Wassenberg 1989).

3.8.3 Spotted shag

Spotted shag (Not Threatened) is an endemic marine shag species, mostly found around the South Island, with a restricted distribution in the North Island (Robertson *et al*. 2007). The population is estimated at 10,000-50,000 pairs; increases have been recorded around Banks Peninsula and Wellington Harbour in recent decades. When not breeding, spotted shags form large feeding and roosting flocks of up to 2,000 birds (Szabo 2013). The Marlborough coastline shag survey located 193 spotted shag colonies (Bell 2010).

Frost (2017) reports that spotted shag feed up to 16 kilometres offshore on small fish and marine invertebrates in waters >10 metres deep (Stonehouse 1967; Marchant and Higgins 1990). In one South Island study, the principal prey species of spotted shag was the small fish ahuru, followed by red cod; Lalas 1983). The species is the most common shag seen in the Cook Strait (eBird records).

3.8.4 Other shag species

The three remaining shag species - black shag (At Risk-Naturally Uncommon), little black shag (At Risk-Naturally Uncommon), and little shag (Not Threatened) - have all been recorded in Cook Strait in low numbers, but are much more common in inshore waters. The large black shag generally dives in shallow water of only a few metres in depth, taking medium-sized fish. An Australian study of black shag, little black shag, and little shag predation of indigenous fish in farm dams found that the three species would travel extensive distances; some farm dams were at least 40 kilometres from the nearest colony, but were visited regularly (Barlow and Bock 1984). The authors found that the largest fish eaten by black shag was 43 cm long, with the smaller shag species eating fish 22 cm and 23 cm long (Barlow and Bock 1984).

3.9 Gulls and skuas

3.9.1 Southern black-backed gull

Southern black-backed gulls (Not Threatened) breed within the Marlborough Sounds. The species has undergone massive population increases since European arrival and may now number more than one million birds. It is widespread throughout the Southern Hemisphere, even as far as the Antarctic Peninsula. It is an unprotected species (Wildlife Act 1953), unlike most New Zealand seabirds (with the exception of some shag species). The gull is a well-known predator of eggs and chicks of shorebirds and braided river birds and is controlled in many areas of New Zealand to protect threatened bird populations.

Southern black-backed gulls are widespread and abundant within the Marlborough Sounds, but breeding locations are not well described. The species is a generalist forager and scavenger and can travel significant distances to feed, often attend fishing vessels well off the coast.

3.9.2 Red-billed gull

Red-billed gull (At Risk-Declining) is also widespread within the Marlborough Sounds. The subspecies is endemic to New Zealand; other subspecies are found in New Caledonia and Australia, where it is known as silver gull. Red-billed gull is one of the most well-studied seabird species in New Zealand; the banding study led by Jim Mills in the Kaikoura colony since 1964 is one of the longest running studies of its kind in the world. In New Zealand, the species was listed as Threatened-Nationally Vulnerable in 2012 due to observed rapid declines (Robertson *et al.* 2012). However, in 2016, the listing was upgraded to At Risk-Declining, as the rate of decline was thought to have decreased. Declines have been observed at several of the main colonies, including the largest colony at Kaikoura, where the species was observed to have declined by 51% between 1983 and 2005 (Mills *et al.* 2008). The key threat is predation by introduced mammals, although the close association between years of good productivity and high availability of krill (Mills *et al.* 2008) also suggests that climate changes have the potential for significant adverse effects on this species.

A recent national survey for red-billed gull undertaken over the 2014-2016 breeding seasons described 17 colonies in the Marlborough Sounds, including five colonies on

Takapourewa/Stephens Island, one of only five colonies of red-billed gull in the country estimated to number over 1,000 pairs. Takapourewa/Stephens Island was estimated to support 1,270 breeding pairs. In total, the nationwide survey located and described 243 colonies containing *c*.27,000 pairs.

The reproductive performance of red-billed gulls at Kaikoura has been studied in depth. It was found to be closely tied to the availability of krill offshore (Mills *et al.* 2008), although earthworms, small fish, garbage and kelp flies are also taken (Mills 2017). Mills (2017) notes that outside of the breeding season, the diet of red-billed gulls at Kaikoura is highly variable; some birds still feed out to sea, including following fishing vessels for discards, but others remain in terrestrial habitats, feeding on the shore on small invertebrates, or scavenging from human sources including rubbish dumps.

3.9.3 Black-billed gull

Black-billed gulls (Threatened-Nationally Critical) are one of New Zealand's most threatened bird species. Massive declines have been reported in Southland (McClellan 2009), and more recently in the South Island (Wildland Consultants 2015), where birds breed mostly on braided and other gravel-bedded rivers. The species is present in the Marlborough Sounds during the non-breeding season. A black-billed gull banded on a river in Southland, and one banded from a river in Marlborough, have both been sighted at Picton (pers. obs.). It is likely that black-billed gulls forage out to sea during these periods, although foraging habitats during the non-breeding season are poorly known, particularly the extent of their use of the marine versus terrestrial environment. Fisheries observers have seen high numbers of black-billed gulls off the east coast of the South Island (P. Langlands, pers. comm.), suggesting the species may also target krill like red-billed gull.

3.9.4 Skua

Four species of skua, a large predatory seabird, are known from Cook Strait (eBird data). They are oceanic birds, rarely seen from shore. Three species are migrants to New Zealand waters, while brown skua (At Risk-Naturally Uncommon) breeds mostly on New Zealand's Subantarctic islands, but also on the Chatham Islands and around Stewart Island. Skua are capable of taking large fish, stealing food from other birds on the wing, scavenging, and even killing other adult birds such as gull species.

3.10 Terns

White-fronted tern (At Risk-Declining) breeds at numerous locations in the Marlborough Sounds. Some white-fronted terns migrate to Australia after breeding, while others remain in New Zealand coastal waters. White-fronted tern will forage many kilometres offshore and have been commonly observed in Cook Strait (eBird). The species is thought to be primarily threatened by predation at breeding colonies.

No recent Caspian tern (Threatened-Nationally Vulnerable) breeding locations are known from the Marlborough Sounds. However, the species is observed throughout the Sounds. Black-fronted tern (Threatened-Nationally Endangered) breeds on South Island riverbeds, dispersing widely during the non-breeding season, particularly within the South Island. Over this time, the species mostly feeds offshore. It is also observed throughout the Sounds, but is not common. For all three tern species, the split between terrestrial, estuarine, and marine foraging for all species during the non-breeding season is poorly understood. eBird records indicate that white-fronted tern is common in the Cook Strait, and even Caspian tern and black-fronted tern have been recorded there, though there may be issues with location and identification.

4. POTENTIAL EFFECTS ON COOK STRAIT SEABIRDS

4.1 Overview

Marine fish farms can have many potential effects on seabirds. This section discusses the potential effects based on a review of available literature, and includes not just marine farms, but also other activities in the marine environment such as commercial fishing and offshore wind farms.

Sagar (2013) identifies the main potential effects on seabirds of 'feed-added' fish farms as:

- Habitat exclusion
- Smothering of benthos
- Changes in abundances of prey
- Provision of roosts
- Disturbance
- Ingestion of foreign objects
- Entanglement
- Collision with marine farm structures.

The following sections discuss each of these potential effects and how they relate to Cook Strait seabirds. Because most authors who discuss potential effects do so in relation to inshore fish farms and developments, the potential effect is also discussed in relation to an open ocean context.

4.2 Habitat exclusion

The presence of an enclosed marine fish farm will stop seabirds from taking food from the surface or diving within the enclosed area. Benthic-feeding seabirds, such as blue penguin and some shag species, may still be able to feed under a farm. However, the area of an open ocean marine farm will comprise a very small proportion of the foraging areas of seabirds that use such areas. This is particularly so for pelagic seabirds such as Procellariformes (albatrosses, shearwaters, and petrels), but will also be the case for other seabird groups such as gulls, terns, shags, penguins, and gannets. In general, species effects will be negligible. Effects at the regional level, in this case, the Marlborough Sounds, will also be low, for the same reason.

The only potential exception is king shag, with the entire population (*c.*800 individuals) restricted to the Marlborough Sounds. Observational studies indicate that king shag can travel a maximum of 24 kilometres from the colony to forage (Schuckard 1994, 2006b). If this is relatively accurate, the proposed marine farm site is within the travelling distance of several colonies: from those in Queen Charlotte Sound through to the Duffers Reef colony in Pelorus Sound.

However, king shags are generally considered to forage within the Marlborough Sounds and not out to sea (e.g. Forest and Bird 2014; Schuckard 2006b), where the proposed marine farm will be sited. Also, the species is thought to be a benthic forager, and so could potentially feed underneath the farm on the seafloor (king shags have been observed feeding within mussel farms within the Marlborough Sounds). Furthermore, the proposed site varies from 70-100 metres depth, which may be at the limit of king shag diving ability, and is considerably deeper than depths where king shag are generally thought to concentrate diving activity. Nevertheless, these assumptions are not backed up by robust research, and it is possible that king shag could use the proposed site, at least occasionally. Given the extent of available foraging area within the Marlborough Sounds and elsewhere out to sea, it is likely that the effect on the species would be low to negligible.

4.3 Smothering of benthos, changes in water quality

Fish farms produce significant quantities of waste in the form of fish food lost outside the enclosure and fish faeces. This accumulates on the sea floor and is dispersed beyond the footprint of the farm by local currents which may reduce water quality. Waste can smother the benthos which may change the availability of food sources for seabirds, particularly those that feed on or above the seafloor, such as blue penguin and some shag species.

The depth of water at the site - 70-120 metres - is likely to be beyond the foraging capabilities of most benthic feeding seabirds. The only possible exception is king shag. King shags are most commonly recorded foraging in water less than 50 metres depth. However, a small percentage have been recorded foraging in deeper water, and up to 90 metres (Schuckard 1994). Other related shag species from the blue-eyed shag complex can dive deeper than 100 metres. If king shag feeds in the open ocean (not yet recorded), and as deep as 70-120 metres, the proposed site still forms a very small part of the species' foraging range.

The process of salmon feeding is closely managed at existing New Zealand King Salmon farms by a combination of camera monitoring, specialised feed distribution systems, and auditing by placing a tarpaulin at the bottom of the pen to check feed loss. The extent of pellet loss has been independently examined. NIWA assessed feed loss at a low and high current site in the Sounds using eight traps in the water column between the feeding depth of the salmon and the floor of the cage. Wastage was estimated to represent less than 0.3% of the total feed supplied, and was usually less than 0.1%, except on one occasion when the feeding system failed to operate correctly. The authors compared these values with those quoted in literature, which were generally 5% or more, and concluded that feed management was effective at these farms (Cairney and Morrisey 2011). Methods to minimise feed loss will also be employed at the open ocean site (feed costs represent up to 65% of production costs; New Zealand King Salmon 2011).

New Zealand King Salmon estimate that approximately 20% of the dry matter consumed is excreted as faeces, given current feeding regimes (New Zealand King Salmon 2011).

Potential effects of the alteration of benthic habitat by an open ocean marine farm on marine seabirds are likely to be minimal, for the same reason as above: the area affected by the farm will be a very small proportion of the extensive foraging ranges of seabirds using the Cook Strait region. An assessment of the extent of any habitat alteration is beyond the scope of this report, as is the extent of water quality effects. The draft benthic assessment by the Cawthron Institute was not available at the time of writing this report.

4.4 Changes in abundance of wild fish populations

Pelagic and benthic wild fish can be attracted to marine fish farms to feed on fish food pellets or fragments of pellets that pass through the fish farm uneaten or partially eaten. Uneaten pellets and pellet fragments can alter the benthic environment which can stimulate the productivity of benthic fauna and epifauna. This, in turn, provides food for benthic fish (Kutti *et al*. 2007). The smallest 'bait fish' can enter the pens through the mesh to feed on pellet fragments. Given the very low pellet loss recorded at two Marlborough salmon farms, the potential effect of pellet loss on wild fish populations may be lower than is reported overseas.

Other factors may attract wild fish. Submerged lighting within pens to prevent maturation of salmon may potentially increase zooplankton and the abundances of wild fish. Fish and zooplankton may also be attracted to the biofouling of pen structures including nets. The fish pellets themselves, and the oily residues that can result from the stock and feed, can also attract a variety of species including gulls, shags, and some petrels and shearwaters (Surman and Dunlop 2015).

Forrest *et al*. (2007) found limited evidence for fish farms affecting the abundance of wild fish populations in New Zealand. Several shark species have been reported from the vicinity of salmon cages, and were thought to be either taking advantage of salmon mortality or the presence of aggregations of wild fish (Forrest *et al*. 2007). There is extensive literature on the effects of marine fish farms on wild fish populations overseas (reviews in Forrest *et al*. 2007, Holmer 2013). Wild fish populations have been shown to significantly decrease the amounts of waste food reaching the sea bed and some studies have suggested fish farms may serve to increase regional fish biomass and maintain wild fish stocks beyond the vicinity of the fish farm (Forrest *et al*. 2007). Some 'off-coast' marine farms have been shown to support significant wild fish biomass (tonnes), and up to 53 species (Dempster *et al*. 2002, Dempster *et al*. 2005, Dempster *et al*. 2009). Holmer's (2010) review examines the implications of open ocean marine farming and considers that open ocean fish farming is also likely to attract wild fish populations. She concludes that such effects are difficult to predict.

Such reviews do not consider the implications for bird populations. However, it is very likely that if wild fish populations aggregate at an open ocean fish farm with a degree of regularity, then the farm will also attract fish-eating seabirds, possibly including species of albatross, shearwaters and petrels, Australasian gannet, and all shag, gull and tern species. If this effect actually increases local wild fish populations from current levels, rather than only attracting fish from elsewhere, then it could be seen as a potential benefit to Cook Strait seabirds. However, it also follows that bird attraction to a marine farm will further increase the risk of avian interactions with the farm, in particular, roosting, and potential ingestion of artificial objects, entanglement, and collision (see the following sections regarding the extent of risk, and possible mitigation measures).

In an impact assessment of proposed finfish aquaculture on birds at the Houtman Abrolhos Islands off Western Australia, populations of pied cormorant, silver gull, and Pacific gull were considered very likely to increase as a result of increased wild fish populations associated with fish farm operations (Surman and Dunlop 2015). This was considered to comprise a negative outcome of fish farming as cormorants would compete for nesting space with more vulnerable bird species on the islands, and predation on the nests of other bird species would increase as a result of the larger gull populations.

Such an effect could potentially occur within the Marlborough Sounds. However, it is unlikely that this would be detrimental in the context of Cook Strait (unlike the Abrolhos Islands), as many of New Zealand’s gull and shag species are uncommon or declining. The main exception to this is southern black-backed gull, a super-abundant species that is known to have significant negative effects on many indigenous threatened bird populations through predation of eggs and chicks. Local increases in this species as a result of increased and predictable food supply may have negative effects on other seabird and shorebird species. However, as noted at the beginning of this section, the low rate of pellet loss at New Zealand King Salmon farms suggests the attraction of wild fish populations may be less than has been reported overseas.

4.5 Provision of roosts

Provision of roosts for birds is generally considered to be a positive effect. Structures such as buoys and ropes provide places for birds to rest between foraging bouts, which may reduce energy expenditure, and possibly predation. Mussel farm buoys in the Marlborough Sounds are extensively used by a variety of seabird species, and appear to often be favoured over terrestrial roosts, possibly because of perceived security from predation, or better visibility from surrounds compared to resting on the water (these factors are likely to be related). Any marine farm structure will require buoys and lighting systems for navigational purposes, and these will also provide roosting opportunities. Vessels that moor at marine farms may also provide temporary roost sites.

However, if a marine farm provides roosting habitat for numerous seabirds, it follows that this will further increase the risk of avian interactions with the farm, such as potential ingestion of artificial objects, entanglement, and collision. Furthermore, if the farm provides predictable food sources in the form of aggregations of wild fish, or food pellet waste, then the provision of roosting habitat will act to amplify this effect by allowing birds to remain at the site for long periods.

Plate 3: Spotted shags on mussel farm buoys, Marlborough Sounds.

This effect is largely limited to shags, terns, and gulls as other species rest on the sea surface (shags, terns and gulls will also rest on the sea surface). Cook Strait seabirds that will likely make use of roosts are:

- Spotted shag, which is abundant in Cook Strait waters, and up to four other species of shag, including king shag if the species uses the open ocean marine area for foraging.
- All three species of gull found in New Zealand (red-billed gull, black-billed gull, southern black-backed gull).
- White-fronted tern, abundant in Cook Strait waters, and possibly Caspian tern and black-fronted tern.
- Possibly skua species.

The Huon Fortress Pens purposefully provide minimal roosting opportunities for birds at the sea pens. In contrast, for example, the Ocean Farm 1 model appears to have multiple roosting areas for seabirds.

4.6 Disturbance

The presence of a fish farm, and the vessels and people attending the farm, have the potential to cause disturbance of breeding and foraging seabirds. This could have significant detrimental effects on breeding seabirds if an inshore marine farm is close to a seabird nesting location. However, if a marine farm is offshore, breeding locations are unaffected. Furthermore, the foraging ranges of offshore-feeding seabirds are very large, and disturbance is likely to be negligible.

Boat traffic between the port(s) and the marine farm also has the potential to disturb birds at breeding locations or roosting locations if vessels pass too close. This is particularly the case for king shag colonies which are easily disturbed if boats pass within tens of metres.

Boat disturbance of shag species has been studied (Lalas 2000). Shag species were king shag, spotted shag, pied shag, and little shag. Foraging (on water) and resting (on buoys or on coastline) shags were approached by a boat at 10 kilometres per hour, and at 50 kilometres per hour, on multiple occasions. Resting king shags were the most tolerant species with no birds disturbed by approaches to 50 metres at either boat speed. Foraging king shags, spotted shags and pied shags escaped approaching boats (by diving or flying away) at very similar distances (all three species escaping at a mean distance of 43 metres at 10 kilometres per hour, and 87, 69, and 74 metres respectively at 50 kilometres per hour). Little shags were significantly less tolerant. Notably, 49 of 50 king shags 'escaped' by diving, suggesting they would be able to recommence foraging in the same location. In contrast, most pied shags and all little shags flew away. Boat approaches to colonies were not assessed.

4.7 Foreign objects and debris

Seabirds commonly ingest foreign objects, primarily plastics, mistaking them for invertebrates such as crustaceans or fish. Adults will regurgitate plastics when feeding chicks. Some seabird populations are believed to be in decline due to plastic ingestion (e.g. flesh-footed shearwater on Lord Howe Island, Australia; Lavers *et al.* 2013). Some studies have shown that all individuals of some seabird populations now contain plastic (e.g. short-tailed shearwater, Phillip Island, Australia; Carey 2011). Many seabird species present in the Cook Strait are likely to ingest plastic waste in various forms, mistaking it for food. It is likely, however, that small plastic debris from fish farm operations will comprise a tiny fraction of what is lost to sea from all anthropogenic sources, but it nevertheless poses a risk.

Entanglement in debris associated with the operation of a marine farm can significantly affect seabirds, particularly broken or discarded nets or ropes. For example, entanglement accounted for 13-29% of observed gannet mortality in the German Bight (Schrey and Vauk 1987; in Sagar 2012). Nets and ropes are visible at the gannet colony at Waimaru, in Pelorus Sound (pers. obs.). Brown and Wilson (2004) commented: "Gannets at the Waimaru colony have used plastic debris as nesting material, 80% of some nests being composed of it. This debris is mostly off-cuts of lashings from marine farms, several hundred of which occur in the Pelorus Sound. A dead adult bird entangled in rope in 2002 (K. Gerard, pers. comm.) was the first known instance of entanglement possibly causing death to birds, but several other instances have occurred. Four adult birds were caught on 20 November 2000 to remove rope fibre from their beaks (P. Gaze, pers. comm.). Entanglement appears to be a problem mainly in the initial nest-building phase, as follow-up monitoring showed the problem did not persist later into the breeding season (S. Ward, pers. comm.)." These observations were made many years ago and, since then, the introduction of codes of conduct and other protocols have sought to reduce this type of incident. The 'lashings' described above are not a product of salmon farming, but are used to secure floats to mussel farm lines.

4.8 Entanglement

4.8.1 Overview

Bird entanglement in permanent net structures could potentially occur within the nets holding the fish, the underwater predator nets used to reduce seal, shark and cormorant/shag predation, and the above water bird nets, used to stop birds diving into the fish pens. The mesh sizes of these three structures vary. For example, New Zealand King Salmon mesh sizes range from 12.5-35.0 mm on the bar for smolt and grower pens, 100-120 mm for underwater predator nets, and 47.5 mm for bird nets (New Zealand King Salmon 2011). A more recent development in smolt and grower pens is a new, stronger mesh that eliminates the need to use predator nets which is not presently in use in New Zealand. The different sizes of mesh are likely to have different entanglement risks for birds; the larger the mesh size on the bar, the greater the risk of entanglement.

Entanglement resulting in loss of adult birds from a population could lead to significant adverse effects on population stability. The extent and impact of such losses is dependent on the location of the farm within the species' foraging range, the level at which the species is attracted to the potential food source, and the size and stability of the population. Of the eight possible effects of marine farms on seabirds, drowning by entanglement has the greatest potential significance.

4.8.2 Examples in literature and media

No seabirds have been reported entangled in aquaculture developments in New Zealand (reviews in Sagar 2012, Butler 2003, Lloyd 2003). Few published accounts exist of bird mortality in overseas fish farms. Papers that describe interactions between birds and fish farms are usually from the standpoint of birds as predators of fish, where incidental mortality of birds is not necessarily seen as an issue, and is not reported. Sagar (2012) cites Iwama *et al.* (1997), observing that drowning of birds, mostly cormorants, has occurred overseas. Two common cormorants (New Zealand's black shag is a subspecies of the same species) were reported drowned in underwater anti-predator netting in a paper examining predation of fish by cormorants (Carss 1993).

Raw data on wildlife interactions, including bird entanglements and other interactions, are available on the Global Salmon Initiative (GSI) website. The Global Salmon Initiative, of which New Zealand King Salmon is a member, is an initiative founded on three principles): improved sustainability, cooperation, and transparency[3]. Members commit to achieving the Aquaculture Stewardship Council (ASC) certification across 100% of farms. Certification requires all wildlife mortality to be made publicly available. As such, data on wildlife interactions are summarised on the Global Salmon Initiative website, and are available in varying forms and to varying degrees among the 14 company websites (which operate over seven countries).

Summary data are reported as the total number of interactions divided by the total number of sites for each of the years 2013-2017 (where data exist). Data indicate that other companies also experience the nil interaction rates of New Zealand King Salmon.

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[3] Information taken from https://globalsalmoninitiative.org.

Mowi, a company that operates in six countries, has reported rates per site per year of 0-0.71 birds in Canada (five years data), no interactions in Chile (three years), 0-9.00 birds in the Faroe Islands (five years), 0-0.11 birds in Ireland (three years), 0.61-6.20 birds in Norway (five years), and no birds in Scotland (five years). Detailed analysis of data is not easily undertaken because only the most recent data is usually available on company websites. Nevertheless, it can be seen that entanglement rates are highly variable between years, and possibly between countries. The species involved are generally not identified; where species are identified, most cases involve gull species including kittiwakes, and occasional cormorants (noting that all data are sources from coastal salmon farms). However, it is noted that the majority of species identifications are not available online.

Huon Aquaculture farms open ocean salmon and kingfish in South Australia, New South Wales, and Tasmania. The Tasmanian farms are located offshore at three locations around Bruny Island. As part of Huon's Aquaculture Stewardship Certification, the company reports on the mortality of birds[4]. At present, Huon appears to be the only company both undertaking open ocean fish farming and reporting on bird interactions.

Table 3: Bird species reported killed at three southeast Tasmania open ocean marine fish farms, January 2016 to April 2018.

Common Name	Number	Relevance to New Zealand
Southern black-backed gull	10	Same subspecies as in New Zealand.
Silver gull	15	Different sub-species to New Zealand red-billed gull.
Pacific gull	14	Not present in New Zealand.
Cormorant spp.	3	Huon Aquaculture reports three species at the farms; great cormorant (same subspecies as black shag), pied cormorant (different subspecies to pied shag), and black-faced cormorant (not found in New Zealand).
Shearwater spp.	3	Unknown.
Tern spp.	1	Unknown.

The Huon Aquaculture website states "The birds commonly found at our farms include; cormorants (black-faced, great and pied), seagulls (Pacific, silver and kelp), eagles (mostly sea, but occasionally wedge-tailed), and the occasional penguin and petrel" (downloaded 1 May 2018). From January 2016 to April 2018, 46 birds have been reported killed at farms in three different locations in southeast Tasmania (Table 3). These deaths have occurred almost exclusively due to entanglement. No further details are provided on the website.

Figure 7 illustrates bird deaths reported at the Tasmanian farms between January 2016 and April 2018. Farms at the three locations appear to differ considerably in their rates of mortality, with farms in Flathead Bay only accounting for five of the 46 birds killed. Four further birds have died up to May 2019; the decreased rate of mortality is not explained (data downloaded May 2019).

4 All information is from the Huon Aquaculture website: https://www.huonaqua.com.au/. Note that Huon Aquaculture is not presently a member of the Global Salmon Initiative.

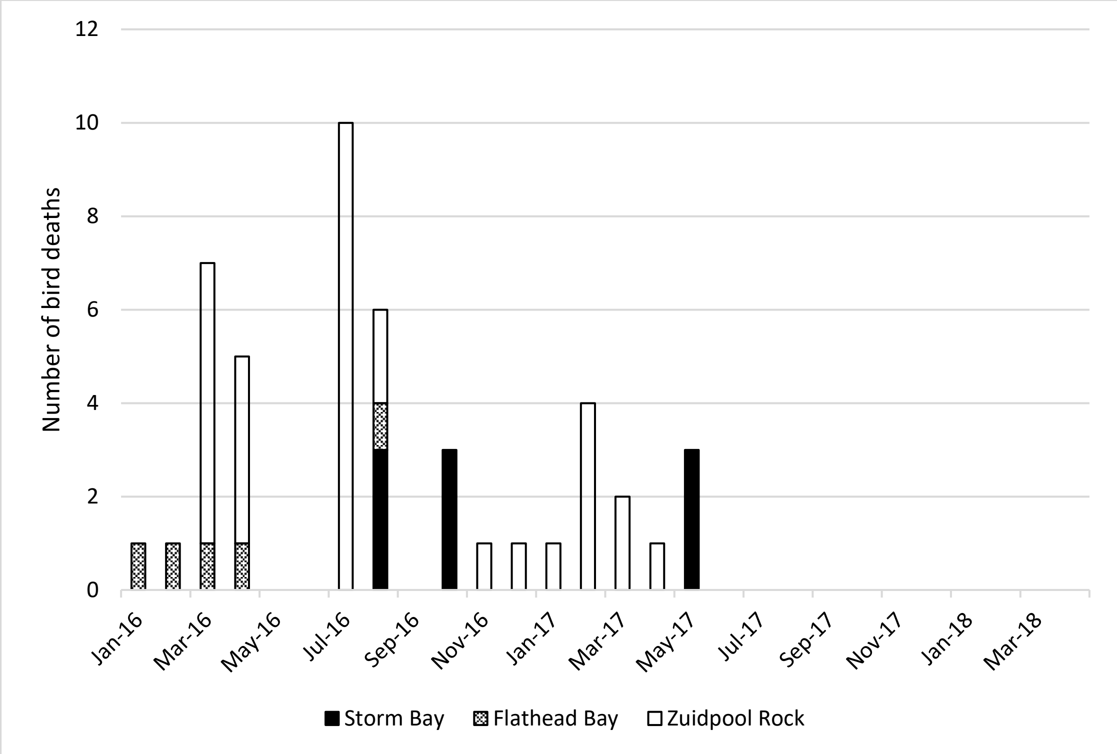

Figure 7: Seabird mortality at three open ocean salmon farms in southeast Tasmania (data from the Huon Aquaculture website[5]).

4.8.3 Preliminary assessment of entanglement risk

Accurate assessment of the entanglement risk of an open ocean fish farm to Cook Strait seabirds is difficult due to the limited number of operational open ocean fish farms worldwide and the detailed reporting of bird entanglement from inshore fish farms around the world.

Furthermore, risk will vary with the type of fish-farming method. The primary differences are between an 'above the water' farm, which will likely have bird nets and predator nets, and a submerged farm, which will only have predator nets. A submerged farm using the new stronger mesh will not have predator nets.

The following is a preliminary assessment of risk to species or species group from entanglement, based on Huon data. The Huon Fortress Pens are an 'above the water' fish farm with bird nets and predator nets, but it is not known in which part of the structure birds were entangled. In addition, depths of water at Huon farm locations, distances from land, and relative seabird abundances at Australian locations compared to the Cook Strait are unknown. Nevertheless, based on these data alone, this particular farming method is likely to pose some level of risk to Cook Strait gull populations, but may also affect shag, petrel/shearwater populations, and tern populations to a lesser degree (entanglements to April 2018 comprise 85% gulls, *c.*7% cormorants, *c.*7% shearwaters, 2% terns; Table 3). The potential entanglement risk of a submerged farm is also discussed for each species or species group.

5 Note that these data have now been taken down from the website, and only recent data are available online. The website notes that historical data are available on request due to changes in reporting systems.

Gull Species

- Southern black-backed gull (Not Threatened). Locally and nationally abundant species. Unprotected. Same species as entangled in Fortress Pens; therefore a similar type of fish farm in Cook Strait is likely to also cause mortality of birds from local populations. Low effect on local populations and negligible effect on national population.

- Red-billed gull (At Risk-Declining). Downgraded from Threatened-Nationally Vulnerable in 2017. National population 27,000 pairs, local population *c.*2,000 pairs, mostly on Takapourewa/Stephens Island. Another subspecies has been entangled in Fortress Pens, and therefore a similar type of fish farm in Cook Strait may cause mortality of birds from eastern Marlborough Sound colonies. This species is believed to be declining nationally due to effects of predation and possibly climate changes. If Marlborough Sound populations are also declining, then further mortality will exacerbate the decline to an unknown extent.

- Black-billed gull (Threatened-Nationally Critical). National population *c.*120,500 breeding birds, declining due to predation and other poorly understood effects. Local population size unknown with birds arriving after breeding in inland colonies from Southland to Marlborough. Will feed offshore during the non-breeding season, but diet is not well known, so the potential for entanglement is difficult to assess. Given the declining status of the species, further mortality will exacerbate the decline to an unknown extent.

As noted previously, it is not known how the gull species became entangled in the Huon Fortress Pens. Gulls do not dive for food, and it is likely that a fully submerged fish pen will not entangle any species of gull. It seems most probable that gulls have been entangled in bird nets that cover the Fortress Pens from above. These nets have a mesh size on the bar of 60 mm.

Shag Species

The risk to each of the six shag species known from Cook Strait environs is described below.

- King shag (Threatened-Nationally Endangered). Restricted to the Marlborough Sounds. Population considered relatively stable for several decades, but numbers only c.800 individuals. King shag is generally thought to be a benthic forager, primarily feeding on flatfish, and largely within the inner Marlborough Sounds; however, few surveys have been undertaken in the open ocean. Likelihood of attraction to pelagic fish in open ocean fish farms is possibly very low, but is not able to be ruled out based on available information. The size of the population means that any 'non-natural' mortality may have significant implications for population stability.

- Black shag (At Risk-Naturally Uncommon). National population estimated at 5,000-10,000 birds (but has never been surveyed) and believed to be stable. Not common in Cook Strait or Marlborough Sounds, and not recorded breeding by Bell (2012); local numbers may be in the low hundreds. Black shag generally forage in shallow waters, but have been observed over deep waters offshore at Huon Fortress Pens. The species feeds on both benthic and pelagic fish, and so may be attracted to the salmon at an open ocean fish farm. There is a potential for entanglement, with subsequent effects on the local population. The level of risk will depend on the rate of entanglement and the ability of the local population to absorb any loss. Effects at a national scale are unlikely.

- Pied shag (At Risk-Recovering). No longer thought to be in decline and was downgraded from Threatened-Nationally Vulnerable in 2017. National population size not well known and estimated at 5,000-20,000 mature birds. Marlborough Sounds population was 438 pairs in 2006 (Bell 2012). This species will forage offshore. Diet is poorly known but pelagic fish are taken, and it may be attracted to a fish farm. Another subspecies has been observed at Fortress Pens. There is a potential for entanglement, with subsequent effects on the local population. The level of risk will depend on the rate of entanglement and the ability of the local population to absorb any loss. Effects at a national scale are unlikely.

- Spotted shag (Not Threatened). National population poorly known and estimated at 10,000-50,000 pairs, and is considered stable. Marlborough Sounds population 1,254 pairs in 2006 (Bell 2012). This is the most likely shag species to be seen foraging offshore, but its diet is very poorly documented. Not present in Australia. There is a potential for entanglement, with subsequent effects on the local population. The level of risk will depend on the rate of entanglement and the ability of the local population to absorb any loss. Effects at a national scale are unlikely.

- Little black shag (At Risk-Naturally Uncommon). National population is thought to number several thousand birds and increasing slowly after a relatively recent self-introduction. Not common in Cook Strait or Marlborough Sounds and not recorded breeding by Bell (2012). Unlikely to be found offshore; low risk of entanglement.

- Little shag (Not Threatened). National population is poorly known and estimated at 5,000-10,000 pairs. Found throughout the country. Not common in Cook Strait or Marlborough Sounds. Recorded breeding at 23 locations in the Marlborough Sounds by Bell (2012). Unlikely to be found offshore; low risk of entanglement.

Shag species primarily dive for their food, and so remain at risk from submerged fish farms. The larger mesh size of predator nets (100-120 mm on the bar) stops shags species from reaching the fish pens, but may allow entanglements to occur, as birds would be able to put their heads and upper bodies through, or possibly wings.

A submerged farm that does not use predator nets, and uses a mesh that can withstand predation attempts by seals and shags, may have a lower risk of shag entanglement given the significantly smaller mesh sizes involved.

<u>Petrels and Shearwaters</u>

Three ‘petrels’ (species not identified) have been entangled in Huon Fortress Pens. eBird and fisheries observer records have recorded 29 species of shearwater, petrel, prion, fulmar, storm petrel and diving petrel (Procellariformes) in Cook Strait. Other species are likely to be present on occasion. Of the 29 species, four are thought to be in decline: flesh-footed shearwater, Hutton’s shearwater, black petrel and sooty shearwater. The extent to which any of the 29 species will be attracted to an open ocean marine fish farm is not known; dietary studies are often lacking or limited, and where they are known, sometimes demonstrate significant variability between the breeding and non-breeding season and within different parts of species' vast foraging ranges.

For example, Lavers *et al*. (2014) state that the diet of flesh-footed shearwater is poorly known, but that limited data from Lord Howe Island indicates birds feed on squid. In contrast, Taylor (2013) notes that the species specialises on small fish caught by shallow dives into shoals, or occasional deeper dives reaching 30 m in depth, and that birds sometimes eat small squid. Another study used digestive tract contents and stable nitrogen isotope ratios to examine flesh-footed shearwater diet in the central North Pacific Ocean (Gould *et al*. 1997). Digestive tract remains indicated that flesh-footed shearwater took small fish, but stable nitrogen isotope values showed the species fed heavily on soft-bodied animals such as *Velella* species (a jellyfish-like creature often known as the 'by-the-wind-sailor').

Flesh-footed shearwaters are attracted to longline bait, and are a common bycatch of that industry. It is not clear that species such as flesh-footed shearwater that are attracted to fisheries vessels would also be attracted to fish pens, but it is a possibility.

Submergence of a marine farm is likely to stop interactions with species that primarily feed on the surface or only undertake shallow dives of a few metres, such as grey-faced petrel, or fluttering shearwater. However, other species such as sooty shearwater have significant diving capabilities (mean maximum dive depth of 39.2 ± 2.9 metres; Dunphy *et al.* 2015). Shearwaters and petrels that dive to obtain food could potentially get entangled in predator nets; the absence of a predator net may reduce entanglement risk. Even small species, such as common diving petrel, show considerable diving ability (maximum dive depth 31 ± 6 metres; Bocher *et al.* 2000). Diving petrels feed on krill and copepods and so are unlikely to be attracted to salmon smolt. However, if a farm increased the abundance of krill and copepods, diving petrels may be attracted to the farm. This species would likely be able to move freely in and out of a predator net of 100-120 mm. The inner nets, which range from 12.5-35.5 mm on the bar, are unlikely to entangle any petrel or shearwater species.

In summary, Fortress Pens in Tasmania have caught three 'petrels' to date. A similar rate of capture would be highly unlikely to have national population consequences for any Procellariformes species given the mostly large population sizes.

<u>Terns</u>

Huon Fortress Pens have caught one tern. White-fronted tern (At Risk-Declining) is the tern species most likely to attend an open ocean fish farm in Cook Strait, if it is attracted to the smolt and smaller fish, and may be at risk of entanglement within above-water bird nets. Its population size is estimated at a maximum of 20,000 mature birds, and the level of risk will depend on the rate of entanglement and the ability of the local population to absorb any loss.

Albatross and Mollymawks

Albatross and mollymawks primarily take prey from the water surface, and so those species that prey on fish would most likely take wild fish attracted to the farms. Albatross and mollymawks have not been reported visiting the Huon Fortress Pens. However, it is not known how the albatross/mollymawk populations around Bruny Island in Tasmania compare with Cook Strait. Given their feeding habits, and the low rates of food loss from New Zealand King Salmon farms (leading to low attraction of wild fish) the risk of entanglement is likely to be very low, but cannot be ruled out. It is possible that albatross species that are attracted to, and caught by, fisheries vessels may be more likely to visit fish pens than other albatross species, although the activity and food sources are significantly different.

Penguins

The Huon Aquaculture website indicates the occasional presence of penguins around the farm, although penguins have not been reported entangled. These are the same species as New Zealand's blue penguins (At Risk-Declining), and are common on Bruny Island where the farms are located. It is not clear whether the birds are attracted to the Huon Fortress Pens, or are simply present in the area and opportunistically observed.

Blue penguin will feed on pelagic fish such as anchovy, slender sprat, barracoota, and pilchard, but are generally thought to feed on or just above the sea floor. Given the sea depth at the proposed location is 70-120 metres, penguins are very unlikely to undertake benthic foraging in this location, but may possibly be attracted to salmon smolt and slightly older fish within the pens, or to small wild fish attracted to the pens (although feed loss is likely to be very low, which in turn is likely to minimise attraction of wild fish).

It is unlikely that there would be a significant difference between an above-water farm versus a submerged farm; both have predator nets that may pose an entanglement risk to blue penguins. The option of using pens with no predator mesh may eliminate entanglement risk.

Gannets

Australasian gannet (Not Threatened) is listed a bird species that frequents New Zealand King Salmon farms (McConnell and Pannell 2014). Australasian gannet is common around Tasmania but has not been reported from the Huon Fortress Pens.

Gannets feed by plunging into the water from a significant height, and can dive to about 15 metres. Bird nets are highly likely to stop gannets from attempting to take fish from within an above-water pen. It also seems likely that the highly developed eyesight of gannets would allow them to see the mesh of smolt or grower pens of a submerged farm, reducing and possibly eliminating the appeal of diving for the fish underneath. Gannets could potentially be attracted to wild fish populations associating with the sea pens, although feed loss is likely to be very low, which in turn is likely to minimise attraction of wild fish. The local Marlborough Sounds gannet population is very small, and mortality due to entanglement may have effects on local population stability.

4.9 Collision with marine farm structures

Seabirds can collide with artificial structures while foraging. The development of offshore wind farms overseas has resulted in extensive literature on the risk to seabirds from collision with such structures. If the structure is associated with an attractive food source, such as commercial fishing vessels, the risk is considerably higher. For example, seabirds colliding with vessels and warp and netsonde cables of longline and trawling boats is a major source of mortality of many seabird species.

The presence of artificial lighting can also attract seabirds, increasing the chances of collision. An extreme case is of a trawler travelling in darkness on a calm, foggy night with strong ice-lights on and at dawn almost 900 prions, storm petrels, and diving petrels were found on deck, of which more than a quarter were dead (Black 2005). The attraction of fledgling petrel and shearwater species to urban areas due to artificial lighting has been known for decades. In the Canary Islands, one study reported nine seabird species being found grounded and several thousand individuals released back to the wild (Rodriguez and Rodriguez 2009). Another study showed that more than 10,000 shearwaters, storm petrels, and Atlantic puffins *Fratercula arctica* had been found grounded in the village of Hirta, St Kilda, Outer Hebrides, attracted to the lights of village buildings at night, and to street lamps along the shorefront (now no longer in use; Miles *et al*. 2010).

Lights used at night on open ocean oil rigs in Western Australia have been found to result in aggregations of zooplankton. This attracts silver gulls (different subspecies to New Zealand's red-billed gull), which undertake nocturnal foraging when preying on the aggregations (Surman and Dunlop 2015).

The risk of collision with marine farm structures could potentially affect any seabird species present. However, the extent to which an open ocean marine farm will pose a collision risk to seabirds will depend on a number of factors:

- The amount of lighting required to ensure visibility of a farm at night to boats and ships, and the brightness or lumens of the lighting.
- The degree of attraction exhibited by individual bird species to light. For example, the smaller petrel and prion species are more likely to be attracted to lights. Nevertheless, larger species can still be affected (Westland petrel have been found disorientated in the township of Westport, pers. obs.).
- Whether a seabird species will forage at night (for example, some shearwaters, petrels and gulls).
- The degree that the marine farm acts as a source of food for seabird populations.
- The structure of a marine farm, such as size, height, and visibility (for example, overhead wires are less visible than larger structures).

The New Zealand King Salmon open ocean farms will be lit by marine navigation lighting only. The farms will not be permanently manned, and boats are very unlikely to be present at night, except in exceptional circumstances. The extent of this lighting will be directed by the Harbourmaster. Such lighting is significantly less powerful than lighting on vessels, and is unlikely to attract seabirds; no reference to attraction to these structures was found in literature.

The salmon farms may use underwater lighting, which is employed to prevent salmon maturation. In general, the submerged lighting only illuminates the pens, and has little spread outside of the pens. Such lighting arrangements are used on some farms in the Marlborough Sounds, and their effects on zooplankton have been examined as well as observations made on the presence of baitfish, birds and other organisms in three different reports. Pens with underwater lighting did not have significantly different levels of a variety of zooplankton than 'dark' pens (e.g. Cornelisen *et al.* 2013). The methods were unable to confirm whether the abundance of small fish was different between light and dark pens. One report noted the presence of six to 10 red-billed gulls within one illuminated pen (with no bird net), but methods were not set up to establish whether bird numbers varied between light and dark pens.

The effects of submerged lighting on zooplankton and bait fish has not been examined in an open ocean situation in New Zealand. If the lighting increased the abundance of bait fish outside the pens, it may act as an attractant for seabirds that take small fish from the surface or dive, potentially increasing interactions with the farm.

5. METHODS TO REDUCE EFFECTS ON SEABIRDS

All of the potential effects discussed in Section 4 above are discussed below in relation to potential methods to avoid or reduce potential adverse effects on sea birds.

5.1 Habitat exclusion

Habitat exclusion is an unavoidable effect of an open ocean marine farm, but its overall effect on seabirds is considered very low given the area of the proposed farm and the foraging areas of most seabirds. The choice of farming method is likely to have minimal influence on this potential effect.

5.2 Smothering of benthos

Marine fish farms release fish and pellet waste to the surrounding waters which can build up on the seafloor. The choice of farming method is likely to have minimal influence on this potential effect.

Studies have shown that New Zealand King Salmon fish farms release very low amounts of pellets to the environment compared to other farms reported in literature due to well-developed monitoring systems.

The release of fish waste is an unavoidable effect of an open ocean marine farm, but the effects on the benthic environment is presumably significantly reduced in the deeper, turbid open ocean marine environment compared to inshore environments. The effect of any smothering on seabird species is likely to be negligible given the depths of water at the proposed site are beyond the diving capabilities of most, if not all, benthic-feeding seabird species in New Zealand.

5.3 Changes in the abundances of prey

New Zealand King Salmon fish farms release very low amounts of pellets to the environment because of well-developed monitoring systems. Systems to minimise feed loss will also be used in an open ocean environment. If the farm is submerged, feeding will also occur underwater, leading to a lack of visual cues above water. This may reduce seabird attraction.

Biofouling will occur on submerged farms and above-water farms, and may attract fish to the pens. This, in turn, may attract seabirds. Biofouling by organisms such as algae, barnacles, tubeworms, and mussels is carefully managed as it can reduce water flow to fish, and create excessive drag. Nets are regularly cleaned to remove algae and encrusting organisms. In general, if a farm is submerged, this would exclude all seabird species that take prey from the surface (like gulls) if wild fish attracted to the pens tend to remain at depths around the submerged pens.

5.4 Foreign objects and debris

All aquaculture facilities, including marine fish farms, must actively work to ensure minimal or no loss of debris from all operations. New Zealand King Salmon is certified under the Marine Farming Association's Environment Certification Programme, which includes adherence to the industry's Standard Operating Procedures and Codes of Practice[6]. Vessels and farms are regularly monitored to ensure compliance. New Zealand King Salmon also has a waste management plan (Gillard and Mant 2014). It is possible that the introduction of open ocean marine farming to New Zealand waters will require an updated manual to address waste management in the novel environment.

Compared with mussel farms, salmon farming does not result in lashing off-cuts (lashings are the ties used to secure floats to lines on a mussel farm). Moreover, staff are typically onsite for a greater number of hours at a salmon farm compared with a mussel farm, so that debris are able to be more readily retrieved from the water. This assists in mitigating risk.

5.5 Provision of roosts

The provision of roosts is a potential benefit for seabirds as it may reduce energy expenditure while foraging. However, roosts are undesirable at open ocean marine farms as their presence may increase the risk of negative interactions such as entanglement and collision. Reducing the attractiveness of a marine farm facility for roosting by birds is relatively widely discussed in the literature (e.g. Williams *et al.* 2013), and studies have examined the effectiveness of measures such as spikes and electric fencing to reduce the presence of birds.

Open ocean marine farm structures clearly vary in the amount of roosting habitat available to birds (see photographs in Section 2). Huon Aquaculture's Fortress Pens have been developed to minimise opportunities for roosting and have few solid surfaces. However, possibly partly because of this, and their flexible nature, they have many

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6 http://www.marinefarming.co.nz/public/mfa-environmental-certification-programme/

wires which may increase the risk of collision. Other proposed open ocean marine structures in the development and trial phase appear to have multiple areas where seabirds are likely to be able to roost, including Havfarm One and Ocean Farm 1 (see photographs in Section 2).

In contrast, fully submersible methods provide no roost sites on the actual farm structures. However, buoys, markers and lights as required by the Harbourmaster are likely to provide roost sites, but these will be limited.

5.6 Disturbance

Disturbance caused by the presence of a marine farm itself on foraging birds is unavoidable. Vessels travelling to and from a farm also have potential to disturb foraging birds, which is likewise largely unavoidable. The Lalas (2000) study indicated foraging king shag were likely to be the least affected by boat disturbance of the four species studied. This is because they were no more intolerant of boat approaches than the other three species, but were the species most likely to dive to escape, rather than fly away, suggesting they would continue foraging in the same location.

Vessels travelling to and from a port can avoid disturbing breeding and roosting birds by maintaining reasonable distances from coastlines where possible, particularly where there are known seabird roosts and colonies. An example of this is Titi Island, which supports a range of seabird species including the only colony of flesh-footed shearwaters in the Marlborough Sounds (approximately eight kilometres to the west). Additionally, king shag colonies should be passed at a distance of at least 100 metres at any time of year[7].

5.7 Entanglement and collision with marine farm structures

The greatest potential adverse impacts on seabirds in the open ocean marine environment come from entanglement and collision with structures.

Many methods have been trialled to reduce interactions between seabirds and aquaculture facilities. Methods are usually focused on reducing stock loss from predation by birds, particularly cormorants. By their nature, these methods are in effect reducing the probability of entanglement and collision.

A major study aimed at reducing conflicts between fisheries and cormorants involving stakeholders and researchers across Europe assessed the effectiveness, cost, and acceptability of numerous methods of reducing cormorant predation at aquaculture sites (Carss 2002). The following is a summary of methods focused on bird management (summarised from Carss 2002 and other sources):

- Human harassment:
  - Human patrol on foot, in vehicles or by boats.

[7] This is appropriately conservative. The most recent recommendation by Forest and Bird was a 100 metre buffer around colonies specifically during the March-August breeding season (Forest and Bird 2015: New Zealand Seabirds: sites on land, coastal sites and islands. The Royal Forest and Bird Protection Society of New Zealand, Wellington. 229 pp).

- Human presence (for example, recreational fishers).

- Audio frightening techniques:
  - Sirens.
  - Vehicle horns.
  - Gas bangers/cannons (propane gas exploders).
  - Pyrotechnics/fireworks (shell crackers, screamers, whistling projectiles, exploding projectiles, bird bangers, flash/detonation cartridges).
  - Live ammunition.
  - Helicopters, light aircraft, and drones (also visual).

- Visual frightening techniques:
  - Simple human effigies, scarecrows, or decoys of predatory birds.
  - Animated scarecrows or decoys (moving and/or in combination with automated sound devices).
  - Mylar tape.
  - Combination of audio and visual techniques.
  - Trained raptors.

- Other deterrents:
  - Chemical deterrents on the water surface.
  - Fogging machines.

- Wildlife management: lethal techniques:
  - Shooting adults and immatures to reinforce non-lethal harassment.
  - Shooting adults and immatures to reduce bird numbers at specific facilities.
  - Shooting adults and immatures to reduce regional population levels.

The Carss (2002) review assessed the effectiveness of most of the above methods and found them to be ineffective or usually only effective in the short term, even those that were often used extensively across many countries and facilities, such as human patrols or presence.

The Carss (2002) review also assessed the following 'bird barriers' through discussion with aquaculture operators:

- Physical exclosures with narrow-meshed systems (mesh sizes <20 cm) using wire.

- Lines or string in parallel or grid patterns:
  - Wire, lines or string in grid patterns (5 m mesh size).
  - Wire, lines or string in grid patterns (7.5 m mesh size).
  - Wire, lines or string in grid patterns (10 m mesh size).
  - Wire, lines or string in grid patterns (>15 m).
  - Wire, lines or string in parallel patterns (0.25 - 0.3 - (0.6) m).
  - Partial exclosures (narrow meshed).
  - Vertical nets in parallel patterns (set 5 - 10 m apart).
  - Submersed anti-predator nets with 10 cm square mesh - submerged as curtains around floating net pens.

Only the submerged anti-predator nets demonstrated consistent long-term effectiveness across aquaculture operations and were considered to be practical and acceptable. Costs were rated as high.

Overall, the general consensus in the literature is that the most effective way to reduce fish mortality by predatory birds is to fully enclose the fish with netting. This is also thought to decrease entanglement of birds as it reduces the attractiveness of the site when birds learn that they cannot secure a meal.

The use of 'anti-predator nets' which surround the fish farm underwater have now been in use on New Zealand King Salmon farms since 2000. The nets are tensioned off the farm anchors to prevent seals pressing against it to close the gap between the predator and grower nets. Trials have shown that above-water bird netting with a mesh size of 47.5 mm on the bar is the most effective mesh size.

Sagar's (2013) review suggests using mesh sizes of less than 60.0 mm to reduce bird entanglements. Huon Aquaculture's Fortress Pen system employs an above-water 'predator (bird) net' which has a mesh size of 60.0 mm[8], and a below-water 'predator (seal and shark) net' which is a heavy, taut 125.0 mm double-knotted mesh with a break load of 1200 kg. The inner net is 15.0-35.0 mm (Huon Aquaculture 2017). The inner nets are described as being higher and tauter, which keeps the nets well above the water, keeping birds away from the fish and fish feed pellets. The way the farms are designed above water with moving wires and poles reduces suitable roost and perching sites. Nevertheless, the farms still entangle a variety of seabirds, mostly gulls (as discussed in Section 4.8). This suggests the 60 mm above-water bird net is not performing well in regard to minimising the impact on birds, particularly gulls. However, it is not known what characteristics of the netting, such as mesh size, colour, tautness etc. are leading to seabird entanglements.

An Israeli paper examined the influence of net type on bird mortality at 101 netted freshwater fish ponds using 11 net types (i.e. above-water nets) which varied according to mesh size, mesh colour, mesh material, and mesh thickness. The levels of mortality were primarily a function of net visibility: fewer birds were entangled and killed as mesh size reduced, and fewer were found dead in thick or dark-coloured netting. The study also found that most birds were found entangled in the tautest nets, which was thought to be a function of the visibility of the nets: the less taut, the more the nets moved, and the more visible they became. This appears to be in contrast to the general recommendation to ensure nets are kept taut to reduce entanglements (e.g. Sagar 2013, Surman and Dunlop 2015). Disproportionally large numbers of dead birds resulted from use of thin monofilament netting (despite the smaller mesh size). National guidelines were developed that included a requirement for thick, dark-coloured material with small mesh sizes (<5 cm), and a total ban on the use of thin monofilament fish nets. The net type that entangled the least number of birds per hectare of mesh had the smallest mesh size of the 11 net types; it was 2-3 cm diameter, black, and made of woven nylon 1.8-2.0 mm thick (Nemtzov and Olsvig-Whittaker 2003).

It is not clear how such findings translate to nets underwater, but they are relevant to bird nets enclosing a marine farm above water. It suggests that the mesh size of the

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8 Huon Aquaculture website, accessed 1 June 2018.

Huon bird nets may be too large, and the 47.5 mm of the New Zealand King Salmon nets is preferable, and possibly an even smaller mesh size may be warranted. Nets should be of a dark colour, with thick mesh. The most appropriate level of tautness is less clear, but is probably the easiest aspect to alter.

No studies or descriptions of fish farms were found where the outer underwater anti-predator structure was solid, such as a wire cage. It is possible that structures that do not use mesh nets on the outside of the farm would reduce seabird entanglements further, and possibly eliminate them, at least underwater. Some of the newly-developed open ocean marine farm systems that are presently in development or in the consenting process overseas may use such a system, particularly the large, solid units like 'Havfarm One', and 'Ocean Farm 1'.

Regular checks of fish farm nets need to be undertaken to detect damaged sections quickly as these are likely to increase risk of entanglements. Repairs should be undertaken as soon as possible.

In general, light emissions should be minimised as much as possible to reduce the chance of young seabirds being attracted to the site (Miles *et al*. 2010; Rodriguez and Rodriguez 2009). The use of shielded lights that decrease upwards lighting has long been known to reduce attraction to birds (e.g. Reed *et al*. 1985). In the case of farming methods such as Havfarm One or Ocean Farm 1 being adopted, which both have large 'control centres', management of light pollution will be important. The Department of Conservation has recently released an advice sheet for cruise ships operating in New Zealand regarding onboard light management to reduce seabird attraction and mortality[9]; this would be applicable to such fish farming operations listed above.

6. SUMMARY OF POTENTIAL EFFECTS AND MITIGATION OPTIONS

Habitat exclusion is an unavoidable effect resulting from the presence of an open ocean marine farm, but is likely to have minimal effect on Cook Strait and Marlborough Sounds seabird populations because species that feed offshore have extensive foraging ranges. Similarly, the potential for smothering of benthos from open ocean marine farm waste is also likely to have minimal effect on seabird populations for the same reason, and because the effect is presumably significantly reduced in the open ocean environment due to water depths and currents.

The extent that an open ocean marine fish farm will change the abundance of seabird prey is partly determined by the amount of fish food pellets lost from the farm. The rates of loss have been shown to be very low at New Zealand King Salmon farms due to robust monitoring systems. Small 'bait fish' will be able to enter and exit from grower pens through the small mesh, and may increase in abundance around the farm due to the availability of pellets and pellet fragments in the pens. Biofouling of pen structures including nets may also attract zooplankton and small fish, though this does not appear to have been studied. Biofouling is carefully managed on New Zealand King Salmon

9 https://www.doc.govt.nz/contentassets/6d5226329ba841bb92ad4b73d35baa28/seabirds-on-cruise-ships-advice-sheet.pdf (accessed 3 April 2019).

farms as water flow to salmon reduces and net weights increase as biofouling levels increase. Submerged lighting may also affect abundances of zooplankton and small fish within and immediately around open ocean fish pens, although zooplankton was not found to be significantly affected by lighting at two inshore Marlborough Sounds salmon farms. Overall, increases in the abundance of zooplankton and wild fish may increase seabird attendance. This may be a positive influence on some seabird populations, but could potentially increase negative interactions, such as collision and entanglement.

The increased availability of a predictable food source could potentially increase the populations of seabirds which regularly attend the farm, for example, gulls and cormorants. If this is the case, then it may have the effect of negating any mortality resulting from entanglement. Increases in southern black-backed gull populations as a result of a novel and predictable food source may have negative effects on other indigenous seabird populations.

The ingestion of foreign objects, specifically plastics, is now a major concern for seabird populations worldwide. Entanglement in marine farm debris, such as broken or discarded nets or ropes is also an issue worldwide. New Zealand King Salmon is certified under the Marine Farming Association's Environment Certification Programme, which includes adherence to the industry's Standard Operating Procedures and Codes of Practice[10]. Vessels and farms are regularly monitored to ensure compliance. New Zealand King Salmon also has a waste management plan (Gillard and Mant 2014). It is possible that the introduction of open ocean marine farming to New Zealand waters will require an updated manual to address waste management in the novel environment.

The siting of a marine farm close to breeding seabird populations has the potential to create significant disturbance. For example, regular disturbance of king shag colonies could cause lowering of productivity and possible abandonment of the breeding location. Siting marine farms in the open ocean eliminates this possibility. Seabirds breeding along the coastline could still potentially be disturbed by increased vessel movements to and from the marine farm. However, this can be managed by ensuring that routes stay away from the coastline as much as possible, and at least 100 metres from any king shag colony.

Entanglement and collision are potentially the most significant effects of marine farming. Rates of entanglement in structures such as nets are not well-reported in literature; rather, research has concentrated on predation by fish-hunting bird species. Cormorants/shags are the most commonly-reported seabird at inshore fish farms overseas, and are also the most commonly-reported as becoming entangled overseas (entanglement has not been reported in New Zealand). In contrast, Huon Aquaculture, the only marine farm company that reports bird mortalities, operates open ocean marine farms in Tasmania, and the majority of mortality to date is of gulls (85% of 46 deaths over 28 months). Other deaths have been of cormorants/shags (7%), shearwaters/petrels (7%), and terns (2%). The exact method of entanglement is not known, although gulls are likely to be caught in above-water bird nets as they do not dive.

10 http://www.marinefarming.co.nz/public/mfa-environmental-certification-programme/

It is not possible to accurately extrapolate the results from the Tasmanian farms to the proposed site in Cook Strait; seabird and wild fish populations and the marine environment will differ significantly between the two locations and the method of fish farming at the proposed site is not known. However, if structures similar to the Fortress Pens were to be adopted, there is potential for similar effects on various gull, shag, tern, and petrel species, several of which are Nationally Threatened or At Risk, as foraging ranges may overlap with the proposed farm location. The level of risk will depend on the rate of entanglement and the size and stability of the population. Furthermore, the risk of entanglement of individuals from other groups of seabirds such as penguins, albatross, and shearwaters and petrels exists, as abundances of zooplankton, marine invertebrates as well as fish can increase around marine fish farms.

Refinement of Fortress Pen technology may be able to reduce bird entanglements further. For example, the below-water 'predator net', which extends above the water for over two metres, is constructed from 125.0 mm mesh, considerably larger than the recommended maximum of 60.0 mm on the bar to reduce bird entanglements. This compares to New Zealand King Salmon predator nets which are 100-120 mm on the bar. Furthermore, the above-water Fortress Pen bird nets are constructed with 60.0 mm mesh. Given this is probably where gulls are becoming entangled, the mesh size may still be too big. New Zealand King Salmon bird nets are 47.5 mm. Different levels of above-water net tautness can be trialled if required. Regular net maintenance is also required to ensure that damage is repaired quickly.

The type of fish farming method will clearly have a significant influence on the risk of entanglement. A submerged fish pen will eliminate gull entanglement as gulls do not dive; whereas blue penguin, many shearwater/petrel species, and shags will still be able to reach a submerged farm. A farm method that does not employ below-water predator nets (therefore relying solely on smolt and grower pen mesh which has a much smaller mesh size on the bar) is likely to significantly reduce the potential for underwater entanglements.

Collision with structures such as wires can lead to mortality. The use of structures such as wires which are difficult to see should be minimised, and where they are required, used in tandem with bird deterrents such as streamers or reflective discs. Lighting at an open ocean marine farm may increase the risk of collision and should be minimised as much as possible by reducing unnecessary exterior lighting, shielding any exterior lighting so it shines downwards, reducing wattages, and on any attending vessels or permanent control centres, shading windows.

Roosting surfaces at an open ocean marine farm, such as the pen structures, buoys, and attending vessels, will provide gulls, terns and shags areas to rest between bouts of foraging. Roosts allow individuals to stay at the site for long periods, even overnight. This will likely increase the risk of negative interactions with the fish farm. Roosting surfaces should be minimised, and bird deterrents used where such areas are unavoidable if possible.

7. SEABIRD MANAGEMENT PLAN

7.1 Content outline

A Seabird Management Plan will be developed, specifically addressing the chosen marine farm technology. The objectives of the Seabird Management Plan are to:

1. Minimise the adverse effects on seabirds from the operation of the marine farm.
2. Minimise the interactions of seabirds with the marine farm.
3. Determine how the operation of the marine farm will be managed adaptively to avoid, remedy and mitigate adverse effects on seabirds.
4. Establish reporting and response procedures in the event of seabird entrapment, entanglement, injury or death.

Methods by which potential effects on seabirds will be avoided or minimised will be described. These should include:

- Management of above and below water lighting.
- Demonstration that vessel movements will avoid seabird breeding areas (for example, a buffer of 100 metres around known king shag colonies and roosts).
- Minimisation and management of roost sites at the farm.
- Specification of underwater and above-water nets, including mesh size, construction, colour, and tautness.
- Management of pellet loss.
- Net maintenance regimes, including net and structure cleaning regimes to minimise biofouling.
- Management of all farm debris and waste.
- Rodent control on all vessels to minimise the possibility of accidental introductions to pest-free islands such as Titi Island.

The Seabird Management Plan will follow an adaptive management process for seabird interactions and mortality. In summary, this means that management seeks to detect issues if they arise, and then address them appropriately. All seabird interactions will be internally recorded and reported, with specific interactions such as mortality of certain species requiring notification of authorities. Certain interactions will trigger an independent review of methods. Internal or independent reviews may recommend the modification of marine farming methods. The method of injury or mortality, if known, may help to identify the issue, which could then lead to adjustments in methods, such as alteration of mesh size or tautness, which are then trialled to test their efficacy.

7.2 Seabird interactions - response and reporting

7.2.1 General interactions

All entanglements, entrapments and collisions, whether they result in injury or death, will be recorded and provided to Marlborough District Council, and publicly available as per the requirements of membership of the Global Salmon Initiative. Birds should be photographed, identified to species, and the method of entanglement or collision described in as much detail as possible, e.g. for entanglements, where the entanglement occurred, and how the bird was entangled. Given the known difficulties with accurately identifying seabird species, photographs will be sent to an expert for confirmation of identification. A dead individual may need to be packaged and sent for expert identification. Deaths and injuries of certain species will be reviewed externally (Section 7.2.2).

Protocols for reporting of entanglements, entrapments, injuries and mortality will be fully described within the Seabird Management Plan, as well as staff training in seabird identification, handling and release of live birds, and management of injured and dead birds. International protocols for dealing with injured and dead seabirds are available and these can be adapted to the New Zealand situation and will be implemented to ensure best practice.

It is proposed that all general seabird interactions are recorded for the first year of operation. This includes birds roosting on pen structures, buoys and markers, or observed in the water within approximately 50 metres of the farm. This is to obtain a picture of the different species and abundances of birds attending the farm, which may assist in identification of potential issues before they result in a notifiable event, such as an injury or death.

A vessel visiting the farm should, before reaching the farm, slow down sufficiently to allow an observer on board to record the species and numbers present at the farm before the approaching vessel disturbs the birds. This can be done when weather permits.

The ability to identify seabird species accurately requires experience. It is recognised that few, if any workers attending the farm will have sufficient experience to identify all the species of seabirds that might present. It is suggested that, as a minimum, species groups are reported. For example:

- Albatross and mollymawks
- Large, medium, and small-sized petrels, shearwaters and prions
- Shags
- Gannets
- Terns
- Gulls
- Penguins.

If possible, photographs should be taken of birds. These can be sent for expert identification if required. In the case of shags and gulls attending the farm, effort should be made to correctly identify species. In the case of gulls, distinguishing between the larger black-backed gull and the two smaller gull species (red or black-billed gull) should be done at a minimum.

If, during work at the farm, seabird abundances of any species increases, this should be recorded as a new set of observations, noting the work undertaken.

A field form will be developed for observations, which will include date, time, weather conditions, work undertaken, and species/species groups and abundances. Boats will need to be equipped with binoculars and cameras. A number of seabird photographic or illustrated guides are available, and can be added to (particularly for shags) to assist with identification at sea. It should be noted that an observation of no birds attending is as valuable as observations of multiple species and individuals.

It is understood that farms are visited relatively regularly for maintenance checks and other management operations, up to every 1-2 weeks. It is recommended that observations are undertaken for a full year. After that, results should be reviewed and the frequency of further observations evaluated. For example, it may be reasonable to scale back general observations to recording only observations of important species or unusual abundances.

7.2.2 Mortality review thresholds

New Zealand King Salmon is a member of the Global Salmon Initiative. Members commit to achieving Aquaculture Stewardship Council[11] (ASC) certification across 100% of farms. The ASC has detailed standards for salmon farming, comprising eight ‘principles’ with associated criteria (Aquaculture Stewardship Council 2019). Principle 2 is to conserve natural habitat, local biodiversity and ecosystem function. The associated Criterion 2.5 covers interaction with wildlife. It requires no mortality of “endangered or red-listed marine mammals or birds on the farm”. This is further explained as “Species listed as endangered or critically endangered by the IUCN or on a national endangered species list’.

Table 4: List of threatened bird species for which zero mortality is required as part of Aquaculture Stewardship Council certification (species obtained from eBird and fisheries observer data).

Common Name	National Threat Classification	IUCN Threat Classification
Erect-crested penguin	At Risk-Declining	Endangered
Fiordland crested penguin	Threatened-Nationally Vulnerable	Vulnerable
Moseley's rockhopper penguin	Vagrant	Endangered
Grey-headed mollymawk	Threatened-Nationally Vulnerable	Endangered
Light-mantled sooty albatross	At Risk-Declining	Endangered
Northern royal albatross	At Risk-Naturally Uncommon	Endangered
Salvin's mollymawk	Threatened-Nationally Critical	Vulnerable
Flesh-footed shearwater	Threatened-Nationally Vulnerable	Near Threatened
Hutton's shearwater	Threatened-Nationally Vulnerable	Endangered
Black petrel	Threatened-Nationally Vulnerable	Vulnerable
Westland petrel	At Risk-Naturally Uncommon	Endangered
King shag	Threatened-Nationally Endangered	Vulnerable
Black-billed gull	Threatened-Nationally Critical	Endangered
Black-fronted tern	Threatened-Nationally Endangered	Endangered
Caspian tern	Threatened-Nationally Vulnerable	Least Concern

This could be interpreted in several ways, leading to different lists of species. For the Seabird Management Plan, species listed on either or both the national list and the IUCN list have been included. This is because national threat status lists for plants and

[11] The Aquaculture Stewardship Council is an independent, international non-profit organisation that manages a certification and labelling programme for responsible aquaculture on a global basis.

animals have been specifically created in part to assist conservation management in New Zealand, and because New Zealand is a signatory to both the Agreement for the Conservation of Albatrosses and Petrels (ACAP) and the Convention on Migratory Species (CMS), international agreements that cover relevant seabird species. As per ASC standards, only IUCN Red List categories Endangered and Critically Endangered have been included in the Seabird Management Plan list, but all nationally threatened species have been included (that is, Nationally Vulnerable, Nationally Endangered, and Nationally Critical). Table 4 provides the resulting list of 15 species (scientific names are provided in Appendix 3).

This list should be reviewed each time the national bird classification lists are updated (every five years). The IUCN Red List should also be checked at this time.

The injury or mortality of one individual of any of the species listed in Table 4 will require independent review by one or more seabird experts. Other nationally threatened or Red List species could potentially be present that have not been recorded in eBird or by fisheries observers. Mortality of these species should be treated the same.

Table 5: List of At Risk bird species (species obtained from eBird and fisheries observer data).

Common Name	National Threat Classification	IUCN Threat Classification
Blue penguin	At Risk-Declining	Least Concern
Buller's mollymawk	At Risk-Naturally Uncommon	Near Threatened
Southern royal albatross	At Risk-Naturally Uncommon	Vulnerable
Shy mollymawk	At Risk-Declining	Near Threatened
Chatham Island mollymawk	At Risk-Naturally Uncommon	Vulnerable
Buller's shearwater	At Risk-Naturally Uncommon	Vulnerable
Fluttering shearwater	At Risk-Relict	Least Concern
North Island little shearwater	At Risk-Recovering	Least Concern
Sooty shearwater	At Risk-Declining	Near Threatened
Snares cape petrel	At Risk-Naturally Uncommon	Least Concern
Cook's petrel	At Risk-Relict	Vulnerable
Grey petrel	At Risk-Naturally Uncommon	Near Threatened
Soft-plumaged petrel	At Risk-Naturally Uncommon	Least Concern
Broad-billed prion	At Risk-Relict	Least Concern
Fairy prion	At Risk-Relict	Least Concern
Northern diving petrel	At Risk-Relict	Least Concern
Southern diving petrel	At Risk-Relict	Least Concern
Grey-backed storm petrel	At Risk-Relict	Least Concern
White-faced storm petrel	At Risk-Relict	Least Concern
Northern giant petrel	At Risk-Recovering	Least Concern
Black shag	At Risk-Naturally Uncommon	Least Concern
Little black shag	At Risk-Naturally Uncommon	Least Concern
Pied shag	At Risk-Recovering	Least Concern
Red-billed gull	At Risk-Declining	Least Concern
Brown skua	At Risk-Naturally Uncommon	Least Concern
White-fronted tern	At Risk-Declining	Near Threatened

In addition, the mortality of five or more seabirds listed as At Risk under the national classification system within a period of one year will also trigger an independent review by one or more seabird experts. This is because the New Zealand Coastal Policy Statement (2010) requires that adverse effects on At Risk species are avoided (Policy

11). All At Risk species identified as present in eBird lists and fisheries observer are listed in Table 5. Note that four At Risk species are listed as Endangered by the IUCN, and appear in Table 4 only (erect-crested penguin, light-mantled sooty albatross, Northern royal albatross, and Westland petrel). The injury or mortality of a single individual of any species in Table 5 will be recorded (see Section 7.2.1).

This list should be reviewed each time the national bird classification lists are updated (every five years). The IUCN Red List should also be checked at this time.

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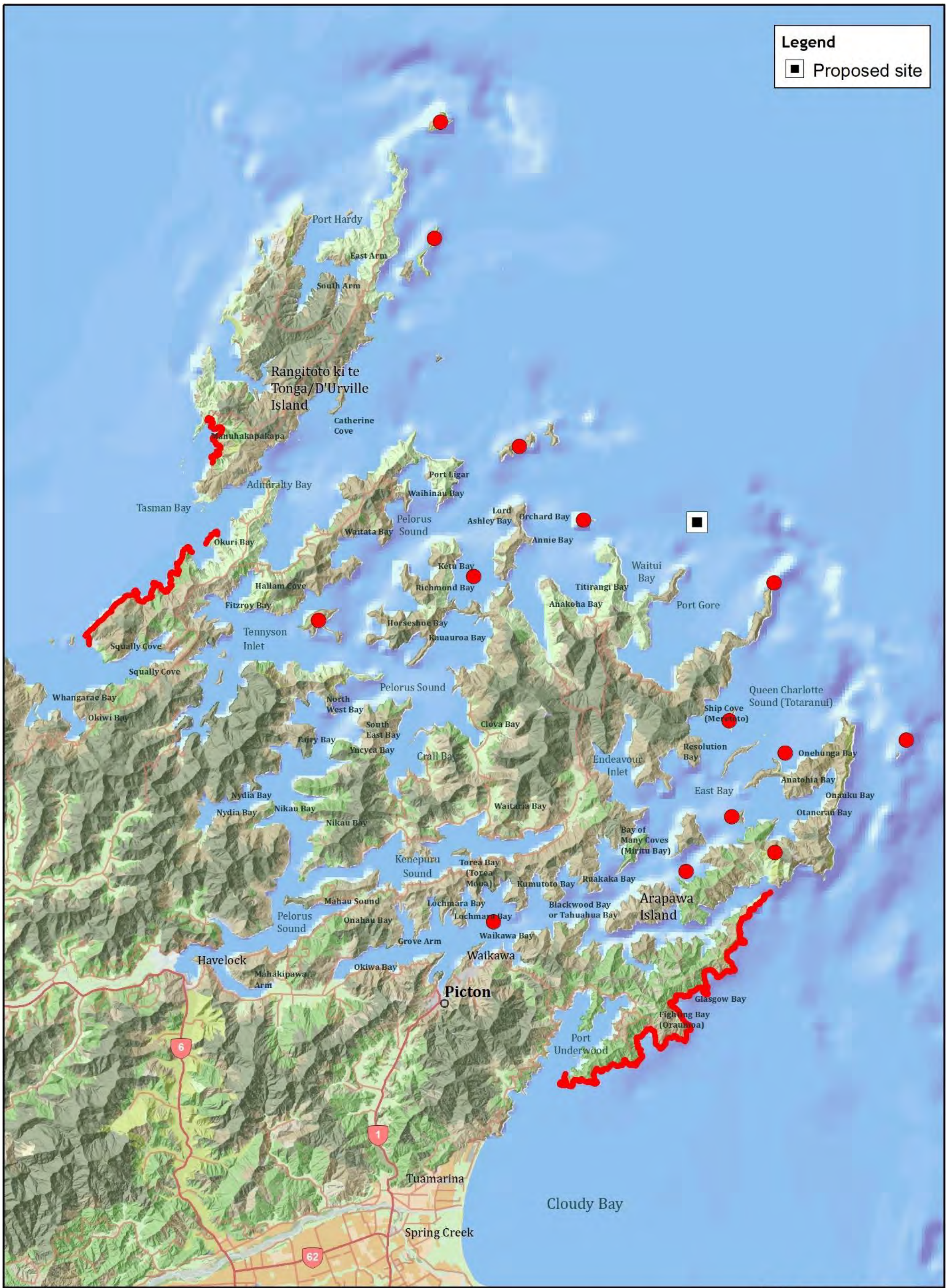
APPENDIX 1

MAPS OF SEABIRD COLONIES IN THE MARLBOROUGH SOUNDS



Data Acknowledgment
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Report: 4594
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File: Figure Little blue penguins.mxd

Map 1. Blue penguin colony locations

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Scale: 1:400,000
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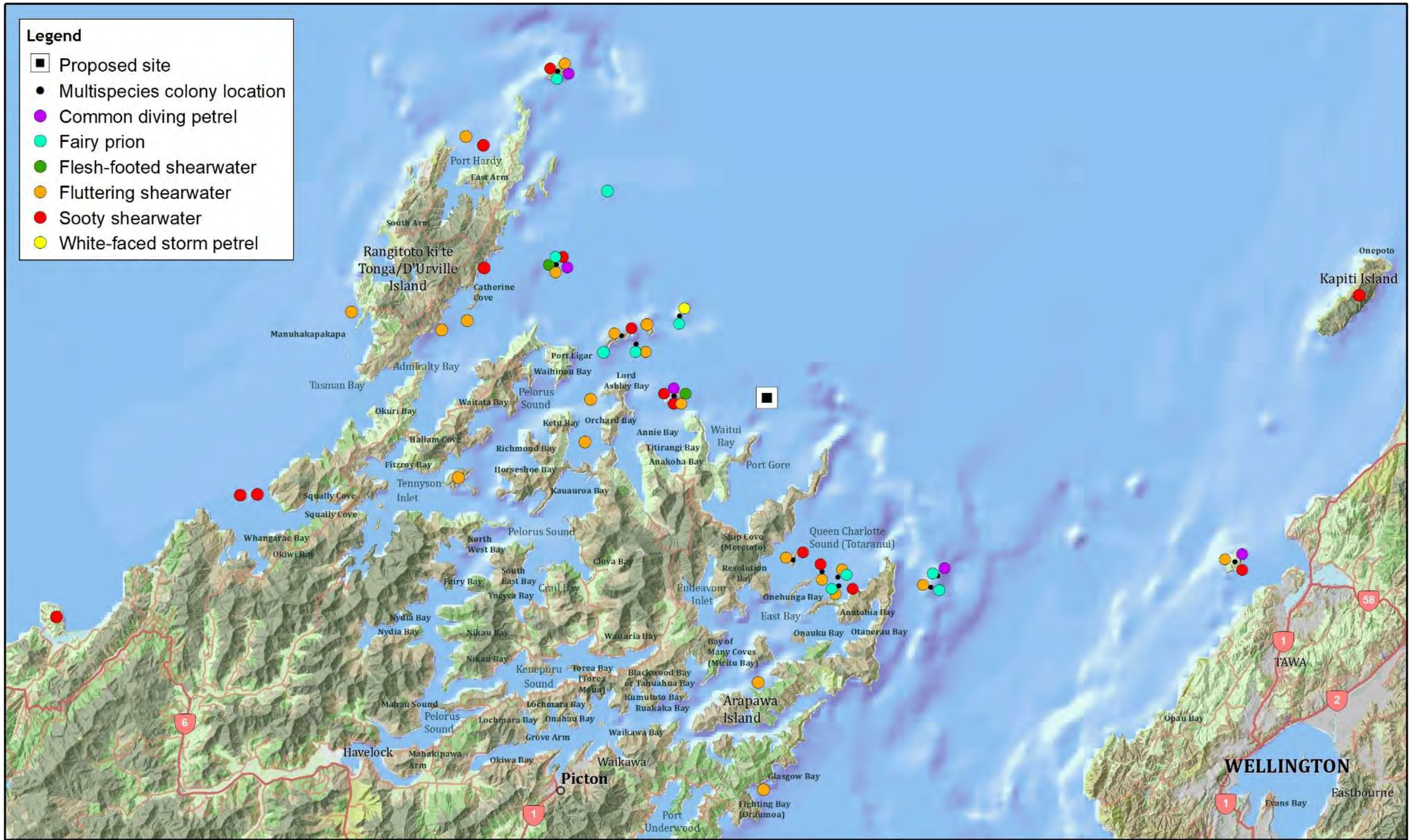
Cartographer: FM
Format: A4



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Report: 4594
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File: Figure Shearwaters_Petrels_v2.mxd

Map 2. Shearwater and petrel colony locations

0 10 20 km

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Scale: 1:500,000
Date: 29/05/2018
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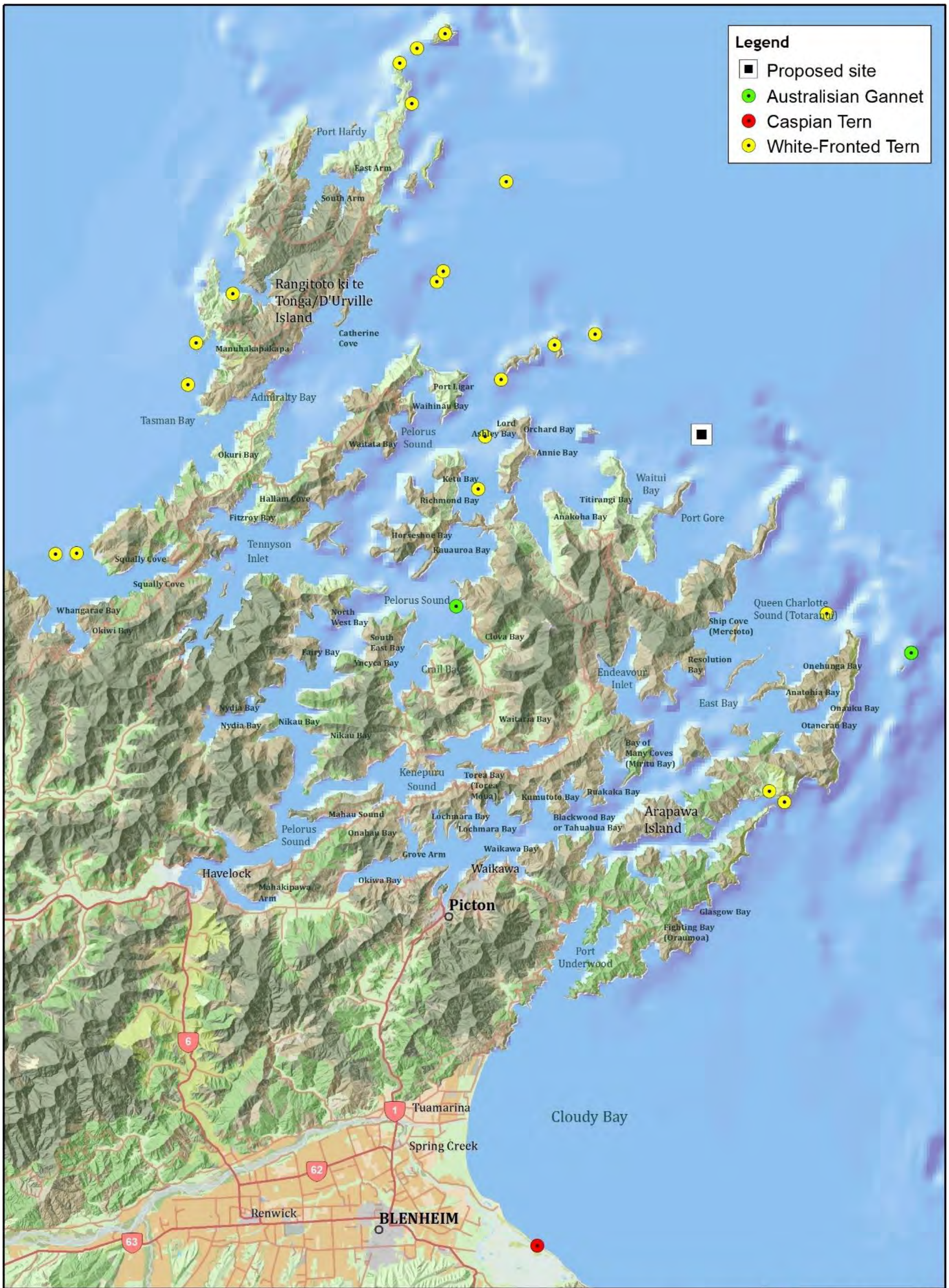

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Report: 4594
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File: Figure Caspian _WhiteFTern_Gann_P_A4.mxd

Map 3. Caspian tern / white-fronted tern / Australasian gannet

0 10 20 km

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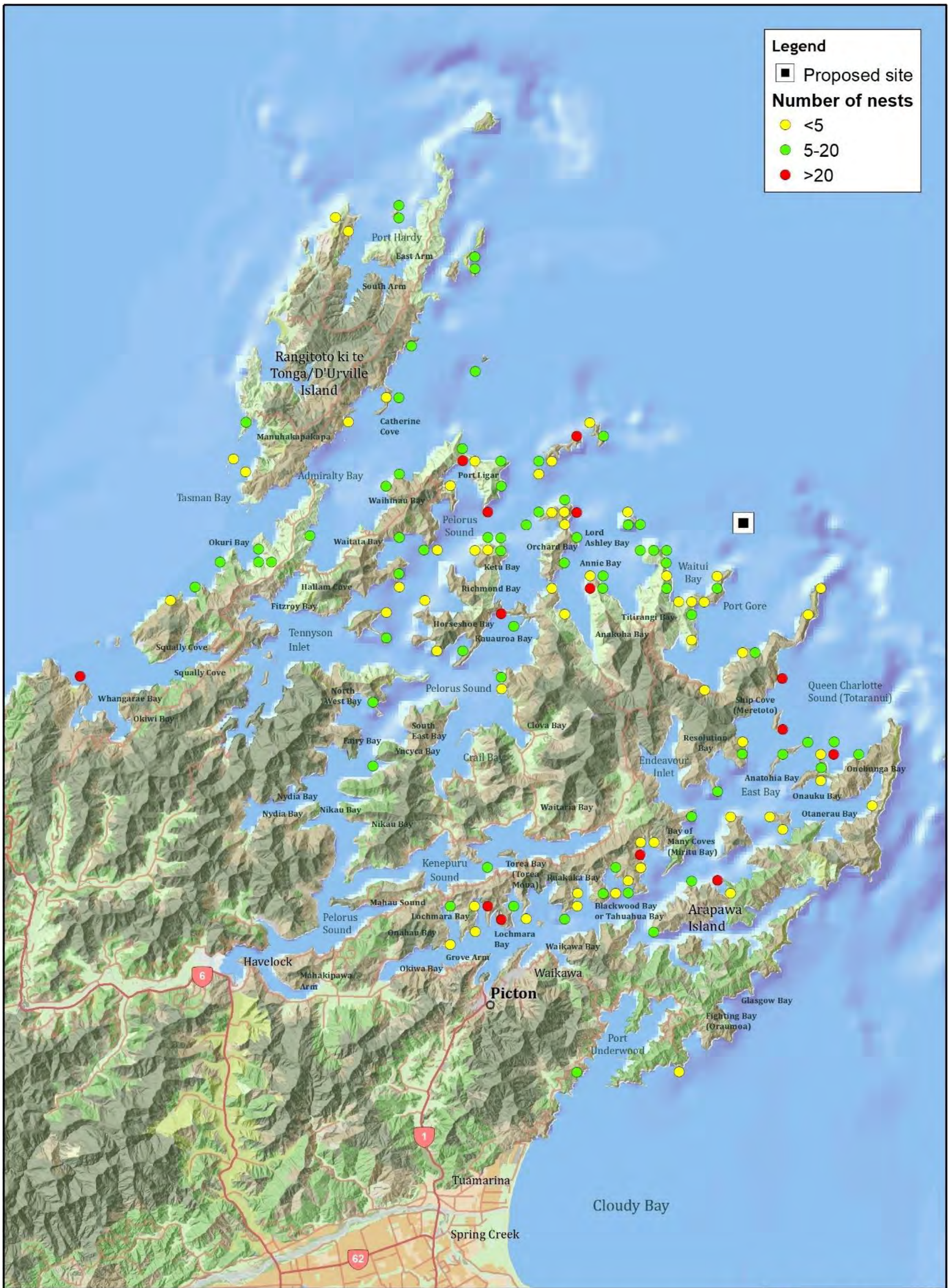
Scale: 1:400,000
Date: 29/05/2018
Cartographer: FM
Format: A4



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Report: 4594
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File: Figure SpottedShag 2006.mxd

Map 4. Spotted shag colony locations 2006

0 10 20 km

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Scale: 1:400,000
Date: 29/05/2018
Cartographer: FM
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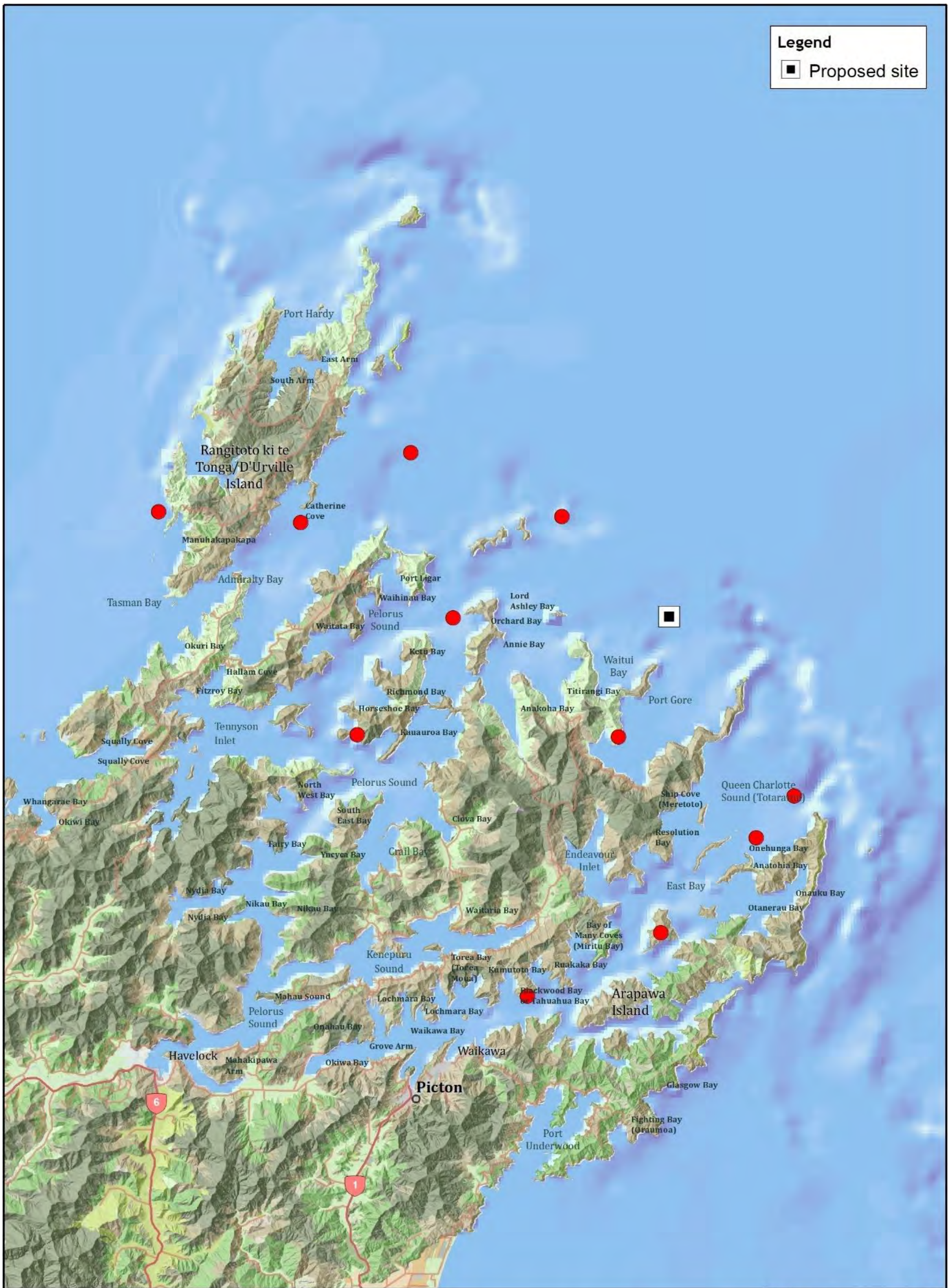

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Report: 4594
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File: Figure KingShag2015.mxd

Map 5. King shag colony locations 2015-2018

0 10 20 km

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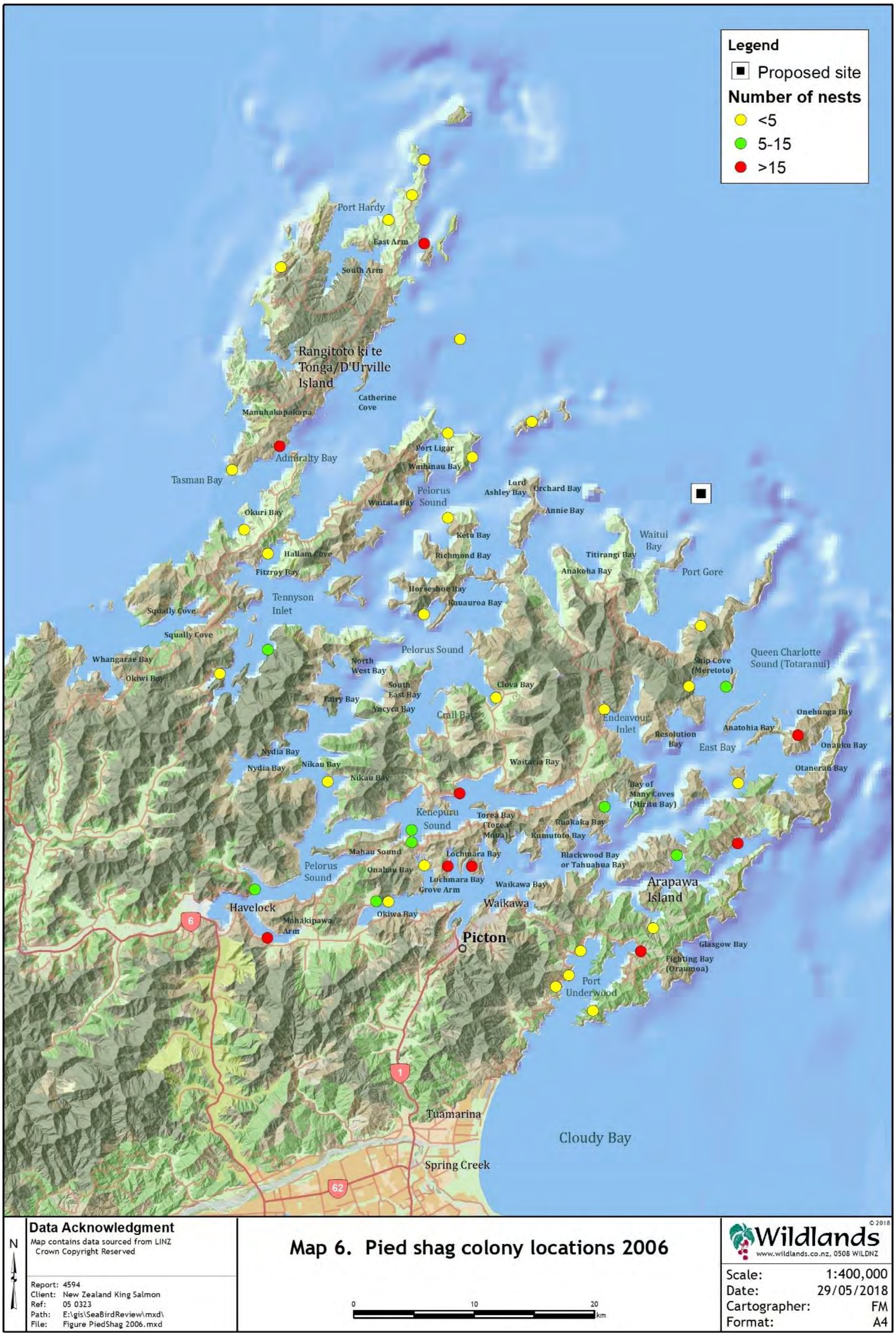
Scale: 1:400,000
Date: 29/05/2018
Cartographer: FM
Format: A4



Legend
Proposed site
Number of nests
<5
5-15
>15
Port Hardy
East Arm
South Arm
Rangitoto ki te Tonga/D'Urville Island
Catherine Cove
Manuhakapakapa
Admiralty Bay
Tasman Bay
Port Ligar
Waihinau Bay
Pelorus Sound
Waitata Bay
Lord Ashley Bay
Orchard Bay
Annie Bay
Okuri Bay
Keta Bay
Waitui Bay
Richmond Bay
Titirangi Bay
Hallam Cove
Fitzroy Bay
Anakoha Bay
Port Gore
Tennyson Inlet
Horseshoe Bay
Ruauroa Bay
Squally Cove
Squally Cove
Pelorus Sound
Whangarae Bay
Okiwi Bay
North West Bay
Ship Cove (Meretoto)
Queen Charlotte Sound (Totaranui)
South East Bay
Clova Bay
Fairy Bay
Yncyca Bay
Crail Bay
Endeavour Inlet
Onehunga Bay
Resolution Bay
Anatohia Bay
East Bay
Onauku Bay
Nydia Bay
Waitaria Bay
Nydia Bay
Nikau Bay
Otanerau Bay
Nikau Bay
Bay of Many Coves (Miritu Bay)
Kenepuru Sound
Torea Bay (Torea Moua)
Ruakaka Bay
Kumutoto Bay
Mahau Sound
Lochmara Bay
Blackwood Bay or Tahuahua Bay
Pelorus Sound
Onahau Bay
Lochmara Bay
Grove Arm
Waikawa Bay
Arapawa Island
Havelock
Waikawa
Okiwa Bay
Mahakipawa Arm
Picton
Glasgow Bay
Fighting Bay (Oraumoa)
Port Underwood
Tuamarina
Cloudy Bay
Spring Creek
6
1
62
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Report: 4594
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Ref: 05 0323
Path: E:\gis\SeaBirdReview\mxd\
File: Figure PiedShag 2006.mxd
Map 6. Pied shag colony locations 2006
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Scale: 1:400,000
Date: 29/05/2018
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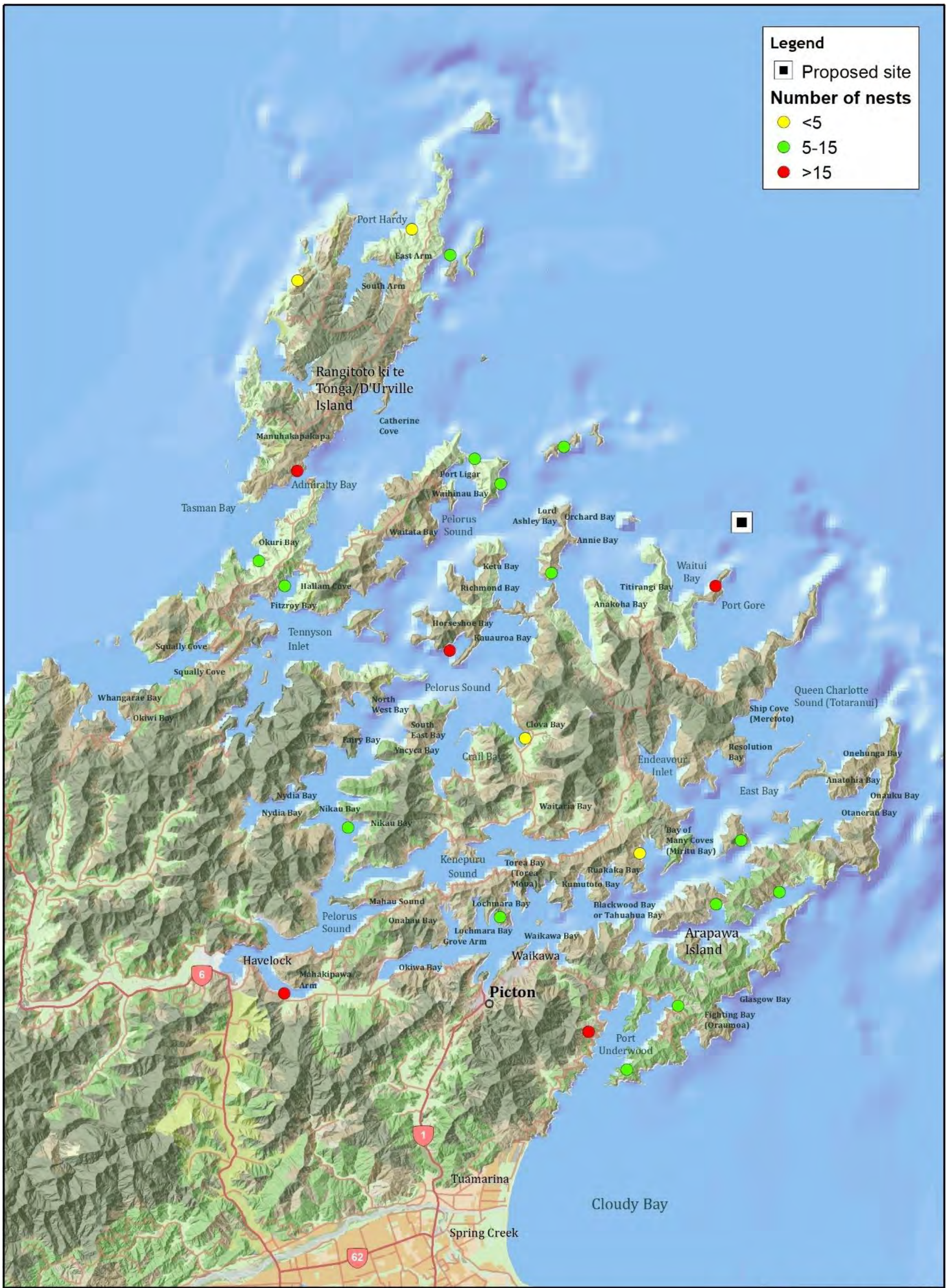

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Report: 05 0323
Client: New Zealand King Salmon
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File: Figure LittleShag 2006.mxd

Map 7. Little shag colony locations 2006

0 10 20 km

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Scale: 1:400,000
Date: 29/05/2018
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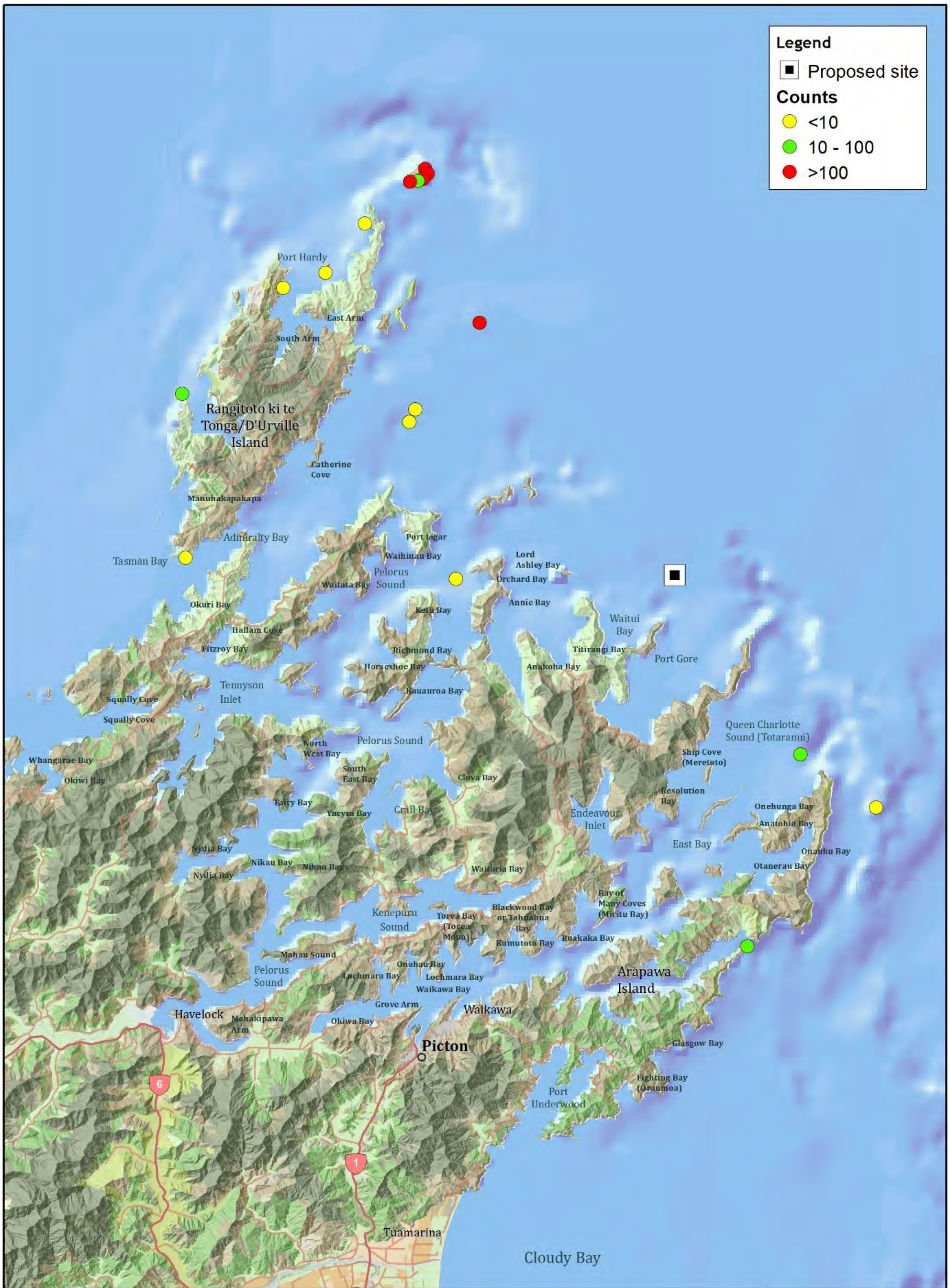

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Report: 4594
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File: Figure RedBilledGulls.mxd

Map 8. Red-billed gull colony locations

0 10 20 km

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Scale: 1:400,000
Date: 29/05/2018
Cartographer: FM
Format: A4

REFERENCES USED TO CREATE SEABIRD COLONY MAPS

Common Name	References Citing Colony Locations
Australasian gannet	Hawkins 1988, Brown and Wilson 2004
Caspian tern	Bell and Bell 2008
Diving petrel	Gaston and Scofield 1995, Gaze 2000 (and citations within), Taylor 2000, Markwell and Daugherty 2002, Miskelly and Taylor 2004
Fairy prion	Gaston and Scofield 1995, Miskelly *et al*. 2009, Jamieson *et al*. 2016 (and citations within)
Fresh-footed shearwater	Gaze 2000, Taylor 2000, Markwell and Daugherty 2002, Waugh *et al*. 2013 (and citations within)
Fluttering shearwater	Gaze 200, Taylor 2000, Wragg 1985, Markwell and Daugherty 2002, Bell 2005, Waugh *et al*. 2013 (and citations within)
Blue penguin	Davidson *et al*. 1995, Gaston and Scofield 1995, Gaze 2000, Markwell and Daugherty 2002
Red-billed gull	Frost P. Pers. Comms. May 2018
Sooty shearwater	Gaze 2000 (and citations within), Markwell and Daugherty 2002, Miskelly and Taylor 2004, Waugh *et al*. 2013 (and citations within)
White-faced storm petrel	Taylor 2000
White-fronted tern	Schuckard 2005 (and citations within)

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APPENDIX 3

SCIENTIFIC NAMES AND THREAT RANKINGS OF BIRD SPECIES

Common Name	Species Name	National Threat Classification	IUCN Threat Classification
Blue penguin	*Eudyptula minor*	At Risk-Declining	Least Concern
Erect-crested penguin	*Eudyptes sclateri*	At Risk-Declining	Endangered
Fiordland crested penguin	*Eudyptes pachyrhynchus*	Threatened-Nationally Vulnerable	Vulnerable
Moseley's rockhopper penguin	*Eudyptes moseleyi*	Vagrant	Endangered
Black-browed mollymawk	*Thalassarche melanophris*	Coloniser	Least Concern
Buller's mollymawk	*Thalassarche bulleri*	At Risk-Naturally Uncommon	Near Threatened
Grey-headed mollymawk	*Thallasarche chrysostoma*	Threatened-Nationally Vulnerable	Endangered
Light-mantled sooty albatross	*Phoebetria palpebrata*	At Risk-Declining	Near Threatened
Northern royal albatross	*Diomedea sanfordi*	At Risk-Naturally Uncommon	Endangered
Southern royal albatross	*Diomedea epomophora epomophora*	At Risk-Naturally Uncommon	Vulnerable
Salvin's mollymawk	*Thalassarche salvini*	Threatened-Nationally Critical	Vulnerable
Snowy (wandering) albatross	*Diomedea exulans*	Migrant	Vulnerable
Shy mollymawk	*Thalassarche cauta steadi*	At Risk-Declining	Near Threatened
Tasmanian mollymawk	*Thalassarche cauta cauta*	Vagrant	Near Threatened
Chatham Island mollymawk	*Thalassarche eremita*	At Risk-Naturally Uncommon	Vulnerable
Buller's shearwater	*Puffinus bulleri*	At Risk-Naturally Uncommon	Vulnerable
Flesh-footed shearwater	*Puffinus carneipus*	Threatened-Nationally Vulnerable	Near Threatened
Fluttering shearwater	*Puffinus gavia*	At Risk-Relict	Least Concern
Great shearwater	*Puffinus gravis*	Vagrant	Least Concern
Hutton's shearwater	*Puffinus huttoni*	Threatened-Nationally Vulnerable	Endangered
North Island little shearwater	*Puffinus assimilis haurakiensis*	At Risk-Recovering	Least Concern
Short-tailed shearwater	*Puffinus tenuirostris*	Migrant	Least Concern
Sooty shearwater	*Puffinus griseus*	At Risk-Declining	Near Threatened
Black-winged petrel	*Pterodroma nigripennis*	Not Threatened	Least Concern
Cape petrel	*Daption capense capense*	Migrant	Least Concern
Snares cape petrel	*Daption capense australe*	At Risk-Naturally Uncommon	Least Concern
Cook's petrel	*Pterodroma cookii*	At Risk-Relict	Vulnerable
Grey petrel	*Procellaria cinerea*	At Risk-Naturally Uncommon	Near Threatened
Grey-faced petrel	*Pterodroma macroptera gouldi*	Not Threatened	Least Concern
Mottled petrel	*Pterodroma inexpectata*	Not Threatened	Near Threatened
Black petrel	*Procellaria parkinsoni*	Threatened-Nationally Vulnerable	Vulnerable

Common Name	Species Name	National Threat Classification	IUCN Threat Classification
Soft-plumaged petrel	*Pterodroma mollis*	At Risk-Naturally Uncommon	Least Concern
Westland petrel	*Procellaria westlandica*	At Risk-Naturally Uncommon	Endangered
White-chinned petrel	*Procellaria aequinoctialis*	Not Threatened	Vulnerable
Broad-billed prion	*Pachyptila vittata*	At Risk-Relict	Least Concern
Fairy prion	*Pachyptila turtur*	At Risk-Relict	Least Concern
Antarctic fulmar	*Fulmarus glacialoides*	Migrant	Least Concern
Northern diving petrel	*Pelecanoides urinatrix urinatrix*	At Risk-Relict	Least Concern
Southern diving petrel	*Pelecanoides urinatrix chathamensis*	At Risk-Relict	Least Concern
Grey-backed storm petrel	*Garrodia nereis*	At Risk-Relict	Least Concern
White-faced storm petrel	*Pelagodroma marina maoriana*	At Risk-Relict	Least Concern
Wilson's storm petrel	*Oceanites oceanicus exasperatus*	Migrant	Least Concern
Northern giant petrel	*Macronectes halli*	At Risk-Recovering	Least Concern
Southern giant petrel	*Macronectes giganteus*	Migrant	Least Concern
Australasian gannet	*Morus serrator*	Not Threatened	Least Concern
King shag	*Leucocarbo carunculatus*	Threatened-Nationally Endangered	Vulnerable
Black shag	*Phalacrocorax carbo novaehollandiae*	At Risk-Naturally Uncommon	Least Concern
Little black shag	*Phalacrocorax sulcirostris*	At Risk-Naturally Uncommon	Least Concern
Little shag	*Phalacrocorax melanoleucos brevirostris*	Not Threatened	Least Concern
Pied shag	*Phalacrocorax varius varius*	At Risk-Recovering	Least Concern
Spotted shag	*Stictocarbo punctatus punctatus*	Not Threatened	Least Concern
Southern black-backed gull	*Larus dominicanus dominicanus*	Not Threatened	Least Concern
Black-billed gull	*Larus bulleri*	Threatened-Nationally Critical	Endangered
Red-billed gull	*Larus scopulinus novaehollandiae*	At Risk-Declining	Least Concern
Brown skua	*Catharacta antarctica lonnbergi*	At Risk-Naturally Uncommon	Least Concern
Long-tailed skua	*Stercorarius longicaudus*	Migrant	Least Concern
Arctic skua	*Stercorarius parasiticus*	Migrant	Least Concern
Pomarine skua	*Coprotheres pomarinus*	Migrant	Least Concern
Arctic tern	*Sterna paradisaea*	Migrant	Least Concern
Black-fronted tern	*Chlidonias albostriatus*	Threatened-Nationally Endangered	Endangered
Caspian tern	*Hydroprogne caspia*	Threatened-Nationally Vulnerable	Least Concern
White-fronted tern	*Sterna striata striata*	At Risk-Declining	Near Threatened
White-winged black tern	*Chlidonias leucopterus*	Migrant	Least Concern

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APPENDIX I: Sharks Comments

Emma Deason | Gascoigne Wicks

From:	Clinton Duffy <cduffy@doc.govt.nz>
Sent:	Thursday, 14 March 2019 11:52 a.m.
To:	Amanda Hills | Gascoigne Wicks
Cc:	Quentin Davies | Gascoigne Wicks; Savannah Carter | Gascoigne Wicks; Maida Jones | Gascoigne Wicks; Mark Gillard; Mark Preece; Guy Kerrison; Ian Angus; Kristopher Ramm
Subject:	RE: Offshore Salmon Farming - Effects on Sharks
Attachments:	Murray-Jones 2004 Shark interactions Workshop FRDC2002-040.pdf; Basking sharks in NZ.PDF

Hello Amanda,

Apologies for the delay in my reply, I have been out of the office quite a bit over February and March.

Nothing much has changed regarding research on shark-aquaculture interactions since the last time I gave evidence on this issue. I attach a copy of Murray-Jones (2004) – proceedings of the Workshop on Shark Interactions with Aquaculture fyi. Some recent publications of relevance are:

- Gaitán-Espitia et al. 2017. Spatial overlap of shark nursery areas and the salmon farming industry influences the trophic ecology of *Squalus acanthias* on the southern coast of Chile. Ecology and Evolution 7(11): 3773–3783. (Open Access)
- Loiseau et al. 2016. Using an unbaited stationary video system to investigate the behaviour and interactions of bull sharks *Carcharhinus leucas* under an aquaculture farm. African Journal of Marine Science, 38(1): 73-79.
- NOAA Technical Memorandum NOS NCCOS 211
http://venturashellfishenterprise.com/pdf/2017_Protected_Species_and_Marine_Aquaculture_Interactions.pdf

I have had a look at the map of the proposed marine farms you provided. The species most likely to be attracted to these farms and their responses to them are essentially the same as those described in my previous evidence. The most common large pelagic species in these areas are common thresher shark, shortfin mako, porbeagle and blue shark. There is potential for interactions with protected great white sharks in all areas, and basking sharks off the east coast South Island, particularly off Canterbury (see Francis & Duffy 2002 attached).

Regards,
Clinton Duffy

From: Amanda Hills | Gascoigne Wicks <ahills@gwlaw.co.nz>
Sent: Friday, 15 February 2019 1:45 p.m.
To: Clinton Duffy <cduffy@doc.govt.nz>
Cc: Quentin Davies | Gascoigne Wicks <qdavies@gwlaw.co.nz>; Savannah Carter | Gascoigne Wicks <scarter@gwlaw.co.nz>; Maida Jones | Gascoigne Wicks <mjones@gwlaw.co.nz>; Mark Gillard <Mark.Gillard@kingsalmon.co.nz>; Mark Preece <mark.preece@kingsalmon.co.nz>
Subject: Offshore Salmon Farming - Effects on Sharks

Good Afternoon Clinton

Please find **attached** correspondence regarding the potential effects of offshore salmon farming on sharks.

Regards

Amanda

Gascoigne Wicks LAWYERS

Amanda Hills | Associate | **Gascoigne Wicks**
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M.P. Francis · C. Duffy

Distribution, seasonal abundance and bycatch of basking sharks (*Cetorhinus maximus*) in New Zealand, with observations on their winter habitat

Received: 30 March 2001 / Accepted: 30 October 2001 / Published online: 8 January 2002

Abstract Basking sharks occur throughout New Zealand, but are most common in cool temperate latitudes of 39–51°S. Inshore records from miscellaneous sources peaked in spring–summer, with few winter records. Two records were of sharks observed in a large brackish water lake. About 203 basking sharks were observed caught by commercial trawlers between 1986 and 1999. Multiple captures were common, including 14 in one tow. Most trawl-caught sharks were taken near or outside the 250 m depth contour, and 91% came from three small regions – East Coast (EC) and West Coast (WC) of South Island and Snares–Auckland Islands (SA). The highest catch (93 sharks) and catch rate (58 sharks per 1,000 tows) were from EC, where sharks were caught only in spring–summer. In SA, sharks were caught mainly in summer, and in WC all were caught in winter. The modal seabed depths for shark tows were 300–400 m at EC, 700–800 m at WC and 150–250 m at SA. Sharks were therefore caught in the deepest water in winter at WC. It was impossible to determine the actual depths of capture, but circumstantial evidence indicates that most sharks were caught on or near the bottom. The capture of some sharks in midwater in winter argues against hibernation, because hibernating sharks are unlikely to hover in midwater. Males dominated catches in all regions, particularly in WC and SA. In WC and SA, most sharks (94%) were 7–8 m long, whereas in EC most sharks (73%) were <7 m. Based on their lengths, many of the WC and SA males could have been mature, but most EC males were probably immature. Few of the females would have been mature. This study provides support for the hypothesis that basking sharks overwinter in deep water on the continental slope.

Communicated by G.F. Humphrey, Sydney

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Introduction

Basking sharks occur in northern and southern temperate waters of both the Atlantic and Pacific Oceans, but are apparently absent from the Indian Ocean (Compagno 1984; Last and Stevens 1994). They are at times highly visible in coastal waters, and have been the subject of increasing scientific scrutiny in recent years. Yet surprisingly little is known about their behaviour, biology and ecology. In most parts of their range, basking sharks appear in inshore waters during spring, and remain there through the summer, feeding intensively on planktonic crustaceans (Berrow and Heardman 1994; Darling and Keogh 1994). They then disappear during autumn and, with the exception of Monterey Bay in California, are rarely seen during winter. Some sharks caught in autumn and winter lacked gill rakers (Van Deinse and Adriani 1953; Parker and Boeseman 1954), leading to suggestions that they cease feeding when zooplankton density declines below the level at which feeding results in a net energy loss (Matthews 1962). The prevailing hypothesis for several decades was that basking sharks migrate to deep water during winter and hibernate (Parker and Boeseman 1954; Matthews 1962). Recent evidence that sharks continue feeding at much lower zooplankton densities than previously believed possible has cast doubt on the hibernation theory (Sims 1999). The existence of an annual migration between deep water and shallow water is supported by most authors (Kunzlik 1988; Stagg 1990), despite there being only weak circumstantial evidence for it.

Little is known about reproduction in basking sharks, except that they are viviparous and, probably, oophagous. There have been only three second-hand accounts of basking shark embryos. Pennant (1769) recorded “a young one about a foot (30 cm) in length being found in the belly" of a basking shark. Sund (1943) reported six embryos about 1.5–2.0 m long being born after their mother was harpooned in Norway. And Matthews (1950) cited an unconfirmed report of a pregnant female having a six foot (1.8 m) long embryo. The dearth of pregnant female records has prompted some workers to suggest that they must remain in deep water rather than taking part in the spring shoreward migration.

Basking sharks have been seen near the surface year-round in Monterey Bay, but this population appears to be atypical. If the winter habitat of basking sharks can be identified in other parts of their range, it may be possible to test the hibernation hypothesis and to locate the elusive pregnant females.

In the southern Pacific Ocean, basking sharks are common around New Zealand, and also occur around southern Australia and along the coast of Chile and Peru. Most records are from continental shelf waters, but captures of basking sharks by driftnets in oceanic waters of the western southern Pacific (150–180°W) and the Tasman Sea indicate that some individuals at least spend some of their lives in the pelagic environment (Sharples et al. 1991; Yatsu 1995).

In the present paper, we aimed to: (1) determine the geographic distribution and depth range of basking sharks around New Zealand, (2) describe their seasonal abundance patterns and (3) determine the length and sex composition of the commercial trawl bycatch.

Materials and methods

Miscellaneous records

Records of basking sharks were compiled from personal communications to the authors, popular magazines and newspapers, and scientific reports (Cheeseman 1891; Phillipps 1946; Grieve 1966; Whitley 1967; Ryan 1974; Fenaughty and O'Sullivan 1978; Dodgshun 1980; Paul et al. 1983; Tennyson 1992; Paulin 1996; Kuban 1997). The Department of Conservation provided records of basking sharks observed during aerial surveys of Hector's dolphins (*Cephalorhynchus hectori*) around Banks Peninsula (Fig. 1) in January–March 1990–1993. Flights were conducted at a height of about 200 m and a speed of 100 knots (185 km h^{-1}).

Scientific observer and research vessel records

Catch weights for basking sharks caught by commercial trawlers in New Zealand waters between 1986 and 1999 were extracted from the Ministry of Fisheries Scientific Observer database. Information on size, sex and number of sharks caught per tow was obtained where possible from the raw data sheets completed by observers. Length was usually measured to the nearest metre total length (TL), but some observers recorded lengths to 0.1 m. Date, location, seabed depth, net type, groundline depth and headline height were also extracted from the database for all basking shark tows. The same data were extracted for all observed trawl tows (whether they caught sharks or not) for comparative purposes. Only a small proportion of the commercial tows were observed, so these data represent a subset of the catches.

Seabed depth was calculated as the mean of the depths at the start and finish of each tow. Net type was recorded by observers as bottom trawl or midwater trawl, but midwater trawl nets towed along the seabed were often coded incorrectly as bottom trawl nets. We therefore defined bottom trawl nets as those having headline heights of ≤ 15 m, and midwater trawl nets as those having headline heights > 15 m. The greatest recorded headline height was 110 m. For midwater trawl nets, tow location was defined as being on the bottom (if either the start or finish groundline depth was within 1 m of the start or finish seabed depth respectively) or in midwater.

Basking shark species identifications were checked, if possible, against photographs taken by observers; one misidentified *Somniosus pacificus* was deleted. Fifteen tows had reported basking shark catches of ≤ 150 kg. These were checked against the raw data sheets, and eight were found to have been other species that were incorrectly coded. The remaining seven records were assumed to be misidentifications and deleted.

The number of sharks caught in each tow was not always recorded by observers. Multiple sharks were caught in two tows having estimated basking shark catch weights of 45 and 50 t, respectively. We assumed a mean shark weight in these two tows of 5 t, producing an estimated nine and ten sharks, respectively. For all other tows with missing counts, we assumed one shark was caught per tow. This approach is conservative, but probably reasonable, as estimated catch weights for these tows averaged 3.3 t (range 0.6–8 t).

Unstandardised catch per unit effort (CPUE) indices were calculated (by dividing the number of sharks caught by the number of tows observed) to identify trends in catch rates by target species, month, depth and year. CPUE values are presented only for strata in which > 100 tows were observed.

Data for 18 basking sharks caught by research trawlers were extracted from the Ministry of Fisheries Trawl database, and treated in the same way as the scientific observer records.

Length conversion

We are not aware of any regression equations in the literature for converting fork length (FL) to TL, or vice versa, and we were unable to find any suitable data for developing such regressions. We converted literature reports of FL to TL using $TL = 1.10 \cdot FL$, determined from the scale drawing in Fig. 1 of Matthews and Parker (1950), which was based on the average measurements of ten sharks.

Results

Miscellaneous records

We compiled 109 miscellaneous records of New Zealand basking sharks. Of these, 39% were sightings of one or more living animals, 32% were individuals that were caught by fishers (mainly using set net, though a few were shot, harpooned or trawled), 18% were observed during aerial surveys and 11% were strandings. Excluding the sharks recorded during the aerial surveys, 84% of the miscellaneous records for which a date was available ($N = 75$) were from September–February (spring–summer) (Fig. 2).

Most miscellaneous records were from the southern North Island and the north-East Coast of South Island (Fig. 1). Only four records were from the northern North Island, and none was from the West Coast of South Island. Regions with the highest frequency of records were New Plymouth, Hawke Bay, Cook Strait, Kaikoura and Banks Peninsula (Fig. 1). Nearly all of these records were within a few kilometres of the coast. The earliest published account was of a 10.43 m shark

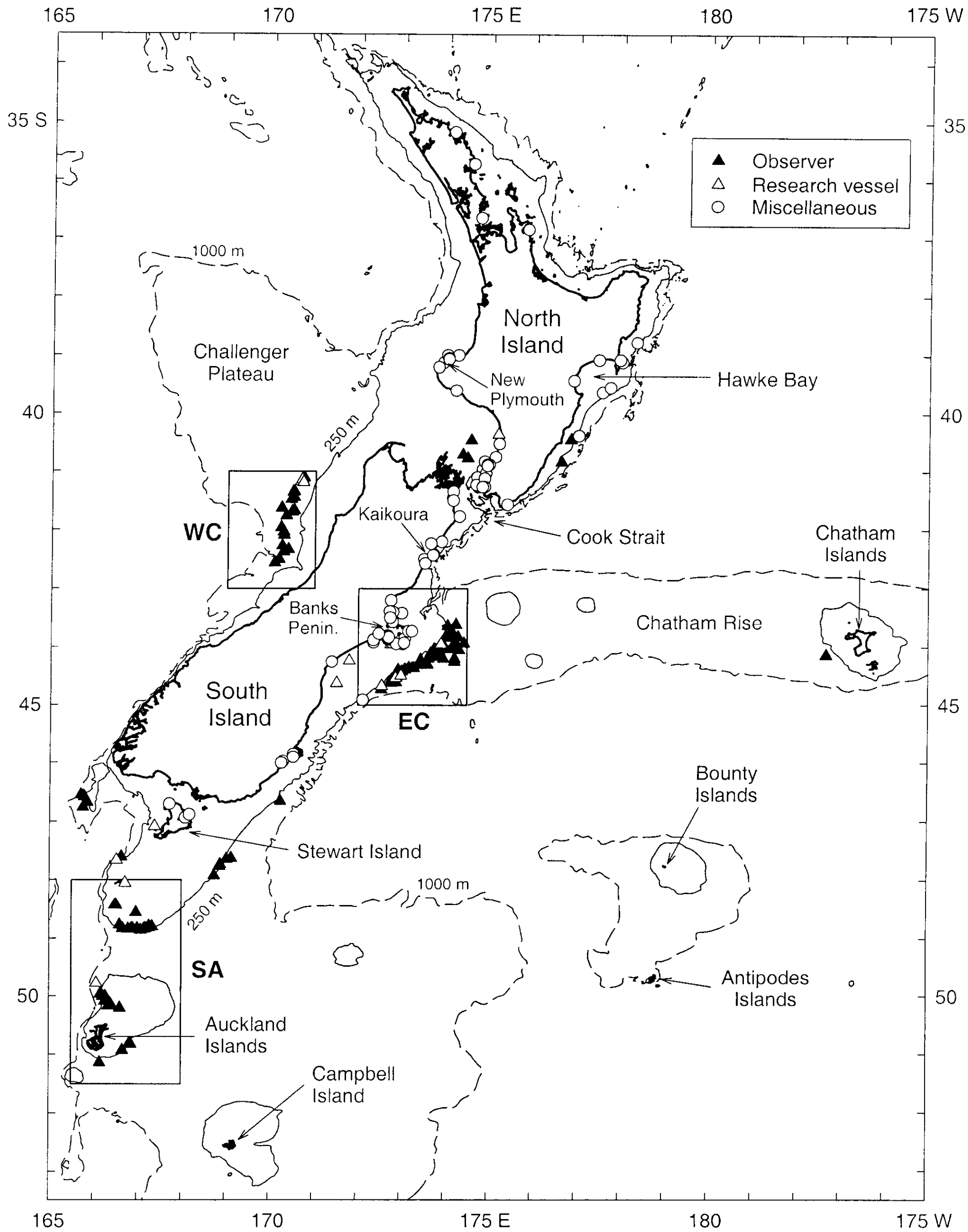


Fig. 1 Map of the New Zealand region showing the locations of *Cetorhinus maximus* recorded by scientific observers aboard commercial trawlers, and research trawlers, and from miscellaneous sources. *Boxes* indicate the main regions where basking sharks were observed aboard commercial trawlers (*EC* East Coast; *WC* West Coast; *SA* Snares–Auckland Islands)

caught in north-eastern New Zealand (36°39′S; 174°45′E) in 1889 (Cheeseman 1891). Cheeseman (1891) reported that several basking sharks were seen in the same region every spring.

Several stranded sharks had been caught in fishing gear, as indicated by net or rope markings on the body, presence of attached fishing gear, or removal of the fins or liver. Incidental captures of basking sharks by bottom trawlers were also reported (Fenaughty and O'Sullivan 1978; Paul et al. 1983; Tennyson 1992). Between October and December 1997, two commercial bottom trawlers caught 32 basking sharks on the seabed in depths of 200–300 m off Hawke Bay (C. Robinson, Pacific Trawling, Napier, personal communication). Vessels from the same company fished the same area of flat continental shelf and slope at the same time of year for 10 years before and 1 year after 1997, but did not catch any other sharks.

Basking sharks were frequently recorded within 8 km of the coast along the south side of Banks Peninsula and off Lake Ellesmere during aerial surveys of Hector's dolphins (M. Rutledge, Department of Conservation, Christchurch, personal communication). Most sightings were of single sharks, but in February 1993, groups of >50 and >100 were seen. Some of these sharks were within 100 m of shore, just outside the surf zone. On one of these occasions, groups of two and three sharks were engaged in close nose-to-tail following behaviour as described by Harvey-Clark et al. (1999) and Sims et al. (2000). Tennyson (1992) reported that a coastal freighter steamed for 20 km through a large aggregation of basking sharks south of Banks Peninsula in January 1992.

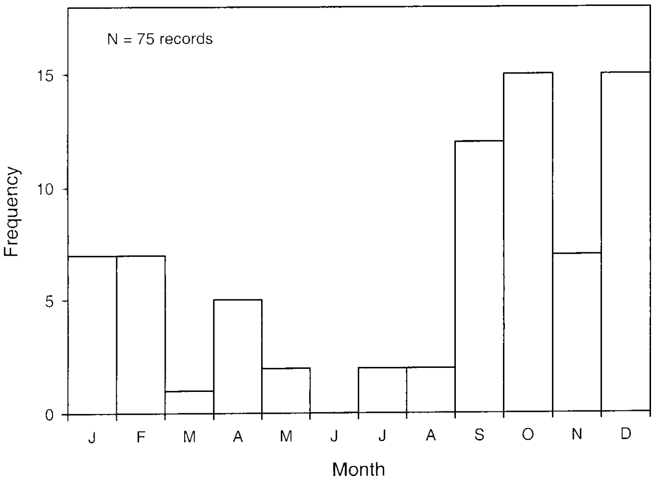


Fig. 2 *Cetorhinus maximus*. Seasonal distribution of miscellaneous records. Some records represent multiple sharks

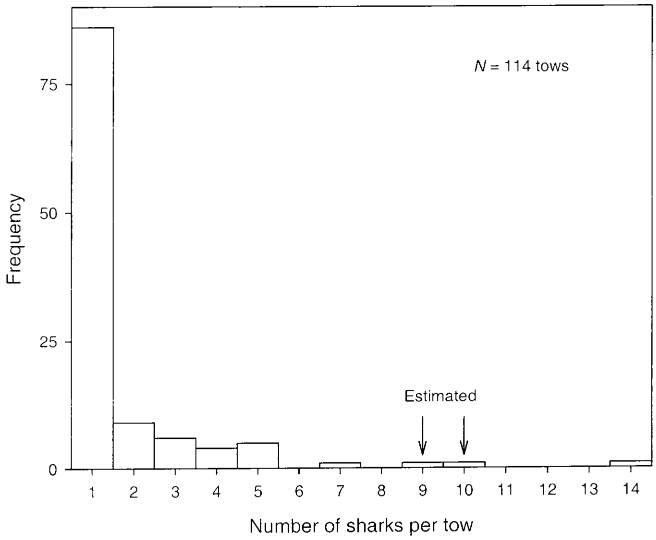


Fig. 3 *Cetorhinus maximus*. Frequency distribution of the number of sharks per tow for observed commercial trawl tows that caught at least one shark

Ryan (1974) reported a 5 m basking shark from Lake Ellesmere, a large, shallow, brackish lake south of Banks Peninsula (see Fig. 4), and, in September 1979, multiple sharks were observed in the same lake over a 1 week period, including 21 individuals on a single day (Dodgshun 1980).

Scientific observer records

About 203 sharks were reported by observers on commercial trawlers between 1986 and 1999. This number is probably an underestimate, because sharks were not always counted. One-quarter of the tows that caught sharks contained more than one shark (Fig. 3). The greatest number in one tow was 14; this observation was confirmed from the estimated lengths (4.0–6.5 m) and sexes (eight males, six females) recorded by the observer. A catch of seven sharks was supported by individual length (3.5–5.0 m) and weight (1.5–2.0 t) estimates. Three other tows that each caught five sharks were also supported by individual length measurements and sex data. Catches of five or more basking sharks per tow were reported from all three main capture regions (see below), and multiple catches were reported in most months. There was no relationship between the number of sharks caught in a tow and headline height, tow duration, towing speed, time of day, or seabed depth.

Most sharks were caught near or outside the 250 m depth contour, and 90.6% came from three small regions – East Coast (EC) and West Coast (WC) of South Island and Snares–Auckland Islands (SA) (Figs. 1, 4, 5, 6; Table 1). No sharks were observed north of 40°S, and only one was recorded from near Chatham Islands (Fig. 1). In the remainder of this section, we focus on the three main regions and their main target fisheries.

East Coast

Most sharks (94.6%) were taken by fisheries targeting hoki (*Macruronus novaezelandiae*) and barracouta (*Thyrsites atun*) (Table 1; Fig. 4). Overall CPUE was much higher in the barracouta fishery (57.6 sharks per 1,000 tows) than in the hoki fishery (16.2 per 1,000 tows). All crotures were reported between September and March (spring–summer), despite good observer coverage in all months except July and August (Fig. 7).

Basking sharks were caught over mean seabed depths of 143–611 m, with a peak at 300–400 m (Fig. 8). Because of the different depth ranges of the target fish species, sharks caught in barracouta tows came from shallower water (143–303 m) than those from hoki tows (281–611 m). It is not possible to determine the depth of capture for any of the sharks, because they may have been caught near the surface while the net travelled to or from the seabed. Most sharks (80%) were caught by bottom trawl tows, and the remainder (20%) by midwater trawl tows on the seabed (Fig. 9). A *G*-test of the data for these two gear types (midwater trawl tows in midwater were excluded because of the zero observed frequency of sharks) showed a significant but weak association between the number of sharks caught and gear type, with more sharks than expected being taken by midwater trawl tows on the seabed ($G_1 = 5.81$, $P = 0.02$).

An EC target fishery for arrow squid operated in a similar depth range to that for barracouta (mainly 100–300 m), but was later in the year (96% of observed tows were in April–June). A reasonable number of tows were observed ($N = 407$, compared with 538 in the barracouta fishery), but no sharks were recorded.

The annual catches of basking sharks were highly variable. Greatest numbers and highest CPUE were

Table 1 *Cetorhinus maximus*. Numbers of sharks reported by scientific observers and numbers of observed trawl tows, classified by target fish species (*EC* East Coast; *WC* West Coast; *SA* Snares–Auckland Islands)

Target species	Number of tows observed			Number of basking sharks				
	EC	WC	SA	EC	WC	SA	Other	Total
Hoki, *Macruronus novaezelandiae*	3,525	20,195	1,794	57	39	2	7	105
Arrow squid, *Nototodarus sloanii*	407	0	14,503			49		49
Barracouta, *Thyrsites atun*	538	474	478	31			1	32
Silver warehou, *Seriolella punctata*	110	9	86	2			3	5
Spiny dogfish, *Squalus acanthias*	89	0	18	3		1		4
Gemfish, *Rexea solandri*	3	54	14				2	2
Jack mackerel, *Trachurus* spp.	53	343	511				2	2
White warehou, *Seriolella caerulea*	2	0	0				2	2
Ling, *Genypterus blacodes*	0	2	54				1	1
Red cod, *Pseudophycis bachus*	59	0	0				1	1
Orange roughy, *Hoplostethus atlanticus*	89	9	262					
Hake, *Merluccius australis*	0	432	41					
Oreos, Oreosomatidae	1,472	0	66					
Other species	41	26	32					
Total	6,388	21,544	17,859	93	39	52	19	203

recorded in the 1987–1988, 1990–1991 and 1997–1998 July–June years (Fig. 10); July–June years were used because catches in each spring–summer basking shark "season" spanned two calendar years.

Only a small percentage of the observed sharks were measured (24%) or sexed (26%). Furthermore, measured sharks were often not sexed, and vice versa. Most sharks (63%) were males, but EC had the highest percentage of females of all three regions (Fig. 11). Measured sharks ranged from 4 to 9 m, but most were <8 m, and most were unsexed. Males spanned the observed length range, but only one female (5 m) was measured.

West Coast

All sharks were taken by the hoki fishery (Table 1; Fig. 5), but the overall CPUE was low (1.9 per 1,000 tows). All sharks were caught between June and August (winter), but few tows were observed in September, and none in other months (Fig. 7).

Basking sharks were caught over mean seabed depths of 512–904 m, with a peak at 700–800 m (Fig. 8). Most sharks were caught by midwater trawl tows on the bottom (56%) or in midwater (38%); only two sharks were caught by bottom trawl (Fig. 9). A *G*-test of the data for the two midwater trawl tow types (bottom trawl tows were excluded because of small sample sizes) showed a significant association between the number of sharks caught and tow type, with more sharks than expected being taken by midwater trawl tows on the seabed ($G_1 = 10.91$, $P < 0.001$).

WC target fisheries for barracouta and jack mackerels (*Trachurus* spp.) operated in shallower water than that for hoki (mainly 100–400 m), over a slightly longer time period (92% of observed tows were in June–September). A moderate number of tows were observed ($N = 817$), but no sharks were caught.

Only a few basking sharks (<5 ind. year^{-1}) were caught in all calendar years except in 1989 when 25 were recorded (Fig. 10).

Few of the observed sharks were measured or sexed (Fig. 11). Males outnumbered females, and those that were measured were all >6 m long. The presence or absence of gill rakers was noted in only one shark: a 7.4 m female caught on 23 July 1998 by a midwater trawl net towed on the bottom had gill rakers (D. Fairfax, Wellington, personal communication).

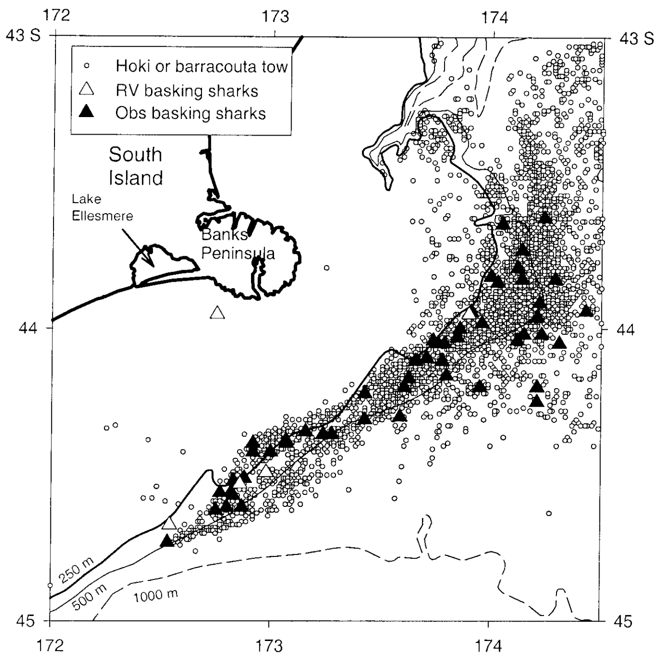


Fig. 4 *Cetorhinus maximus*. Locations of sharks observed aboard commercial trawlers (*Obs*) and research trawlers (*RV*), and the distribution of hoki and barracouta target commercial trawl tows in the East Coast region (EC area in Fig. 1)

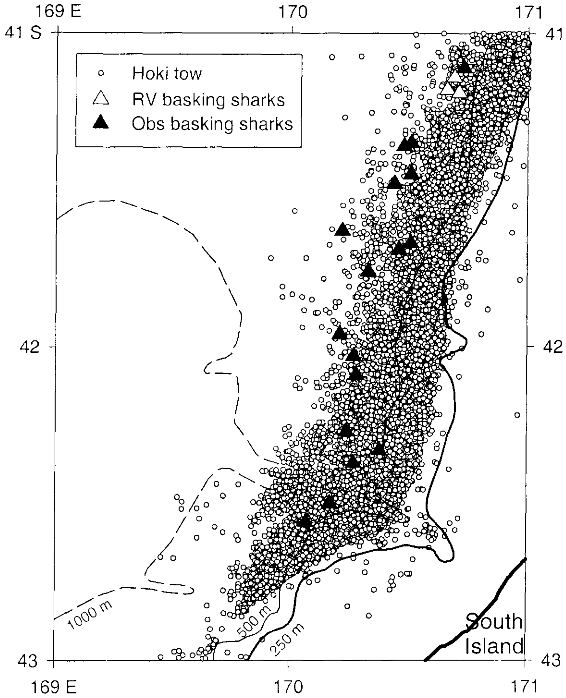


Fig. 5 *Cetorhinus maximus*. Locations of sharks observed aboard commercial trawlers (*Obs*) and research trawlers (*RV*), and the distribution of hoki target commercial trawl tows in the West Coast region (WC area in Fig. 1)

Snares–Auckland Islands

Most sharks (94.2%) were taken by the arrow squid (*Nototodarus sloanii*) fishery (Table 1; Fig. 6), and the overall CPUE was low (3.4 per 1,000 tows). All sharks were caught between December and April (late spring–early autumn), but few tows were observed outside those months (Fig. 7).

In the arrow squid fishery, basking sharks were caught over mean seabed depths of 152–251 m (Fig. 8). Two sharks caught by vessels targeting hoki came from a single tow in water 510 m deep. Most sharks were caught by bottom trawl tows (65%), and the rest (35%), by midwater trawl tows on the bottom (Fig. 9). A *G*-test of the data for those two gear types showed a significant association between the number of sharks caught and tow type, with more sharks than expected being taken by bottom trawl tows ($G_1 = 26.30$, $P < 0.001$).

Target fisheries for barracouta and jack mackerel operated in the same area and depths (mainly 100–200 m) and during the same months (mainly February–April) as the arrow squid fishery, but caught no sharks. However, the number of tows was low ($N = 989$) compared with the arrow squid fishery ($N = 14{,}503$). A target fishery for hoki in greater depths (mainly 300–800 m) in spring and autumn (September–December and March–June) caught only two sharks in 1,794 tows.

Most sharks were caught in 1988–1989 and 1989–1990 (Fig. 10). Thirty-five sharks were measured and sexed, and one was measured only. All but three of the measured sharks were measured to a precision of 0.1 m. All but one of the sharks were males, and most of them were 7–8 m long (Fig. 11).

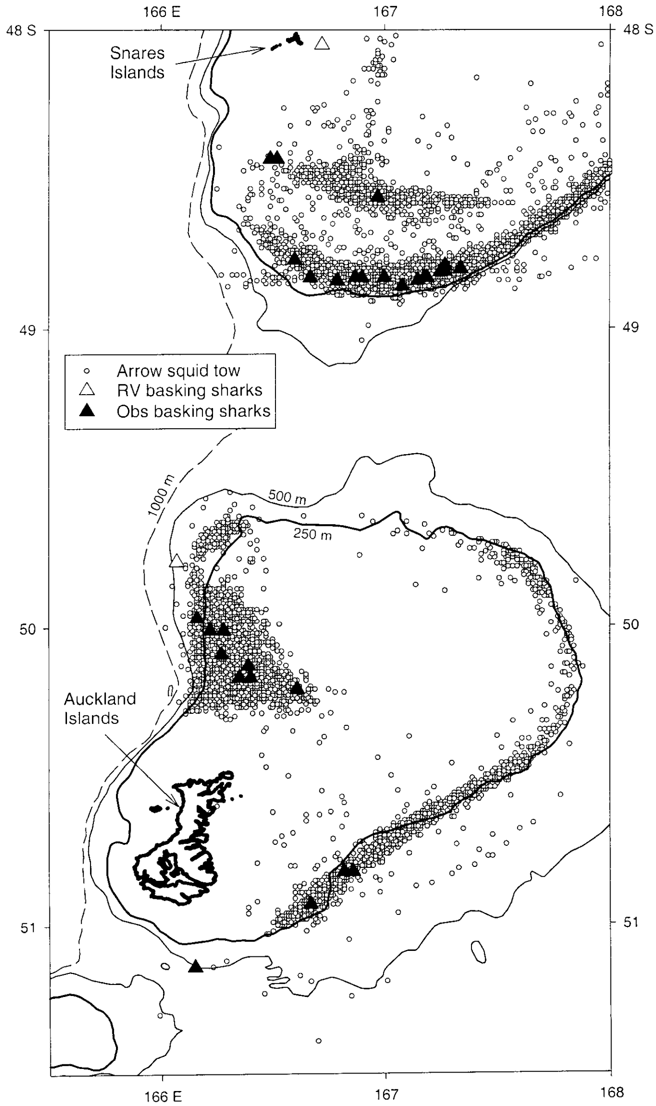


Fig. 6 *Cetorhinus maximus*. Locations of sharks observed aboard commercial trawlers (*Obs*) and research trawlers (*RV*), and the distribution of arrow squid target commercial trawl tows in the Snares–Auckland Islands region (SA area in Fig. 1)

Discussion

Most New Zealand records of basking sharks have come from cool temperate latitudes of 39–51°S. Sharks have rarely been reported from the warm temperate waters of the northern North Island, although Cheeseman (1891) noted that they were regular spring visitors to the Hauraki Gulf (37°S; 175°E) during the 1880s. The northern North Island is home to a large proportion of New Zealand's human population, so the paucity of reports from there during the last century probably

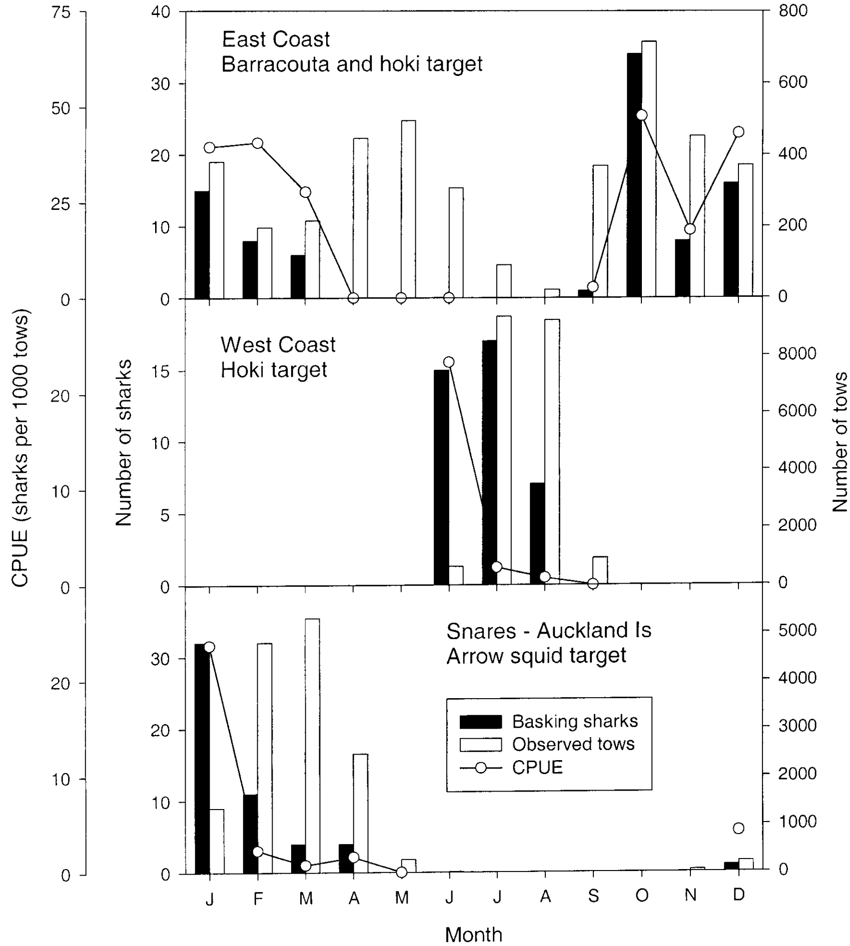


Fig. 7 *Cetorhinus maximus*. Seasonal distribution of sharks recorded by scientific observers aboard commercial trawlers, number of trawl tows and catch per unit effort (*CPUE*) for specific target fisheries in three geographic regions

indicates a low abundance of sharks rather than low observational effort.

The records of basking sharks from a brackish lake (Ryan 1974; Dodgshun 1980) appear to be unique. The salinity of Lake Ellesmere varies spatially and temporally; it is greatest nearest the gravel spit that separates it from the sea, and peaks during periods when the spit is breached or over-topped by seawater during storms (Ward et al. 1996). Salinity near the narrowest part of the spit at the time of the shark observations in September 1979 was about 18‰ (Ward et al. 1996). The sharks penetrated at least 4 km into the lake from the seaward entrance (Dodgshun 1980). Basking sharks were also frequently seen patrolling the coastline just offshore from the spit, sometimes almost in the surf zone (M. Rutledge, personal communication). Sharks may be attracted by the presence in, and discharge from, the lake of large amounts of calanoid copepods (*Gladioferans* spp.) and mysids (*Tenagomysis* spp.) (Chapman et al. 1975; Davis et al. 1996). At least one of the copepods, *G. pectinatus*, is a euryhaline, open-water species (Chapman and Lewis 1976) that is likely to survive flushing into the sea.

Our miscellaneous records were mainly sightings of live sharks or incidental captures made within a few kilometres of the coast during spring–summer. Although observational effort was probably biased towards summer, many of the spring–summer sightings consisted of multiple sharks, and sometimes large groups, suggesting that there is a real increase in abundance in inshore waters at that time. The miscellaneous records therefore conform to a near-universal, world-wide pattern of seasonal abundance.

The annual number of basking sharks caught aboard observed commercial trawlers was highly variable, with short periods of high captures being separated by long periods of minimal catches. A similar pattern has been noted over a much longer time period in the north-east Atlantic (Fairfax 1998).

Most (90.6%) of the basking sharks observed on commercial trawlers were caught in three discrete regions (EC, WC and SA), suggesting that they were most abundant there. However, because most of the observed fisheries are strongly seasonal, an alternative explanation is that low shark catches elsewhere may have resulted from seasonal shark abundance peaks that were out of phase with the fisheries.

The highest catches and catch rates of basking sharks came from the EC region, particularly in the barracouta target fishery. EC shark captures were made exclusively

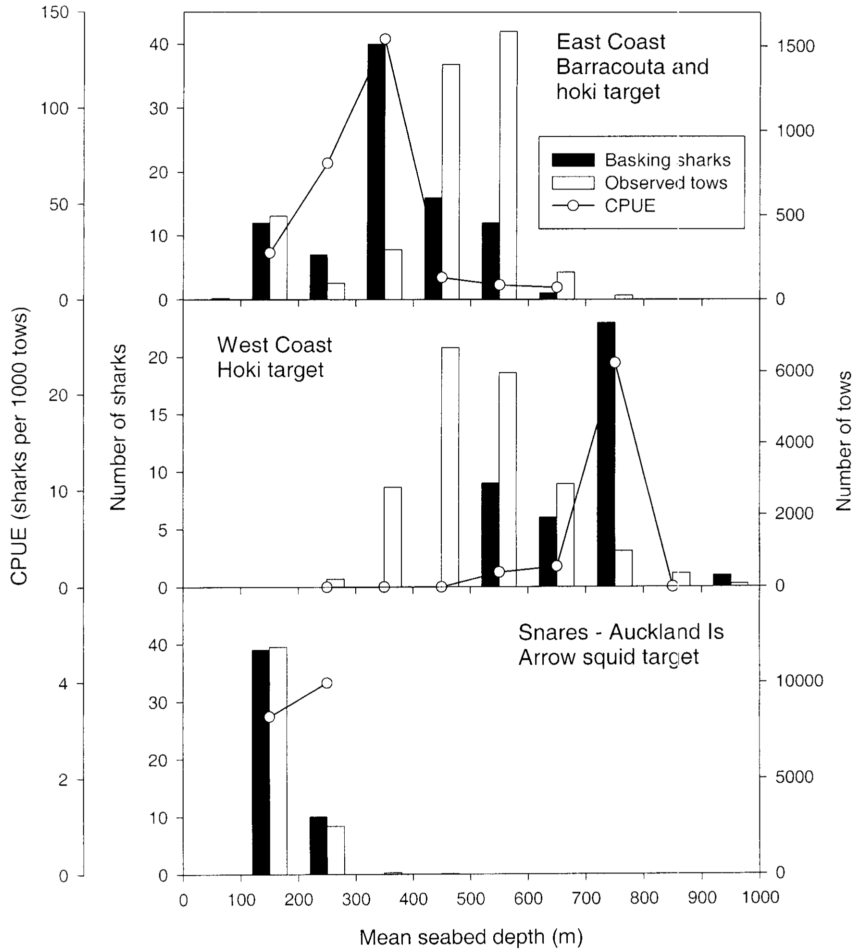


Fig. 8 *Cetorhinus maximus*. Depth distribution of sharks recorded by scientific observers aboard commercial trawlers, number of trawl tows and catch per unit effort (*CPUE*) for specific target fisheries in three geographic regions

in spring–summer, and fishing effort was high enough in other seasons to have detected them if they had been present in substantial numbers. The seasonal abundance pattern near the edge of the continental shelf is therefore similar to that in the adjacent inshore waters around Banks Peninsula, where many of the miscellaneous records, including sightings of large schools, were made in spring–summer. This contrasts with the north-west Atlantic, where most basking shark sightings near the shelf edge are in spring, whereas inshore sightings peak in summer (Owen 1984).

The observed fishing effort in the WC hoki and SA arrow squid fisheries was restricted to short seasons, and few tows were observed in other fisheries during the rest of the year. It is therefore impossible to define the seasonal pattern of shark abundance in these two regions. In SA, sharks were caught mainly in summer, but in WC considerable numbers were caught in winter. This is remarkable, because although basking sharks have been caught occasionally during winter elsewhere (Matthews 1950; Parker and Boeseman 1954; Lien and Aldrich 1982; Fairfax 1998), only Monterey Bay in California provides regular sightings of basking sharks during winter (Phillips 1948; Squire 1967, 1990).

Most sharks observed on New Zealand trawlers were caught near or beyond the edge of the continental shelf. The modal seabed depth for shark captures was markedly different in the three main regions: 300–400 m at EC, 700–800 m at WC and 150–250 m at SA. Sharks were therefore caught in the deepest water in winter at WC. It was impossible to determine the actual depth of capture, because sharks may have been caught while the net travelled to or from the seabed. Nevertheless, the following points show that there is circumstantial evidence that some, if not most, sharks were caught on or near the bottom.

1. Many sharks were caught in bottom trawl nets. The capture of sharks in such nets while they are moving through midwater is probably rare, because of their low headline heights and small lateral openings when the trawl doors are not in contact with the seabed.
2. Japanese bottom trawlers working off Banks Peninsula during the early 1980s frequently caught (and sometimes targeted) basking sharks on the seabed, as evidenced by shaking of the net and increased tension on the trawl warps as the sharks entered the net (Y. Suzuki, NIWA, Wellington, personal communication). New Zealand bottom trawlers working in Hawke Bay have also caught basking sharks on the seabed in 200–300 m of water (C. Robinson, personal communication).

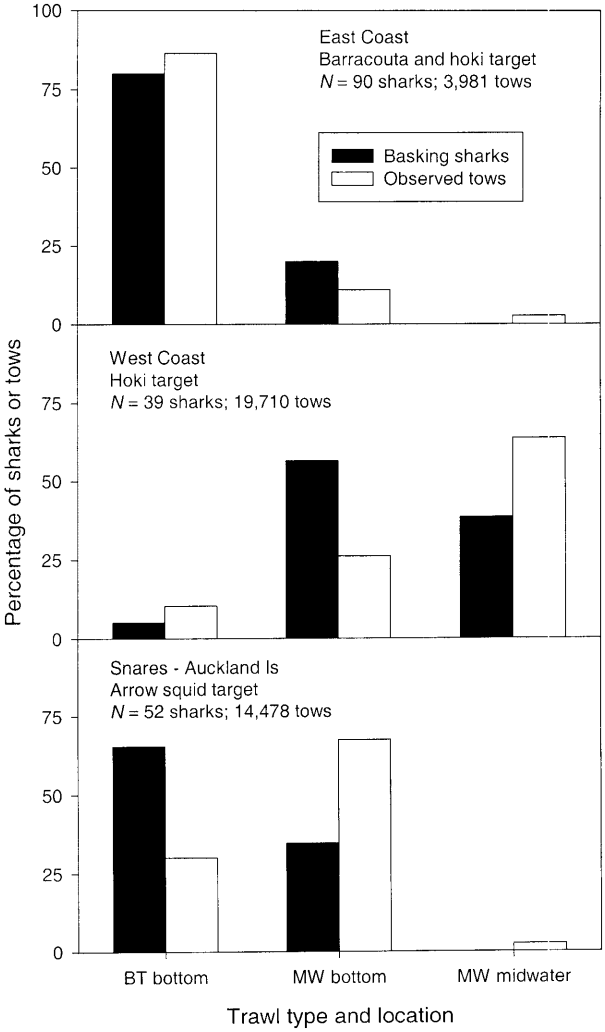


Fig. 9 *Cetorhinus maximus*. Observed sharks and observed trawl tows, classified by trawl type and location, in three geographic regions (*BT bottom* bottom trawl net towed on the seabed; *MW bottom* midwater trawl net towed on the seabed; *MW midwater* midwater trawl net towed in midwater)

3. In WC, the catch rate of basking sharks was significantly higher in midwater trawl nets towed on the bottom than in midwater trawls towed off the bottom. Furthermore, 10 of the 15 sharks caught in midwater trawls towed off the bottom were caught in a single tow that came within 12 m of the seabed.

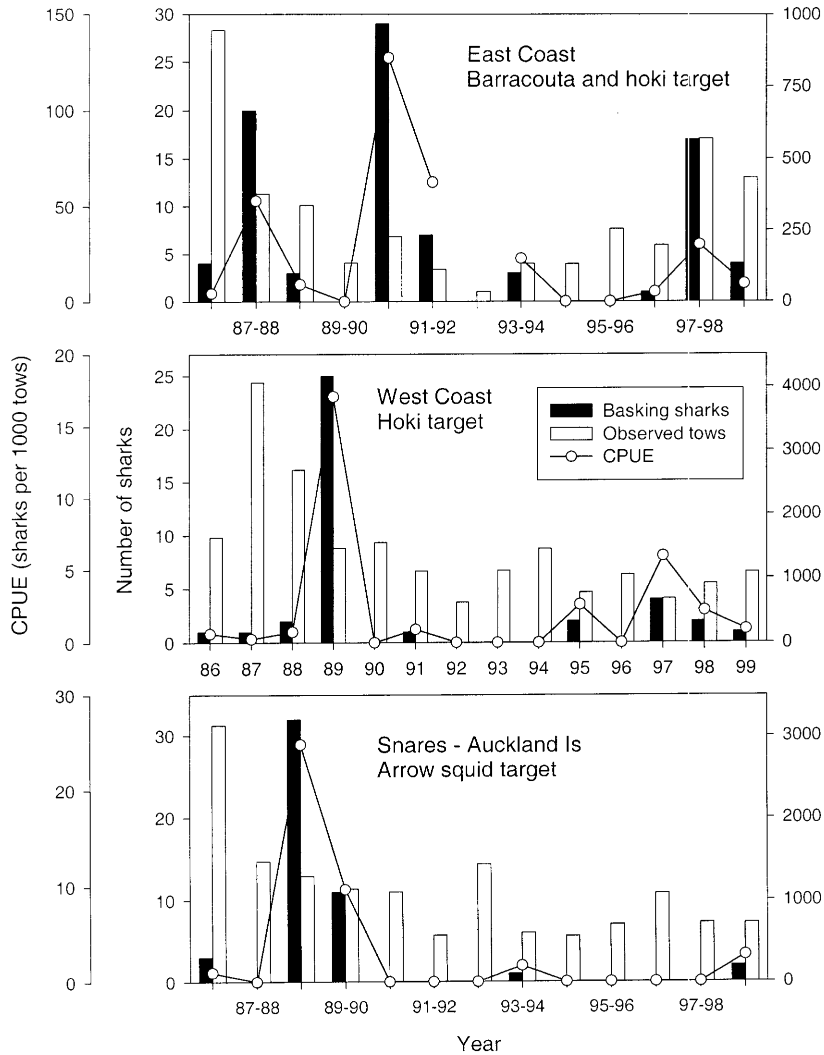
Many authors have speculated that basking sharks migrate to deep water during winter, based primarily on their disappearance from shallow coastal waters, but also on observations that the earliest sightings in spring tend to be near deep water (Lien and Aldrich 1982; Owen 1984). Evidence to support such a deep-water habitat is slim. Nevertheless, there have been a number of direct observations of sharks being caught in or over deep water in winter. Trawlers occasionally catch basking sharks in depths of 200–500 m in the Gulf of St. Lawrence, Canada, in winter (Lien and Aldrich 1982; L. Marks, Department of Fisheries and Oceans, Canada, personal communication). Fairfax (1998) cited fishermen's reports of sharks being taken in midwater trawl nets in depths of 160 m in western Scotland in winter, and being observed on echo-sounders to depths of 190 m. Basking sharks have also been caught during summer in bottom-set gill nets off Ireland at depths of 250–300 m (Berrow 1994; Berrow and Heardman 1994).

Additional evidence for a deep-water habitat during at least part of the year is provided by the composition of the liver oil of basking sharks. The oil contains moderately high, but variable, levels of squalene (Schmidt-Nielsen and Eriksen 1944; Karnovsky et al. 1948), a hydrocarbon that is typically present only in deep-water sharks.

Our data indicate that basking sharks spend at least part of their lives well beyond the edge of the continental shelf. Our deepest record was from 904 m, and Owen (1984) observed sharks at the surface over depths exceeding 1,000 m, and possibly as great as 2,000 m, in the north-west Atlantic. There have been rare reports of basking sharks from the Tasman Sea and southern Pacific Ocean over much greater depths (Sharples et al. 1991; Yatsu 1995). The habitat of basking sharks therefore ranges from brackish coastal lakes and shallow coastal waters to the open ocean. However, much remains to be learnt about how the sharks use the various components of their habitat. The capture of some New Zealand basking sharks in midwater during winter argues against hibernation, because it seems unlikely that a hibernating shark would hover neutrally buoyant in midwater.

Although sharks lacking gill rakers have been found during autumn and winter, other sharks, including one from our study, possessed rakers (Kershaw 1903; Van Deinse and Adriani 1953; Parker and Boeseman 1954; Backus 1957; Springer and Gilbert 1976). Shedding of gill rakers may be a sporadic, non-synchronous activity that serves to renew worn feeding apparatus. Recent studies have shown that basking sharks continue feeding at plankton densities much lower than previously thought possible (Sims 1999), suggesting that food availability in winter may not be a limitation. Sharks have been seen feeding at the surface during winter in Monterey Bay (Squire 1990; Baduini 1995). Pelagic shrimps from depths > 100 m have been found in the stomach of a shark in Japan (Mutoh and Omori 1978), raising the possibility that they also exploit mesopelagic food sources. Fish eggs, small fish and an eel have been found in the stomachs of some sharks (Stendall 1933; Matthews and Parker 1950; Van Deinse and Adriani 1953). One of us (C.D.) recorded fish remains in the intestine of a basking shark stranded north of Banks Peninsula. The WC winter hoki fishery exploits a large biomass of fish aggregated for spawning, raising the possibility that the basking sharks may be feeding on the huge numbers of energy-rich eggs.

Fig. 10 *Cetorhinus maximus*. Annual distribution of sharks recorded by scientific observers aboard commercial trawlers, number of trawl tows and catch per unit effort (*CPUE*) for specific target fisheries in three geographic regions. West coast data are given by calendar years, and East Coast and Snares–Auckland Islands data by "July–June years" (see "Results" for explanation)



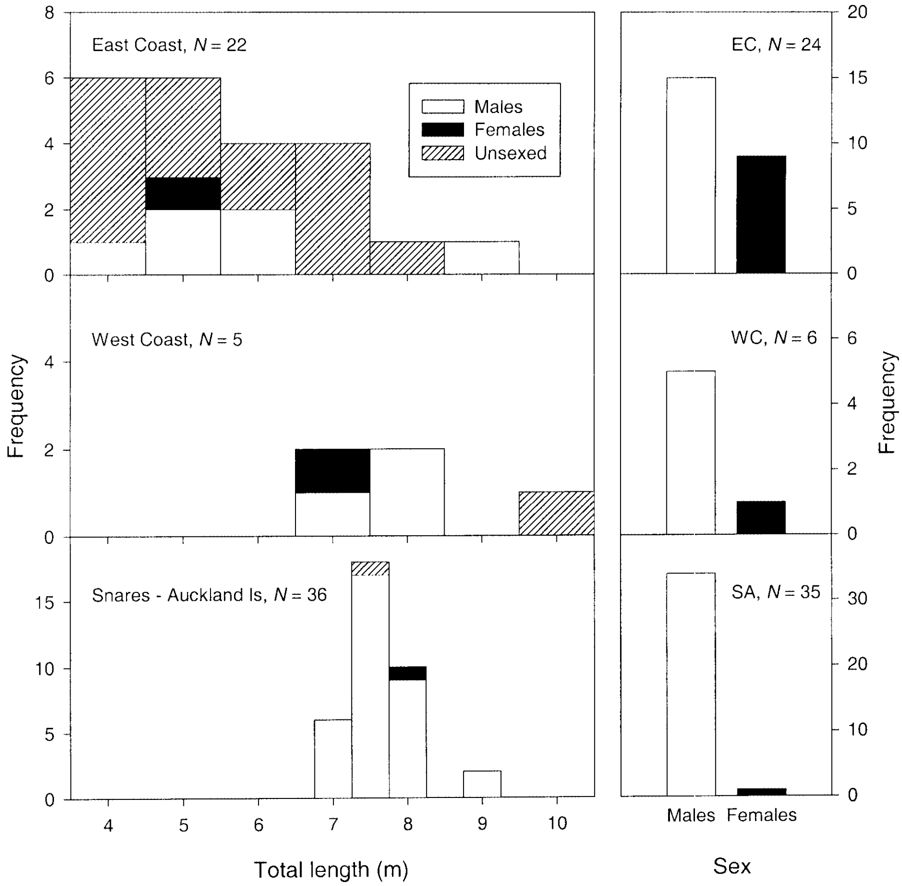
The sex ratio and size composition of WC and SA sharks were similar (i.e. mainly 7–8 m males), but differed substantially from those in EC (both sexes, mainly < 8 m). Sharks < 7 m comprised about 70% of the EC catch, but were apparently absent from WC and SA. Thus the part of the shark population that is vulnerable to capture at EC is not the same as that which is caught in the other two regions. Segregation by sex has also been reported for basking sharks elsewhere. In Scotland, the catch of the harpoon fisheries was overwhelmingly dominated by females (Matthews 1950; Kunzlik 1988), whereas in Newfoundland spring captures were dominated by males and summer catches by females (Lien and Aldrich 1982; Lien and Fawcett 1986).

In the north-eastern Atlantic, Matthews (1950) and Matthews and Parker (1950) observed a 6.8 m, maturing male basking shark, and mature males of 7.6–8.1 m "in vigorous sexual activity". Data obtained from the literature [principally Siccardi (1961) and Lien and Aldrich (1982)] show a rapid increase in clasper length between 6 and 7.5 m, with little change thereafter (Fig. 12). However, few sharks were available over the crucial 6–8 m length range, and no account has been taken of geographical variation or differences in clasper measurement methods. Sexual maturity in lamnoid sharks may be attained at a length somewhat greater than the length at which the claspers reach their maximum size (Pratt 1996). Nevertheless, it appears that male maturity in basking sharks occurs at about 7.5 m TL. Female length at maturity is more uncertain, but Matthews (1950) and Matthews and Parker (1950) considered five females of 7.7–8.2 m to be mature.

Based on these estimates of length at maturity, many of the WC and SA males could have been mature. In contrast, most of the sharks measured in the EC area were < 7 m long, and were probably immature. Significant numbers of females were caught only in the EC area, but only one was measured and it was almost certainly immature. The habitat of mature females therefore remains a mystery.

Acknowledgements We are indebted to the Ministry of Fisheries' scientific observers, and numerous other informants, for the observations that formed the basis of this paper. We particularly

Fig. 11 *Cetorhinus maximus*. Length-frequency distributions and sex ratios recorded by scientific observers aboard commercial trawlers in three geographical regions. Total length data are given in 1 m intervals for East Coast and West Coast, and 0.5 m intervals for Snares–Auckland Islands



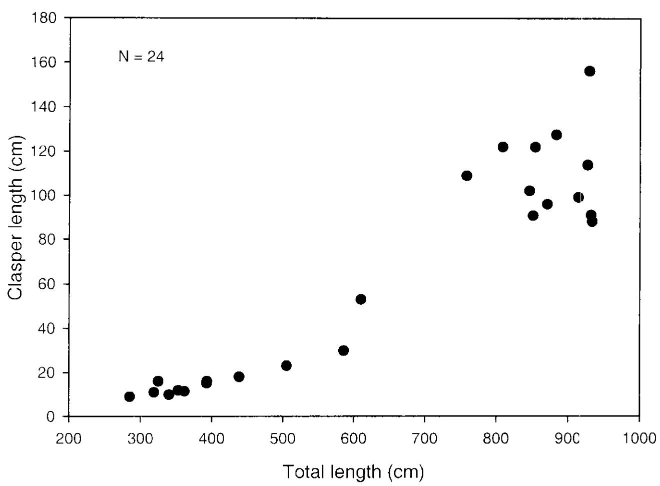


Fig. 12 *Cetorhinus maximus*. Relationship between clasper length and total length for males. Data were obtained from the literature for sharks caught world-wide (Bigelow and Schroeder 1948; Matthews 1950; Matthews and Parker 1950; Siccardi 1961; Springer and Gilbert 1976; Lien and Aldrich 1982)

thank M. Rutledge, A. Tennyson and D. Fairfax for providing unpublished records, literature and other information. The Ministry of Fisheries allowed us access to the Scientific Observer and Trawl databases, and permission to report the results here. M. Leppä kindly translated the paper by Sund (1943).

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APPENDIX J: Pelagic Fish Report

Effects of salmon farming on the pelagic habitat and fish fauna of an area in north western Cook Strait and management options for avoiding, remedying, and mitigating adverse effects

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EXECUTIVE SUMMARY

Effects of salmon farming on the pelagic habitat and fish fauna of an area in western Cook Strait, with management options for avoiding, remedying, and mitigating adverse effects and a proposed method for investigating the impact of deploying a sea-cage salmon farm in the area. Taylor, P.R.; Dempster, T. 101 pp.

This report was contracted by the New Zealand King Salmon Co. Ltd (NZ King Salmon) to provide information on wild fish species in the vicinity of a proposed farm site in north-western Cook Strait and the possible effects installation of a salmon farm at the site would have on these species. Information was gathered from a variety of sources including extensive literature searches on specific aspects of the issues considered, work completed previously by the authors including two earlier reports prepared by them for NZ King Salmon, data extracts under the Official Information Act (1982) from the Ministry of Primary Industries' commercial and recreational fishing databases, and data on wild fish species collected at existing NZ King Salmon sites.

As part of the work, NZ King Salmon requested that a methodology be developed for assessing the impact of farm deployment on wild fish species. The aim for this methodology was to provide a general tool for assessing potential farm sites, using the proposed site as a reference example during development of the method.

The authors were asked to provide a report assessing the effects on pelagic fish of marine farming structures and activities in this area. This required descriptions and discussion on the following:

- A characterisation of the pelagic habitat in the vicinity of the proposed site.
- An appraisal of the effect of habitat changes resulting from installation of a salmon farm at the proposed site on wild finfish (including sharks).
- A discussion of the effect of changes in the pelagic habitat on pelagic finfish species.
- An assessment of the attraction of sharks to a salmon farm at the proposed site.
- An assessment of the potential of such farming on quota fish species in the area of the proposed site.
- A review of potential indigenous biodiversity issues in relation to Policy 11 of the NZ Coastal Policy Statement (NZCPS) in terms of finfish species in the area of the proposed site.
- Description of a methodology for assessing the impact of farm deployment on wild fish benthic and pelagic species in the vicinity of the farm site.

The following is a summary of the main points.

Pelagic habitat

1. A 1986 study from the literature demonstrates that the pelagic habitat in the area of the proposed site was characterised by a zone of tidal mixing throughout the water column that was moderately productive with moderate levels of chlorophyll *a*. This study showed that this zone displayed a uniform temperature regime under summer conditions, somewhere about 15°C. By contrast, the zone outside it was thermally stratified under similar conditions suggesting the presence of a deep water front separating the two. There is no information as to whether this structure occurs during other seasons.

2. Recent studies under the current project show similar results on productivity. They also report high current velocities in the range 35–40 cm s^{-1} tending in a north-westerly direction.

3. Under summertime El Niño conditions, cool upwelled water containing higher levels of dissolved inorganic nutrients (nitrates, phosphate, silicate) are advected into the area of the proposed site within the expanse of the Kahurangi Plume. However, it seems that despite this nutrient intensification of the tidally mixed zone in the area of interest, chlorophyll *a* levels

may not rise appreciably because light is attenuated to 1% from about 30m depth, limiting photosynthesis and therefore phytoplankton growth.

Finfish species

4. The highest probability of potential colonisers comes from the commercial and recreational charter boat data, particularly those recorded close to the proposed site. A species' presence on the recreational fishing list for Alligator Head also represents a relatively high probability for it being there, assuming a low level of misidentification by recreational fishers. Based on this it is expected that kahawai and barracouta (pelagic species), conger eel, sea perch, blue moki, and butterfish (reef/rock bottom species), red gurnard, tarakihi, snapper, blue cod, and hapuku (benthic/demersal species), and rig (shark species) would be present in this area.

5. There is clearly sampling bias in using recreational fishing data to determine quantitative distributions of species, but biases can be offset by data from other sources. Observational data from existing farms in the Marlborough Sounds shows high sightings for the small plankton feeders, yellow-eyed mullet, anchovy, pilchard, and the larger jack mackerel. This provides alternative evidence for inclusion of these species which may be overlooked as potential colonisers because of their absence from the other lists, either because they are not taken by recreational fishers or because they are usually not reef or rocky bottom dwelling.

Effects on the pelagic habitat and wild finfish

6. Fish farms attract large, multi-species assemblages of wild fish which aggregate in their immediate vicinity. While no specific information exists for how wild fish interact with New Zealand's existing salmon farms, this effect appears universal as it has been detected in many places globally. Many of the functional and/or taxonomic fish groups that have been observed aggregating at fish farms elsewhere are also present in the Cook Strait–Marlborough Sounds area (e.g. carangids, sparids, mugilids), suggesting that we can expect similar behaviour here.

7. Aggregations are temporally persistent, although specific species within the aggregated assemblage will likely vary with season, reproductive stage and feeding regime, and aggregations are typically made up of a high proportion of adult fish, making them particularly attractive locations for fishers.

8. Previous research suggests that although it is difficult to predict the types of fish and their numbers that will aggregate at a new farming site, fish farms are most attractive to most wild fish species when the farm is large, located in shallow water, and close to the coast. The proposed site matches some of these criteria, but is characterised by relatively deep water, which may reduce the range of wild fish species attracted to the cages.

9. Aggregation at fish farms leads to a shift away from a natural diet to a farm-modified diet for wild fish. Wild fish consume more food around fish farms than they do in natural habitats, and they feed extensively on feed that is lost from the farm cages. Modified dietary intake leads to marked changes in the condition and physiological composition of wild fish.

10. Elevated heavy metal concentrations are common in sediments beneath fish farms, and the presence of farms may elevate or reduce levels of some heavy metals in wild fish tissues, depending on the wild fish species. Elevated levels of mercury in the tissues of one long-lived, highly resident, demersal fish species and one mobile, pelagic fish species have been detected beneath salmon farms, but they were below health limits set for safe consumption by humans.

11. Loads of specific parasites may be elevated in some farm-associated wild fish, while loads of some parasites may be reduced. Levels of some organohalogenated contaminants may be elevated or reduced in wild fish tissues, depending on the wild fish species.

12. Traditional, recreational and commercial fishers have the potential to capture wild fish populations adjacent to fish farms, where wild fish are aggregated and more susceptible to fishing pressure. Fishing at fish farms has the potential to increase fishing pressure on wild fish stocks as catch per unit effort will likely be high in the near vicinity of farms (unless a fishing exclusion zone around the farms is established).

Effects on quota species

13. Commercial catches in the immediate vicinity of the proposed site are low, suggesting low numbers of target species in this area. Greatest representation in the data are of benthic species with pelagic species poorly represented. Therefore, the commercially fished species most likely to be affected by installation of a farm at the proposed site are those from the benthic group, including bentho-pelagic species and the reef dwellers.

14. Farm discharge comprises the components waste feed as well as faecal and other organic waste material from the fish themselves. These components can impact finfish in four ways: (1) by making accessible artificial feed, (2) by impacting the benthos with farm derived organic material, (3) by communicating the presence of the farm through suspension/resuspension as fine particles within the water column, and (4) through a "fertilisation" effect at the fringes of the overall farm footprint. Each of these represents a mode of action by which the farm impacts the finfish population and there are differences in the way they might affect the three components of the population, the benthic, reef dwelling, and pelagic species and the distance over which these modes of action operate.

15. Although the highest represented, benthic species are vulnerable to a range of effects. The greatest potential influence is through farm generated organic material impacting the benthos and providing access to waste feed, but benthic and bentho-pelagic species can become members of the group resident in the pelagic zone beneath the farm.

Interactions of farms with sharks

16. Although fish farms do not attract sharks into a particular region, they are likely to attract sharks inhabiting the area or passing through; this could result in temporary local concentrations of sharks around farms, depending on the species concerned. There are 14 species of shark occurring naturally in the Cook Strait–Marlborough Sounds area.

17. The nature of shark-fish farm interactions varies according to a number of factors, including the species of shark, the farm site, the season, farm size, management practices and the species being farmed. Although there is little knowledge on shark-farm interactions and shark populations in the Cook Strait–Marlborough Sounds area to allow definitive conclusions regarding the potential effects of salmon farming on local shark populations, mortality of large sharks due to entanglement or confinement in fish farms seems to occur infrequently.

Interactions with indigenous biological diversity of wild fish

18. Four wild fish species were identified as meeting the NZTCS Policy 11 criteria for protection. All are endemic and diadromous (i.e., migrate between the sea and freshwater), and, according to the best available information, are found within the Marlborough Sounds.

19. Little information is available for the marine phase of these species, but, given the non-aggregated behaviour that appears to be characteristic of them during that phase, vulnerability to any marine farm is expected to be low.

A proposed methodology

20. It is intended that the proposed method can be used to determine the effect of farm installation at any site being considered in the future. In the present case, which serves only as a reference example for the purpose of this discussion, the study area is the 1792 ha area in north western Cook Strait proposed as a possible farm site by NZ King Salmon, whereas *the farm operational area* is the area immediately surrounding or including the sea cages comprising the farm. The position of the farm operational site within the proposed site has yet to be finally defined.

21. The overall study comprises the following three phase programme:
    - Phase 1: developing a general description here and in a more detailed technical document for discussion by NZ King Salmon of the plan for Phase 2;
    - Phase 2: carrying out the plan outlined here and documentation of a finalised impact study methodology, including the monitoring/sampling system and the collection of test data for testing the analytical component of the methodology; and
    - Phase 3: execution and reporting of the finalised impact study following development and assessment under Phase 2; a general outline of Phase 3 is included below in paragraphs 23 to 27.

22. The plan is to carry out Phase 2 at the northwest Cook Strait site and other existing sites as necessary. Phase 3 is for execution later at further sites of interest to NZ King Salmon. This approach allows for the development of a robust method within Phase 2 without the pressures of completing development over a short time frame.

23. The aim of the proposed work under Phase 3 is to determine the extent to which wild fish species are affected by installation of a farm at any proposed operational site and whether there is any seasonal variation in the response. Vulnerability of each species to farm installation can be examined in terms of at least four factors: its preferred habitat, its ecological requirements, the mode of action of the farm effect, and the distance from the farm that members of that species are distributed. Because of their behavioural differences as a result of differences in the first two of these factors, there is a clear natural separation in the wild finfish population into a benthic group and a pelagic group.

24. The first hypothesis to be tested for the members of the benthic group is that their abundances will undergo greater change at the farm site than at control locations and that this effect will occur after the farm is installed. For the pelagic group the first hypothesis to be tested is that increase in their abundances will be greater at the farm operational site than control sites and that this will occur after the farm cages are installed. A second hypothesis applies to each of the two groups independently. Specifically, the hypothesis to be tested is that abundance and biomass, as well as species composition and fish sizes of aggregations will vary with season.

25. The aim is to follow a BACI experimental design which requires that sampling begin at least one, ideally more, full temporal cycle(s) before sea cages are deployed at the site of interest. Because an examination of seasonal variation is necessary to understand the extent of the impact, sampling for a minimum of 1 year is necessary before cages are deployed.

26. An asymmetrical sampling design will be employed for the data collection, consisting of one, possibly two, treatment plot(s) (farm operational site(s)) and multiple control plots beyond the influence of the cages but relatively close by in an area of similar habitat and other related environmental conditions.

27. The sampling design will be based on the premise that *every level of sampling should be replicated*. Thus, sampling will be completed on several days within each season when several sampling units or sets of fish counts of each sub-population will be recorded.

Contents

1. SCOPE

In this report we synthesize existing background information on the pelagic habitat and the wild fish fauna of an area in western Cook Strait adjacent to Pelorus Sound proposed by NZ King Salmon as a possible farm site. We characterise the nature of the pelagic habitat in the area of the site from the many published studies of Cook Strait, and summarise the extensive international literature on farmed-wild fish interactions, both in terms of the effects on wild fish populations and interactions that affect traditional, recreational and commercial harvests. Where discussion includes the area of the site and the Marlborough Sounds we usually refer to "*the Cook Strait–Marlborough Sounds area*"; occasionally we refer to "*the outer Sounds*"; inclusion of the proposed site is clear from the context.

Based on commercial and recreational catches of wild fish in the area of interest, background knowledge of fish farms and wild fish interactions, and knowledge of the pelagic habitat and the fish fauna present in the Marlborough Sounds, we make predictions regarding the likely nature of interactions. This discussion is completed with suggestions as to how interactions can be managed to enhance any potentially positive and minimise any potentially negative interactions.

Also incorporated into the report is a brief description of a methodology being developed to investigate the impact of farm installation on finfish species inhabiting the region of future proposed farm sites. This description is intended to provide an overview of the methodology. Details are still being worked on, with a testing phase requiring work in the field before the method can be finalised. The objective is to develop and finalise a method within the current knowledge of the northwest Cook Strait site that can then be applied at all future sites NZ King Salmon is interested in investigating.

2. THE PELAGIC[1] ENVIRONMENT AND WILD FISH SPECIES AT THE PROPOSED SITE

2.1 The Existing Pelagic Habitat at the Proposed Site

2.1.1 Background

There appears to be no study that has aimed specifically at characterising the pelagic habitat of Cook Strait or any part of it. Cook Strait is a unique body of water showing some of the world's strongest tides (Bowman 1983a) while acting as a mixing zone for water from several different sources (Heath 1971). This, the importance of the strait as a shipping lane, and the presence of regular high winds from opposite quarters (e.g., Harris 1990), has led to a long history of study, from the earliest explorers to a wealth of investigations into the geology, circulation, hydrology and meteorology since about the 1950s (e.g., Garner 1954; see reviews by Harris, 1990, and Shirtcliffe, 1990). While all of these studies provide interesting insights into the various aspects of the area, not all are directly relevant to the area of interest in the present context.

After consideration of the extensive available information, selected studies of three specific subjects were included in attempting to define the pelagic habitat in the vicinity of the proposed site.

1. The large-scale circulation system Kahurangi-Tasman Bay-Cook Strait.
2. The plume extending from the area of Kahurangi upwelling into western Cook Strait in the vicinity of the proposed site.
3. Primary production of the area.

2.1.2 Summary of published studies

Greater Cook Strait stretches from its northwestern extremity, the Egmont Terrace, which forms a 100m deep sill linking the North and South Islands from about Cape Egmont to Cape Farewell, to its

[1] See Appendix A for definition.

southeastern boundary where it has been described as forming the head of a deep canyon penetrating from the east coast of the North Island as an extension of the 4000m Hikurangi Trough (see review by Bowman 1983a). The relatively shallow northwestern shelf prevents deeper waters of the Tasman Sea entering the strait, contrasting with the southeastern area where several deep water sources feed into the strait. The Narrows Basin is an area of more than 200m depth near the centre of Cook Strait, extending from the southeast to about 15km northeast of the farm site proposed by NZ King Salmon.

The proposed site is located over a narrow shelf approximately due east and 7 km from the entrance to Pelorus Sound (marked as /Te Hoiere in Figure 1, which actually refers to Maud Island). The bathymetry in this area is relatively flat, ranging from about 50m to 80m depth with shallower areas of about 20–40m near the Chetwode and Titi Islands. This flat area is bounded on the outside by the shelf edge, where the bottom depth drops steeply to more than 110m. The shelf edge coincides closely with the southeastern boundary of the proposed site, particularly at one point, and is within about 3000m of the northeastern boundary. Harris (1990) describes bottom sediments in this area as fine sand.

The circulation and hydrology of Cook Strait are complex, with our current understanding of them based on contributions from a number of studies. The aspect of upwelling near Cape Farewell is an important feature in the present context and the review by Shirtcliffe et al. (1990) identified two papers by Garner (1954, 1959) as the first published records of cold upwelled water in that area. The review discussed detailed studies by Stanton (1971), which concluded upwelling being a general event along the coast with particular points of local intensification, and Stanton (1976) which identified the importance of south-westerly winds in the functioning of the Westland Current described by Brodie (1960). Shirtcliffe (1990) summarised two further studies documented by Bowman et al. (1983a, b, c) and Bradford et al. (1986) which show "persistent Westland Current leading to persistent upwelling at Kahurangi Shoals, with the production of cold-core eddies resulting from the modulation of the process by wind".

Because of the ongoing persistence of these processes of upwelling and current, these individual cold-core eddies are produced as a series which has been shown to trace a partially circular path from the Kahurangi Shoals, first moving towards the north, then gradually circling northeast, then east into greater Cook Strait, and eventually following a southeast track past D'Urville Island down into the vicinity of the entrance to Pelorus Sound. This process and the extended area it occupies has become known as the Kahurangi Upwelling Plume (Heath & Gilmour, 1987). It is well illustrated in the review by Harris (1990), with a sketch incorporating the US National Oceanographic and Atmospheric Administration (NOAA) satellite infrared image from February 1982, which formed an important part of the study published by Foster & Battaerd (1985).

Coupled with the work describing the upwelling plume and contributing to it have been studies investigating the production of plankton in the area. In a January-February 1980 study investigating phytoplankton production and the factors controlling it, Bradford et al. (1986) observed oceanographic processes occurring in the area offshore of Pelorus Sound entrance. Using a series of seven sampling stations covering an approximately 60 km NNE straight line transect from Waitui Bay (see Figure 1), these researchers, in collaboration with Bowman et al. (1982), produced profiles from the surface to the bottom (maximum depth approx 135 m) for temperature, salinity, water density, nitrates, phosphate, silicate; and from the surface to a little more than 50 m, chlorophyll *a* (mg m^{-3}) and potential primary production (mgC m^{-3} h^{-1}); using data recorded during January–February 1980 on the second research voyage in a series of three.

The results from these voyages showed that inshore waters out to almost 25 km offshore (the area encompassing the proposed site) were tidally mixed with no strong temperature or salinity stratification either vertically or horizontally. By contrast there was strong horizontal stratification of nutrients (i.e., nitrates) which Bradford et al. (1986) explained as resulting from the combination of nutrient uptake in the sunlit surface layer by phytoplankton and the tidal stirring below the euphotic zone. Moderate concentrations of chlorophyll *a* > 0.4 mg m^{-3} were measured in this area, prompting the conclusion of moderate productivity by these workers.

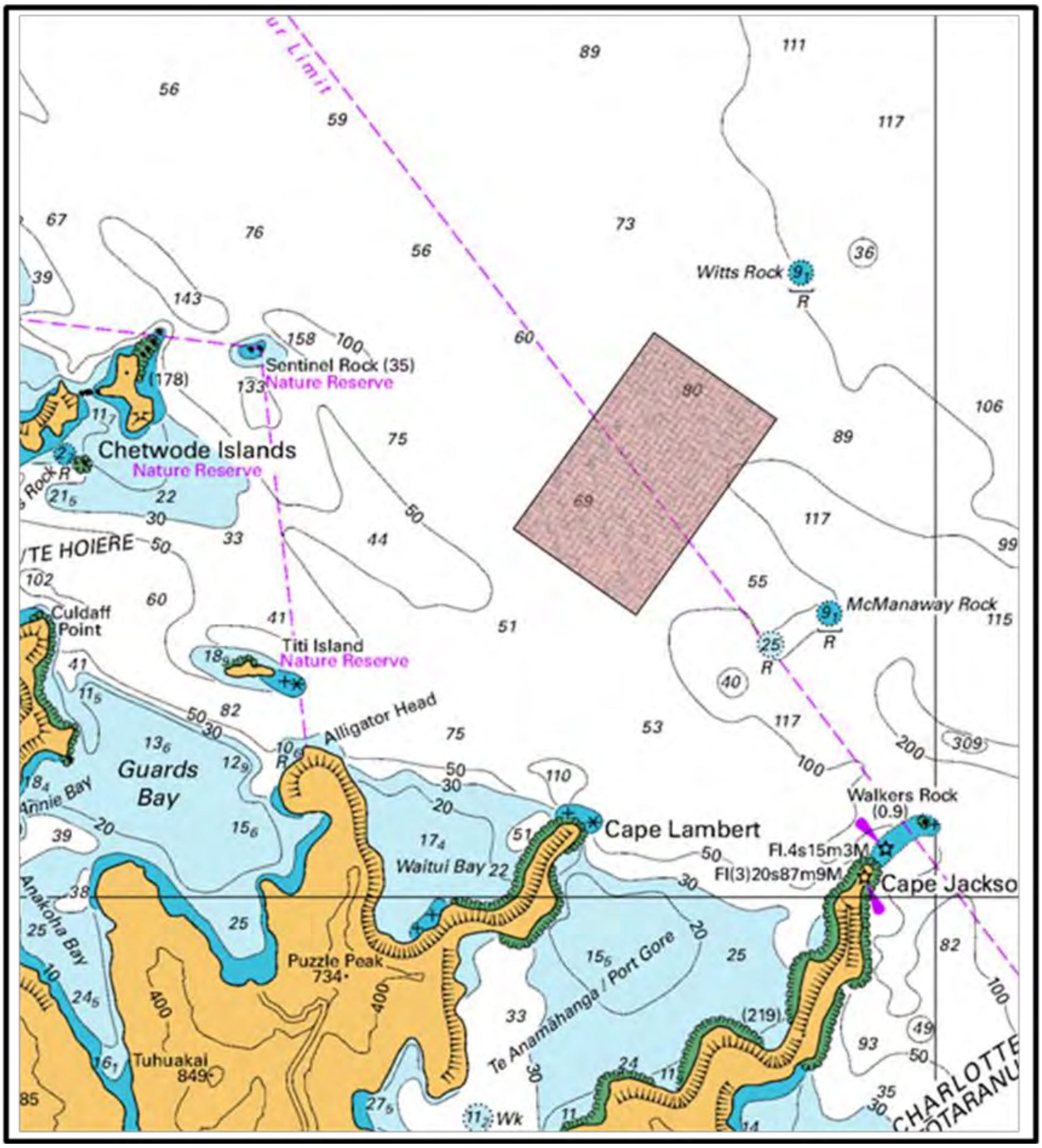

Figure 1: Approximate position of the proposed site (cross hatched polygon) showing bottom bathymetry including shelf edge (100m isobath) and other local features. Source: the polygon was drawn on a tiff version of the LINZ Marine Chart, Marlborough Sounds NZ300615 downloaded from https://www.linz.govt.nz/sea/charts/nz-chart-catalogue-list-view?page=1.

The distribution of chlorophyll *a* evenly throughout the water column within the inshore zone (i.e., out to about 25km) was explained as the result of both tidal mixing and light limitation, with photosynthesis not occurring below the depth of 1% of light penetration, which was determined to be at about 30m depth in this area. The combination of this inshore zone remaining nutrient rich because of the low light limitation on photosynthesis and the relatively high chlorophyll *a* levels in the weakly stratified zone immediately outside it, prompted Bradford et al. (1986) to invoke the definition of Pingree et al. (1978) denoting the presence of a deep water front in this area.

These levels of dissolved inorganic nutrients within this tidally mixed region off Pelorus Sound on the coastal side of the deep water front were observed during summer and were higher than those usually found in stratified coastal waters (Bradford et al., 1986). The timing of this “nutrient intensification”, which is essentially the result of advection within the Kahurangi Plume, has been further defined through the work of Zeldis et al. (2008, 2013), who have demonstrated a link with periods of negative

Southern Oscillation Index (SOI) during summer. In other words, nutrient intensification of the tidally mixed zone outside Pelorus Sound occurs during periods of summertime El Niño conditions.

It is unknown however, what levels of nutrients characterise this zone outside of summertime El Niño conditions. The work of Zeldis et al. (2008, 2013) also demonstrated a causal link between winter riverine flow and increased nutrient levels within Pelorus Sound which provided some balance when the ENSO-mediated (El Niño-Southern Oscillation) intensification was not operating, but it is unknown whether there is any related effect that flows through into the coastal zone discussed above.

2.1.3 The Cawthron Institute Benthic and Water Column Studies

The benthic study completed by Cawthron Institute as an initial investigation into seabed effects at the proposed site (Elvines et al., 2019) provides information on water currents that can be directly related to the pelagic environment. These researchers report that the site is a high-flow environment characterised by strong water current velocities averaging 31 and 35 cm/sec near the seabed and in midwater respectively, and that rich infaunal communities are evident across the proposed area comprising species "typical of deep, high-flow areas throughout the Marlborough Sounds". The predominant axis of current flow is described as southeast/northwest.

With regards the depositional footprint of the proposed farm, Elvines et al., (2019) discuss sites with strong current velocities (>15 cm s^{-1}) in deep water (> 30m), indicating that they will be characterised by a more dispersed footprint and less organic enrichment in contrast with more shallow/lower flushed sites with reference to the researchers who demonstrated these relationships. This results from higher levels of particle resuspension and dispersal of fine particles and flocculent material over a greater spatial range. Given that the proposed site fits the physical profile, the resulting characteristics are clearly applicable in this case, complete with increased spatial effect within the pelagic habitat over farms with more shallow/lower flushed sites.

Elvines et al., (2019) have identified four primary epifaunal seabed strata: 1.) biogenic habitat[2] (>45% of the surveyed area) comprising two substrata — mixed horse mussel (*Atrina zelandica*)-brachiopod beds (approx. 30% of the total surveyed area) and horse mussel patch reef (approx. 15%); 2.) bryozoan fields (approx. 35%); 3.) reef edge assemblages "dominated by shell debris, with whole shells and finer shell hash, gravel and cobbles, as well as underlying bedrock substrate in some areas (approx. 10%); and 4.) sparsely populated mud communities (approx. 10%)". Defining the relationships between such strata, particularly that of biogenic habitats, to particular fish species is in the early stages of investigation (Morrison et al., 2014), although these latter researchers suggest a more general link in that a range of finfish species, particularly juvenile stages, are provided with several benefits — shelter from predation, access to prey species, surfaces for specialised reproductive strategies for some species, and indirect benefits from primary production. While these functions are not directly part of the pelagic zone they do affect the productivity of finfish species inhabiting the pelagic zone.

The Cawthron Institute water column study (Newcombe et al., 2019) also provides information on water currents that can be directly related to the pelagic environment. These researchers report that the site is a region of fast currents with mean mid-depth current speeds of 40 cm s^{-1} and little current variation with depth, but slightly higher values near the surface. There is a tendency for currents in the upper 35m to follow a north-westerly direction. Temperature, salinity, and turbidity were shown to be uniform with depth and nutrient levels were referred to as "unremarkable and within the range of concentrations measured at an existing farm in Port Gore". The diatoms taken in water samples indicated "a moderately-nutrient enriched and well-mixed water column".

[2] Often termed *biogenic reefs*, which are hard structures created by living creatures that provide habitat for a variety of marine life.

2.1.4 The Pelagic Habitat at the Proposed Site – Conclusions

Results of the study by Bradford et al. (1986), showed that the area of the proposed site was characterised by a zone of tidal mixing throughout the water column that was moderately productive with moderate levels of chlorophyll *a*, observations that were also reported by Newcombe et al., (2019). This zone displayed a uniform temperature regime under summer conditions, somewhere about 15°C. By contrast, the zone outside it was thermally stratified under similar conditions suggesting the presence of a deep water front separating the two. There is no information as to whether this structure occurs during other seasons.

Under summertime El Niño conditions, cool upwelled water containing higher levels of dissolved inorganic nutrients (nitrates, phosphate, silicate) are advected into the area of the proposed site within the expanse of the Kahurangi Plume. However, it seems that despite this nutrient intensification of the tidally mixed zone in the area of interest, chlorophyll *a* levels will not rise appreciably because light is attenuated to 1% from about 30m depth, limiting photosynthesis and therefore phytoplankton growth.

The research that defined these features of the pelagic habitat along an approximately 60 km NNE straight line transect (Bradford et al., 1986; Bowman et al., 1982) was carried out in the summer of 1980, from January 26 to February 4. The information from this study provides useful insight into the farm site proposed by NZ King Salmon, but is restricted to a single year as well as being limited seasonally. With respect to the farm site, however, the governing factor would appear to be the tidal mixing which probably persists through all seasons and years. Even during the period of nutrient intensification evident in January-February 1980[3], the biological response in the area of interest was muted, largely because of the tidal mixing and its coupling with low light levels. It seems reasonable to conclude therefore, that the summer pelagic habitat in this area is often characterised by relatively high nutrient levels that are stratified both vertically and horizontally, but is homogeneous thermally and with respect to its salinity as a result of tidal mixing.

Recent information reported by Elvines et al., (2019) is focused on the benthic habitat but also contributes to our understanding of the pelagic zone, particularly with regards water movements. Average midwater current velocities are described as being high at 35 cm sec^{-1} (peaking 60-90 cm s^{-1} range), which is consistent with values published elsewhere (Walters et al., 2010, Fig 5) and may be related to the high tidal mixing documented by Bradford et al. (1986). The southeast/northwest axis of current flow documented by Elvines et al., (2019) is partly consistent with the action of the Kahurangi Plume (Heath & Gilmore 1987).

In the context of farm impact on the pelagic environment, this high-flow feature is perhaps most important when coupled with the high level of discharge expected from the proposed farm and the resultant diffuse nature of the farm footprint. Results from the benthic study show that the spatial scale over which the farm's chemical influence will operate within the pelagic zone will be relatively high compared with farms in shallower water and/or with lower flushing rates. Given that both factors are part of the proposed site's profile, this influence will operate over a wide area particularly with regards the potential attraction of pelagic-dwelling finfish species.

[3] Weak El Niño conditions occurred during these two months with SOI values of 0.4 and 0.3 respectively (Source: https://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/). Bradford et al. (1986) describe the presence of a steady northwesterly wind with mean velocity of 9 ms^{-1} during the January 1980 survey and a northerly of similar magnitude in the January-February 1980 survey; Periods of El Niño conditions are characterised by winds from this quarter.

2.1.5 The Pelagic Habitat in Pelorus Sound

Pelorus Sound is closely related to the area of the outer Sounds that contains the proposed farm site. Discussion later in the document refers to the pelagic habitat in Pelorus Sound so the following description from Taylor & Dempster (2016) is included here for ease of reference.

For Pelorus Sound there are two main sources of water: 1) seawater from Cook Strait feeding into the outer sound, and 2) freshwater from the Pelorus River feeding into the head of the sound. These sources, the relationship between them, and their relationship with the morphometry of the sound all interact to result in a complex pattern of circulation (Gibbs et al 2002) that drives the quality of the pelagic habitat in the outer sound.

Important features of the circulation in Pelorus Sound are:

- the incoming seawater moves along the bottom of the main channel; the outward-bound freshwater moves over the seawater; these two elements provide the basis for the Gibbs et al (1991) “conveyor belt system” within the sound:
- the sidearm (Keneperu Sound) at the head of Pelorus Sound damps the circulation (Heath 1982) in such a way that pulses of high-density plankton water are released into the main channel, producing bands of higher productivity that migrate down the sound (Gibbs 1993);
- the portion of the main channel immediately below Beatrix Bay represents a high deposition zone for suspended solids, resulting in clear water as it moves towards Maud Island and into the outer sound (Carter 1976: 271; confirmed by Vincent et al 1989a & b; Bradford et al 1987);
- stratification of the water column for most of the year is not thermally driven but is salinity stratification, and results in two layers within the water column with separation occurring at the bottom of the pycnocline (Gibbs et al 2002) — an important outcome is that there is little nitrogen contributed to phytoplankton production in the surface waters from the bottom sediments.

As a result of these features, the depth of the photic zone increases with distance towards Cook Strait from Beatrix Bay, thus resulting in increasing productivity throughout the water column as surface phytoplankton become mixed into deeper layers and increasing light penetration with decreasing turbidity results in higher growth rates throughout a greater proportion of its volume.

Bradford et al (1987) showed that, in a comparison of samples taken along Pelorus Sound in July 1981, the largest near-surface concentrations of chlorophyll *a* (>10 mg m^{-3}) were located at a sampling station about 3.5 km west of the Richmond site. Bradford et al (1987) also showed that diatoms dominated the Pelorus Sound phytoplankton — *Nitzschia pseudoseriata* was the dominant species in the outer sound’s algal assemblage in July 1981 instead of *Thalassiosira gravida* which had been dominant in August 1974 (and *T. hyalina*, Burns 1977). Bradford et al (1987) suggested that the accumulation of phytoplankton in the outer Pelorus Sound might be the result of more than just the phytoplankton growth processes, but also of predation by the jellyfish *Aurelia aurita* on herbivorous zooplankton such as copepods. *Aurelia aurita* dominated the zooplankton of the outer sound in August 1974 (Bradford et al 1987) and winter 1984 (Max Gibbs, NIWA, pers. comm.) while swarms of an unknown species of *Munida* were abundant throughout Queen Charlotte Sound and Tory Channel in February 1983 (Gibbs, pers. comm.).

Vincent et al (1989a & b) suggest that herbivore grazing is the most likely factor contributing to the low standing stocks of phytoplankton in Pelorus Sound in late summer 1985, although the relevance of this result is a little unclear in the present context because the outer-most site where sampling was carried out was at Yncyca Bay, which is above the sediment deposition zone referred to above.

Zeldis et al (2008) considered results from a number of the papers referenced above that documented previous work. Based on prior knowledge of river inputs and ENSO-related (El Niño-Southern Oscillation) meteorology, these researchers seasonally stratified by summer (Oct–Mar) and winter (Apr–Sep) their analysis of catchment and oceanic forcing of nutrient loading and biomass formation in Pelorus Sound. They analysed the two datasets separately and suggested a model for the two seasons that fluctuated between two extremes in each and accounted for years of high and low phytoplankton production in the sound, and hence productivity that was manifested in mussel yield. Within this scheme, NNW wind stress intensified upwelling and advection of these cool waters into the sounds, resulting in increased productivity (it is generally considered that cool, upwelled waters are nutrient and oxygen rich); by contrast, SSE wind stress had the opposite effect. In summer, NNW wind stress was coupled with a negative southern oscillation index (SOI), indicating the presence of El Niño conditions; SSE stress was coupled with La Niña (positive SOI). The winter effects were not coupled with ENSO but had a similar result through rainfall and river flow that was increased by NNW wind stress, producing increased terrestrial nitrogen input and higher productivity. Once again, SSE wind stress resulted in decreased productivity, this time through decreased rainfall-induced terrestrial nitrogen input. This provides a good working model for the annual fluctuations we might expect at the proposed sites in outer Pelorus Sound.

Zeldis et al. (2013) used multiple regression models to test three hypothesis as a method of investigating whether seston abundance and aquaculture yield within Pelorus Sound can be predicted using only the physical variables measured distant from the farming region (i.e. distal variables) which are routinely available in national databases, or whether local chemical or biological data collected within the farming region are necessary. This new work provided insight into propositions suggested during the previous work by Zeldis et al. (2008) and showed that, although using the locally collected chemical and biological information produced the best predictions, physical data contained in national databases could be used alone to show why growing conditions diverged above or below average.

There is less information available from the early studies for the other sounds, particularly (with reference to the present context) Queen Charlotte Sound and Tory Channel. Heath (1974) showed that the tidal current in Tory Channel was "exceptionally high" at 3.4 ms^{-1} (measured by the Hydrographic Department in 1956), compared with that in the outer Queen Charlotte Sound (0.5 ms^{-1} measured by Heath 1974). He explained this speed in terms of the flow out of the sound with a rising tide at Picton and a flow into the sound on a falling tide at Picton, with the suggestion that these flows are balanced with a flow through Tory Channel. This seems to explain the relative flow speeds at these sites as presented by Cawthron Institute (Marine Report, Table 1) (*see also* Harris 1990).

Given the results of Zeldis et al (2008) showing that "conditions favouring advection of upwelled waters through the southwestern Strait toward the Pelorus Sound entrance (Harris 1990)", it is likely that Tory Channel is similarly affected by the ENSO mediated high-low productivity, although the absence of a freshwater source the size of the Pelorus River probably means that the volume of a winter influx of nutrients under NNW wind conditions would be much lower than in Pelorus Sound.

2.2 Finfish Species Inhabiting the Proposed Site, Including Sharks

2.2.1 Introduction

The information presented in this section is summarised from a variety of sources that differ widely in methodological details including geographical/environmental focus, data collection method, and statistical analysis. It is summarised here as a possible list of finfish species that might be encountered within the vicinity of the site proposed by NZ King Salmon. There is no intention to provide a definitive list, only to suggest a starting point for an inventory that can be defined as work at the site proceeds. Although some of the information relates to sites within the Marlborough Sounds, it is clear that features of the habitats outside the Sounds will differ somewhat and some or even many of the species listed may not be observed.

2.2.2 Potential Colonisers of Longline Mussel Farms in the Marlborough Sounds

A study by Morrisey et al. (2006) provides a useful basis for developing such an inventory. They identified a group of species "that might associate with marine farms[4] in the geographical area" and compiled their list using mostly published information on fish species found in the area (Davidson, 2001; Cole, unpublished data — see Morrisey et al 2006), families and species that are known to associate with floating structures (Kingsford and Choat, 1985; Kingsford, 1992, 1993), information previously described for New Zealand coastal fish on relationships between species and their habitats (Choat and Ayling, 1987; Jones, 1988; Syms, 1995) and distributional patterns of larval fish (Kingsford and Milicich, 1987; Kingsford, 1988; Kingsford and Choat, 1989; Tricklebank et al., 1992; Hickford and Schiel, 2003).

Morrisey et al (2006) based their list on information from these authors and on personal observations. Species were included either because they were locally common, or they or their taxonomic family had been recorded in association with drift algae or sessile invertebrates. Although their list was aimed at providing information for mussel farms, there is common ground in that both mussel and salmon farms are floating structures and a degree of similarity is evident between them. Species listed by Morrisey et al (2006) are included as Column A in Table 1.

2.2.3 Rocky Reef Species

A study by Smith et al. (2013) also provided a useful contribution to our species inventory. For this study, the statistical modelling method *boosted regression trees* was used to predict the distribution and relative abundance of 72 species of rocky reef fishes on shallow subtidal reefs around New Zealand. Data for the modelling included relative abundance data for reef fishes obtained from 467 SCUBA dives around the New Zealand coast over the 18 years from November 1986 to December 2004, as well as relevant environmental, geographic and dive-specific variables. Predictions from the models were used to map the occurrence and relative abundance of the selected species at the scale of a $1km^2$ grid.

Further details of the study and the method used to summarise its results for inclusion here are given below in §6.3.1, where conclusions for the Marlborough Sounds as a whole are briefly discussed. The area relevant here is the outer Sounds, which comprises the sub-areas Chetwodes–Alligator Head, Port Gore, Long Island vicinity, and Port Underwood. The study predicted the greatest number of different species for the outer Sounds areas.

The list of predicted species for Chetwodes–Alligator Head was similar to that for Port Gore except for the absence of kingfish (*Seriola lalandi*) and goatfish (*Upeneichthys lineatus*) from Port Gore. In total, 32 species were predicted for the area of interest (Chetwodes–Alligator Head). Bearing in mind the authors' warning of derived lists not being definitive locations for the predicted species, and the fact that this list was limited to rocky reef dwelling species, the predicted species for this area was used as a basis for a list of possible finfish that might be encountered at the proposed site at some stage during the period from preliminary investigations through to a time when sea cages have been deployed there for several years. This list is included as Column B in Table 1.

2.2.4 Species identified from the commercial fishing database

The commercial data provide useful information in identifying potential colonisers of a farm at the proposed site because, unlike most of the other data sources, the commercial data are for species taken from the locality of the proposed site. On the other hand, the data are limited by the fishing method used and therefore show a predominance of benthic species.

[4] Mussel farms

Table 1: Finfish and shark species listed by Morrisey et al. (2006) (column A), Smith et al. (2013) (column B), Bell (2001) (B in column C), Davey et al (2008) (D in column C), Taylor & Dempster (2016) (column D), MPI OIA extract from the commercial fishing database (column E, see §4.1 & Appendix C), and MPI OIA extract from the recreational charter boat database (column F, see §4.2 & Appendix B); ticks indicate those species listed by the particular author(s), but in column "C" (recreational catch data), ticks are replaced by researcher's initial; and in columns D, E & F, codes shown in table footnotes are used.

Species	Common name	Family	A	B	C	D	E	F
Pelagic finfish								
Arripis trutta	Kahawai	Arripidae	✓		BD	2,4	C	N,O
Engraulis australis	Anchovy	Engraulididae	✓			3,1		
Hyporhamphus ihi	Garfish/Piper	Hemiramphidae	✓			2,2		
Pseudocaranx dentex	Trevally	Carangidae				1,1		
Sardinops neopilchardus	**Pilchard	Clupeidae	✓			3,3		
Scomber australasicus	Blue mackerel	Scombridae				1,1		
Seriola lalandi	Yellowtail kingfish	Carangidae	✓	✓		2,2		N,O
Seriolella brama	Warehou	Centrolophidae				1,1	B,C	
Thyristes atun	Barracouta	Gempylidae	✓		BD	2,2	A,B,C	M,N,O
Trachurus novaezelandiae	Jack mackerel	Carangidae	✓			3,2	C	
Zeus faber	John dory	Zeidae	✓			4,1	A,B,C	
	**Herring							
Reef/rocky bottom species								
Aldrichetta forsteri	**Yellow-eyed mullet	Mugilidae	✓	✓		3,4		
Aplodactylus arctidens	Marblefish	Aplodactylidae		✓			C	
Caesioperca lepidoptera	Butterfly perch	Serranidae		✓				
Cheilodactylus spectabilis	☼Red moki	Cheilodactylidae		✓				N,O
Conger spp.	Conger eel	Congridae		✓	D		B,C	M,N,O
Helicolenus percoides†	Sea perch	Scorpaenidae		✓	BD		C	M,N,O
Hippocampus abdominalis	Seahorse	Syngnathidae	✓			2,1		
Hypoplectrodes huntii	Red-banded perch	Serranidae		✓				
Latridopsis ciliaris	Blue moki	Latrididae		✓	D		A,B,C	M,N,O
Latris lineate	Trumpeter	Latrididae						
Notolabrus celidotus	Spotty	Labridae	✓	✓		2,1		
Notolabrus cinctus	Girdled wrasse	Labridae		✓				
Notolabrus fucicola	Banded wrasse	Labridae		✓			C	
Odax pullus	Butterfish	Odacidae		✓	D		A,B,C	O
Optivus elongatus	Slender roughy	Trachichthyidae		✓				
Paratrachichthys trailli	Common roughy	Trachichthyidae		✓				
Parika scaber	Leather jacket	Monacanthidae	✓	✓		1,1	B,C	
Pseudophycis barbata	Southern bastard cod	Moridae		✓				
Pseudolabrus miles	Scarlet wrasse	Labridae		✓	‡B			
Lotella rhacinus	Rock cod	Moridae		✓				
Scorpaena papillosus†	Dwarf scorpionfish	Scorpaenidae		✓				
Scorpis lineolatus	Sweep	Kyphosidae						
Stigmatopora spp.	Pipefishes	Syngnathidae	✓					
Lissocampus spp.	Pipefishes	Syngnathidae	✓					
Upeneichthys lineatus	Goatfish	Mullidae		✓				
	Unspecified wrasse							O
Reef/rocky bottom species — Triplefins						2,2		
Forsterygion flavonigrum	Yellow-black triplefin	Tripterygiidae	✓☆	✓				
Forsterygion lapillum	Common triplefin	Tripterygiidae	✓☆	✓				
Forsterygion malcolmi	Banded triplefin	Tripterygiidae	✓☆	✓				
Forsterygion varium	Variable triplefin	Tripterygiidae	✓☆	✓				
Grahamina gymnota	Robust triplefin	Tripterygiidae	✓☆	✓				
Karalepis stewarti	Scaly-headed triplefin	Tripterygiidae		✓				
Notoclinops caerulepunctus	Blue dot triplefin	Tripterygiidae		✓				
Notoclinops segmentatus	Blue-eyed triplefin	Tripterygiidae		✓				
Notoclinops yaldwyni	Yaldwyn's triplefin	Tripterygiidae		✓				
Obliquichthys maryannae	Oblique-swimming triplefin	Tripterygiidae		✓				
Ruanoho whero	Spectacled triplefin	Tripterygiidae	✓☆	✓				

Table 1 continued								
Species	**Common name**	**Family**	**A**	**B**	**C**	**D**	**E**	**F**
Benthic/Demersal species								
Chelidonichthys kumu	(Red) Gurnard	Triglidae			BD	1,1	A,B,C	M,N,O
Nemadactylus macropterus	Tarakihi	Cheilodactylidae		✓	BD	4,3	A,B,C	M,N,O
Pagrus auratus	Snapper	Sparidae	✓		D	4,2	A,B,C	M,N,O
Parapercis colias	Blue cod	Pinguipedidae		✓	BD	4,1	C	M,N,O
Pelotretis/Peltorhamphus spp.	Sole	Pleuronectidae						
Polyprion oxygeneios	Hapuku	Percichthyidae			D		A,B,C	M,N,O
Pseudophycis bachus	Red cod	Moridae					A,B,C	O
Rhombosolea spp.	Flounder	Pleuronectidae						
Unspecified	Stargazer	Leptoscpidae			D			
Unspecified	Rattails	Macrouridae					A,B,C	
Unspecified	Flat fish	Bothidae/Pleuronectidae					B,C	
Kathetostoma giganteum	Giant stargazer	Leptoscpidae					B,C	
Genyagnus novaezelandiae	Spotted stargazer	Leptoscpidae					B,C	
Hyperoglyphe antartica	Bluenose	Centrolophidae						O
Sharks								
Alopias vulpinus	Thresher shark	Aulopiidae						O
Galeorhinus galeus	Sand shark	Triakidae						
Mustelus lenticulatus	Rig	Triakidae			D		A,B,C	
Notorynchus cepedianus	Seven-gill shark	Hexanchidae						
Squalus acanthias	Spiny dogfish	Squalidae				3,3		
Galeorhinus australis	School shark	Carcharhinidae					A,B,C	M,N,O
Cephaloscyllium isabella	Carpet shark	Scyliorhinidae					A,B,C	
Other Elasmobranchs								
Unspecified	Stingray	Dasyatidae					C	
Myliobatis tenuicaudatus	Eagle ray	Myliobatidae					C	
Unspecified	Skate	Rajidae						
Unspecified	Ghost shark	Chimaeridae					B,C	
Callorhynchus milii	Elephant fish	Callorhinchidae					B,C	
Raja nasuta	Rough skate	Rajidae					C	
Dasyatis brevicaudata (?)	Short-tailed black ray	Dasyatidae					C	
Torpedo fairchildi	Electric ray	Torpedinidae					C	

* Not included in lists by Davey et al (2008), but unlikely targets for fishers.
**Pilchard, herring, yellow-eyed mullet, and sprat sometimes misidentified for each other; herring was included in lists by Davey et al (2008).
†There may be some confusion in separating these two species.
‡Only "wrasse" specified by Bell (2001); some could be the banded wrasse, *Notolabrus fucicola*.
⭒ Morrisey et al. (2006) identified *Forsterygion*, [5]*Gramahina*, and *Ruanoho* to species only.
Entries for Davey et al (2008) refer to records from Alligator Head.
Entries for Bell (2001) refer to records from Port Gore. Note that these allocations are coarse in some cases.
Codes for column D (information from 4 existing salmon farms) comprise a combination of two numbers: the first number indicates frequency of sightings: 1—low, 2—medium, 3—high, 4—cryptic; the second number indicates the total number of farms the species was sighted at; (NB, *cryptic* is not a measure of frequency and categorises those species that are known to be present but are seldom observed in the water column; the presence of cryptic species was usually known from angling events only, although they were observed in the water column at some sites. Blue cod was listed at only one farm, but may be cryptic and therefore overlooked at others).
Codes for column E: A and B refer to areas A and B (see explanation in Table 2); C refers to total area of OIA (see Fig. C1).
Codes for column F: M and N refer to areas M and N (see explanation in Table 4); O refers to total area of OIA (see Fig. B1).

[5] Taxonomic comment by Roberts et al. (2015, p. 1505) re-categorises *Gramahina* spp. as *Forsterygion gymnotum*.

Initial analysis of the data is documented in §4.1 and a summarised list from the discussion there is included as Column E in Table 1. The analysis used two, approximately concentric, contiguous areas, Area A centred directly on the proposed site and Area B situated immediately outside it – Area A is represented as "1" in column E in Table 1; Area B is represented as "2". The overall area containing all the data and therefore Areas A and B, is represented by "3" in column E.

The presence of species in column E is perhaps the strongest evidence for their probable interaction with a farm at the proposed site, particularly those recorded from Area A. The most likely active colonisers are those categorised as pelagic species: barracouta, john dory, warehou, jack mackerel, and kahawai. The commercial dataset also provides a number of additional elasmobranchs from the area which have been added to Table 1 and flagged in column E.

2.2.5 Species taken by Recreational Fishers Around the Marlborough Sounds

a. Recreational fishing surveys

Also available were data from two recreational fishing diary surveys. Bell (2001) documented a characterisation survey of the Marlborough Sounds carried out in 1998, which identified locations fished, species caught, methods used, and estimated a catch-per-unit-of-effort (CPUE) for key species. Davey et al. (2008) also carried out a survey to characterise the recreational fishery of the Sounds, this time in 2005–06, with the specific aims of determining the areas fished and catch per unit effort, estimating the recreational harvest of key species in the Marlborough Sounds, and estimating the recreational harvest of snapper in the Fishstock SNA 7, the area including Marlborough Sounds, and Tasman and Golden Bays.

Davey et al (2008) produced lists by several locations, but species listed in Table 1 for these authors have been limited to records for Alligator Head only, which are the most relevant for the proposed site. A similar treatment was made of the lists by Bell (2001), although area definitions were different than those of Davey et al (2008). Species listed in Table 1 for Bell (2001) have been limited to Port Gore only. Bell's (2001) list contained 11 finfish species, where Davey et al (2008) included 40 species including elasmobranchs. Both studies collected data over 12 months. Bell (2001) worked with 297 diarists; Davey et al (2008) collected data from 200 diarists. Note that these allocations are coarse in some cases and that species were not originally listed with scientific names, so they were added here. There is the possibility of species being misidentified by recreational fishers.

The species recorded from Port Gore by Bell (2001) are listed with the code "B" in Column C of Table 1 and the species recorded from Alligator Head by Davey et al. (2008) are listed with the code "D" in Column C of Table 1.

b. Charter vessel activity

Recreational finfish catch data from charter vessel activity in the area of the proposed site lists 18 species, with catch summarised as number of fish rather than the measure of green weight tonne standard used in the commercial data. A notable absence from the charter vessel catch is john dory, which is strongly represented in the commercial data. Several species absent from the commercial data but present here include yellowtail kingfish, thresher shark, red moki and bluenose, although numbers of the latter two species are very low (12 and 10 respectively).

Sea perch was recorded from the charter data in the area immediately surrounding the proposed site but not from the commercial data, although it was recorded from outside Areas A and B in the commercial data.

2.2.6 Information from Existing NZ King Salmon Farms

Table 1 also contains a list of finfish species observed by NZ King Salmon staff at the existing farms Otanerau, Ruakaka, Te Pangu, and Waihinau. In compiling this list, the aim of Taylor and Dempster (2016) was to focus more sharply the information from previous research by Morrisey et al.(2006), Davey et al. (2008), and Bell (2001). Note that this information from existing farms is all anecdotal and based only on observations above the water. In an attempt to quantify these observations, they were assigned non-numeric frequencies, which are not based on count data but on the accumulated knowledge of the staff member providing the information. In three of the four cases this was the farm manager, who had spent long-standing, regular periods at the farm and had developed an understanding of the species observed and the relative frequency with which they were seen.

To express the anecdotal nature of the information, relative frequencies were categorised as low, medium, and high. However, there is a group of fish that are seldom observed occupying the water column, but are known to be present because they are often caught during recreational fishing events at or near the farms. Because of their cryptic nature, it is not possible to determine a measure of their relative frequency. They were included in the summary under the fourth category "cryptic", which is not a measure of frequency but highlights their presence at a non-quantifiable level in this context.

From discussions with the farm managers it was clear that yellow-eyed mullet (family Muglidae) (Table 1) was the predominant species in cages at times when it was present, followed closely by pilchard (Clupeidae), anchovy (Engraulididae), and jack mackerel (Carangidae). It was also clear that the presence of these species was highly seasonal, and that they may appear as small juveniles because they are able to swim through the mesh into the cages. Cryptic species included snapper (Sparidae) and tarakihi (Cheilodactylidae). Results of previous research show that these two cryptic species have a wide distribution in the Sounds and can be expected at all proposed sites. Such a comparison cannot be made for the more common species however, because distributions from recreational fishing data are inconclusive, mainly because they are unlikely target species of recreational fishers.

2.2.7 The Attraction of Offshore Farms for Oceanic Finfish Species

Offshore fish farming is increasingly being promoted in response to problems associated with coastal sea cage fish farming (Holmer 2010), as offshore farming may alleviate spatial conflict, facilitate dispersal or amelioration of farm waste and reduce disease transmission risks. There are few genuinely offshore fish farms in existence (Froehlich et al. 2017) and little is known about how their effects on wild fish differ from those of coastal farms, but some predictions are possible. A major difference from coastal farms is likely to be a predominance of pelagic species around farms. In the Mediterranean Sea, offshore tuna ranching cages attract large pelagic predators such as bluefin tuna (Arechavala-Lopez et al. 2015b), while in New Zealand, analogous offshore wild fish aggregations might include several species of large tuna (Scombridae) and sharks (Table 6). Such species may be more likely to have undesirable interactions with farms and stock (outlined in §5.3), but this should not in itself preclude offshore fish farming. Future offshore fish farms are also likely to be larger than coastal farms. Larger farms may lead to larger aggregations of wild fish, but are otherwise unlikely to change the nature of interactions between farms and wild fish.

2.2.8 Discussion on the compiled lists

Table 1 is a mixture of "projected" information (Morrisey et al., 2006; Smith et al., 2013), data collected from the recreational fishery (Bell, 2001; Davey et al., 2008), anecdotal information collected from existing NZ Salmon Farms within the Marlborough Sounds (Taylor & Dempster, 2016), and data collected from the vicinity of the proposed site (commercial and recreational charter boat data). The projected information is included here to provide a range of species that might be expected at farm sites, based on considerations of the researchers. The recreational data are included to provide the only available recently published information on the range of finfish species present in the area of the proposed site, which, because of the targeting strategies of recreational fishers, cannot provide unbiased numerical estimates of species presence and distribution, although they do provide useful information on area caught. The sources included here provide a broader view of possible species than can be gained from the commercial and recreational charter boat data only.

The predicted distributions by Smith et al. (2013) are specific to the area from the Chetwode Islands to Alligator Head, and the recreational data are restricted to Alligator Head (Davey et al., 2008) and Port Gore (Bell (2001). By contrast, the observations from existing farms are data collected from sites within the Sounds. The species list from Morrisey et al., 2006) is based on observations from a more widespread geographic range around New Zealand using criteria such as attraction to floating structures for inclusion (see §2.2.2). Note that sharks and other elasmobranchs are included in Table 1 for completeness, but are not discussed in the present context.

The certainty with which a species can be expected to inhabit the vicinity of the proposed site varies somewhat according to the list in which they appear. The highest probability of potential colonisers comes from the commercial and recreational charter boat data particularly those recorded in close proximity to the proposed site. A species' presence on the recreational fishing list for Alligator Head also represents a relatively high probability for it being there, assuming a low probability of misidentification by recreational fishers. Based on this we would expect that kahawai and barracouta (pelagic species), conger eel, sea perch, blue moki, and butterfish (reef/rock bottom species), red gurnard, tarakihi, snapper, blue cod, and hapuku (benthic/demersal species), and rig (shark species) would be present in this area. Note that *benthic* and *demersal* are alternative terms for fish species that maintain more or less continuous contact with the ocean floor (Barton & Bond 2007; Roberts et al., 2015), but should be distinguished from bentho-pelagic species "which are bottom-affiliated but swim up in the water column". Hereafter, *benthic* is used for species commonly known as either *benthic* or *demersal.*

Also positively identified under the same assumption related to misidentification are the species recorded during the recreational survey by Bell (2001) from Port Gore. Mostly this list only reinforces several of the species from the Alligator Head data mentioned above, but it does suggest the addition of scarlet wrasse. Port Gore is some distance from the proposed site and may offer conditions that suit this species that are unavailable at Alligator Head, but its possible presence suggested by Bell's data is reinforced by its inclusion in the list from Smith et al. (2013). The list of Smith et al. (2013) provides a relatively high likelihood of the named species being encountered within the Chetwodes-Alligator Head vicinity and includes most of the species in the rocky reef list and all of the triple fin species.

It is clear from the targeting data for the recreational fishing survey of Davey et al (2008) that a number of species in the lists are not preferred target species of recreational fishers. Targeting is affected by a number of factors including average size (e.g., Beardmore et al., 2014). Yellow-eyed mullet, anchovy, garfish, and pilchard are all small species, and only yellow-eyed mullet is reported as a very minor target (targeted on 7 of 27,846 trips). It is possible that fishers consider trevally and warehou lower value species, with trevally seldom targeted (on 3 of 2784 trips) and warehou never recorded as a target species. Barracouta is likely to be avoided and was never listed as a target species and jack mackerel is targeted on only 3 of 2784 trips (see Davey et al. 2008, Table 20). Therefore, there is clearly sampling bias in using these data to determine quantitative distributions of species.

Consideration of the data from existing farms shows that, for the small plankton feeders, yellow-eyed mullet, anchovy, and pilchard, along with the larger jack mackerel with its diet of crustaceans, the frequency of sightings is high. This provides alternative evidence for inclusion of these species which may be overlooked as potential colonisers of cages at the proposed site because of their absence from the other lists, either because they are not taken by recreational fishers or because, in most cases, they

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[6] More than one species could be targeted on a fishing trip, which inflates the trip count from the actual trip number of 2148 quoted elsewhere e.g, Table 5 (see Davey et al. 2008, Table 20).

are not reef or rocky bottom dwelling. Consideration of existing information, this time of results from the study of Bradford et al. (1987), suggest that the pelagic habitat in the area of interest should support planktivores. As was discussed above (see §2.1.2), results from that study indicate moderate levels of phytoplankton productivity in what is now the vicinity of the proposed site and, perhaps more significantly, that plankton productivity was considerably higher further offshore. The significance of small plankton feeding finfish species is discussed in the next section (§2.3).

Yellowtail kingfish have a distribution restricted to the outer Queen Charlotte Sound in the recreational survey data which is difficult to explain. It seems that some other factor was operating to prevent the data showing a more widespread distribution for this species. Perhaps fishers avoid them because they are known to be under-sized or, if they did catch them during the survey period, they were not recorded because they were undersized and therefore released. The prediction of Smith et al. (2013) for this species in the Chetwodes-Alligator Head area seems more likely and it is recorded in the charter boat data from the overall, 10 nmi area (see Figure B1).

According to the discussion in §3.1 below, there have been around 160 fish species, belonging to 60 families, observed globally in close proximity of fish farms. The most common families appear to be Clupeidae, Sparidae, Mugilidae, Carangidae, and possibly Gadidae, and Lotidae as well, the first 4 of which are present in Table 1. Dempster et al., (2002) includes a list of 33 species in 12 families and from this we can add the family Scombridae as another represented in Table 1. There are also species in New Zealand belonging to several of the other families listed in Dempster et al., (2002) e.g., Atherinidae, Sphyraenidae, and Coryphainidae, but these species inhabit warm water, are unlikely to be found in the area of Cook Strait and have a clear alibi for being absent from Table 1. Given that 60 families are globally represented, it is not unreasonable to expect that others of those listed in Table 1 will prove to become associated with local farms as work is carried out identifying actual colonisers.

2.3 Ecosystem Productivity and Feeding in Pelagic Finfish Species

When characterising a pelagic habitat in the context of the finfish species that inhabit it, one must consider both the species themselves and the trophic relations between them, as well as their relationships with other members of the food web. Thus, one can develop an overall picture of where the energy originates, how it moves through the system, and add this information to our understanding of the current status of the habitat. In the pelagic habitat, particularly in relation to seacage farming, this includes consideration of the benthic and reef finfish species, many of which enter the pelagic habitat from time to time. However, the discussion presented here is primarily concerned with the status of the pelagic habitat, and therefore focuses on plankton productivity and the capacity of the plankton community structure to provide forage for planktivorous/omnivorous fish species, which are central to pelagic trophic dynamics.

A pelagic food chain provides a simplified food web that illustrates a major channel of energy flow. It could include several elements in a relationship like the following schematic, although omnivorous fish (e.g., yellow-eyed mullet) may prey on more than one element of the chain as well as a variety of other organisms not included here (Taylor & Paul 1998).

Within such a system, energy captured through primary production (phytoplankton) is fundamental to its function. The energy is then passed up to larger and more complex organisms through grazing and predation. For the finfish species listed in Table 1, the smallest (anchovy and pilchard) are known to be plankton feeders (see review by Paul et al 2001), although an understanding of which elements (i.e., large or small, phytoplankton or zooplankton) (Blaxter & Hunter 1982) of the plankton they target is not certain. Current knowledge for similar species elsewhere has recently been revised. For example, in the Benguela Current system, van der Lingen et al (2006a & b) have shown that the anchovy species *Engraulis encrasicolus* ingests larger particle sizes than the pilchard/sardine species *Sardinops sagax*. Similarly for the Humbolt Current system, Espinoza et al (2009) have shown that the anchovy species *Engraulis ringens* prefers larger particle sizes than *Sardinops sagax*. In addition, both of these studies have shown that zooplankton are the more important component of the diet of these species, a conclusion that has replaced earlier knowledge that phytoplankton species were the most important component in their diets.

At a global scale, the Benguela and Humbolt Currents are two of several boundary systems that support major fisheries for small pelagic species such as pilchard/sardine and/or anchovy. The structure of the biological communities of these large marine ecosystems is often characterised by large numbers of species at the lower (e.g., planktonic) and upper (i.e., apex and near apex) trophic levels, but with intermediate trophic levels dominated by one to only several species of small plankton-foraging finfish (see review by Bakun 2012). Modelling studies have been used to show that trophic dynamic variability in these ecosystems is usually the result of changes in the populations of the species inhabiting these intermediate trophic levels (Rice 1995). The structural shape of these communities has resulted in the intermediate-level species being referred to as wasp-waist populations.

Within ecosystems, trophic control is referred to as either "bottom up" (i.e., increased production results in increased productivity for all trophic levels above) or "top down" (i.e., consumers depress the trophic level on which they feed, thereby indirectly increasing the next lower level). Within a wasp-waist system however, control is in both directions from the middle. As Bakun (2012) puts it, "The small clupeoid fishes that most often constitute the wasp-waist populations feature notable weak links in their life cycles, through which the variability in the physical ocean-atmosphere system is potentially able to exert direct control on their population dynamics, and thus on the trophic dynamics of the entire ecosystem".

For example, varying environmental conditions can affect the community structure of a plankton population and exert control. In their paper, van der Lingen et al (2009) reference the work of Mitchell-Innes & Pitcher (1992) and others in discussing the predominance of high-biomass species such as large chain-forming diatoms under the cool (12–15 °C), intermittent mixing conditions that occur during upwelling, and contrast these with more stable, warmer (> 15 °C) conditions, under which diatom growth becomes limited, therefore allowing small nanoflagellate populations to predominate. As a result, zooplankton community structure can be affected, such that large copepods ingest large phytoplankton cells at a higher rate than small cells (Peterson 1989) and consequently exhibit higher growth rates when diatoms dominate rather than flagellated species (Walker & Peterson 1991); whereas when small phytoplankton cells predominate small copepods seem to do better (van der Lingen et al. 2009).

It seems that the effect of the varying environmental conditions can then flow on to determine the structure of the wasp-waist population. As was discussed above, two different anchovy species in two different ecosystems prefer larger food particle size than the pilchard *S. Sagax*. Based on this type of information, van der Lingen et al. (2006a) have suggested that different physical conditions can result in the available forage being dominated by either large or small particles, which would in turn favour either anchovy or pilchard/sardine respectively.

This information represents current understanding of the trophic dynamics of small, planktivorous pelagic fishes inhabiting wasp-waist populations in large marine ecosystems. The pilchard and anchovy analogues within the Cook Strait-Marlborough Sounds region probably also act as an energy conduit between phytoplankton/zooplankton and the higher finfish species that provide the basis of our commercial, recreational, and customary fisheries, but we know very little about their trophic dynamics or how valid it might be to describe their populations as wasp-waist. Some inference could be made from working through the discussion of van der Lingen (2009) and relating it to what is known about the local species. For example, a comparison of branchial basket sizes would provide insight into relative forage particle size.

An understanding of the habitat at this level of detail is required for a complete appraisal of the status of a pelagic habitat. Obviously, our knowledge of the Cook Strait-Marlborough Sounds pelagic habitat in this regard is limited. While we have had some knowledge of the phytoplankton species present within Pelorus Sound during particular years (Bradford et al 1987, Burns 1977) (see §2.1.5), which is close to the proposed site and could influence its pelagic ecology, it is uncertain that existing information can be summarised to provide useful data over several years and between El Niño/La Niña years. Zeldis et al (2008, 2013) have provided a model of varying productivity between summers characterised by El Niño or La Niña conditions in Pelorus Sound, but without a substantial time series of appropriate plankton data we cannot determine the degree to which the findings of van der Lingen et al. (2006a, 2006b, 2009) and others such as Mitchell-Innes & Pitcher (1992) are relevant here.

Under these constraints we must lift our focus from a level this fine and consider the status of the components that we know to be present in the system. The work of Morrisey et al (2006) indicates the presence of the key small pelagic finfish species, pilchard and anchovy, and this is largely supported by observations at the existing farms. The results of Gibbs (e.g., 1993), Gibbs et al (e.g., 1992, 2002) and others indicate systems by which productivity and physical conditions in the outer sounds provide potential for high levels of primary production. The results of Bradford et al (1987) and Burns (1977) show production of high levels of diatom species, which are important components of the systems described by van der Lingen (2006a & b) and Espinoza et al (2009).

All of this suggests that the pelagic habitat in the Marlborough Sounds is likely to support productive populations of pelagic fish species, and recreational catches (Taylor & Dempster 2016) are testament to its continued functioning. However, the situation at the proposed farm site is not so clear. Pelagic finfish species occur only seldom in data recorded from its vicinity, including the MPI commercial and recreational charter boat data, and lists produced from the recreational surveys by Bell (2001) and Davey et al., (2008) (see Table 1). Barracouta was the most ubiquitous in these lists, along with kahawai, and john dory was well represented in the commercial data. Plankton feeders such as pilchard and anchovy were absent, mainly because they are unlikely targets for either commercial or recreational fishers and are therefore unexpected in the data. Jack mackerel, which is a common target for recreationalists as live bait when targeting pelagics such as kingfish, only appeared in the charter boat data but well away from the proposed site. It will be interesting to observe the species composition of cage colonisers during the proposed field work described in §8.

3. EFFECTS OF CHANGES IN THE PELAGIC HABITAT ON PELAGIC FISH SPECIES

There is little specific information on the interactions of wild fish with New Zealand's existing salmon farms. However, a range of studies conducted globally provide extensive information on wild-farmed fish interactions, both for salmon farms specifically and other fish farms. This information, combined with the anecdotal information on the species of fish observed around salmon farms in the Marlborough Sounds by farm managers, can be used to infer potential interactions of the proposed new salmon farm leases with wild fish stocks.

As it is not possible to predict the specific make-up (i.e. abundance and composition) of wild fish aggregations that will occur at any proposed farming sites, the information and inferences drawn in this section apply equally to all potential sites in locations similar to the north western Cook Strait site.

3.1 Size and Composition of Wild Fish Aggregations around Fish Farms

Coastal sea-cage fish farms modify the abundance, biomass, and species diversity of wild fish wherever they occur (Callier et al. 2017; Barrett et al. 2018a). Globally, around 160 fish species, belonging to 60 families, have been observed in close proximity of fish farms. Strong evidence of association of wild fish with farms, where abundances at farms far exceed those at control locations, exists for 24 species of fish. These 24 species can be largely described as planktivorous or carnivorous.

Most aggregations around farms are dominated by pelagic or benthopelagic fish, which occur in close proximity to the cage structures (Arechavala-Lopez et al. 2015a, b, Bacher et al. 2012, Bagdonas et al. 2012, Boyra et al. 2004, Dempster et al. 2002, 2009, Goodbrand et al. 2012, Özgül and Angel 2013, Segvić Bubić et al. 2011), although aggregations of benthic fish are also important in some locations (Boyra et al. 2004, Dempster et al. 2009, Özgül and Angel 2013). Aggregations of wild fish that are typical target species of fisheries (e.g., carangids, mugilids and sparids; Figure 2) in a concentrated area may affect local fisheries in several ways.

Figure 2. Wild sparids and carangids massed beneath a sea-cage fish farm in the Mediterranean Sea. The bottom of the cage structure can be seen as the dark area at the top of the frame.

Dempster et al. (2009) described 15 fish species around salmon farms throughout the latitudinal extent of Norway. The most common families observed at both farm and control locations were Gadidae (6 species) and Lotidae (2 species). Saithe (*Pollachius virens*), Atlantic cod (*Gadus morhua*), Atlantic mackerel (*Scomber scombrus*), haddock (*Melanogrammus aeglefinus*) and horse mackerel (*Trachurus trachurus*) were the most abundant species around salmon farms. Combined farm-aggregated biomass of the dominant species averaged 10.2 tons per farm. Early studies by Carss (1990) in Scotland and Bjordal and Skar (1992) in southern Norway also indicated that saithe (*Pollachius virens*) aggregated at farms in considerable numbers. Up to 250 tonnes of saithe were present under a single farm in western Norway (Gudmundsen et al. 2012 cited in Otterå and Skilbrei 2014).

In the Mediterranean, large aggregations of up to 40 tons of wild fish composed of up to 33 fish taxa belonging to 17 families (Dempster et al., 2002, 2004, 2005; Fernandez-Jover et al., 2008) have been recorded around fish farms, with the average aggregated biomass across 9 farms sampled in the summer months estimated to be 12 tons. The most common families observed were Clupeidae, Sparidae, Mugilidae, and Carangidae (see Figure 2). Several pelagic planktivorous fish species (*Boops boops*, *Oblada melanura*, *Trachurus mediterraneus*, *Trachinotus ovatus*, *Sardinella aurita*) and several species belonging to the family Mugilidae were numerically dominant in assemblages, depending on both the farm and season (Fernandez-Jover et al., 2008). Larger predators (*Seriola dumerili* and *Pomatomus saltatrix*) are also present at many of the farms in large schools. Similarly large aggregations of wild fish have been noted around fish farms in Greece (Smith et al. 2003, Thetmeyer et al. 2003), the Canary Islands (Boyra et al. 2004, Tuya et al. 2005) and Australia (Dempster et al. 2004).

Table 1, Column D shows the species observed by farm managers around existing salmon farms in the Marlborough Sounds. This anecdotal information indicates that pelagic planktivorous fish, benthic species and higher trophic level predators are present. These functional groups of fish are similar to the groups of fish that occur around fish farms in other locations globally (Dempster et al. 2002, 2009). Furthermore, many of the families that are present around Marlborough Sounds farms (e.g. Carangidae, Mugilidae, Sparidae) are known to be highly attracted to fish farms in other areas. Thus, many of the interactions between wild fish and fish farms in New Zealand are likely to be similar to those documented elsewhere.

Lights are frequently used in salmonid farming to control maturation, including in the NZ King Salmon farms in the Marlborough Sounds. Certain species of wild pelagic fish (e.g. Pacific herring) occurred in greater abundance at lit farms than unlit farms in British Columbia, Canada (McConnell et al. 2010). While the implications of attraction of some pelagic species to salmon farms due to artificial lighting at night are unknown, the use of artificial lights increases the probability that those attracted may be vulnerable to enhanced night-time predation and that farmed and wild fish interact directly and indirectly (see Artificial Lighting Report: Ch. 7 in the Water Column Report, Newcombe et al., 2019).

3.2 Spatial and Temporal Variability in Aggregations

Abundance and assemblage composition of wild fish around farms vary significantly across geographical areas (Dempster et al. 2002, 2009). Aggregations are temporally stable over the scale of several weeks to months, both in relative size and species composition, indicating some degree of residency of wild fish at farms (Dempster et al. 2002, 2009, Otterå and Skilbrei 2014, Skilbrei and Otterå 2016). However, large seasonal differences in the species composition and biomass of wild fish assemblages have been noted around farms in the Spanish Mediterranean (Fernandez-Jover et al. 2007, Valle et al. 2006, Arechavala-Lopez et al. 2015a), yet this pattern is not consistent for all locations, since such strong seasonal differences have not been recorded from farms in other areas (e.g. Canary Islands; Boyra et al. 2004). Ballester-Molto et al. (2015), also in the Spanish Mediterranean, found that the fish assemblage exhibited significant fluctuations in composition and abundance according to feeding times, periods of high and low feeding intensity, and the reproductive cycle of the respective species (with peak abundance during the reproductive period). These results imply that it is difficult to predict the wild fish aggregation sizes at any particular farm prior to its establishment, although subsequent temporal fluctuations may become predictable at some locations.

Previous studies of aggregated wild fish abundance and biomass around fish farms have determined several relationships with farm attributes that may be used to predict the size and nature of assemblages at new farming locations. A recent meta-analysis found larger increases in relative fish abundance at farms when reference sites lacked structural complexity, for example when fish abundance at farms was compared to soft sediment or midwater sites rather than rocky reefs (Barrett et al. 2018a). However, absolute fish abundance may still be higher at farms that are in shallow water or near rocky reefs. In the Mediterranean, where pelagic species were dominant at farms and few benthic wild fish occurred, the abundance, biomass and number of wild fish species were negatively correlated with distance of farms from shore and positively correlated with size of farms (Dempster et al. 2002). In contrast, farm age and farm depth were not strongly related to any of these variables, although Bacher et al. (2015) found that fish aggregations at a Spanish sea bream farm were larger where rocky reef was present. Around salmon farms in the Norwegian coastal ecosystem, the bentho-pelagic *Gadus morhua* were significantly more abundant on rocky bottoms than on plain sand or mud bottoms beneath salmon farms (Dempster et al. 2009). Similarly, *G. morhua* abundance was negatively correlated with water depth, indicating that farms in shallower areas aggregated more of this species. Several other species that were abundant around salmon farms (e.g. *Pollachius virens* and *Melanogrammus aeglefinus*) were unaffected by any of the farm attributes tested (benthic habitat type, depth, farm size; Dempster et al. 2009). Taken together, the results suggest that fish farms are most attractive to wild fishes when they are large in size, located in shallow waters, are close to the coast, and are placed over a rocky substrate, although there are certain species that will likely be attracted regardless of these features. Strong attraction to fish farms may interfere with spawning migrations or other behaviours. Otterå and Skilbrei (2014) tagged and tracked saithe in western Norway, and compared their findings to similar studies conducted prior to the expansion of salmon farming there. They found that distribution of saithe is strongly influenced by salmon farms, and that saithe are now less likely to undertake offshore spawning migration than before, especially smaller individuals. Whether this residence at salmon farms has a net negative effect on the population is unknown.

From the existing evidence, we can infer that wild fish aggregations around existing and proposed new sites in the Marlborough Sounds will likely vary among farming locations and the species composition of assemblages will vary with season.

Offshore fish farming is increasingly being promoted in response to problems associated with coastal sea cage fish farming (Holmer 2010), as offshore farming may alleviate spatial conflict, facilitate dispersal or amelioration of farm waste and reduce disease transmission risks. There are few genuinely offshore fish farms in existence (Froehlich et al. 2017) and little is known about how their effects on wild fish differ from those of coastal farms, but some predictions are possible. A major difference from coastal farms is likely to be a predominance of pelagic species around farms. In the Mediterranean Sea, offshore tuna ranching cages attract large pelagic predators such as bluefin tuna (Arechavala-Lopez et al. 2015b), while in New Zealand, analogous offshore wild fish aggregations might include several species of large tuna (Scombridae) and sharks (Table 6). Such species may be more likely to have undesirable interactions with farms and stock (outlined in §5.3), but this should not in itself preclude offshore fish farming. Future offshore fish farms are also likely to be larger than coastal farms. Larger farms may lead to larger aggregations of wild fish, but are otherwise unlikely to change the nature of interactions between farms and wild fish.

3.3 Settlement of Juvenile Fish around Fish Farms

Fish recruit to a wide variety of anthropogenically altered environments, including artificial structures such as docks, jetties (Rilov and Benayahu, 2000), oil platforms (Love et al., 1994), fish attraction devices, and artificial reefs (Beets, 1989). The majority of small juvenile fish that associate with artificial habitats only do so for a specific period of their life history and, as such, spawning periods are thought to regulate the appearance of these species around artificial structures (Dempster and Taquet, 2004). Information on the role of fish farms as settlement habitat is scarce. Oakes and Pondella (2009) found that juvenile fish populations were less dense on sea cage structures than natural reefs, while the opposite occurred for adult fish. On Mediterranean fish farms, Fernandez-Jover et al. (2009) found that 20 juvenile fish species settle at farms throughout the year, mainly belonging to the families Sparidae, Mugilidae, and Atherinidae. The abundance of postlarvae and juveniles around a single cage of 12 m diameter may include tens of individuals of *Diplodus* spp. to thousands of individuals of *Atherina* spp. and *Mugil* spp. Fernandez-Jover and Sanchez-Jerez (2015) extended this work and reported juvenile carangids, clupeids, atherinids, sparids and mugilids present on sea cages at comparable densities to natural shallow rocky habitats. Otolith analysis indicated changes in growth rates of farm-associated juvenile fish (Fernandez-Jover and Sanchez-Jerez 2015). The influence of fish cages on the pelagic postlarval stage could affect the connectivity between recruits and fishing stocks, through a spatial modification of the available settlement habitat, alteration of mortality, and modification of trophic resources (e.g., increase of particulate organic matter or zooplankton abundance).

From the existing evidence, we can infer that certain species of larval and early juvenile fish will aggregate around existing and proposed farming sites in the Marlborough Sounds. The effects of this on populations of this species, if any, are unknown.

3.4 Consequences of association with Fish Farms for Wild Fish Diets, Body Condition and Parasite Loads

Diet, condition and parasite loads are all altered when wild fish closely associate with fish farms (Fernandez-Jover et al. 2007, Fernandez-Jover et al. 2010, Dempster et al. 2011). As wild fish in the vicinity of farms consume large amounts of waste feed that falls through the sea-cages, farm-associated fish usually have a significantly higher Fulton's condition index and/or hepatosomatic index and/or tissue fat content than control individuals, as has been described for saithe, Atlantic cod, horse mackerel (*Trachurus sp.*) and two sparids (*Boops boops and Sarpa salpa*) (Abaad et al. 2016;

Fernandez-Jover et al. 2007, 2011, Arechavala-Lopez et al., 2010, 2015c; Dempster et al., 2011). Salmon farms in the Norwegian coastal ecosystem modified wild fish diets in both quality and quantity, thereby providing farm-associated wild fish with a strong trophic subsidy. This translated to greater body (saithe: 1.06–1.12 times; cod: 1.06–1.11 times) and liver condition indices (saithe: 1.4–1.8 times; cod: 2.0–2.8 times) than control fish caught distant from farms (Figure 3). While waste feed dominated diets of farm-associated saithe and cod, the composition of dietary items other than waste feed still differed, indicating that the availability of other types of prey differed between farm and non-farm locations. The sea floor beneath salmon farms have modified meio- and macro-fauna communities (Kutti et al. 2007) and modified fish assemblages (Dempster et al. 2009) compared to control locations, and wild fish associated with farms clearly also prey upon these fauna.

Figure 3. Marked difference in morphology between wild saithe (*Pollachius virens*) of similar length caught at a control location (top fish) and associated with a fjord-based salmon farm (bottom fish) in Norway.

The increased body and liver condition observed in farm-associated saithe and cod is likely linked to the trophic subsidy that farms provide. Livers are the principal lipid and thus energy stores in gadoids (Lambert & Dutil 1997). A high liver index is indicative of high total lipid energy, which is known as a direct proxy to egg production in gadoid fish (Marshall et al. 1999). Lipid energy reserves 3 to 4 months prior to spawning are the best proxy for fecundity (Skjæraasen et al. 2006). In this context, association with fish farms throughout summer and autumn could increase the fecundity of saithe and cod, which spawn in early spring, even if these fish migrate away from farms months prior to spawning.

While fecundity, in terms of egg numbers or size, may increase through farm-associated fish having high energy reserves, the composition of stored lipids in farm-associated saithe and cod may differ from those of unassociated fish which consume a natural diet (Fernandez-Jover et al. 2011). This may affect egg quality, as farm-feeds contain low proportions of highly unsaturated fatty acids (HUFAs) and arachidonic acids, which are key to fertilization rates and egg quality (Salze et al. 2005). If the waste-feed dominated diet alters the fatty acid composition of saithe and cod livers and has a negative effect upon egg quality during vitellogenesis, the increased condition evident in farm-associated fish may not translate to a proportional increase in spawning success. Experimental manipulations of wild saithe and cod fed diets containing different proportions of waste feed for various durations and the subsequent evaluation of the effect this has on egg and larval quality are required to determine the extent of this potentially negative effect.

Parasite and pathogen loads of farm-associated wild fish are modified from control fish, but this effect is bi-directional (Fernandez-Jover et al. 2010, Dempster et al. 2011). In the Norwegian coastal ecosystem, Dempster et al. (2011) found slightly elevated levels of the external parasites *Caligus* spp. and *Clavella* spp. on farm-associated wild fish, while the internal parasite *Anisakis simplex* was significantly less abundant in the livers of farm-associated saithe than wild saithe. Overall, these modified parasite loads appeared to have little detrimental effect upon wild fish condition. While abundances of parasites were altered, the strong effect of the trophic subsidy appeared to override any effects of altered loads upon wild fish condition. Little is known about viral and bacterial transmission between farmed and wild fish. This issue is beyond the scope of the work documented here and is covered in the NZ King Salmon Disease Risk Assessment Report.

The rate of feed loss from sea-cage aquaculture is likely to vary considerably with location, environmental conditions (e.g. current strengths) and the feed-monitoring technologies in use. Current consensus is that few good, independent estimates of feed loss have been made for salmon aquaculture, but estimates of 1% to 5% feed loss within the Norwegian salmon farms have been made (Otterå et al., 2009). An independent estimate based on the amount of waste feed found in the stomachs of wild fish living around 9 Norwegian salmon farms put feed loss at a minimum of 1.4% in the summer months (Dempster et al. 2009).

NZ King Salmon has made some estimates of rates of feed loss from the existing Te Pangu and Ruakaka farms in the Marlborough Sounds using a lift-up system and direct estimates by divers 3 hours after a feeding event concluded. These estimates indicate that feed loss is typically low (<0.1%). Feed loss has been identified as the primary driver of wild fish aggregation around fish farms (Tuya et al. 2006; Bacher et al. 2015), and can be considered a key issue in determining the effects of salmon farming on wild fish species. To determine the extent to which this is likely to drive wild fish aggregations at the proposed new farming sites, and to avoid any future debate on possible bias in the estimates, independent verification of feed loss rates from NZ King Salmon farms is required.

Within the Marlborough Sounds, no specific information exists on how the existing salmon farms might modify the condition and parasite loads of wild fish caught in the vicinity of salmon farms. However, as many of the same types of fish found (i.e. small planktivores, demersal fish and higher trophic level carnivores) around fish farms worldwide are found around the existing Marlborough Sounds farms (e.g. kahawai, jack mackerel, kingfish, pilchard, anchovy, mullet, tarakihi, spiny dogfish and snapper; Table 1 Column D), it is likely that the condition of the pelagic planktivores often observed around farms will be similarly increased.

Whether the parasite levels of wild fish that will likely reside around the new farming sites in the Marlborough Sounds will be modified can only be known after direct assessments are made. However, the existing evidence from the literature suggests that parasite loads of wild marine fish that live in the vicinity of salmon farms are not greatly affected.

3.5 Physiological Consequences of Association with Fish Farms for Wild Fish

The consumption of food pellets by aggregated fish causes changes in their biological condition due to the different availability of food and its composition compared to natural resources. Aquafeeds are composed of fish meal and fish oil, as well as vegetable-based ingredients. They contain a high-protein content (40%–70%), are highly digestible and have low amounts of ash, salts, total volatile nitrogen, and dimethylnitrosamine (Autin, 1997).

This enhanced biological condition is a typical marker of higher spawning success. However, the fat content and fatty acid composition of commercial aquafeeds may differ so greatly from typical natural fish diets that negative effects may occur. The fat concentration in food pellets used to feed sea bass and sea bream vary from 17% to 24% (Fernandez-Jover et al. 2007). In addition, due to difficulties in obtaining fish oil and fish feed and their elevated prices, vegetable oils of terrestrial origin are used in the formulation. These vegetable oils include high concentrations of other ingredients such as oleic acid (18:1ω9), linoleic acid (18:2ω6), and α-linolenic acid (18:3ω3). The introduction of this source of food to the marine environment modifies the fatty acid (FA) composition, and fat content levels of tissues of wild fish that feed on the lost pellets may also be elevated (Fernandez-Jover et al. 2007). This has been demonstrated for saithe (*Pollachius virens*) (Arechavala-Lopez et al. 2015d; Skog et al., 2003; Fernandez-Jover et al., 2011) and cod (*Gadus morhua*) (Fernandez-Jover et al., 2011) living close to salmon farms along the Norwegian coastline. Farm-associated saithe and cod have significantly increased concentrations of terrestrial-derived FAs such as linoleic (18:2ω6) and oleic (18:1ω9) acids and decreased concentrations of long-chain omega-3 fatty acids (DHA) (22:6ω3) in the muscle and/or liver compared to wild control fish living in waters distant from farms. In addition, the ω3:ω6 ratio clearly differed between farm-associated and control fish. Physiological changes can occur rapidly after switching to a farm feed diet (2-8 weeks: Gonzalez-Silvera et al. 2017). Whether these modified fatty acid compositions alter egg composition and larval survival and thus alter reproductive success rates is largely unknown. Captive feeding trials suggest that a heavy reliance on farm feed has deleterious effects on egg quality in some species (e.g. Salze et al. 2005), while a captive spawning trial with cod caught from areas of high and low salmon farming density found evidence for negative effects on the offspring of farm-associated cod (Barrett et al. 2018b). However, evidence for biosynthesis of essential fatty acids in marine fish and invertebrates indicates that at least some farm-associated organisms are likely to be resilient to changes in dietary fatty acids (e.g. Laurel et al. 2010).

The dietary composition of feeds used in the existing Marlborough Sounds salmon farms are broadly similar to those used in Norwegian salmon farming, with inclusion of terrestrial-derived vegetable oils (see NZ King Salmon Feed Report). Thus, we can infer that the effects detected for the wild fish that aggregate around salmon farms and consume waste feed and organisms in the vicinity of farms will be broadly similar for the Marlborough Sounds farms and the farm proposed at the northwestern Cook Strait site. The strength of any effect will be largely determined by the amount of waste feed available.

3.6 Organohalogenated Contaminants

Organohalogenated contaminants (OHCs) include a wide range of chlorinated, brominated and fluorinated pollutants that are commonly found in marine ecosystems. These include: organochlorines (OCs; PCB, and OC-pesticides), brominated flame retardants (BFRs; polybrominated diphenyl ethers (PBDE), hexabromocyclododecane (HBCD) and perfluorooctanesulfonate (PFOS). Many of these compounds biomagnify and are prevalent in marine fish, both as a result of long-range transport and local sources.

3.6.1 Organohalogenated Contaminants in salmon feeds

Organohalogenated Contaminants (OCs) include well-studied legacy compounds (i.e. polychlorinated biphenyls (PCBs) and OC-pesticides), and emerging pollutants such as polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD), in addition to perfluorooctane sulfonate (PFOS).The fish-based component of salmon feed (fish oil and fish meal which comprises approximately 25% of the Skretting salmon feed used by NZ King Salmon) is mostly produced from fish meal and oil from lipid-rich oceanic fishes, and contain traces of lipid-soluble OHCs such as organochlorines (OCs) and brominated flame retardants (BFRs) (Jacobs et al. 2002, Hellou et al. 2005, Kelly et al. 2008a, Berntssen et al. 2010).

The amounts of some of these compounds for which documentation is available in the Skretting feeds used by NZ King Salmon are lower than both current Australian and European Union standards, according to Skretting Australia's Residue Monitoring Report (2006-2010). Specifically, concentrations of dioxins (PCDD / PCDF) were between 0.059-0.384 ng/kg from 2006-2010 (EU limit = 2.25 ng/kg), and the sum of Dioxins & Dioxin-like PCBs (WHO-PCDD/F+PCB) were 0.181-0.652 ng/kg from 2006-2010 (EU limit = 7 ng/kg).

No consistent evidence has arisen to suggest that farmed salmon worldwide have elevated concentrations of OHCs compared to wild salmon (Hites et al. 2004a, b, Shaw et al. 2006, 2008, Cole et al. 2009) and detected concentrations are below those considered safe for human consumption by EU or US standards. Wild fish that occur near salmon farms have different diets than the farmed salmon, as they consume a mixture of waste feed and other invertebrate and fish prey (Dempster et al. 2011), thus levels of OHCs in farmed salmon cannot be used to infer likely levels in the wild fish that occur in the vicinity of salmon farms.

3.6.2 Organohalogenated Contaminants in sediments and wild fish around salmon farms

OHCs may accumulate beneath salmon farms due to the sedimentation of waste feed and fish waste (e.g. Sather et al. 2006, Russell et al. 2011). In both cases where OHCs have been measured in sediments beneath salmon farms, concentrations were elevated only at a local scale (to 100 m). While elevated relative to control sites, PCBs were found to be below the EAC (environmental assessment criteria) for most samples in Scotland (Russell et al. 2011) and those measured in Canada (Sather et al. 2006) were considered low relative to polluted marine sediments worldwide. No information is available concerning whether, or to what extent, these OHCs bioaccumulate in benthic invertebrates that may be prey items for wild fish below salmon farms.

Bustnes et al. (2010) found that salmon farms in the Norwegian coastal ecosystem act as an additional source of lipid-soluble OHCs, resulting in a 20-50% increase of such compounds in wild fish that were captured in their vicinity, depending on the species (Bustnes et al. 2010). Salmon farms are a source of lipid-soluble OHCs to wild marine fish, but variation in life-history and habitat use seems to affect the levels of OHCs in the different fish species.

In contrast to the lipid soluble OHCs, control fish had 67% higher PFOS levels than farm-associated wild fish, which suggests that natural food contains higher loads of this compound than the commercial feed used in salmon farms (Bustnes et al. 2010). Salmon farms thus drove a decrease in the level of this group of OHC contaminants in wild fish.

The elevated levels of lipid-soluble OHCs detected by Bustnes et al. (2010) in farm-associated wild fish were below European standards for safe consumption. To date, there are no studies that demonstrate negative consequences of OHCs to the wild fish themselves at the levels detected. As some OHCs are known to act as endocrine disruptors, Bustnes et al. (2010) suggested that further work is required to determine if OHCs negatively affect reproductive processes of wild fish associated with salmon farms.

Within the Marlborough Sounds, observations suggest that several long-lived demersal fish species (e.g. blue cod, snapper, spiny dogfish; Table 1, Column D) of commercial, recreational and traditional fishing interest reside in the vicinity of salmon farms. The existing evidence suggests that if organohalogenated contaminants occur in their tissues due to periods of extended residence and feeding on benthic invertebrates beneath salmon farms, levels are likely to remain below those that will affect the fish themselves and below those considered safe for human consumption. In addition, it may be possible that some lipid soluble OHCs (e.g. PFOS) may decrease in their tissues due to their association with farms as determined by Bustnes et al. (2010) for saithe.

As the Bustnes et al. (2010) study was conducted at farming sites established for 5-10 years, it is likely that the statements in the above paragraph will hold true over a similar time scale in the proposed new Marlborough Sounds farming sites. As no study has been conducted at farming sites that have been in operation over multi-decadal time scales, we cannot reliably infer if longer term effects may occur.

3.7 Heavy Metals

3.7.1 Heavy metal accumulation at fish farms

Fish feeds may contain trace concentrations of mercury (Hg) and other elements such as zinc (Zn), copper (Cu), cadmium (Cd), Iron (Fe), manganese (Mn), cobalt (Co), nickel (Ni) and lead (Pb) (Choi & Chec 1998; Lorentzen et al. 1998; Lorentzen & Maage 1999) in low levels. As trace metals in feed are likely to accumulate in both sediments and cultured fish (e.g. Liang et al. 2016), monitoring of metal concentrations in feed is crucial.

The amounts of these elements in the Skretting feeds used by NZ King Salmon that have been measured are lower than current Australian and European Union standards, according to Skretting Australia's Residue Monitoring Report (2006-2010). Specifically, concentrations of lead were between 0.05-0.207 mg/kg from 2006-2010 (EU limit = 5 mg/kg), cadmium ranged from 0.19-0.59 mg/kg (EU limit = 1 mg/kg) and mercury ranged from 0.009 – 0.026 mg/kg (EU limit = 0.1 mg/kg).

As the most detailed existing information on heavy metal concentrations in the tissues of wild fish around salmon farms comes from Norway (e.g. Bustnes et al. 2011), comparison of the current levels in NZ King Salmon diets with diets used in the Norwegian salmon industry will enable evaluation of whether effects found elsewhere are likely to be comparable to the Marlborough Sounds and the proposed site plan changes. Heavy metal concentrations determined in salmon feeds produced by EWOS, a major salmon producing feed company in Norway, from 2003-2005, which corresponds to the period before fish were sampled in the Bustnes et al. (2011) study described in detail below, were between 0.05-0.21 mg/kg for lead, 0.04-0.17 mg/kg for cadmium and 0.01 – 0.05 mg/kg for mercury. These are broadly similar to the ranges detected in current feeds used by NZ King Salmon.

No consistent evidence has arisen to date that suggests that farmed salmon have elevated concentrations of Hg and other elements compared to wild salmon (Foran et al. 2004, Kelly et al. 2008b, Jardine et al. 2009). Wild fish that occur near salmon farms are subject to different processes and have different diets than the farmed salmon, thus levels of heavy metals in farmed salmon cannot be used to infer likely levels in the wild fish that occur in the vicinity of salmon farms.

While only trace concentrations are present in salmon feeds, the volume of feed introduced to the limited area of a salmon farm on a multi-year time scale may result in bio-accumulation of certain elements in sediments below farms. Where they are used, antifouling treatments such as Zn or Cu are also likely to contribute to metal accumulation in sediments (e.g. Nikolaou et al. 2014). Sediments below salmon cages hold elevated concentrations of some elements such as Zn, Cu Cd and Fe (e.g.

Dean et al. 2007; Naylor et al. 1999). As benthic invertebrate abundance and biomass is typically also higher in farm-influenced locations (e.g. Kutti et al. 2007), and wild fish aggregated at salmon farms feed upon benthic invertebrates as well as salmon feed (e.g. Dempster et al. 2011), studies have sought to determine if heavy metals in wild fish around salmon farms are elevated.

3.7.2 Heavy metals in wild fish around salmon farms

Relatively little is known about the influence of salmon farms on the distribution of different metals and elements, including potentially toxic metals, such as Hg, Cd, Pb and Zn in wild fish. A study from Pacific Canada suggested that salmon farms may act as a source of Hg at a local scale. Demersal rockfish (*Sebastes* sp.) caught near salmon farms had higher levels of Hg compared to fish from reference sites (deBruyn et al. 2006), which might be due to rockfish feeding at a higher trophic level around fish farms compared to reference sites and thus bio-accumulating more Hg. Alternatively, the anoxic conditions in sediments beneath salmon farms may have made mercury more bio-available through bio-methylation to benthic organisms which rockfish then consumed (deBruyn et al. 2006).

A further study documented the concentrations of 30 elements in the livers of demersal Atlantic cod (*Gadus morhua*) and pelagic saithe (*Pollachius virens*) caught in association with salmon farms or at reference locations in three regions throughout the latitudinal extent of Norway (59º-70ºN; Bustnes et al. 2011). Nine of the 30 elements were significantly different between saithe caught near salmon farms and control saithe caught at distant sites, but only four (Hg, U-238, Cr and Mn) were highest in farm-associated saithe, and this pattern was only detected consistently across all locations for Hg. Thirteen elements differed in concentration between cod caught near salmon farms and control cod caught at distant sites. Only three elements (U-238, Aluminium (Al) and Ba) were higher in farm-associated cod than controls, and this pattern was only detected consistently across all locations for Al. After controlling for confounding variables (e.g. fish size and weight, region, sex), estimated concentrations of Hg in saithe livers were ~80% higher in farm-associated fish compared to controls. In contrast, Hg concentrations were ~40% higher in control cod compared to farm-associated cod. The authors concluded that salmon farms do not lead to a general increase in the concentrations of potentially harmful elements in wild fish and suggested that the distribution of Hg and other elements in wild fish in Norwegian coastal waters may be more influenced by habitat use, diet, geochemical conditions and water chemistry.

While Hg levels were elevated in the demersal rockfish (deBruyn et al. 2006) and saithe (Bustnes et al. 2011) compared to control fish, these levels remained below those considered safe for human consumption. To date, there exist no studies that demonstrate negative consequences of mercury to the wild fish themselves at the levels detected. Kalantzi et al. (2014) measured metal concentrations in macroinvertebrates and fish adjacent to fish farms in the Greek Mediterranean. Arsenic (As), sodium (Na), zinc (Zn) and cadmium (Cd) accumulated in macroinvertebrate tissues at equal or higher concentrations to that of the sediment. Hg was accumulated at lower concentrations by macroinvertebrates, but biomagnified in the farm-associated fish that fed on macroinvertebrates.

Within the Marlborough Sounds, anecdotal evidence suggests that several long-lived demersal fish species (e.g. blue cod, snapper, spiny dogfish; Table 1, Column D) reside in the vicinity of salmon farms. Blue cod and snapper, in particular, are targets for commercial, recreational and traditional fisheries. The existing evidence from studies elsewhere suggests that Hg levels in their tissues are likely to remain at levels below those considered safe for human consumption.

3.8 Movements of Farm-Associated Fish

Wild fish attracted to fish farms might move among farms and also to other areas of ecological and commercial interest. Such movements may affect the local fish population and, implicitly, the fisheries in several ways. For instance, diseases and parasites are persistent problems in marine fish farming (e.g., Bergh 2007), and wild fish moving among farms and to other areas might carry pathogens. Movement patterns of several farm-associated fish species have been studied using acoustic telemetry methodology, which involves tagging fish with acoustic transmitters that emit unique sound signals that are recorded by automatic listening stations positioned throughout a study area (Uglem et al., 2009; Arechavala et al. 2010; Otterå and Skilbrei 2014, Skilbrei and Otterå 2016). These studies have shown that saithe in Norway and mullet (*Liza aurata* and *Chelon labrosus*) in Spain that were captured at farms and subsequently equipped with transmitters move rapidly and repeatedly among fish farms located several kilometres apart in typical farming areas. Tagged fish were also detected on local traditional fishing areas close to the fish farms. Similar tracking studies on farm-associated Atlantic cod have shown that cod repeatedly move from and between fish farms (Uglem et al., 2008). Therefore, these species exhibit movement patterns that make them potential vectors for transmission of diseases and parasites both to farms and from farms into wild fish populations (Uglem et al. 2014).

The possibility that wild fish may spread diseases or parasites that occur on cultured fish assumes that wild fish share pathogens with the farmed fish and that these pathogens can be transferred among wild and farmed species under natural conditions. Fernandez-Jover et al. (2010) found that reared sea bass and sea bream did not share macroparasites with farm-associated wild fish (bogue and Mediterranean horse mackerel). Similarly, no effect of farms on the total parasite community was detected when farm-associated and not farm-associated wild bogue and horse mackerel were compared.

In contrast to this potentially negative effect, consumption of greater amounts of food while resident near fish farms implicitly involves an increased biomass of wild fish. Therefore, movements of fish from farms to other areas in the sea may create an export of "added biomass" to the fisheries. Little is known about the extent of such biomass export, but tag and recapture studies of Atlantic cod caught at fish farms have shown that a high proportion (32%) of externally tagged fish was recaptured at local traditional cod fishing areas (Bjørn et al., 2007). Farm-associated fish might also leave the fish farms during their reproductive period to spawn. This possibility has hitherto received little attention. If and how this might affect the reproductive ability of wild fish is unclear. However, acoustically tagged, farm-associated cod may move rapidly and frequently between a fish farm and local spawning grounds during the natural spawning season (Uglem et al., 2008).

3.9 Wild Fish as Agents of Pelagic and Benthic Amelioration around Fish Farms

Wild fish appear to play a significant role in assimilating nutrient wastes emitted by salmon farms. Within coastal salmon farming areas in Norway, the main species of aggregated fish, saithe (*Pollachius virens*), rely on waste feed for over 70% of their diet when in the vicinity of farms, while several other species (*Gadus morhua*, *Melanogrammus aeglefinus* and *Scomber scombrus*) also consume lost pellets around farms (Dempster et al. 2011). Farm-associated saithe caught during summer had an average of 14.2 g of waste pellets in their stomachs (Dempster et al. 2011). An aggregation size of 10 000 saithe, which is within the range observed at many farms (Dempster et al. 2009), would therefore equate to 142 kg of pellets consumed each day during summer, totalling 12.8 t of waste food consumed over a 3 mo period. For a farm with 1000 t of salmon that feeds at a rate of 1% of biomass (or 10 t) per day, 142 kg represents a minimum food loss of 1.4%. These estimates illustrate the capacity wild saithe schools have in reducing particulate sedimentation around salmon farms, thus providing an 'ecosystem service' to fish farmers. Similar results have been found for wild fish aggregated around fish farms elsewhere. In Australia, excluding wild fish from the water column under salmonid sea cages resulted in a doubling of waste accumulation under the cage (Felsing et al. 2005). Two studies in the Mediterranean Sea found similar or higher levels of amelioration (Vita et al. 2004; Sanz-Lázaro et al. 2011), while a recent experimental study, also in the Mediterranean Sea, estimated that 18 % of particulate waste was consumed by wild fish (Ballester-Molto et al. 2017).

Current models to predict sedimentation and nutrient dispersal around salmon farms do not account for this process. Widely used models (e.g. DEPOMOD) may overestimate sedimentation of food pellets at farms by tens of tons per year. Incorporating the effects of wild fish into models will resolve this inaccuracy. It is likely that most modelling conducted in New Zealand to estimate nutrient dispersal and sedimentation due to salmon farms does not account for this significant ecological process.

3.10 Interactions of Salmon Farms with Wild Salmonid Populations

For salmonid aquaculture in northern Europe and North America where farmed and wild salmon co-occur in coastal waters, two substantial environmental effects are of concern: 1) escape of cultured fish and their subsequent mixing with wild stocks (Dempster 2007; see review by Glover et al. 2017); and 2) that the large numbers of cultured fish held in coastal areas may increase parasite loads of their wild counterparts (Bjorn et al. 2001, Morton et al. 2004, 2008, Krkošek et al. 2005; Ford & Myers 2008). Inter-breeding and competitive interactions of escapees with wild salmon within rivers may have detrimental effects on wild populations. Likewise, high parasite loads on seaward-migrating salmon smolts have been implicated as a potential cause of high mortality at sea and reduced return of adults to rivers (Bjorn et al. 2001; Krkosek et al. 2013). In Ireland, Jackson et al. (2013) found no evidence that the distribution of aquaculture affected wild salmon stocks; rather, changes in the quality of freshwater habitat was implicated. As salmonids are non-native to New Zealand's waters, these two concerns of how salmon aquaculture interacts with native wild salmonid populations are of limited relevance to the NZ King Salmon Marlborough Sounds proposal.

3.11 Quality of Farm-Associated Wild Fish for Human Consumption

Many species of wild fish that occur in salmon farming areas constitute important local fisheries. The interaction of wild fish with salmon farms has created conflicts between farmers and local fishers in Norway. Many local fishers believe that wild saithe, which have resided around farms and consumed food intended for salmon, have inferior flesh quality. This has led to some local fishermen in Norway avoiding fishing in salmon farming areas as they claim that the flesh quality of farm-associated fish is inferior to saithe that do not interact with salmon farms (Bjørn et al., 2007).

The assumed negative relationship between association with fish farms and inferior flesh quality is, however, poorly supported by scientific studies (Skog et al., 2003; Bjørn et al., 2007; Otterå et al., 2009). Differences in the fatty acid composition, fat content and other tissue attributes have been detected between saithe caught near and distant from salmon farms (Fernandez-Jover et al. 2011), but in a controlled experiment, a sensory panel could not distinguish the taste of saithe fed an exclusively salmon feed diet for 8 months from saithe fed typical wild diets (Otterå et al., 2009). However, the wild saithe was different in tissue 'dullness' and chewing resistance. Both these attributes could have been due to saithe fed the exclusive salmon feed diet having a higher energetic status, with more muscle protein than saithe fed a typical wild diet. A more recent study reported that non-expert tasters either did not distinguish between wild saithe caught near or distant from farms (when served as burgers) or preferred the near-farm saithe (when served as oven-baked fillets) (Uglem et al. 2017). In the Mediterranean, farm-associated bogue (*Boops boops*) were 'gentler' in flavour and softer in texture than control samples, perhaps due to higher fat and lower water content (Bogdanović et al. 2012), indicating that any effects on the culinary quality of farm-associated fish are not necessarily negative.

Within the Marlborough Sounds, there is no specific information available to assess how the quality of wild fish caught in the vicinity of salmon farms may be affected. As the effects detected elsewhere are limited to only two species, we cannot reliably draw inference from these data.

3.12 Ecosystem-Based Management of Fish Farming and Local Fisheries

As fish farms typically lead to large aggregations of fish species that are targets of traditional, recreational and commercial fisheries, they have the potential to generate substantial local-scale interactions between aquaculture and fishing (Dempster & Sanchez-Jerez 2008). Where fish farms are concentrated in coastal waters, these effects are likely to be amplified and may interact with fisheries at a regional scale. Sea-cage aquaculture should be taken into account in fisheries management, as it may affect the spatial distribution and demographic processes of a range of important fisheries species.

Increased commercial and recreational fishing pressure around fish farms has been noticed by farm managers in the Mediterranean Sea (Valle et al. 2006) and is evident from studies that have assessed the extent of catches made around fish farms (Akyol & Ertosluk 2010). Fisheries also target wild fish aggregated at salmon farms in the Norwegian coastal ecosystem, although the extent of this interaction has not been quantified (Maurstad et al. 2007). Farm-aggregated wild fish have been targeted through the deployment of gillnets and purse seines close to farms, that capture large quantities of wild fish when they move away from the farm or seasonally migrate. Farm-associated fish have been identified from samples taken from local fish markets through their distinct farm-modified fatty acid profiles (Fernandez-Jover et al., 2007; Arechavala-Lopez et al., 2010, 2011). In addition, local fishermen along the Norwegian coast report relatively high amounts of saithe (*Pollachius virens*) with salmon pellets in their stomach are being caught in fjords with intensive fish farming. In general, farm-associated saithe are significantly fatter and have much larger livers than non-associated fish (Skog et al., 2003, Fernandez-Jover et al. 2011). Previous studies have also shown that saithe caught, tagged, and released at a salmon farm later occurred in the catches of commercial fishermen (Bjordal and Skar, 1992).

Coastal fish farms have been suggested to have the potential to act either as ecological traps (Hale and Swearer 2016) or population sources for wild fish populations, depending on how the interaction of fishing with fish farms is managed (Dempster et al. 2006, 2009, 2011). An ecological trap arises when artificial structures are added to natural habitats and induce mismatches between habitat preferences and fitness consequences (Hallier and Gaerner 2008). In the case of fish farms, if fishing is extensive on wild fish populations when they are aggregated and vulnerable, this may drive a local decline in fish populations through increasing mortality rates. As farms are attractive to wild fish, they will continue to draw fish into their vicinity where they can be fished, which could drive populations down. Alternately, if fishing is prohibited from the immediate surrounds of farms and farm-associated diet is of sufficient quantity and nutritional quality for reproductive provisioning, this may allow the enhanced condition that wild fish generate due to their association with fish farms to translate to enhanced spawning success. With spatial protection from fishing, this may allow fish farms to act as population sources for certain fish stocks.

Spatial protection from fishing may not have to be extensive to be effective in protecting farm-associated wild fish, as wild fish are typically very tightly aggregated to the underwater farming structures (Dempster et al. 2002, 2010). In several Mediterranean countries, no fishing is allowed within the farm leasehold area (typically defined by corner marker buoys positioned 50 – 100 m from cages), and in Norway, no fishing is allowed within 100 m of fish farming structures. This relatively small spatial exclusion from fishing has the added advantage of reducing interactions of fishing gear with fish farming gear, and thus greatly reduces incidences of gear damage that may also lead to escapes of farmed fish.

A further advantage of the no fishing restrictions in the immediate vicinity of fish farms is that wild fish are able to provide their ‘ecosystem service’ of consuming waste feed, and thus reducing the severity of any benthic impacts (e.g. Vita et al. 2004). In addition, recent evidence suggests a further useful ecosystem service in that the abundant large wild fish that aggregate around farms consume a significant proportion of the escapees and thus reduce their potential negative interactions with wild populations (Dempster et al. 2016; Glover et al. 2017). Spatial protection from fishing will also reduce the possibility of harvesting any long lived benthic fish species in the vicinity of fish farms that may acquire elevated loads of mercury due to their association with farm-impacted sediments (e.g. deBruyn et al. 2006). Pelagic wild fish that aggregate at fish farms are likely to do so for shorter periods than more sedentary benthic species (Uglem et al. 2008, 2009). Thus, pelagic fish will not become 'locked away' from the regional fishery for extended periods. Spatial protection in the immediate surrounds of fish farms would provide only temporary protection while they were aggregated and more vulnerable at fish farms. Once they move away from farms, they will return to being subject to the standard fishing pressure of the region.

Consideration of a no fishing restriction is generally relevant in the New Zealand situation, although, in the case of the proposed site in northwest Cook Strait, the relatively high water depth of 60–100m (Newcombe et al., 2019) requires longer mooring lines than in shallower water. In this case, the mooring lines will be anchored about 100m laterally from the farm cages, which would result in a "natural" restriction area out to about 100m for a fishing method such as trawling. Other netting and line methods may be deployable up to some point within the 100m zone, but potential risk may well outweigh possible benefit and limit such operations in cases where restrictions are not set, particularly given the absence of available information on aggregations in the New Zealand context.

4. THE EFFECTS OF FARM INSTALLATION ON COMMERCIAL AND RECREATIONAL FISHERIES – AN APPRAISAL USING CATCH DATA

4.1 Commercial Catch in the Vicinity of the Proposed Site

4.1.1 Background and approach

The aim of the work documented in this section was to consider the potential effect on commercial quota species of installing populated farm enclosures at sites similar to that proposed in north western Cook Strait. Using that site as a working example, an analysis was developed using New Zealand commercial fisheries landings data from a local area centred on the proposed farm site, extending a distance beyond what might be considered to be under any direct influence of the deployed enclosures or the farmed fish populating them. The approach was to compare and contrast landings of relevant species at the immediate site and over an intermediate distance, with total landings for the entire local area.

An application was made to the Ministry of Primary Industries (MPI) for extracts of data from the commercial catch-effort database for the 8 fishing years[7] 2010-11 to 2017-18 under the Official Information Act 1982 (OIA). The application included the intended use for the data to examine the potential impact on commercial fisheries of installing a salmon farm at the proposed site. Some discussion was required, relating mainly to the spatial scale of data summaries allowed under MPI protocols designed to protect the privacy of fisher's target areas.

A graphical summary of the geographical range, spatial structure, and time basis of the commercial fisheries catch dataset supplied by MPI is shown in Appendix C (Figure C1). Catch data were summarised according to a rectangular grid centred on the proposed farm site extending slightly beyond a circular radius of approximately 10 nmi. Raw data were supplied by MPI and a summary of catch totals for all species in this area (Table C1) shows that a total of almost 2,280 metric tonnes (t)[8] of all species were harvested by the commercial fleet in this area over the 8 fishing years, with 47 named species contributing 2,057 t and a general category of "All other species" (i.e., unspecified) contributing 221 t. The annual mean catch of all species was a little more than 250 t.

The data providing the summary in Appendix C were summarised further (Table 2) to examine the impact that farm installation might have on the commercial fishery by selecting two areas restricted more closely to the farm site: Area A used species catches from grid-rectangles D6, D7, E6, and E7 only, whereas Area B was more extensive and based on the next "layer" of grid-rectangles outside Area A, comprising C5-C8, D5 & D8, E5 & E8, and F5-F8 (see Figure C1). In each case species catches were summed and compared with the total species catches for all rectangles in the

[7] A fishing year is defined as the 12 months from October 1 to September 30 inclusive.
[8] Note that total green weights in the text are in metric tonnes as most values are >1t whereas they are included in the tables as kg as they were supplied; retaining the kg scale allows easier reading for the frequent values <1t.

Table 2: Total commercial catch by species during fishing years 2010-11 to 2017-18 for Area A (grid codes D6, D7, E6, E7), Area B (grid codes C5-C8, D5&D8, E5&E8, and F5-F8) and overall area (see Figure C1) including annual averages for Areas A and B, and percentages of the overall area catch of species in Areas A and B; sorted by total species green weights. *Source*: Ministry for Primary Industries OIA (4 Dec 2018).

Species name	Total green weight (kg)	Annual average (kg)	Total green weight in overall area (kg)	% Overall area green weight
Area A				
School shark	15,241	1,905	272,724	6
Hapuku-Bass	12,601	1,575	86,096	15
All other species†	7,424	928	568,349	1
John dory	6,617	827	111,299	6
Blue moki	5,360	670	24,596	22
Tarakihi	5,327	666	180,912	3
Red cod	5,182	648	215,121	2
Snapper	5,063	633	68,928	7
Spiny dogfish	2,962	370	193,929	2
(Red) gurnard	2,435	304	158,863	2
Rattails	1,555	194	197,389	1
Carpet shark	1,341	168	26,021	5
Rig	1,160	145	42,901	3
Butterfish	1,125	141	22,380	5
Barracouta	462	58	95,463	0.5
Area B				
All other species†	73,569	9,196	411,610	18
Red cod	66,250	8,281	215,121	31
School shark	55,873	6,984	272,724	20
Tarakihi	47,074	5,884	180,912	26
(Red) gurnard	41,865	5,233	158,863	26
Spiny dogfish	34,311	4,289	193,929	18
Barracouta	31,845	3,981	95,463	33
John dory	30,682	3,835	111,299	28
Snapper	29,311	3,664	68,928	43
Warehou	28,342	3,543	75,034	38
Hapuku-Bass	27,932	3,492	99,441	28
Rattails	16,072	2,009	197,389	8
Blue moki	10,469	1,309	24,596	43
Rig	7,236	905	42,901	17
Butterfish	6,819	852	22,380	30
Carpet shark	4,995	624	26,021	19
Ghost shark	4,993	624	26,101	19
Elephant fish	3,064	383	7,089	43
Giant stargazer	2,109	264	4,660	45
Flatfish	500	63	16,269	3
Conger eel	350	44	354	99
Leatherjacket	343	43	26,759	1
Spotted stargazer	115	14	473	24

†*All other species* is the sum of the catch for those categorised as such in Table C1 plus the totals for those individual species listed in Table C1 but absent here, which differs for Area A and B.

approximately 10 nmi diameter area summarised in Figure C1. Spatially, Area A and B covered 5.3% and 15.8% respectively of the overall area represented by the rectangles.

For each of the two areas, catches of the individual species recorded in the component rectangles were summed and tabulated, and sorted high to low on green weight totals for the area. In neither case did the resulting species list reflect the species list of the overall area. Therefore, the "All other species" category for the overall area was added to with the green weights of the individual species absent from the species lists of the area of interest (Area A or B). Because the species lists of the two areas differed, total green weight of this category for the overall area also differed in the two smaller areas.

The original dataset received from MPI included catch data for both hapuku and hapuku-bass. The latter of these two is designed to provide a category where catch of the two groper species, *Polyprion oxygeneios* (hapuku) and *P. Americanus* (bass), which are managed as a single entity, can be reported without fishers needing to distinguish between the two. According to the MPI Fisheries Assessment Plenary document for May 2018 (Fisheries New Zealand, 2018), which provides information on stock assessment and stock status of all species managed under the Quota Management System (QMS), generally no distinction is made between the two species in reported catches, and published data combine them. Therefore, to reduce confusion in the present document, catch under the two categories hapuka (HAP) and hapuka-bass (HPB) were summed and are included here as HPB (see Table 2).

The MPI dataset provided useful information on commercial catches in the vicinity of the proposed farm site, but could not be used to provide context in terms of the scale of commercial catch, either within the local Fishstock for each species or with reference to national landings. To provide perspective, catches of the quota species represented in the two areas were summarised from the most recent Fisheries Assessment Plenary document (Fisheries New Zealand, 2018). This summary is presented in Table 3 as the mean annual catch (by fishing year) over the period 2010–11 to 2016–17, for both the local Fishstock (i.e., the Fishstock containing the area summarised in the MPI dataset) and the national catch total, 2016–17 being the most recent year with available data. Although not exactly identical to the period over which annual averages from Area A and B were calculated (the MPI OIA data could not be broken down by year), it was considered similar enough for present purposes.

The final feature in this assessment was to calculate the annual means of the most commercially valuable species from Areas A and B as percentages of their annual mean catches taken in the local Fishstock and in the national catch (Table 3).

4.1.2 Results

A total of 47 species were recorded from the approximately 10 nmi radius area centred on the proposed site. This included 5 "unspecified" categories: flatfish, hapuku-bass, rattails, stingray, and wrasses; the catch-all, "all other species", is not included in these figures. The 8 year overall catch ranged from 1 or 2 kg for butterfly perch (*Caesioperca lepidoptera*), northern bastard cod (*Pseudophycis breviuscula*), and ling (*Genypterus blacodes*), to about 273t for school shark (Table C1). Catches of two species exceeded 200t (red cod and school shark), 6 species ranged between 100t and 200t (gurnard, john dory, jack mackerel, rattails, spiny dogfish, and tarakihi), 12 provided catches >10t and <100t (barracouta, butterfish, carpet shark, capro dory (*Capromimus abbreviatus*), flatfish, ghost shark, hapuku, hapuku-bass, leatherjacket, blue moki, snapper, rig, and common warehou), 11 ranged from 1t to 10t (eagle ray, elephant fish, frostfish (*Lepidopus caudatus*), hoki (*Macruronus novaezelandiae*), lemon sole (*Pelotretis flavilatus*), porcupine fish (*Allomycterus jaculiferus*), common roughy, sand flounder (*Rhombosolea plebeia*), gemfish (*Rexea solandri*), giant stargazer, and trevally), and the remainder (15 spp.) registered less than 1t.

The two species landed most frequently in the more restricted Area A over the 8 year period 2010 to 2018 were school shark (15.2 t) and hapuku-bass (12.6 t), producing annual average catches of 1.7 t and 1.4 t respectively (Table 2). Catches of other species in this area were lower, producing annual

Table 3: Mean annual local Fishstock and national catches (t) for the quota species represented in Areas A and B (see text) over the period of †fishing years from 2010–11 to 2016–17 inc. and percentages of these annual mean catches represented by the annual mean catch of each species calculated in Area A, B, and the overall area (see Table 2); annual means are for both the local Fishstock (i.e., that containing the area of interest centred on the proposed farm site), and the overall national catch for each species; percentages are calculated for each. *Source*: Fisheries New Zealand (2018) and MPI OIA December 2018.

		Local Fishstock Catch (FC)				National Catch (NC)			
Species Common Name	Fishstock	*Annual mean (t)	A as % of FC	B as % of FC	C as % of FC	*Annual mean (t)	A as % of NC	B as % of NC	C as % of NC
Barracouta[P]	BAR 7	6,843	<0.01	0.06	0.17	25,525	<0.01	0.02	0.05
Blue moki[B&R]	MOK 1	398	0.17	0.33	0.77	557	0.12	0.24	0.55
Blue warehou[BP]	WAR 7	713	NA	0.50	1.32	3,118	NA	0.11	0.30
Butterfish[R]	BUT 7	20	0.71	4.26	13.99	107	0.13	0.80	2.61
Elephant fish[B]	ELE 7	103	NA	0.37	0.86	1,380	NA	0.03	0.06
Flatfish[B]	FLA 7	653	NA	0.01	0.31	2,700	NA	0.002	0.08
Ghost shark[B]	GSH 7	548	NA	0.11	0.6	1,731	NA	0.04	0.19
Stargazer[B]	STA 7	1,084	NA	0.02	0.05	2,497	NA	0.01	0.02
Hapuku-Bass[B]	HPB 7	168	0.94	2.08	6.41	1,338	0.12	0.26	0.80
John dory[BP]	JDO 7	142	0.58	2.70	9.8	639	0.13	0.60	2.18
Leather jacket[R]	LEA 2	151	NA	0.03	2.22	436	NA	0.01	0.77
Red cod[B]	RCO 7	1,524	0.04	0.54	1.76	6,203	0.01	0.13	0.43
Red gurnard[B]	GUR 7	777	0.04	0.67	2.56	3,705	0.01	0.14	0.54
Rig[B]	SPO 7	236	0.06	0.38	2.27	1,353	0.01	0.07	0.40
School shark[BP]	SCH 7	612	0.31	1.14	5.57	3,132	0.06	0.22	1.09
Snapper[B]	SNA 7	215	0.29	1.70	4.01	6,362	0.01	0.06	0.14
Spiny dogfish[BP]	SPD 7	1,205	0.03	0.36	2.01	5,509	0.01	0.08	0.44
Tarakihi[B&R]	TAR 7	1,076	0.06	0.55	2.1	5,815	0.01	0.10	0.39

*Annual means for the local Fishstock and national catches are based on fishing years 2010–11 to 2016–17, whereas annual means for Area A and Area B are based on fishing years 2010–11 to 2017–18.
†The 12 months from October 1 to September 30 inclusive.
Superscripts following common names are habitat codes: B benthic; BP bentho-pelagic; B&R benthic & reef dwelling; P pelagic; R reef dwelling.

averages of less than 1 t. Overall, they generally represented a small proportion of the total catch for each species in the overall 10 nmi area, reflecting the spatial percentage Area A is of the total area (5.3%) — i.e., 13 of the 15 species were 7% or less of the total and 10 species were 5% or less. The catch of blue moki in this area contrasted somewhat with this trend, representing 22% (5.4 t) of the overall total of 24.6 t and the catch for hapuku-bass was 15% (12.6 t) of the overall total of 86.1 t. Catch of the unspecified species category was 1% of the overall total.

In Area B (Table 2) the catch of conger eel was relatively low at 350 kg but represented 99% of the total from the overall area. The giant stargazer catch of around 2t was 45% that of the overall area and several species (snapper, elephant fish, and blue moki) represented similar proportions of the total (43%) although catches of snapper (>29t) and blue moki (~10.5t) were considerably higher than both giant stargazer and elephant fish (~3t). The catch of warehou in Area B was similar to snapper at >28t which represented a similar proportion of the catch from the overall area (38%). It is interesting to note that all 350 kg of conger eel landed in Area B were taken in a single grid rectangle.

A total of 8 of the 22 species represented proportions in the range 24% to 33% although their Area B catches ranged widely from 115 kg (spotted stargazer) to 66t (red cod). This included the catch of barracouta, the only pelagic species in the list for both areas, at a little less than 32t representing 33% of the overall catch, tarakihi and gurnard (~47t and ~42t respectively), john dory (~31t), hapuku-bass (28t), and butterfish, which, with a catch of a little less than 7t, represented 30% of the total. Catch of the unspecified species category in Area B was 18% of the overall total.

As percentages of the local Fishstock annual mean catch (Table 3), annual mean catches of quota species from Area A were all less than 1% and several (barracouta, red cod, red gurnard, rig, spiny dogfish and tarakihi) were less than 0.1%; barracouta was less than 0.01%. The highest were hapuku-bass (0.94%), butterfish (0.71%) and john dory (0.58%). This pattern was largely repeated in Area B with butterfish (4.26%), hapuku-bass (2.08%) and john dory (2.70%) producing the highest percentages again. There was no catch of common warehou in Area A.

As percentages of the national annual mean catch, several annual mean catches (barracouta, red cod, red gurnard, rig, snapper, spiny dogfish and tarakihi) from Area A were 0.01% or less. The highest were john dory (0.13%), butterfish (0.13%), hapuku-bass (0.12%) and blue moki (0.12%). This pattern was largely repeated in Area B with butterfish and john dory producing the highest percentages (2.61% and 2.18% respectively).

4.1.3 Discussion

The analysis presented here aims to provide some insight into which commercially targeted finfish species may be affected by deploying farm enclosures at sites such as that proposed in northwestern Cook Strait. While the data provide a useful catch history of the species taken within the vicinity of the proposed site, we know little about the nature and extent of any effect. For example, the distance over which any effect may operate is unknown, and knowledge about the specific impact of any effect on different species is limited, an issue that is complicated further by differences in an effect's mode of action as it impacts either highly mobile pelagic species inhabiting midwater to the surface or less active benthic species closely associated with the sea floor, or species groupings based on other aspects of their "ecological profiles". And finally, we might ask whether the impact will be negative, or is it possible that that some component of the finfish population might be enhanced in some way?

Information on the interactions of wild fish with salmon farms is discussed extensively above in §3 where it is appropriately referenced; those references are omitted here. Based on that discussion, reference will be to a summary of effects and their actions as they might affect the quota species listed in Table 3, to determine whether a species is vulnerable to farm installation.

Farm discharge comprises the components waste feed as well as faecal and other organic waste material from the fish themselves. These components can impact finfish in four ways: (1) by making accessible artificial feed, (2) by impacting the benthos with farm derived organic material, (3) by communicating the presence of the farm through suspension/resuspension as fine particles within the water column, and (4) through a "fertilisation" effect at the fringes of the overall farm footprint. Each of these represents a mode of action by which the farm impacts the finfish population and there are differences in the way they might affect the three components of the population, the benthic, reef dwelling, and pelagic species. There are also differences in the distance over which these modes of action operate.

The mode of action may also operate according to the functional feeding method used by the species and other more subtle requirements. In a study aimed at detecting changes in abundance and the composition of wild fish species associated with a sea-cage fish farm before and after farming ceased, Tuya et al., (2006) grouped fishes into six categories according to their "ecological requirements": (1) particulate organic matter (POM) feeders, (2) meso- and macro-carnivorous members of the family Sparidae, (3) herbivorous fish, (4) bentho-demersal meso-carnivores, (5) bentho-demersal macro-carnivores, and (6) large-sized benthic Chondrichthyid rays. The approach produced qualitative and quantitative analyses of assemblages beneath the farm compared with two nearby control areas.

Aggregation under the farm was estimated at 50x greater than the control areas during full operation of the farm, which fell to <2x when operations ceased and the farm was reduced to cage structures only. POM feeders and large Chondrichthyid rays underwent a marked decline under the farm after farming ceased, suggesting that it was the waste feed that attracted these groups. By contrast, abundances of herbivores, benthic macro- and meso-carnivores remained at similar levels and the benthic macro-carnivores were more abundant at the farm site after farming ceased than at the control sites, which supported the hypothesis that increased physical structure of the sediments as a result of the farming contributes to the aggregating function.

Also important in this context is the "FAD[9] attraction" of the farm, or the tendency of fish species to be attracted to floating objects and structures. As is discussed above in §3.3, this effect is well known, although the mode of action does not seem to be clear. What has been shown is that species taking up residence under a aquatic farm is a different group to the species that take up residence under a FAD. Therefore it has been concluded (see §3) that the mode of action attracting potential residents to a fish farm includes some chemical cue(s) which is part of that component of the farm discharge that acts to communicate the presence of the farm over some unknown distance.

Each of the quota species listed in Table 3 is categorised as either benthic, pelagic, bentho-pelagic, or reef dwelling, the latter being probable residents within the biogenic habitats identified by Elvines et al., (2019). The fifth category included in Table 3 (benthic & reef) is for species described in Roberts et al., (2015) as benthic and associated with reefs. The majority (9 species) of those listed are benthic species, 4 are bentho-pelagic, 2 are benthic & reef dwelling, 1 is pelagic, and 2 are reef dwelling. Broadly speaking, we can describe the vulnerability to farm installation at the proposed site of each species represented in the data in terms of four factors: (1) the category that describes its habitat, (2) the category that describes its ecological requirements, (3) the mode of action of the farm effect, and (4) the distance from the farm to the area where members of that species were caught i.e., whether it is present in the Area A catch or observed in the data only from Area B. Categories 1 and 2 are closely related, but are not mutually equivalent.

Although there is no absolute certainty about the degree of impact we might expect from farm installation at the proposed site, the results of Elvines et al., (2019) with regards farm discharge are important in considering vulnerability. We might expect that, potentially, the benthic species identified from Area A are the most vulnerable to farm discharge as it impacts the benthos with farm derived organic material. The impact here may be direct, for example through reduction of habitat quality to a species such as stargazer, or indirect through its ultimate effect on a species' prey. Given that the impact is likely to be similar for all species targeting benthic prey, it has the potential in the present context to impact all species taken in Area A except barracouta.

This conclusion also needs to be conditional on distance from the farm cages. One difficulty in reaching a conclusion about vulnerability is the spatial scale of the MPI dataset. The size of the grid rectangles underlying the data summary (see Figure C1) was chosen by MPI to meet protocols related to fisher privacy. When summarising the dataset after receiving it from MPI, Area A was the minimum area encompassing the proposed site that could be selected. Consequently we have no information on species distribution within Area A and must assume it is something like homogeneous, perhaps with some structure according to the strata identified by Elvines et al., (2019). The area is very large so that the overall impact on benthic finfish of this aspect of the farm's discharge is unlikely to be high, although localised effects will occur in a more restricted spatial area centred on the cages according to the main findings of Elvines et al., (2019). This also means that it is unlikely that benthic species absent in Area A but present in Area B will be unaffected by farm discharge under this mode of action because the outer boundary of Area A is probably well outside the zone where an appreciable enough amount of discharge to affect the benthos would be deposited.

[9] fish aggregating device

Initially following deployment of farm cages, only the FAD attraction will impact any pelagic wild fish species. Once the cages are populated with farmed fish the attraction will also include the action of suspended/re-suspended farm discharge as fine particles within the water column. This latter action will operate over a wider area than the benthos impact of farm derived organic material. Although the actual distance is unknown it may affect the entire range of Area B, particularly in a north-westerly direction along the main southeast-northwest current axis identified by Newcombe et al., (2019) and Elvines et al., (2019), and therefore impact all pelagic and bentho-pelagic species over that range. Once any pelagic/bentho-pelagic individuals arrive at the farm, then the waste feed becomes available to them as a potential alternative to their natural diet.

The impact of this effect, whether short or long term, is then a function of whether their presence is temporary or they become resident, either intermittently or on a permanent basis. As is discussed in §3.2, it has been shown by some researchers overseas that aggregations are temporally stable over the scale of several weeks to months, both in relative size and species composition, indicating some degree of residency of wild fish at farms. Other researchers have found fluctuations in composition and abundance according to feeding times, periods of high and low feeding intensity, and the reproductive cycle of the respective species, implying that it is difficult to predict aggregation sizes at any particular farm prior to its establishment, although subsequent temporal fluctuations may become predictable at some locations. Also interesting in this context is the discussion below in §3.8 regarding the movement of some species between farms suggesting, perhaps, that residence may actually be over an extended distance in some instances.

The fertilisation effect is discussed in Elvines et al., (2019), where its outcome is suggested as depending on the degree of deposition and that it ranges from a situation of increased abundances and taxa richness, through reduced taxa richness but with extremely heightened abundances of the few that are represented, to a situation of almost total habitat degradation and loss of life. Anything beyond the lowest level is obviously to be avoided, and at the lowest level the potential effect on finfish species would be to enhance their abundances by providing increased abundance of prey species.

Essentially, the vulnerabilities suggested here are from an ecological perspective. They do not fully equate with a species' vulnerability from a fishery perspective. What is important in the present context is whether the impact of the farm removes the species as a target from the fishery. Therefore, the outcome of the vulnerability assignment must be followed by consideration of the final outcome of the species as it affects its availability to the fishery. For example, a pelagic species that is attracted to the farm and takes up residence there may become the permanent victim of an ecological trap (see §3.12, para. 3), thus being removed from the fishery. An alternative possible outcome is increased vulnerability to fishing from being concentrated at a location known to fishers, particularly where no restriction is made to fishing in the vicinity of salmon farms (see §3.8).

The outcomes that provide an opportunity for increased abundance and/or biomass in the finfish population do not appear to add to their vulnerability. In fact, they could be viewed as a mechanism by which losses elsewhere are offset and this may be the final outcome. However, there is also the possibility that an individual's fitness is compromised through, for example, a reduction in food quality caused by their replacing their natural diet with one dominated by artificial feed. These issues are discussed extensively above in §3.

4.1.4 Conclusions

Generally, commercial catches are low in the immediate vicinity of the proposed farm site, possibly reflecting low numbers of target species. Greatest representation in the data are of benthic species. Overall, there are only 3 pelagic species apparent in catches from the approximately 10 nmi radius area and only 1 of these, barracouta, is present in one of the sub-areas (Area B). The catch of jack mackerel over the 8 year period was relatively high at 153t, but none was taken in Areas A and B (see Table C1) and the small catch of kahawai (25kg) was also recorded from outside Areas A and B.

Therefore, the commercially fished species most likely to be affected by installation of a farm at the proposed site are those from the benthic group, including bentho-pelagic species and the reef dwellers, all of which exist mainly on a diet of benthic organisms. A total of 17 such quota species were identified from Areas A and B (see Table 3), but only 11 of these were landed in Area A. The 6 species landed only in Area B are far less likely to be affected by components of farm discharge impacting the benthos.

The benthic species discussed in the previous paragraph are vulnerable to all the effects discussed above. Greatest potential influence is through farm generated organic material impacting the benthos and access to waste feed, but bentho-pelagic species can also become members of the group resident beneath the farm in the pelagic zone and benthic species are also known to contribute (see §3.2). For bentho-pelagics in the commercial data, potential residence includes members of this group from Area B, which depends on the effective attraction range of the suspended/re-suspended fine particulate matter and the distance over which such species might follow migratory corridors to come under the influence of the FAD attraction of the farm. Altogether, there are 4 bentho-pelagic species recorded from the quota species data recorded in Areas A and B; 3 were landed in Area A.

Ultimately it is impossible to make any direct predictions about the fisheries-related vulnerability of the species listed in Table 3 without first knowing the intended geographic placement of the cages comprising the farm. Selecting a deployment site with the aim of minimising the ecological effects and adopting the type of mitigation strategies suggested by Elvines et al., (2019) will reduce the negative effects on finfish species. And, although it could be argued that the potential loss of such small proportions of the fisheries as have been discussed here (see Table 3) would have a minor effect in the long run, a major aim of utilising high flow sites is to enable expansion of the industry while sustainably managing resources, thus minimising erosion of the wild fish population.

4.2 Recreational Charter Vessel Catch in the Vicinity of the Proposed Site

4.2.1 Background and approach

The aim of the work documented in this section was to consider the potential effect on charter boat catch of deploying farm enclosures at sites similar to that proposed in north western Cook Strait. A similar method to that described for the commercial data in §4.1 was applied here. As part of the application made to the MPI for extracts of data from the commercial fishing database for the 8 fishing years 2010-11 to 2017-18 (see §4.1) charter vessel harvest data were requested from the recreational database. A graphical summary of the geographical range, spatial structure, and time basis of the charter vessel catch dataset (numbers of fish taken) supplied by MPI is shown in Appendix B (Figure B1).

Catch data are summarised there according to a rectangular grid centred on the proposed farm site extending a little beyond a circular radius of approximately 10 nmi. This grid differed in the scale of the component rectangles from the grid employed for the commercial data (see Figure C1) and therefore summaries by two sub-areas used the labels Area M and Area N to avoid confusion with the sub-areas used for the commercial data (Areas A and B), although the same rectangle labels were set by MPI and could not be changed. Raw data were supplied by MPI.

The data providing the summary in Appendix B were summarised further using a method similar to that described for the commercial fishing data in §4.1. Data from the 6 innermost grid rectangles (see Figure B1) were assigned to two contiguous, vaguely concentric areas centred on the proposed site: Area M used species catches from grid-rectangles B4 and C4, whereas Area N was more extensive and based on the next "layer" of grid-rectangles, comprising B3, B5, C3, C5. In each case species catches were summed and compared with the total species catches for all rectangles in the approximately 10 nmi diameter area summarised in Figure B1. Spatially, Areas M and N covered 9.1% and 18.2% respectively of the overall area represented by the rectangles.

For each of Areas M and N, and for the overall area, catches of individual species recorded in the component rectangles were summed and tabulated, and sorted high to low on total number of species for the overall area (Table 4). In neither Area M or N did the resulting species list reflect the species list of the overall area. Therefore, the "All other species" category for the overall area was added to with the fish numbers of the individual species absent from the species lists of the area of interest (Area M or N). Because the species lists of the two areas differed, total green weight of this category for the overall area also differed in the two smaller areas: 5,929 for Area M, 5,442 for Area N. Catches of hapuku and hapuku-bass were aggregated as hapuku-bass according to the discussion in §4.1.

4.2.2 Results

A summary of catch totals for all species (Table 4) shows that a total of 93,395 individual finfish[10] of all species were harvested during recreational charter vessel operations in this area over the 8 fishing years between 2010 to 2018, with 18 named species contributing 88,105 fish and a general category of "All other species" (i.e., unspecified) contributing 5,290 fish. This produces an annual mean catch of all finfish species as 10,377 individual fish.

Although consisting of considerably fewer finfish species than the commercial dataset (18 c/f 47), the species composition of finfish in the list is similar to the more frequently caught species in the commercial list (Table C1). Blue cod catch was the highest at almost 63,000 fish, reflecting the importance as number 1 recreational finfish in Marlborough (Fisheries NZ, 2018), and considerably more than the overall commercial harvest of 119 kg (see Table C1), which may be related to the TACC[11] of the local Fishstock (BCO 7) being 70t only and catches being more available elsewhere. Absent from the charter data are most of the elasmobranchs, except for school shark and thresher shark. The most obvious omission is probably john dory, given that it was the eighth highest caught species in the commercial dataset. Also of interest are several finfish species present here but absent from the commercial list, including bluenose, red moki, yellowtail kingfish and thresher shark.

Harvest of individual finfish in Areas M and N was 18,128 and 11,495 respectively (Table 4), and of individual non-finfish was 977 and 910 respectively, indicating higher numbers and therefore a higher percentage of the overall harvest taken in Area M than Area N, despite the fact that Area M covers half the area. This result may reflect a difference in effort, but that is unknown without information on number of vessel fishing days and is unimportant here. This trend was true for 8 of the 14 species recorded from both areas.

In addition to finfish, three non-finfish species were included in the dataset. The largest harvest by number of fish was of scallop (*Pecten novaezelandiae*), with a total number of almost 160,000 taken in the overall area over the 8 year period. Scallop numbers in Areas M and N were relatively low, with the harvest in both representing similar percentages around 0.58% of the overall suggesting that larger numbers come from elsewhere. The overall crayfish (rock lobster, *Jasus edwardsii*) total number was considerably lower at 1,218 which translates to an annual mean of 135 individuals, although it is interesting that the Area M harvest is relatively high at about 24% of the total, contrast with the Area N take of about 12% of the total. The third non-finfish species recorded was paua (*Haliotis iris, Haliotis australis*), with a low mean harvest rate of about 9 individuals per year.

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[10] These figures are based on the assumption that the category "All other species" comprises finfish only, which may be incorrect but any adjustments are probably negligible given that the main non-fish species (scallops, rock lobster, and paua) are listed in the dataset.

[11] Total allowable commercial catch.

Table 4: Total recreational charter vessel harvest by species during fishing years 2010-11 to 2017-18 for Area M (grid-rectangles B4, C4), Area N (grid-rectangles B3, B5, C3, C5) and overall area (see Figure B1) including percentages of the overall area catch of each species in Areas M and N; sorted by total species green weights for the overall area. *Source*: Ministry for Primary Industries OIA (4 Dec 2018).

	Area M		Area N		Overall Area (OA)
Species	Numbers caught	% of catch in OA	Numbers caught	% of catch in OA	Numbers caught
Scallop[NF]	920	0.58	900	0.57	157,847
Blue cod[B]	11,402	18.22	6,401	10.21	62,772
Tarakihi[B&R]	1,815	17.24	731	6.94	10,527
Hapuku-Bass[B]	2,206	36.86	2,546	43.47	5,985
All other species	193	3.26	365	6.71	*5,290/5,442
Sea perch[R]	1,476	28.74	902	17.57	5,135
Snapper[B]	545	41.07	62	4.67	1,327
Rock lobster[NF]	292	23.97	147	12.07	1,218
Red gurnard[B]	67	5.74	89	7.62	1,168
School shark[BP]	76	18.63	76	18.63	408
Kahawai[P]			60	25	240
Blue moki[B&R]	20	8.97	39	17.49	223
Barracouta[P]	30	27.03	6	5.41	111
Paua[NF]	57	65.52	10	11.49	87
Yellowtail kingfish[P]			55	73.33	75
Thresher shark[P]					45
Wrasses[R]					36
Conger eel[R]	6	31.58	13	68.42	19
Red moki[R]			6	50	12
Bluenose[BP]					10
Butterfish[R]					6
Red cod[B]					6
Total all species	19,105	7.56	12,408	4.91	252,547
Total finfish	18,128	19.41	11,498	12.31	93,395
Total non finfish	977	0.61	910	0.57	159,152

Superscripts following common names are habitat codes: NF non-finfish; B benthic; BP bentho-pelagic; B&R benthic & reef dwelling; P pelagic; R reef dwelling. *Total numbers of this category varied by area; see text for explanation.

4.2.3 Discussion and Conclusions

The discussion regarding wild fish species recorded in the commercial catch data presented in §4.1.3 is also relevant here and needs no additions. Similarly, the conclusions reached in §4.1.3 are equally relevant here, except for some variations in the species composition and the fact that several non-finfish species are included in the charter data.

Greatest representation in the charter data are of benthic species. There are only 3 pelagic species (barracouta, kahawai, and thresher shark) and 2 bentho-pelagic species (school shark and bluenose). No pelagics were caught in Area M; small catches of kahawai and kingfish (60 and 55 fish) were recorded in Area N, and thresher shark was only taken outside Area N. Therefore, as with the commercially fished species, the species taken by recreational charter vessels most likely to be affected by installation of a farm at the proposed site are those from the benthic group, including bentho-pelagic species and the reef dwellers, all of which exist mainly on a diet of benthic organisms. A total of 14 such species are identified from the overall area; 9 from Area M and 11 from Area N (see

Table 4). Red moki was landed only in Area B and is therefore far less likely to be affected by components of farm discharge impacting the benthos.

4.3 Commercial Scallop Catch in the Vicinity of the Proposed Site

The Fisheries Statistical Area encompassing the proposed site is Area 7KK (Figure 4). Data from the MPI commercial database indicates that for the years of the data extract, there were only 2 events that caught low numbers of scallops within the area of the proposed site, which were included in the "All other species" category for commercial catch data (see §4.1). This low number of events and catch is consistent with the low numbers of scallop taken by recreational charter boat in Areas M and N (see Table 4).

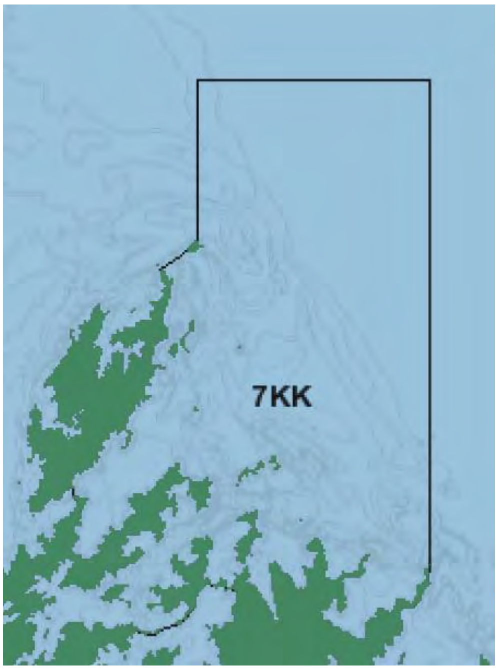

Figure 4. Map of northeastern Marlborough Sounds showing boundaries of the local scallop Fisheries Statistical Area 7KK as it encompasses the proposed farm site in north western Cook Strait.

Estimated catches from Area 7KK are listed in Table 5. This area is much larger than the proposed site, such that these catches cannot be used to infer anything about the proposed site except for the last three years of the data extract when no catch was recorded, probably as a result of temporary area closures.

Table 5: Total commercial scallop harvest in Stat Area 7KK during 2008–18 inc. *Source*: Ministry for Primary Industries OIA (4 Dec 2018).

Calendar Year	Estimated catch meat weight (kgs)		Calendar Year	Estimated catch meat weight (kgs)
2008	72,881		2014	30,060
2009	271,712		2015	20,639
2010	90,426		2016	0
2011	48,596		2017	0
2012	83,005		2018	0
2013	99,816			

5. ATTRACTION OF SHARKS TO MARINE FARMS; CONSEQUENCES FOR HUMANS

5.1 Fish Farms and Predatory Fish

Fish farms, due to the high concentrations of wild and reared fish, attract numerous predatory fish species. Sharks are a common cause of cage damage and loss of fish in tropical and subtropical areas. In particular, great white sharks have been detected around tuna farms in the Mediterranean Sea. In Norway, dogfish (*Squalus acanthias*) are attracted to salmon farms, especially dead fish occurring in the bottom of cages.

The assemblages of small wild fish concentrated in large numbers around fish farms attract larger predatory fish species, such as *Coryphaena hippurus*, *Seriola dumerili*, *Pomatomus saltatrix*, *Dentex dentex*, and *Thunnus thynnus* (Dempster et al., 2002). The attraction of *P. saltatrix* (bluefish) to Mediterranean fish farms is of particular interest (Sanchez-Jerez et al., 2008) because it is an aggressive predator of economic importance. In some farms, bluefish intrude into cages, where they may kill or harm large numbers of farmed fish. This is a serious problem for farmers in terms of economic loss and added technical difficulties in the production process. Bluefish appear to use farms as a new and productive feeding habitat, which may be related to a reduction in trophic resources for these predators due to overfishing of their normal pelagic fish prey stocks. As bluefish are widely distributed, increased development of marine net pen farms in coastal and offshore areas will most likely also involve an increasing level of interaction between fish farms and bluefish populations.
Despite the attention given to the interaction of predators with aquaculture, there is little evidence of positive or negative interactions of aggregations of predatory fish with local fishermen. A higher concentration of predatory fish, such as bluefish, in coastal waters where fisheries operate could result in economic distress for fishers (Bearzi, 2002). However, few studies have addressed conflict between fishers and predators in areas where coastal aquaculture has developed.

5.2 Shark Species in the Marlborough Sounds and the Vicinity of the Proposed Site

At least 14 species of shark are known to occur naturally in the Marlborough Sounds (Clinton Duffy, DOC, pers. Comm.) (Table 6). These species may be encountered anywhere within the Sounds, with examples including instances of bronze whaler (*Carcharhinus brachyurus*) and smooth hammerhead (*Sphyrna zygaena*) sharks taken near the entrance to Mahau Sound, inner Pelorus Sound, and bronze whalers being seen by divers in Lochmara Bay, inner Queen Charlotte Sound. However, the occurrence of most sharks in the Marlborough Sounds, including the smaller bottom-inhabiting species, appears to be highly seasonal and is most likely related to several factors including the distribution of prey and behaviours related to reproductive cycles. Observations of most large pelagic sharks in the region usually occur only during late spring and summer, although great white sharks(*Carcharodon carcharias*) are present year round in the Cook Strait area. Most historical observations of great white sharks from Marlborough Sounds have been recorded during autumn and winter (May to August) in association with commercial whaling operations, but recent satellite tracking data have shown that they are also present during summer.

It is expected that a similar group of shark species as those listed in Table 6 inhabits the vicinity of the proposed site, although most sightings would probably be of blue sharks, mako, broadsnouted sevengill, great white, and porbeagle sharks (Clinton Duffy, DOC, pers. comm.). Note that carpet shark, rig, school shark, spiny dogfish and ghost shark were recorded in the commercial data from the 10 nmi diameter area around the proposed site (see Table C1), although not all were taken within the area immediately containing it (see Table 2).

Information from existing NZ King Salmon salmon farms includes observations of four shark species. The most common is the spiny dogfish (*Squalus acanthias*) which can appear in large numbers during

Table 6: Shark species known to occur in Marlborough Sounds, South Island, New Zealand. Source: Clinton Duffy, Dept of Conservation.

Species	Common name	Family	Risk to humans
Alopias vulpinus	Common thresher shark	Alopiidae	Traumatogenic
Carcharhinus brachyurus	Bronze whaler	Carcharhinidae	Potentially dangerous
Carcharodon carcharias	Great white shark	Lamnidae	Potentially dangerous
Cephaloscylium isabella	Carpet shark	Scyliorhinidae	Harmless
Cetorhinus maximus	Basking shark	Cetorhinidae	Traumatogenic
Galeorhinus galeus	School shark	Triakidae	Traumatogenic
Isurus oxyrinchus	Mako	Lamnidae	Potentially dangerous
Lamna nasus	Porbeagle	Lamnidae	Potentially dangerous
Mustelus lenticulatus	Rig / spotted dogfish	Triakidae	Harmless
Notorhynchus cepedianus	Broadsnouted sevengill shark	Hexanchidae	Potentially dangerous
Prionace glauca	Blue shark	Carcharhinidae	Potentially dangerous
Sphyrna zygaena	Smooth hammerhead	Sphyrnidae	Potentially dangerous
Squalus acanthias	Spotted spiny dogfish	Squalidae	Traumatogenic
Squalus griffini	Northern spiny dogfish	Squalidae	Traumatogenic

Definition of risk to humans: Potentially dangerous = any shark species known to engage in, or implicated in, unprovoked injurious attacks on humans or vessels; Traumatogenic = species capable of inflicting serious injury if provoked or mistreated; Harmless = species unlikely to, or incapable of, inflicting serious injury except in exceptional circumstances.

March–May and again during spring (Rick Smale, Waihinau Farm Manager, pers. obs.). Sightings of bronze whalers (*Carcharhinus brachyurus*) have been common in summer months, though none were observed during the 2010–11 summer (Rick Smale, pers. obs.). There have also been occasional sightings of blue shark (*Prionace glauca*) and seven-gilled shark (*Notorynchus cepedianus*).

5.3 Attraction of Shark Species to Fish Farms and Consequences for Humans

Little work has been done on this issue. Papastamatiou et al. (2010) found a marked difference between sandbar sharks (*Carcharhinus plumbeus*), which exhibited site fidelity to cages over a period of up to 2.5 yr, and tiger sharks (*Galeocerdo cuvier*), which were more transient and displayed short-term fidelity, although some sporadic reappearance did occur. Video monitoring under a sea cage fish farm at Reunion Island revealed large numbers of bull sharks (*Carcharhinus leucas*), with some individuals resident throughout the month-long study (Loiseau et al. 2016).

Considering the acuteness of sharks' senses, it is reasonable to assume that most sharks would be attracted to a number of stimuli associated with fish farms, including the presence of the live fish being farmed, the presence of any dead fish in the cages, the odour trail generated during feeding, sounds caused by the farming operation or structures, the physical presence of the structures, and the presence of wild fish around the farm.

Interactions have been recorded between fish farms and a number of small bottom dwelling species and large pelagic species. Large pelagic species can economically impact fish farming operations through loss of stock (escapement and predation), damage to structures, and decreased production from cultured fish under regular attack. The impact of bottom-dwelling shark species is usually focused on scavenging uneaten food beneath farms and dead fish accumulating in cages.
Shark mortalities relative to fish farms have resulted from entanglement, confinement in nets/pens, and culling. For safety some farm owners/managers have killed sharks before removing them from cages. In South Australia, methods of live release have been developed and in some cases reduction of

shark numbers during periods of high abundance has been carried out by commercial fishers (Murray-Jones 2004). In New Zealand, culling in and around farms happens infrequently, if at all. According to anecdotal information, shark mortalities from entanglement or confinement are rare in New Zealand. Clinton Duffy (DOC) is not aware of any deaths of great white sharks in fish farms in New Zealand.

A workshop on shark interactions with aquaculture was held in South Australia in July 2003 (Murray-Jones 2004). At this meeting, farm owners and managers indicated that interactions between sharks and farms are very limited and that they have varied by site, season, the species being cultured, and the stage of the farming cycle. There was agreement that leaving dead fish in cages was the main cause of interactions and that it was fresh dead fish that had the greatest effect. Most interactions in kingfish (*Seriola lalandi*) farms were with bronze whalers and occurred in October-December, after pupping had finished.

A set of best practices were identified by industry members to minimise interactions. These included:

- Good farm husbandry, which minimises the number of fish dying in the cages;
- Prompt removal of dead fish from cages;
- Utilisation of predator exclusion nets or shark-resistant materials in cage construction.

The risk to humans from sharks is generally overstated and, within the bounds of considering any shark greater than 1.8 m in length as potentially dangerous, it is possible to safely undertake most aquatic activities in the presence of sharks under most conditions (Clinton Duffy, DOC, pers. comm.). In the present context, divers are exposed to the greatest risk of attack because of the close proximity of feeding stimuli — live, and possibly some dead, fish in the cages — and the relatively high frequency with which they are likely to encounter sharks in foraging mode. Despite these risks, Clinton Duffy (DOC) does not know of any attacks at or near fish farms in New Zealand or South Australia (after discussing this subject with S. Murray-Jones of the Australian Department of Environment and Heritage) nor have any attacks been recorded on the International Shark Attack File (ISAF; after consulting R. Busch of ISAF).

Although blue sharks and bronze whalers have been positively identified or implicated in shark attacks on humans, the risk presented by these species is considered to be low. The blue shark is possibly the most abundant large shark in New Zealand waters. This species frequently investigates floating objects with a bite and has been identified in several unprovoked non-fatal attacks in New Zealand on swimmers, divers, and a life raft. The number of incidents is small relative to the abundance of the species, probably because individuals encountered in coastal waters are small and non-aggressive.

Bronze whalers have been implicated in one fatality in New Zealand and several fatal and numerous injurious attacks in Australia. However, it is most likely misapplication of its name that has led to the relatively high number of reported attacks and incidents for this species. In New Zealand and Australia, "whaler" is the common name given sharks of the genus *Carcharinus*. In New Zealand the only species in this genus that commonly occurs around the North and northern South Island is the bronze whaler (*C. brachyrus*). By contrast, 20 species are reported in this genus from Australia and many of these require a detailed knowledge of shark taxonomy for positive identification because they lack distinctive markings.

Aggressive incidents between bronze whalers and humans have most often involved spearfishing and these attacks may be the result of competitive behaviour and not identification of the diver as prey. It seems that the aggressive behaviour is usually defused by surrendering any struggling or bleeding fish to the shark. In other circumstances, bronze whalers are disinterested and avoid divers.

6. CONSIDERING POLICY 11 OF THE NEW ZEALAND COASTAL POLICY STATEMENT

The following is presented as a summary to the New Zealand Coastal Policy Statement (NZCPS):

The purpose of the NZCPS (Department of Conservation 2010) is to state policies in order to achieve the purpose of the Resource Management Act in relation to the coastal environment of New Zealand.

The work completed here has aimed to consider Policy 11 of the NZCPS (Appendix D) in terms of five questions. Policy 11 deals with indigenous biological diversity. The five questions refer to the Cook Strait–Marlborough Sounds area with the aim of providing a summary for the north western Cook Strait farm site proposed by NZ King Salmon. The questions are as follows:

1. Are there any indigenous fish that are listed as threatened or at risk in the NZ Threat Classification System (NZTCS) or listed by the International Union for the Conservation of Nature (IUCN) as threatened?
2. Are there habitats for fish species that are at the limit of their natural range, or naturally rare?
3. Are there any nationally significant fish communities?
4. Are there habitats that are important during the vulnerable life history stages of fish species?
5. Are the concepts of areas and routes for migratory species and ecological corridors relevant to the pelagic fish community?

Note that in Q1 it is indigenous species that are being considered, so the criteria for inclusion in any list is that species are endemic and distributed within the Cook Strait–Marlborough Sounds area where the proposed site is situated.

6.1 Indigenous fish species listed as threatened or at risk[12]

6.1.1 Background

A working list of relevant New Zealand fish species was compiled using selections from the NZTCS threatened and at risk lists and the IUCN red list. Included in this compilation were marine finfish species and diadromous[13] species from the freshwater lists.

At the time of writing this text (May 2019), the threatened and at risk lists for both marine fish and freshwater fish had been recently updated in 2018. The 2008 NZTCS Manual was in use and documented a number of updates to classifications, which are consistent with Policy 11 as reproduced here in Appendix D. Essentially, the categories for "Threatened" and "At Risk" status are as follows — note that these are abbreviated versions used to re-categorise marine fish species from the 2005 NZTCS list.

- 'Threatened' taxa are grouped into three categories: 'Nationally Critical', 'Nationally Endangered' and 'Nationally Vulnerable'.
- Taxa that qualify as 'At Risk' do not meet the criteria for any of the 'Threatened' categories. Four 'At Risk' categories exist: 'Declining', 'Recovering', 'Relict' and 'Naturally Uncommon'.
- 'Chronically Threatened', 'Serious Decline' and 'Gradual Decline' have been mostly replaced by a single new category, 'Declining'.

[12] Common and scientific names used here are consistent with those used by IUCN and Roberts et al (2015).
[13] Diadromous fishes migrate between the sea and freshwater; they are either anadromous (adults migrate from the sea up into freshwater to spawn) or catadromous (adults migrate from freshwater down into the sea to spawn).

- The 'At Risk' categories 'Range Restricted' and 'Sparse' have been replaced by a single category called 'Naturally Uncommon'.

The conservation status of great white shark/white pointer (*Carcharodon carcharias*) and basking shark (*Cetorhinus maximus*) were re-categorised in 2018 from 'Declining' to 'Threatened–Nationally Endangered' and 'Threatened–Nationally Vulnerable' respectively. However, neither are endemic so are not included in the final list.

Of a total of 24 possible candidates in the current NZTCS freshwater fish threatened and at risk lists, four species met the criteria of endemic, diadromous, and (probably) distributed within the Cook Strait–Marlborough Sounds. These were shortjaw kokopu (*Galaxias postvectis*) in the Threatened-Nationally vulnerable list, and longfin eel (*Anguilla dieffenbachii*), giant kokopu (*Galaxias argenteus*), and bluegill bully (*Gobiomorphus hubbsi*) in the At risk-Declining list. The redfin bully (*Gobiomorphus huttoni*) had been re-categorised to not threatened.

The torrentfish (*Cheimarrichthys fosteri*), is an endemic New Zealand freshwater fish that is widely distributed around New Zealand. It is amphidromous, a life history strategy that includes a marine-living juvenile stage but, according to McDowall (2000), is absent from Cook and Foveaux straits and the Marlborough Sounds as well as other areas, such as around Fiordland and Stewart and Chatham Islands, which may be the result of oceanographic conditions that are not favourable for the return to rivers of the marine-inhabiting juvenile phase.

Currently, the conservation status of elephant fish (*Callorhinchus milii*) and rough skate (*Raja nasuta*), is "not threatened". Their spawning areas are considered ecologically significant marine sites in the Marlborough Sounds. However, there is no information to suggest any spawning area in the vicinity of the proposed north western Cook Strait site.

6.1.2 List of marine and diadromous species meeting the Policy 11 criteria for the Cook Strait–Marlborough Sounds Area

The four species included in this section meet the NZTCS Policy 11 criteria for protection under clauses (a)(i) and (a)(ii) (see Appendix D). They are all endemic and diadromous, and, according to the best available information, are found within the Cook Strait–Marlborough Sounds.

Bluegilled bully (*Gobiomorphus hubbsi*)
An endemic, diadromous (anadromous) species distributed throughout coastal regions of New Zealand including the South Island (McDowall 1978, Roberts et al 2015). It is expected that this includes the vicinity of Cook Strait — Marlborough Sounds although there is no specific mention of the area in these publications. It is described as cryptic and secretive and rarely seen (Roberts et al 2015). Larvae spend several months at sea, their return coinciding with the whitebait runs.

Giant kokopu (*Galaxias argenteus*)
An endemic, diadromous (anadromous) species distributed throughout lowland areas of the North and South Islands as well as several offshore islands (Roberts et al 2015). In the South Island, less common down the east coast to the Otago Peninsula. There is no specific reference to Cook Strait–Marlborough Sounds in the literature. A voucher specimen has been collected in Marlborough, but according to the map in Roberts et al (2015), appears to be from outside the area of the Sounds. Larvae return to freshwater as whitebait after a marine phase of about 18 weeks but, according to McDowall (1978), this species is in the whitebait catch late in the season. The "known distribution" map on the NIWA online site[14] includes several identification sites for this species in the Marlborough Sounds. This species spawns in autumn or early winter; "when the young hatch they must be washed out to sea" (McDowall 1978).

[14] https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/giant_kokopu

Longfinned eel (*Anguilla dieffenbachii*)

An endemic, diadromous (catadromous) species widespread throughout New Zealand in freshwater, except above swift rapids and waterfalls. Not referenced specifically to the Cook Strait–Marlborough Sounds area in the literature, and there is some uncertainty about what level of abundance the longfin might have in the Marlborough Sounds given its documented preference for fast flowing stony rivers and highland lakes, in contrast to the shortfin eel (*A. australis*) which prefers slow-flowing, soft-bottomed rivers and streams and lowland lakes (see review of freshwater eel biology in Ministry of Primary Industries 2015). Furthermore, Jellyman et al. (2002) showed higher densities for this species on the west coast. However, the "known distribution" map on the NIWA online site includes many[15] identification sites for this species around Cook Strait and in the Marlborough Sounds. Adults migrate to the sea during autumn, spawning in the sub-tropical Pacific. The leptocephalus larvae somehow returns to NZ waters, metamorphoses into the glass eel and, upon reaching freshwater in August to November, migrates up rivers and streams.

Shortjawed kokopu (*Galaxias postvectis*)

An endemic, diadromous (anadromous) species distributed throughout the North and South Islands. There is no specific reference in the literature to the Cook Strait–Marlborough Sounds. According to Roberts et al (2015) this species "is found in small streams and rivers with extensive marginal podocarp/broadleaf forest cover and complex structure (logs, large boulders, and overhangs) in the waterway". The "known distribution" map on the NIWA online site[16] includes several identification sites for this species in the Marlborough Sounds.

According to McDowall (1978), "nothing is known about the breeding of this fish except that the adults seem to be ready to spawn during the autumn and early winter " and "like those of other whitebait species, [the newly hatched larvae] are almost certainly carried out to sea when they hatch".

Summary

Of the 67 species in the relevant NZTCS marine and freshwater fish lists and the 21 species selected from the IUCN red-list, only four species fit the criteria of endemic to New Zealand and distributed within the Sounds area. All are diadromous. There is no clear evidence that the bluegill bully occurs in the Cook Strait–Sounds area. It is described as widespread in New Zealand and, because of its cryptic, secretive habit, it is likely that the bluegill bully also inhabits the Sounds, particularly Pelorus Sound with its large freshwater component from the Pelorus River. Similarly for the remaining three species whose presence in the Sounds is not actually specified.

All of these species spend their larval stages in the marine environment, although the longfinned eel differs from the others in that it is catadromous so that adults first migrate to a marine spawning ground before spawning and dying. Knowledge of aspects of the marine phases of the bluegill bully appears to be almost non-existent, apart from its being diadromous, migrating downstream soon after hatching to the sea for their larval stage and returning to freshwater as juveniles during spring at a length of about 15–20 mm in both cases; the bluegill being taken by whitebaiters in some rivers on the West Coast "and constitute a considerable nuisance at times" (McDowall 1978). Roberts et al (2015) make no mention of the marine phase of this species; Paul (2000) makes a brief mention of bullies generally, referring to them as "mainly freshwater and estuarine". The marine phase of the galaxiid species is also poorly known. Generally, all of these species appear to return to freshwater at roughly the same time, the earliest being the longfinned eel in August and the latest the giant kokopu towards the end of the whitebait run in spring–late spring..

[15] https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/longfin_eel

[16] https://www.niwa.co.nz/freshwater-and-estuaries/nzffd/NIWA-fish-atlas/fish-species/shortjaw_kokopu

6.1.4 Implications

The diadromous habit of the species of interest means that the larval stage of all of them occurs within the marine environment. There is little information characterising the marine phase in any of these species, except the longfinned eel. It is therefore difficult to suggest the passage that may be utilised within the Sounds and whether the larvae of the bluegill bully and galaxiidae travel beyond the Sounds. This introduces a level of uncertainty because there are no permanent freshwater streams or rivers in the close vicinity of the north western Cook Strait site, so the origin of any these species in the present context is more distant and would probably need to be within the Sounds, most likely Pelorus Sound. Given the size of the Pelorus River and the high volume of water it delivers during Autumn-Winter, it is not unreasonable to suggest that larvae will be flushed beyond the confines of the Sounds.

Migrations during the marine phases of these species comprise two components: the outward migration, from freshwater into the sea and beyond; and the returning migration, from Cook Strait, up the Sound, and into freshwater. Although it is unknown how far the migrations of larval bullies and galaxiidae take them, it is assumed that, unless they maintain a geographical position within the Sounds for a reason such as the availability of forage, they continue beyond the confines of the Sounds into habitat similar to that entered by individuals of these species undertaking similar migrations in other areas of New Zealand. For the longfinned eel, it is well known that this species undertakes the entire journey, although no individual travels both legs of this journey consecutively.

The outward migration of these species begins in Autumn. Because of their size and strong swimming ability (see Jellyman & Tsukamoto 2005), it seems unlikely that adult eels are vulnerable to marine farms. It might be argued however, that larval bullies and galaxiidae could be vulnerable because of their size and distribution in the water column.

If we assume that the greatest density of the larvae of these species are produced from the Pelorus River, then as part of the plankton moving from Mokau Sound past Kenepuru Sound they will enter the pulses of high-density plankton water that are released into the main channel of Pelorus Sound, which produces bands of higher productivity that migrate down the sound (Gibbs 1993).

As is discussed in §2.1.5, the depth of the photic zone increases with distance towards Cook Strait from Beatrix Bay, thus resulting in increasing productivity throughout the water column as surface phytoplankton become mixed into deeper layers and increasing light penetration with decreasing turbidity results in higher growth rates throughout a greater proportion of its volume. Consequently, as the bully and galaxiidae larvae move towards the outer Sounds, forage items become available deeper within the water column, so that, if they are maintaining their position within some geographical boundaries within the Sound, by riding the Gibbs conveyor they may be distributed at greater depth to maintain a positive energy balance as they swim.

This suggests that, under these conditions within Pelorus Sound, forage items for the larval species that are of interest here will be near the sea surface at points up the Sound away from the mouth of Pelorus Sound, whereas as they approach Cook Strait they will be distributed throughout a much greater proportion of the depth range. If this is the case, one would expect a reduction in the numbers of larvae near the surface as pulses move toward the Strait. The timing of this mechanism seems to be about right, given that sampling for a number of the studies included in the discussion in §2.1.5 was carried out during winter, the time that outward migrations of the species of interest occur.

While this model is based on the results of sound scientific methodology by a number of successful researchers (e.g., Gibbs 1993; Gibbs et al., 1991, 2002; Heath 1982; Carter 1976: 271; Vincent et al 1989a & b; Bradford et al 1987), there are a number of unanswered questions associated with it. For example, we do not know how it fits reality with respect to the biology of the bully and galaxiid larvae. Nevertheless, based on what we do know, it seems likely that if and when larvae reach the waters of the outer Sounds and Cook Strait, their distribution within the water column would be scattered to such a degree that only a small percentage could come in contact with a farm structure and enter the cage.

A final factor that could influence this outward migration, and one that is particularly relevant with regards the north west Cook Strait site, is the predominant current direction in the vicinity of the site. Information from Elvines et al., (2019) indicates a current axis of south-east to north-west and Newcombe et al., (2019) report current moving in a north-westerly direction. This suggests that, if these larvae reach northwest Cook Strait, and are moving with the current, then there would be no tendency for them to move towards the proposed site. Movement with the current seems more likely than actively swimming against the current because such an adaptation would be required for them to be delivered to the lower reaches of Pelorus Sound within the Gibbs conveyor.

The inward migrations of these species begins in August with the arrival of the glass eels of the longfinned eel. Metamorphosis to the glass eel occurs with the depth change when the larvae reach the continental shelf (Jellyman 1987). Migration continues until the glass eel enters the freshwater habitat mainly at night (Jellyman 1987) and moves up rivers and streams. Pigmentation occurs as the glass eel enters freshwater.

The question here, with reference to the possible vulnerability of glass eels to a salmon farm at the proposed site, is also related to distribution. Any type of schooling behaviour close to the farm site might increase vulnerability by concentrating the glass eels. Although glass eels have been known to migrate up rivers and streams in large numbers and mixed in shoals with whitebait (Graham 1956), it seems that they do not form aggregations before invading a stream or river. Jellyman (1977) makes the following statement:

> Glass-eels arrive in the mouth of the stream individually, swimming at or near the surface. Any small aggregations which occurred could be explained by water flow. In contrast, pigmented glass-eels form definite schools, and this is one of several behavioural characteristics used by Deelder (1958) to distinguish between newly arrived glass-eels and those about to migrate upstream.

Given the reference to Deelder (1958), whose work was with the European Eel, *Anguilla vulgaris*, it seems that this observation can be taken as being generally applicable to glass eels. Its significance in the present context is that as the glass eels migrate over the shelf as well as up the sound, their distribution is as single individuals, suggesting that their vulnerability to any cages installed at the proposed site would be relatively low.

Schooling behaviour in finfish has for some time been known in particular as a foraging and anti-predator strategy (e.g., Pitcher 1993, Magguran 1990). Recently, there has been renewed interest in the energetic benefits that fish gain from swimming in schools (e.g., Hemelrijk et al 2015, Killen et al 2011), which may provide a useful explanation in the present context. The clear behavioural change described by Jellyman (1977) indicates that glass eels require some benefit of aggregated behaviour in the freshwater stream or river that they had no need of in the marine habitat.

Information on the returning migration of the galaxiid juveniles is almost non-existent, apart from their size at this time, which is about 45–55mm. Five galaxiid species contribute to the whitebait fishery (Charteris & Ritchie 2002) and schooling behaviour is a well known characteristic. Although there does not appear to be a description of the transition from marine to freshwater habitat in the literature as there is for the glass eel, it seems reasonable to expect that something similar occurs in the returning galaxiid juveniles of interest, which are a minor component of the New Zealand whitebait fishery (McDowall 1991). This assumption is supported to some degree by the fact that the whitebait fishery occurs within freshwater, not saltwater, as shoals of juvenile galaxiid fish are targeted when moving into New Zealand rivers and streams during the spring (McDowall 1991). Based on this assumption, it is suggested that the vulnerability to any cages installed at the proposed site of returning juvenile giant kokopu and shortjaw kokopu is low, for the same reason as that given for the returning glass eel.

Although this dearth of information also applies to the bluegill bully, there is no evidence that they display the same tendency to form schools as the galaxiid species and the glass eel. It is therefore concluded that they are most likely distributed singly within the marine water column with the same factors operating as were suggested for the outgoing larvae that caused them to be scattered throughout the water column, and that their vulnerability to any cages installed at the proposed site would be low.

6.1.5 Summary

From the available information it seems that the early life history stages of the bully and galaxiid species of interest are mostly characterised by a dispersed distribution during their marine phase. This, and the likelihood that they are adapted to moving in the same direction as local currents supports the conclusion that their vulnerability to farm cages at the proposed north-west Cook Strait site is likely to be low. It is also concluded that the vulnerability of both the outgoing adult eels and returning glass eels is low.

6.2 Habitats for species at the limit of their range

It appears that there is no finfish species that fits this category within the Cook Strait–Marlborough Sounds area.

6.3 Nationally significant fish communities

A community comprises a number of species that are identifiable by both their taxonomic characterisation and their "role", which is defined by the habitat they occupy and the resources they utilise. With regards fish communities in the Cook Strait–Marlborough Sounds area, there appears to be little work, if any, describing or defining assemblages of taxonomically related species in this region and how they may function together within the framework of a community. Although Davidson et al (2011, 2015) discuss some 129 significant marine sites in Marlborough, it is beyond the scope of their work to include information on fish communities. With this in mind, this section is presented as a first step in identifying any nationally significant fish communities in this area

One aim of the present work has been to construct an inventory of fish species that might interact with the NZ King Salmon farm at the proposed site. However, there has been little information available on which to base this work. Essentially, the approach has been limited to the works of Morrisey et al (2006), a list of species that is largely inferred from several previous authors (see §2.2.2), two recreational fishing surveys by Bell (2001) and Davey et al (2008), information that was collected from farm managers, and catch data from the MPI commercial fishing and recreational charter boat databases. While this information is useful here in a supplementary sense, it cannot be used as a basis for developing definitive descriptions of nationally significant fish communities.

6.3.1 Rocky reef fish communities

A publication that contains relevant information, particularly in the communities context, is Smith et al (2013). These authors used boosted regression trees to predict the distribution and relative abundance of 72 species of rocky reef fishes on shallow subtidal reefs around New Zealand. Data for the modelling included relative abundance data for reef fishes obtained from 467 SCUBA dives around the New Zealand coast over the 18 years from November 1986 to December 2004, as well as relevant environmental, geographic and dive specific variables. Predictions from the models were used to map the occurrence and relative abundance of the selected species at the scale of a 1-km^2 grid.

The authors stress that "it is important to note the limitations of these predictions imposed by the input data and the methods" and that "they are not intended to be a definitive account of where each species can be found". Instead, "the layers represent predictions of the fish assemblages that might be seen on a typical dive at each of these locations, which can fairly safely be assumed to be correlated with true local abundance".

Distribution maps of the 72 species are included in the supplementary material to the main publication. Of these, 36 show predicted distributions within the Marlborough Sounds (including the outer Sounds) along with their estimated abundance on a 0–4 ordinal scale. This information seemed that it might be useful in the present context but needed summarising from the maps. I used the following method to achieve this.

Method

- Based on the locations of dive sites, the Sounds were divided into the following areas: Admiralty Bay, Waitata Reach to Tennyson Inlet, Pelorus Sound, Chetwode Islands to Alligator Head, Port Gore, Vicinity of Long Is, Outer Queen Charlotte Sound, Inner Queen Charlotte Sound, Tory Channel, and Port Underwood.
- The range of ordinal scale values were identified for each area from each species map and tabulated as a range e.g., 1.2–3.7.
- Species with zero values in all areas were removed from the list.
- Because of difficulties rationalising the ordinal ranges containing zero, the values were translated to provide a presence-absence summary.
- The data were sorted by taxonomic family and species and used to create Table E1[17]

Results

- A total of 36 species of rocky reef fishes from 29 genera and 16 Families were predicted to be present in the areas of the Sounds defined above.
- Family Tripterygiidae (triplefins) is the most highly represented taxon (11 of the 36 species), followed by Labridae (wrasses, 4 spp.), Cheilodactylidae, Latridae, Moridae, Scorpaenidae, Serranidae and Trachichthyidae (2 spp. each); all other families (Aplodactylidae, Carangidae, Congridae, Kyphosidae, Monacanthidae, Mugilidae, Mullidae, Odacidae, Pinguipedidae) were represented by 1 spp each.
- The greatest number of different species was predicted for the outer Sounds areas: Chetwodes to Alligator Head (32 spp.), Port Gore (30 spp.), Long Island vicinity (31 spp.), and Port Underwood (26 spp.).
- The lowest number of different species was predicted for Pelorus Sound (14 spp.).

Conclusions

- Based on these predictions, the rocky reef community is well represented in most areas of the Sounds, though it is noteworthy that no diving occurred beyond about Nydia Bay, which precludes any information from Kenepuru Sound or Mahau Sound.
- Variations in the number of taxa predicted for different areas, particularly between Pelorus Sound and the outer Sounds areas mentioned in the results above, is most likely a function of environmental variation and the specific biological requirements of at least some of these species.

6.3.2 The pelagic fish community

Although there is no result of any community study specific to this group, it is worth noting that the population of pilchard inhabiting the area of western Cook Strait-Marlborough Sounds-Tasman Bay is extensive and, although not the subject of any ongoing study, was investigated in depth by Baker

[17] See Appendix E

(1972), including the use of drift cards to characterise the movement of eggs and larvae from the spawning ground in Tasman Bay through French Pass into Admiralty Bay and into the outer Sounds–Cook Strait area, where the most eastwards plankton sampling site coincided approximately with the southeastern corner of the site proposed by NZ King Salmon that is under discussion here. Plankton samples from Baker's Admiralty Bay station indicated numbers of pilchard eggs and larvae from that area to be as high as the highest registering sampling stations in Tasman Bay and higher than any throughout the remainder of the Sounds. Plankton samples from Baker's station coinciding with the north western Cook Strait farm site indicated lower, but still significant egg numbers.

Apart from the Baker (1972) study, all information pertinent to the pelagic fish community is summarised in §2 of this report.

6.3.3 The demersal fish community

No information additional to that summarised in §2 of this report has been identified for the demersal fish community in the area of interest.

6.4 Habitats of importance during vulnerable life history stages

Two species inhabiting the Cook Strait–Sounds area and recorded in the MPI commercial catch data (Table C1 & Table 2) have vulnerable life history stages because of their low fecundity and the long gestation period of the eggs after laying. The elephant fish (*Callorhinchus milii*) is oviparous, usually laying its egg cases on sand or muddy substrate; gestation is from 6 to 12 months (Roberts et al 2015). The rough skate (*Zearaja nasuta*) probably lays its fertilised eggs in leathery egg cases in pairs (Francis 1997, Roberts et al 2015). In both species, each egg case produces a single embryo.

Within the Sounds, rough skate spawn in Grove Arm between Ngakuta and Governor's Bays. Elephant fish spawn between Ngakuta and Blackwood Bays, with most spawning appearing to be in Kaipakirikiri Bay and the western arm of Kumutoto Bay at 4-12m depth. As was mentioned above in §6.1.1, there is no information suggesting any spawning area of these two species in the vicinity of the proposed farm site in north western Cook Strait.

6.5 Relevance of the concepts of areas, routes and ecological corridors

6.5.1 Overview

In their very useful review on ecological corridors and boundaries, Puth & Wilson (2001) use the research of many workers to trace development of the concept of ecological corridors, from the traditional approach as "structures that facilitate the movement of game between forested remnants in agricultural landscapes", to their more general definition "as a structure that channelizes and directs the flow of organisms, materials, or energy between patches". Here patches are concentrations of energy and materials within a broader matrix that are rarely distributed homogeneously across a landscape. The authors point out that the traditional definition needs to be recognised as a special case of the more general concept, which places emphasis on movement rather than form.

Similarly with ecological boundaries, these authors refer to the historical approach of recognising them "more for their structural distinction on the landscape than for their role in landscape function" and define boundary "as an area of sharp gradients in ecological flows that slows or redirects flows of organisms, matter, or energy between patches".

Thus, they state that the function of corridors is "to channel and increase the rate of flow of whatever is moving along them relative to the diffuse flow of the same mover in the surrounding matrix" by linking patches in structurally diverse ways and at many scales, the key components being channelization and movement. Boundaries become the interaction points between patches, regulating fluxes and being the site where "the rate or magnitude of ecological flows (nutrients, organisms, matter energy, or information) change abruptly relative to those of the surrounding patches".

Puth & Wilson (2001) see boundaries and corridors as entities that are linked by their strong influence on ecological flows, not separate landscape components as they were usually considered. Instead they represent opposite ends of a continuum of flow regulation, with different effects on rates and direction of flow. Boundaries change flow direction through reflecting, stopping, or "shuttling[18]"; corridors provide unlimited movement across boundaries, and can even increase flow rates.

The human experience is largely with the terrestrial environment, so we tend to adopt known concepts from this experience when attempting to understand the aquatic environment, which is not necessarily the best approach. For example, Bakun (2012) observed that gravity is the most important dynamic constraint in the lives of terrestrial organisms, affecting all active movements and providing a particular system of ascendancy/refuge in predator/prey relationships i.e., prey can climb away from predators; some predators (e.g., birds of prey) can adopt a position of dominance above prey; and increasing body size requires increasing structural mass with associated weight increases, which can reduce speed and agility. However, this model does not effectively represent the aquatic environment, particularly marine habitats where Bakun (2012) suggests organisms are most often almost neutrally buoyant, so that the law of gravity is replaced by the laws of hydrodynamics in acting to constrain behaviour, and gravitational pull gives way to frictional drag as the main force opposing active movement.

Therefore, strategies adopted by marine organisms to achieve a positive energy balance include those that reduce this frictional drag. For finfish species, Bakun (2012) points out that "many aspects of the biology and behaviour of fish give strong evidence for the importance of optimizing energy costs", citing Lighthill (1977) and Wardle & Reid (1977) as researchers who have shown that there is a high degree of tuning in the swimming mechanics of fishes, effectively reducing the energy requirement for swimming. He also refers to the available information on fish migration routes, including work on the pink salmon (*Oncorhynchus gorbuscha*) by Royce et al (1968), skipjack tuna (*Katsuwonas pelamis*) by Seckel (1972), and plaice and cod by Harden Jones (1977), to conclude that migrating fish tend to utilise ocean currents rather than oppose them, even when the fishes' swimming speed is considerably higher than the current speed.

Bakun (2012) summarises the Harden Jones (1977) study further, indicating that it documents the ability of these fish species to adjust their depth according to the tidal cycle, thereby accessing the oscillating tidal currents to achieve a positive energy balance during migratory swimming. The study highlights the structurally complex nature of the aquatic environment, where adjusting depth to gain advantage is a common strategy utilised by several different life history stages. In this adult cod and plaice case use depth adjustment to access the environmental corridors offered by tidal currents.

Bakun (2012) also discusses depth adjustment by larval fish to maintain their position within a boundary-delineated zone associated with a shelf-sea front. He cites the work of Iles and Sinclair (1982) who describe the presence of herring larvae within such a zone, suggesting that by maintaining their position either near the ocean surface or near the bottom, where water movement is on-shore (contrasted with midwater depths that are characterised by flow in the opposite direction), they avoid being carried offshore and could take advantage of the high concentration of preferred forage items such as crustacean nauplii in the pycnocline[19] region associated with the front. Bakun (2012) supports this suggestion by referencing the results of Buckley & Lough (1987), who describe more numerous,

[18] Diversion of flows along the boundary instead of movement through it, thus transforming the boundary into a corridor (Forman & Moore 1992, Naiman and Décamps 1997, Haddad 1999).
[19] A zone where water density increases with depth.

faster growing haddock larvae in such a region of the Georges Bank compared with other zones of that shelf complex.

Zones that exist at the surface and provide a system that inhibits oceanic flow are perhaps the most obvious areas where ecological boundaries operate. For example, Bakun (2012) refers to the Southern Californian Bight where a gyral geostrophic circulation pattern is dominant for most of the year and probably retains eggs and larvae. The sheltered nature of the area, from strong coastal winds, ensures a very low level of turbulent mixing and produces a layer of concentrated food particles (Lasker 1978), and the productivity is sustained at what appears to be a high level by strong local upwelling. The Bight is a major spawning ground for "the pelagic fishes that dominate the exploitable biomass of the California Current ecosystem" and Bakun (2012) references the work of Parrish et al (1981) who describe probable long-distance migrations of species such as the Pacific sardine (*Sardinops sagax*), hake (*Merluccius productus*), and blue mackerel (*Scomber japonicus*) to spawn in this area .

Clearly then, the concept of the corridor-boundary continuum of Puth & Wilson (2001) is applicable to marine finfish species. However, what constitutes a boundary or corridor is not necessarily immediately clear. For example, in discussing the effects of the physical environment on the behaviour of highly migratory tunas (family Scombridae) and billfishes (families Istiophoridae and Xiphiidae), Brill and Lutcavage (2001) observe that these species regularly move vertically through thermal gradients (1°C m^{-1}) that are steeper by orders of magnitude than the horizontal gradients (1°C km^{-1}) they regularly experience and suggest, therefore, that it is probably not sea surface temperature gradients alone that influence their horizontal movements or aggregation. The authors suggest that what is required are direct observations of the behaviours of tuna and billfish, which can be collected using acoustic telemetry or electronic data-recording tags. These observations can then be combined with information on the fishes' physiological tolerances to environmental extremes, distributions of forage abundance, and relevant oceanographic data, to develop models of the relationship between behaviour and physical environment.

Fish movements are, of course, not only related to spawning migrations. Green et al (2015) distinguish three types of movement of adult and juvenile coral reef and coastal pelagic fish species: home ranges, spawning migrations and ontogenetic shifts in habitat. However, it is not necessary that all individuals of a species' population will display these movements in the same way at a given time. For example, Afonso et al (2009) worked on the movements and habitat use patterns of trevally (*Pseudocaranx dentex*) using active acoustic tracking, passive acoustic monitoring and standard tag-release in the Faial Channel of the Azores Islands. Individuals of the same population were taken at both inshore and offshore reefs but, where daily movements of inshore fish were alongshore within "large activity spaces" of up to 370 ha, offshore trevally were somehow constrained in their short-term movements to summits of the reefs.

Afonso et al (2009) used passive telemetry to show that 'offshore' trevally can relinquish their seasonal attachment to the reef and replace it with periods of migratory behaviour, when, in short periods of only hours to just a few days, they can travel between areas and habitat types separated by tens of kilometres. These results show that the home ranges of trevally in this environment change substantially, and that this occurs not only between individuals comprising the two groups (coastal and offshore) within the population, but also for individuals during the course of a year.

Essentially, this question of fish movements and how they relate to the boundary-corridor continuum is complex, obscure, and varies both between and within species in a variety of ways, although there are certain aspects that are generally applicable over most species. However, the summary presented here is but a scratch upon the surface, not only of what actually exists in the wild, but also of what is known. The challenge in providing a useful overview is that while there is undoubtedly extensive knowledge that could be included, this knowledge has been documented from perspectives that are different to the one that interests us here, which adds a barrier to easy access and information flow.

6.5.2 Relevance

The relevance of this information to the Cook Strait–Marlborough Sounds situation can be seen if we consider certain aspects of the pelagic habitat of Pelorus Sound with reference to finfish species of interest here described in §6.1.4 under "*The outward migration of these species*". This discussion of bluegill bullies, along with giant and shortjaw kokopu, provides a good example of how the corridor-barrier continuum might apply to the larvae of four fish species. The work of Baker (1972) indicates that at least one pelagic species (pilchard) utilises a corridor provided by a current system from Tasman Bay, through Admiralty Bay and into the Sounds (including the outer Sounds) to assist in moving eggs and larvae from a spawning ground to an area that is potentially highly productive offering optimum conditions for development through to recruitment to the adult population.

However, what we do not have is any knowledge of what is actually happening with the fish. We can speculate about their behaviour based on information from elsewhere, but without appropriately designed experimental work we are without tests of any of the hypotheses that might be developed from this discussion. As was suggested in §6.1, it seems unlikely that the nett effect on the finfish fauna of farms at sites similar to that proposed in north western Cook Strait through impacts on movement corridors and other components of the corridor-barrier continuum would be anything but low.

It is in our best interests to begin investigating some of the ecological issues related to wild finfish species. These species are almost always overlooked in the allocation of research funding, but like pilchard[20] and other small pelagic species, can occupy key positions in energy flow through inshore food webs. A method designed to examine the impact of farms on these species is presented in §8.

7. IMPLICATIONS FOR A FISH FARM IN NORTH WESTERN COOK STRAIT

7.1 The Pelagic Habitat

Information from several studies provides us with some insight into the pelagic habitat at the proposed site. Nutrient advection into the zone outside Pelorus Sound is high during periods of summertime El Niño conditions, although the best available information suggests that tidal mixing and light attenuation keep primary production at moderate levels. Currents along the northwest-southeast axis are strong indicating the probable development of an extensive farm footprint and therefore the operation of a relatively wide-ranging finfish attraction.

7.2 Finfish Distributions and Existing NZ King Salmon Farms

A comparison of data from the various sources in Table 1 suggests some contradictions, which can be clarified to some degree in terms of targeting strategies by commercial and recreational fishers (see §2.2.8). By keeping these conditions in mind, the various datasets can be used together to suggest which species are most likely to occur at the proposed site. Ultimately, it is the commercial and recreational data from the vicinity of the proposed site that provide the most likely set of potential colonisers, but targeting strategies and gear types limit species representation. The observational data from existing farms provides a list of known colonisers, therefore extending the overall list. Although these are from farms within the Sounds, it is reasonable to expect that they will be attracted to cages at the proposed site.

[20] Although fished commercially, pilchard ITQ is very low, as are annual catches from the fishery. Therefore, there is never funding available to undertake research into this ecologically very important species.

There is a strong correlation[21] between the data of Morrisey et al. (2006) and the data from existing NZ King Salmon farms — 65–70% of the species listed by Morrisey et al. (2006) were identified in the data from existing farms (see Table 1, Column D) (the upper value is dependent on the inclusion of a Synganathidae species, which differ between the two datasets but for which misidentification is likely). Existing farm data indicate very high observations of seasonally moderated numbers of the baitfish species, yellow-eyed mullet, pilchard, anchovy, and jack mackerel, all of which were listed by Morrisey et al. (2006). The larger, predatory yellowtail kingfish was also described as a frequent visitor to existing farms (though in much lower numbers) and was listed by Morrisey et al. (2006).

Several other species show interesting relationships. John dory is recorded in the commercial catch data from throughout the area but only from Port Ligar in the recreational data and is included only from 1 existing farm (Waihinau, close to Port Ligar) as a cryptic species in the existing farm data; it is absent from the recreational charter data. Despite being observed at the highest frequency category, jack mackerel was seen at only 2 of 4 farms — Waihinau and Te Pangu (Tory Channel); it was absent from the various recreational datasets and only recorded from the northeastern area in the commercial data (grid rectangles A7-A9, B7, B8, B10, B11, C11, D9), a result possibly related to the gear/targeting strategy used. Generally the highest correlation between the recreational *survey* data and existing farm data is for larger, most often higher angler-valuable species, such as kahawai, tarakihi, and snapper, (the latter three being recorded most often as cryptic species from the existing farms), as well as barracouta. Species were categorised as cryptic because they were seldom observed despite often being taken in fishing events close to the farms. These species are mostly demersal, so their cryptic behaviour is expected.

7.3 Implications for customary, recreational, and commercial fisheries

An examination of commercial fisheries catches over the nine year period 2010 to 2018 inc. in the area of the proposed site from the MPI database showed that the majority of the catch is of benthic species, which probably is mostly a reflection of the particular fishing method used in the area of interest. Only 3 pelagic species were apparent in catches from the approximately 10 nmi radius area and only 1 of these, barracouta, was present within 10 km of the site. The catch of jack mackerel over the 9 year period was relatively high, but most was taken more than 10 km away and the small catch of kahawai (25kg) was also recorded from a similar distance.

Therefore, the commercially fished species most likely to be affected by installation of a farm at the proposed site are those from the benthic group, including bentho-pelagic species and the reef dwellers, all of which exist mainly on a diet of benthic organisms. A total of 17 quota species were identified from a relatively extended area beyond the proposed site (see Table 3), but only 11 of these were landed in its immediate vicinity. The 6 species landed outside the immediate vicinity are far less likely to be affected by components of farm discharge impacting the benthos.

The greatest potential influence on these species is through farm generated organic material impacting the benthos and access to waste feed, although both benthic and bentho-pelagic species can also become members of the group resident beneath the farm in the pelagic zone. With regards bentho-pelagics in the commercial data, this includes members of this group from outside the immediate vicinity of the proposed site, which depends on the effective attraction range of the suspended/re-suspended fine particulate matter and the distance over which such species might follow migratory corridors to come under the influence of the FAD attraction of the farm. Altogether, there are 4 bentho-pelagic species recorded from the quota species data: blue warehou, john dory, school shark and spiny dogfish; blue warehou was not recorded in the immediate vicinity of the proposed site but the other three were.

[21] *Correlation* in this section relates only to simple eyeball and percentage estimation for comparisons of datasets. It does not include statistical testing.

Greatest representation in the recreational charter vessel catches are also of benthic species. Only 3 pelagic species (barracouta, kahawai, and thresher shark) and 2 bentho-pelagic species (school shark and bluenose) were recorded in the data, with no pelagic species caught in the immediate vicinity of the farm and only small catches of kahawai and kingfish (60 and 55 fish) recorded over a more extended area (see §4.2). Consequently, the situation is similar to the commercially fished species, that species most likely to be are those from the benthic group, including bentho-pelagic species and the reef dwellers, all of which exist mainly on a diet of benthic organisms. A total of 14 such species were identified from the overall area; 9 from the immediate vicinity and 11 from the area outside that (see Table 4).

The discussion regarding wild fish species recorded in the commercial and recreational charter vessel catch data is also relevant in the case of customary fisheries. However, making more certain predictions about the vulnerability of the wild fish species is impossible without first knowing the intended geographic placement of the farm cages. Selecting a deployment site with the aim of minimising the ecological impacts and adopting the type of mitigation strategies suggested by Elvines et al., (2019) will, by minimising effects on the benthos, reduce the negative effects on wild finfish species. And, while it appears from the summary shown in Table 3 that potential loss is only of small proportions of the commercial fisheries discussed here, there is clearly a potential impact on the recreational fishery and an unknown but potential effect on customary fisheries also. This effect is minimised by achieving the aim of utilising offshore sites which enables expansion of the industry while sustainably managing resources.

7.4 Effects of Farms

From the information compiled here, it is clear that interactions occur between wild pelagic finfish species and NZ King Salmon farms. Undoubtedly, such species are attracted to farms, often in such numbers that the result is higher densities than in areas where farms do not exist. There are several causes of attraction, including light, sound, at least two sources of food (i.e., other fish and feed pellets), and the action of the farm structure in providing protection from predators.

Discussion here of results from overseas research suggests that the potential for farms to act as ecological traps is of concern in avoiding adverse effects on wild finfish species. Fundamental to this action is the continued attraction of the farm for fish that incorrectly select the habitat surrounding a farm as one that will provide the resources they require to maximise their biological fitness. Under this scenario, increased body condition from consuming feed pellets actually reduces their reproductive fitness when feed composition is of lower quality than their natural diet. At present, no direct evidence suggests that this is the case.

An alternative outcome occurs when artificial feed is of equal or higher quality than the natural diet and adds condition that increases the reproductive fitness of wild fish. Evidence from numerous overseas studies suggests that the condition of wild fish living around farms is significantly increased. However, an ecological trap may continue to operate if fish are harvested from around the farm at a rate that exceeds the maximum mortality in areas where there is no artificial aggregation. Because the farm continues to attract fish, such harvesting over a medium to long time frame could result in local depletions.

As is discussed above (§3.12), the alternative to the ecological trap is the population source, where any reproductive benefit gained by fish inhabiting the water column close to a farm increases their reproductive success. This is the result often expected from marine protected areas, where fish reproduction is allowed to occur without any anthropogenic interruption, which should increase reproductive success. The additional benefit that may be gained near a fish farm is any increased fitness from greater access to feed. If harvesting is prevented, increased wild fish biomass resulting from these reproductive gains adds to the overall biomass for the species that are present.

The discussion above indicates that increased condition is not the only possible outcome of consuming feed pellets. An important second effect concerns the various contaminants of wild fish with the implication of possible impacts on human health. This contamination introduces a number of potentially dangerous chemical species to the pelagic food web, but this danger is usually only realised when contamination reaches a level that is a health threat to humans. While some organohalogenated contaminants and mercury have been detected as slightly elevated in the tissues of wild fish that reside around salmon farms compared to other fish, these have never exceeded levels considered safe for human consumption. As was stated above, such levels are also an unlikely result for farms in the Marlborough Sounds area under present conditions, but the long term effects through the function of bioaccumulation are seldom considered. To ensure that no such effects emerge, monitoring of key contaminants of public health interest should occur in long-lived, bentho-pelagic fish species that are of recreational, commercial or traditional fishing interest, and that reside in the near vicinity of salmon farms. Such monitoring would first depend upon such species being identified to occur in the near vicinity of the salmon farms. Frequency of monitoring should be determined relative to the status of the benthic conditions beneath farms, as biological availability of certain heavy metals increases in anoxic sediments, and should also be compared to relevant control locations.

In the context of the overseas research discussed here, the volume and composition of feed pellets consumed by wild fish is probably the most important effect of fish farms on the wild fish population. The summaries from the international literature describe feed wastage from the cages in the order of 1 to 5%. It is the contention of NZ King Salmon however, that feed wastage levels at existing farms are low (<0.1%). Under these conditions, the effects on wild fish are likely to be lower than those described above, but such a conclusion cannot be reached without independent data on measurement of feed fallout from existing NZ King Salmon farms. We therefore recommend that independent monitoring of feed loss levels, and how these levels vary with location and time, be undertaken at any newly established farming locations.

7.5 Interactions of Fish Farms with Sharks

Information from existing NZ King Salmon farms indicates that a total of four shark species have been known to visit the farms. These include spiny dogfish, bronze whaler, blue shark, and seven-gill shark. According to information from DOC (Clinton Duffy, pers. comm., see Table 6) the latter three of these are "potentially dangerous", which is defined as any shark species known to engage in, or has been implicated in, unprovoked injurious attacks on humans or vessels. Spiny dogfish are "traumatogenic" which refers to species capable of inflicting serious injury if provoked or mistreated. Therefore, all shark species known to occur at existing NZ King Salmon farms require a careful management approach.

During the South Australian workshop in 2003, agreement was reached that fresh dead fish caused most interactions with sharks and that most interactions were with bronze whalers after pupping in October–December. A useful strategy for NZ King Salmon to minimise interactions would be the adoption of the following set of best practices identified by industry members at that workshop:

- Good farm husbandry, which minimises the number of fish dying in the cages;
- Prompt removal of dead fish from cages;
- Utilisation of predator exclusion nets or shark-resistant materials in cage construction.

8. A PROPOSED METHOD FOR ASSESSING THE IMPACT OF FARM DEPLOYMENT ON WILD FISH SPECIES

8.1 Background and approach

As was stated in §3.1, coastal sea-cage fish farms modify the abundance, biomass, and species diversity of wild fish wherever they occur (Callier et al. 2017; Barrett et al. 2018a). In the present context, this impact can occur in at least two ways. Highly mobile pelagic species will be attracted to the structures as they are to most floating objects, a fact that has been exploited by fishers through the use of fish aggregating devices (FADs) (see Bakun 2012 for useful discussion), although it is clear that other factors such as the continual dispensing of artificial food and chemical attraction from farmed fish also act as attractants. The actions of these factors were suggested by Dempster et al., (2002) and Boyra et al., (2004) recognised them as potentially explaining their observed variations in the presence of species at farm cages and their conclusion that fish farms do not act as conventional artificial reefs or FADs in the attraction of wild fishes. By contrast, the impact on demersal and benthic species is perhaps a little more direct in that the potential affect is more from farm discharge as it is deposited on the seafloor and alters the composition of the local sediments (see discussion in §3.6.2).

As a consequence of this clear difference in impact on each of the two groups, any method designed to examine the impact of farm installation requires an approach that collects data from both of these components of the wild fish population. A key difference between the two is that farm installation will impact the benthic group as a population existing within the farm site at the time of cage deployment, while the expected impact on the pelagic population is that it will increase from a low level, possibly one that is undetectable, to a level that is measurable to some unknown but higher degree. With this in mind, the term "population" used here actually refers to the "local population" of each of these components, although what becomes the local pelagic population is drawn from a wide geographical range. Note that there is no intention to investigate the effect of farm installation on physiological or anatomical changes in wild fish species in this study although changing size structure is of interest.

A key summary on the ecological effects of aquaculture by the Ministry of Primary Industries (MPI) states that "*Aquaculture planning must be supported and underpinned by science-based information on ecological effects"* (Ministry of Primary Industries 2013). However, little information is available on the relationship between pelagic finfish and sea-cage farms in the New Zealand context. By contrast, an extensive overseas literature exists for this relationship in the Mediterranean and Norway, which is summarised above (see §3) to develop an overview of the possible effects of salmon farms on the pelagic habitat and finfish species. This summary includes information on various aspects of wild fish aggregations and the taxa (i.e., species and family) they represent. In the present context, installation of cages at the site proposed by NZ King Salmon provides an opportunity for the development of finfish community structure to be recorded and examined from the earliest point, thus allowing a timeline based assessment for the site.

By undertaking development of an impact study and monitoring method for such a study, NZ King Salmon are demonstrating their intention to work from a basis of reliable scientific information in planning and establishing a farm at the proposed and any future site. An understanding of the existing finfish population can be used as a basis for measuring the impact of the farm as it becomes established, on a variety of predatory organisms including marine mammals, seabirds, and sharks. Developing a reliable monitoring method for wild finfish is the first step in gathering the required data for the impact study when seeking to establish farms elsewhere in the future.

The main objective of the work proposed here is to complete development of a methodology for carrying out an ecological impact study based on well-documented, well-established procedures published elsewhere (e.g., Green, 1979; Steel & Torrie, 1981; Hurlbert, 1984; Kingsford & Battershill, 1998). The impact study itself aims to determine whether the deployment of sea cages at the farm site proposed by NZ King Salmon has an effect on wild finfish species (hereafter wild fish species), which species are affected, and whether this effect is influenced seasonally. For operational reasons, including determining the best sampling techniques, and to provide accessible information at each stage, the overall study comprises the following three phase programme:

- Phase 1: developing a general description here and in a more detailed technical document for discussion by NZ King Salmon of the plan for Phase 2;
- Phase 2: carrying out the plan outlined here and documentation of a finalised impact study methodology, including the monitoring/sampling system and the collection of test data for testing the analytical component of the methodology; and
- Phase 3: execution and reporting of the finalised impact study following development and assessment under Phase 2.

The plan is to carry out Phase 2 at the northwest Cook Strait site and other existing sites as necessary; Phase 3 is for execution later at a further site of interest to NZ King Salmon. This approach allows for the development of a robust method within Phase 2 without the pressures of completing development over a short time frame.

A number of studies have been completed overseas with similar objectives to those proposed here. However, none of those completed to date have begun before the farm installation was completed. Ideally ecological studies include in the analysis data collected from before the perturbation begins. Such is referred to as a before-after-control-impact (BACI) design, a term introduced by Green (1979), which included the use of a control site. This approach has been modified since, probably as a result of the discussion of pseudoreplication by Hurlbert (1984).

The review by Kingsford and Battershill (1998) provides an excellent summary of the improved approaches. Once development under Phase 2 is complete and a robust methodology is available, undertaking the impact study at a site of interest using a modified BACI approach would provide, for the first time, results from a study investigating the effect of sea cages on species of wild fish from before the sea cages are first deployed. From a practical perspective, such an approach avoids the limitation of inferring the impact from spatial patterns only, providing the additional aspect of inference from temporal patterns and eliminating grounds for the criticism that some measurable difference pre-existed deployment of the cages. The results documented above in §3.2 imply that it is difficult to predict the wild fish aggregation sizes at any particular farm prior to its establishment, although subsequent temporal fluctuations may become predictable at some locations.

The following is a description of the proposed methodology to be carried out under Phase 3. Essentially, this overview aims to describe a straight forward sampling method and analysis for each of the two components of the fish population expected to be encountered, but a number of details will change as further development is completed under Phase 2. Consequently, the method is presented as a discussion of the various aspects being considered and aims to provide the reader with a synopsis.

8.2 The Study Area

It is intended that the method described here can be used to determine the effect of farm installation at any proposed site being considered in the future. In the present case, which serves only as a reference example for the purpose of this discussion, the study area is the 1792 ha area in north western Cook Strait proposed as a possible farm site by NZ King Salmon (Figure F1), whereas *the farm operational area* is the area immediately surrounding or including the sea cages comprising the farm. The position of the farm operational site within the proposed site has not yet been defined.

The method described here is being developed on the basis that the farm will comprise approximately 10 Fortress style pens of about 200m circumference, which provides useful spatial perspective although the method is not limited to such dimensions. A 200m circumference translates to a single cage diameter of approximately 65m. One configuration of the sea cages might be 2 parallel rows of 5 cages in each which would cover an area of approximately 325m x 130 m = 42,250m^2 or 4.225ha.

Therefore, the total farm operational area would cover approximately 0.24% of the total 1792ha proposed site, which provides a good working area for selecting appropriate control sites in areas of similar habitat relatively close to, but beyond the influence of, the area of cage deployment.

According to the Cawthron Institute Benthic Report, particle grain size throughout the proposed farm site includes gravel, five sand grades from very coarse to very fine, and a silt/clay grade. Silt/clay seems to be frequently represented in the samples, often comprising 25-50% of the profiles. The mapped area extensively exceeds the area of the 1792 ha proposed site.

The estimated zones from the Benthic Report habitat map suggest extensive areas of horse mussels (*Atrina zelandica*, family Pinnidae), with approximately 30% of the area supporting beds of mixed horse mussel–brachiopod beds, about 15% of horse mussel patch reef, approximately 35% of bryozoan beds, about 10% reef edge assemblages "dominated by shell debris, with whole shells and finer shell hash, gravel and cobbles, as well as underlying bedrock substrate in some areas, and about 10% sparsely populated mud communities. Therefore, there are several potential bentho-demersal finfish habitat strata throughout the mapped area.

8.3 Specific habitat

Benthic species inhabit the benthic realm, the habitat of organisms closely associated with the sea floor (Roberts et al 2015). According to that publication, "the area of continental shelf between reef structures is sedimentary seabed, which is formed largely by river deposits and shell debris from shelled invertebrates of infaunal and reef epifaunal communities". In this habitat, benthic fish species most often inhabit the seabed surface with some living within the bottom sediments. Other bottom-associated fish species (bentho-pelagic) form schools and inhabit the water column from the seabed to within several metres of the bottom.

Pelagic species inhabit the pelagic habitat (see Appendix A), which occupies the water column from the top of the benthic realm to the surface. For ease of explanation, this group is referred to in discussion here as those contributing to the population taking up residence within the pelagic zone beneath and around aquatic farms. However, this is a simplified explanation such that certain species recognised as being benthic (see e.g., Roberts et al 2015) migrate into midwater, with some having been identified as residents within the "pelagic" population attracted to sea cages housing farmed finfish. Thus, for the purposes of the discussion on the proposed methodology the terms *benthic/demersal* and *pelagic* refer to the zone of the water column being targeted — the species identified in each are grouped accordingly.

Therefore, the targeted area of the water column for data collection of the benthic group will be from the seabed up to several metres off the bottom, whereas the targeted area of the water column for data collection of the pelagic group will be from the surface down to within several metres of the bottom.

8.4 Aims and hypotheses

The aim of the work proposed here is to determine the extent to which wild fish species are affected by installation of a farm at a proposed operational site and whether there is any seasonal variation in the response. As was discussed in §4.1.3, the vulnerability of each species to farm installation can be examined in terms of at least four factors: its preferred habitat, its ecological requirements, the mode of action of the farm effect, and the distance from the farm that members of that species are distributed. Because of their behavioural differences as a result of differences in the first two of these factors, there is a clear natural separation in the wild finfish population into a benthic group and a pelagic group.

From work completed overseas (see §3), we would expect an increase in the abundance/biomass of pelagic species at the operational site following farm installation, although we know nothing about the species composition or the magnitude of the response in the New Zealand context. The affect on benthic species is less clear. Based on current knowledge the response of benthic species may well be variable in terms of abundance and biomass. Because of differences in their ecological requirements some may increase while others may decrease with the advent of the farm operation.

Step one in achieving the aim requires the formulation of specific hypotheses. The first hypothesis to be tested for the members of the benthic group is that their abundances will undergo greater change at the farm site than at control locations and that this effect will occur after the farm is installed. The result of this work could provide an answer on the response of functional sub-groups (e.g., herbivores) to farm installation. For the pelagic group the first hypothesis to be tested is that abundances will undergo greater increases at the farm operational site than at control locations and that this effect will occur after the farm cages are installed.

A second hypothesis applies to each of the two groups independently. Specifically, the hypothesis to be tested is that abundance and biomass, as well as species composition and fish sizes of aggregations will vary on a seasonal basis.

8.5 Data collection

8.5.1 Spatial considerations

An asymmetrical sampling design (Underwood 1992, Kingsford & Battershill 1998) will be employed for the data collection, consisting of a single treatment plot (the farm operational site) and multiple control plots beyond the influence of the cages but relatively close by in an area of similar habitat and other related environmental conditions. Treatment plots must be independent, but the logistical requirement of farm cages to be closely deployed within a relatively restricted area would usually preclude such independence for multiple treatment plots, given the fluid nature of the marine environment and the extended footprint of a farm, which therefore limits the design to a single treatment site. In the case of a site like that in northwest Cook Strait however, it is likely that the cages will be separated into two operational sites comprising a similar number of cages in each, which could allow for two treatment plots, as long as it can be shown that the two are independent of one another. Note that in any case, treatment and control plots will all be the same size and are therefore dictated by the size of the operational area.

A number of studies have been completed overseas that provide useful background for developing a methodology here (e.g., Carss 1990; Dempster et al. 2002, 2004, 2005, 2009, 2010; Tuya et al., 2005, 2006; Boyra et al., 2004). These studies utilise approaches with similar underlying designs but also show a clear evolution through time as aspects of the methodology are tuned or varied to investigate different hypotheses under different conditions in different environments and additional technologies are incorporated into their design. For example, the transect approach used in previous studies was modified by Dempster et al. (2005) when investigating vertical variability of wild fish assemblages around sea-cage fish farms because of the likelihood of visibility varying with depth and of the difficulty in sampling using transects of specified lengths in midwater. The modification resulted in stationary timed counts when a technique was designed to be robust at a range of depths and visibilities.

Consideration of these studies suggests two possible methods of data collection for sampling the benthic finfish species. Under the first option, data collection would be carried out with the use of several transects, randomly placed within each plot but grouped according to different strata or areas of varying habitat (see Cawthron benthic map in Elvines et al., 2019) as is useful and/or necessary to allow the broadest inference from the experimental results. Total transect numbers would be the same within the treatment plot and each of the control plots to ensure a balanced design. Data collection would comprise counts along the transects, and because water depth at the proposed site prevents data collection by divers, a method deploying a remote camera would be necessary. While it seems that the most logical choice, the use of drift underwater video (DUV) (Carbines & Cole 2009), may not be viable in this case because of mooring lines on the sea cages preventing unobstructed passage through the farm area once the cages are deployed. One alternative is to use a camera mounted on a remote operated vehicle (ROV), an approach that will be investigated as part of the preliminary work under Phase 2. Use of a camera also requires the need for artificial lighting, a consequence of the attenuation of natural light at such high water depths. Note that use of the DUV remains an option being considered — it will also be investigated under Phase 2.

The second choice for sampling the benthic group is to adopt the method of Dempster et al. (2010) where data collection is included with that of pelagic species using a revolving camera to perform stationary timed counts at several depths including the approximate top of the benthic zone (see below): Dempster et al., (2009) used surface (defined as 5 m water depth); cage; 20 m water depth; mid-water; 5 m above bottom; bottom. This is the more recently developed method using stationary timed counts mentioned above, which avoids the transect approach and may be more viable here. The camera is used to record all fish present within a cylindrical count volume of known size for later identification. The count volume in which fish are identifiable is determined during preliminary work using objects at known distances from the camera.

Data collection methods for the pelagic group are also suggested by the overseas studies referenced above. One of two different methods could be employed, either being carried out by divers using rapid visual counts (RVCs) while remaining at a predetermined position and rotating through 360° or using the video-based stationary timed counts recording method (Dempster et al., 2009, 2010), in which a camera contained within a half-spherical housing records footage while slowly revolving through 360°. For both of these cases, the spatial range for each sample is a cylindrical volume defined during preliminary work (Dempster 2010 used an approximately 700 m^3 volume of 4 m height x 7.5 m radius from the camera) which can be applied according to a predetermined series of depths and distances from the cages.

8.5.2 Temporal considerations

The aim of this work is to follow a BACI experimental design which requires that sampling begin at least one, ideally more, full temporal cycle(s) before sea cages are deployed at the site. Because an examination of seasonal variation is necessary to understand the extent of the impact, sampling for a minimum of 1 year is necessary before cages are deployed.

The second hypothesis to be tested for each group (benthic and pelagic) separately is that farm effects will vary on a seasonal basis. To achieve this, a seasonal sampling regime will be adopted. The plan is that several days sampling will be carried out as a block during each season (i.e., summer: December–February; autumn: March–May; winter: June–August; spring: September–November). The number of days required, and the number of samples in terms of the transect layout, will be finalised during Phase 2.

8.5.3 Fish counts

Counts of fish are fundamental to the methods discussed here. They provide the data for estimating abundance and biomass. The method of obtaining reliable data varies with the sampling method adopted. The RVC method requires that divers are capable of identifying the species they encounter as a basis for recording the count data. Video-based stationary counts provides a permanent record which can be viewed later.

As was discussed by Dempster et al., (2002), neither of the two major problems with visual counts (i.e., inaccurate identification of taxa underwater where assemblages are diverse, and underestimation of the abundance of cryptic species) apply around sea-cage fish farms because there is low diversity in the assemblages that occur there and complex habitat that provides refuge for cryptic species is absent. This may be true of the pelagic aggregations that develop under and around the cages, but it probably does not apply to species inhabiting the benthic zone. However, water at offshore sites such as the northwestern Cook Strait site is too deep for divers to record data from the benthic dwellers, therefore forcing the use of a camera-based method in this case.

Some investigation is required under Phase 2 for the pelagic zone to decide between a camera-based or a diver-based method. Dempster et al., (2002) discuss the limitations of visual counts including the underestimation of fish numbers, particularly under- and over-estimation of "diver-negative" and "diver-positive[22]" fish species respectively, but conclude that potential biases should be consistent between locations. Logistics of the method developed by these workers included two divers, with the first concentrating on estimating the abundance of the dominant species present by counting fish and recording them in tally-groups ranging from 1, 2-5, 5-10 through to 201-500 and 500+. The second diver "followed slightly behind and the first and specifically looked for both highly mobile species and smaller, less obvious fish that may have been missed by the first diver." Because of the circling of cages by fishes, total counts around cages were considered inappropriate as independent replicates and the method of RVCs was adopted, with the divers beginning at one cage and proceeding to a second. Each count covered a volume of approximately 11 250 m^3 (15 m wide x 15 m deep x 50 m long).

Estimation of average total lengths of groups was aided by the use of a ruler which was checked at a later date by sampling actual fish. Count data were entered into a custom-built program, which was used to calculate abundance by species and size class and conversions to biomass for each species based on published length-weight relationships. An explanation of the method used to scale abundance and biomass up to the total farm volume is provided by Dempster et al (2004). The average count for the farm over the replicated count events was multiplied by the total number of count events possible within the total farm volume. The farm volume was defined as the total volume encompassing the cages, minus the volume enclosed by the cages. The same amount as their respective farm volume was used to scale the volume at control areas.

Essentially, the method presented in this section in summarised form was the basis for collecting fish count data and estimating abundance and biomass for the studies described in Dempster et al., (2002, 2004, 2005, 2009, 2010) and Fernandez-Jover et al., (2008). These studies include methods for investigating abundance and biomass variations using both diver RVCs and video-based stationary timed counts and provide a useful basis for developing a sampling method under Phase 2 for use in studying the farm impact at sites such as that proposed for offshore in north western Cook Strait. Video-based stationary timed counts at multiple positions beneath the farm focused on the benthic population could provide a viable method for sampling that sub-population.

Use of the DUV is described by Carbines and Cole (2009) who used it to examine dredge impacts on demersal fishes and benthic habitat complexity in Foveaux Strait. Simply speaking, this is a transect-based method using the camera attached to a mounting platform with a bulb keel and tail fin, suspended on a rope and cable with attached scaling lasers and lights, the latter incorporated to illuminate the field of view. Deployment was from a medium sized vessel and the apparatus was operated while drifting down-current over the area of interest following a randomly placed virtual transect. The scaling lasers were used to "back-calculate the size and variations of transect width". Fish count data were transposed from the video footage.

[22] Positive and negative in this context refers to attraction towards the diver and covert or escape behaviour away from the diver respectively.

8.5.3 Fish capture

Fish capture is necessary to calibrate the method being employed for estimating fish length. Reliable length data are required for calculating biomass using published length-weight relationships, which are available for many species from stock assessment plenary documents and the associated publications listed therein (e.g., Fisheries New Zealand 2018). The most appropriate method of fish capture will be determined during Phase 2, and needs to minimise difficulties related to farm structure and deep water while providing representative samples from the population.

For work investigating the size structure of aggregated assemblages and estimating total aggregated biomass of the resident pelagic group immediately under sea-cage farms, Dempster et al., (2009) captured specimens of the 4 most abundant wild fish species (saithe, *Pollachius virens*, n = 323 captured at 9 farms; Atlantic cod, *Gadus morhua*, n = 168, 8 farms; Atlantic mackerel, *Scomber scombrus*, n = 106, 5 farms; and haddock, *Melanogrammus aeglefinus*, n = 48, 8 farms) using "standardized hook-and-line fishing gear on days when camera sampling was conducted. All wild fish were measured (fork length. FL) and weighed to the nearest 5 g."

This approach was successful in achieving the aim of the work undertaken by these workers. An alternative might be spear fishing, particularly if the adopted method is based on diver RVCs. Netting methods have been considered for the work proposed here, but are probably too difficult employ in the vicinity of the cages. Because of water depth, hook-and-line may be the only alternative for sampling the benthic population at offshore sites.

8.6 Sampling design

The sampling design will be based on the premise that *every level of sampling should be replicated* (Kingsford & Battershill, 1998). Thus, sampling will be completed on several days within each season when several sampling units or sets of fish counts of each sub-population (i.e., benthic and pelagic) will be recorded. The method of recording each set of fish counts will be determined during Phase 2.

In keeping with this approach and to avoid the pseudoreplication trap (Hurlbert, 1984), multiple control sites will be utilised, with several fish count events of the same number taken in each and at the farm operational site. Control sites with similar characteristics (e.g., substrate and bottom depth) as the farm operational site will be selected. Given the extensive area of the substrate types identified by Elvines et al., (2019) for the northwest Cook Strait site, it seems unlikely that a stratified sampling design will be required for the benthic population, but this is very unlikely to remain the same between sites. This will be investigated during Phase 2.

8.7 Data processing and analysis

Details of the data analysis method depends to some degree on the sampling method decided in Phase 2. Analysis of variance (ANOVA) is the commonly used method of analysing the relationship between farm sites and control sites, both for data collection using RVCs (e.g., Dempster, 2002) or visual census techniques with transects (e.g., Boyra et al., 2004), and for video-based stationary timed counts (e.g., Dempster et al., 2009) or use of DUV (Carbines & Cole 2009). The first three of these studies used Cochran's test for heterogeneity of variances prior to ANOVA, with appropriate data transformation as necessary. The latter study calculated Pearson correlation coefficients between number of fish and measures of benthic habitat features (e.g., topographic complexity, epifauna cover, tunicates).

Fernandez-Jover et al., (2008) investigated seasonal variation using ANOVA, although their experimental design included sampling from several farms and incorporated an extra level of complexity than would be required at a site such as the north western Cook Strait site; such could be a useful approach for comparing multiple farms in the New Zealand context at a later time. Four factors were included in the design by Fernandez-Jover et al., (2008): season (Spring, Summer, Autumn, Winter), year (2004, 2005), farm (3 farms), and day (three different days per season). Six RVC censuses were performed each sampling day. Season and Year were considered fixed and orthogonal factors; Farm and Day were random effects. Cochran's C-test was used to test for heterogeneity of variance before the ANOVA with data then log(x+1) transformed (Underwood 1997).

Non-parametric methods have a clear use in these studies. Fernandez-Jover et al., (2008) used the PRIMER package to run non-parametric multivariate techniques to compare species composition of the assemblages from the different farms. This package had been used for similar analyses by Dempster et al., (2002, 2009). Carbines & Cole (2009) used Canonical analysis of principle coordinates to investigate links between fish and habitat with positive results.

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APPENDIX A: A Brief General Description of the Pelagic Habitat

"The marine pelagic ecosystem is the greatest in size among all ecosystems on the earth. It encompasses 99% of the total biosphere volume and is generally considered to have high resilience" (Würtz 2010).

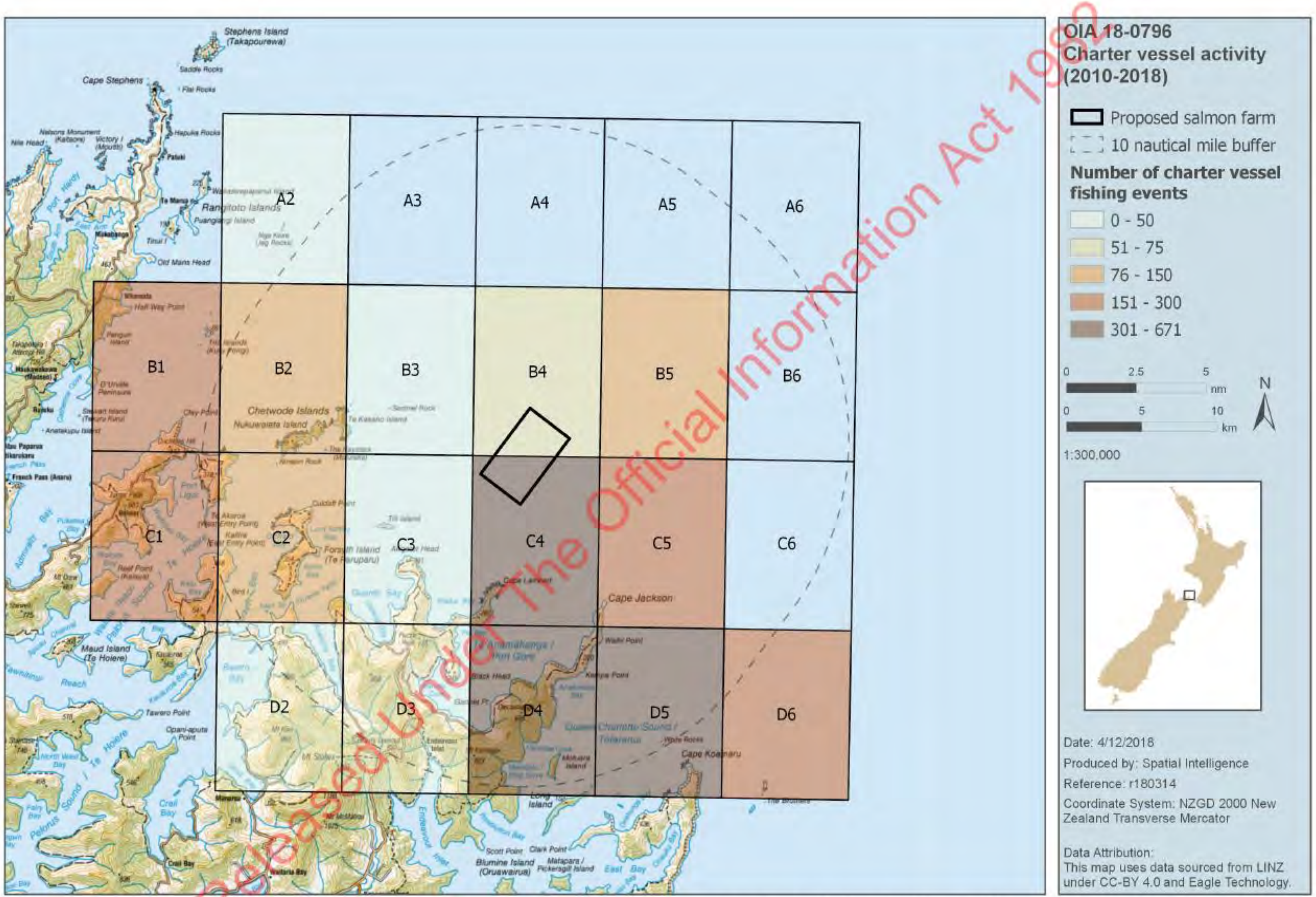
The term pelagic refers to those aquatic habitats within the water column that are off the bottom, and that range from just above the bottom, through midwater, to the surface. The pelagic habitat can be partitioned into several finer-scale habitats or zones, based largely on depth — for example, the epipelagic zone extends down from the surface to about 200 m. When the pelagic habitat is within the boundaries of the continental shelf it is referred to as neritic. The pelagic habitat can be characterised by particular features within the two broad categories of abiotic (non-living) and biotic (living).

The principal abiotic characteristics of a pelagic habitat include its physical characteristics such as temperature, light and turbidity, pressure (which is directly related to depth), current speeds, turbulence, and sound, and its water chemistry such as salinity, pH, dissolved oxygen concentration, and nutrient concentrations. The variables salinity and temperature define the density of a water body and its potential for stratification and stability (i.e., its resistance to vertical mixing) (Cloern 1991a, from Gibbs 1993). These features can strongly affect planktonic processes within the water body.

Members of the pelagic biota are classified as either planktonic (those organisms that are moved passively by the currents) or nektonic (those organisms that can swim strongly enough to propel themselves independently of the currents). Planktonic organisms may inhabit the plankton throughout their entire life cycle as holoplankton, or live only part of their life cycle in the plankton as meroplankton. Many invertebrate animals and fish have life histories that include planktonic eggs, larvae, and/or juveniles, followed by nektonic or benthic (bottom dwelling) stages as larger animals.

Compared with the full range of pelagic habitats, the neritic epipelagic habitat is relatively shallow and includes the water's surface (i.e., the air-water interface). It contains the photic zone, which is generally defined as that part of the water column extending from the surface to a depth where light intensity falls to 1% of the intensity at the surface, and is where most primary production (photosynthesis) occurs. The neuston defines that group of planktonic organisms that occur in the upper metre of the water column and include the meroplanktonic larval stages of a broad variety of fish and invertebrates.

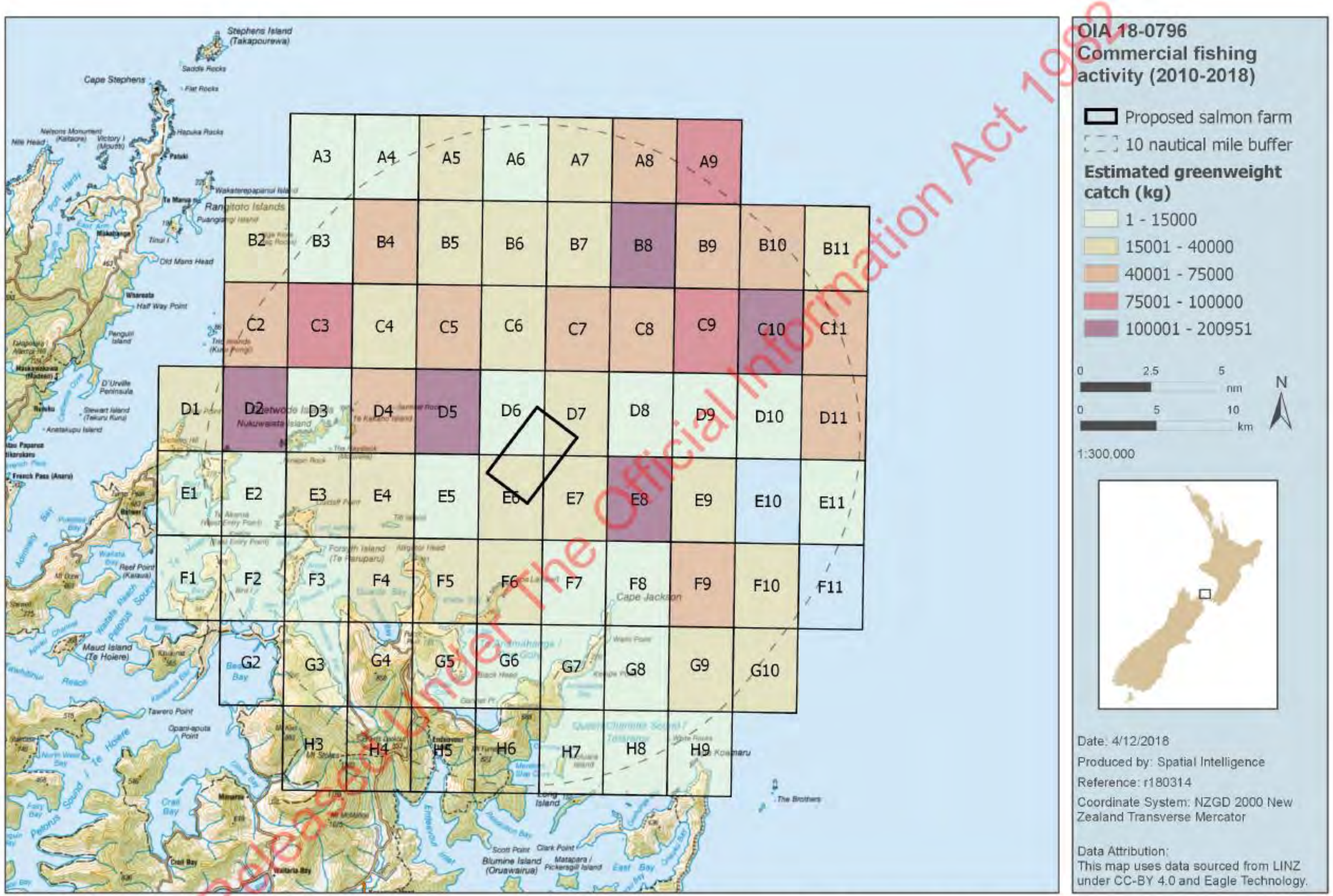
APPENDIX B: Charter vessel activity in an area centred on the proposed farm site



Fisheries New Zealand

Figure B1. Summary of charter vessel activity, 2010-2018, in an area centred on the proposed farm site. Source: Ministry of Primary Industries OIA 4/12/18

APPENDIX C: Commercial fishing activity in an area centred on the proposed farm site.



Disclaimer: This map and all information accompanying it (the "Map") is intended to be used as a guide only, in conjunction with other data sources and methods, and should only be used for the purpose for which it was developed. The information shown in this Map is based on a summary of data obtained from various sources. While all reasonable measures have been taken to ensure the accuracy of the Map, MPI: (a) gives no warranty or representation in relation to the accuracy, completeness, reliability or fitness for purpose of the Map; and (b) accepts no liability whatsoever in relation to any loss, damage or other costs relating to any person's use of the Map, including but not limited to any compilations, derivative works or modifications of the Map. Crown copyright ©. This map is subject to Crown copyright administered by Ministry for Primary Industries (MPI).

Figure C1. Summary of commercial fishing activity, 2010-2018 inc., in an area centred on the proposed farm site. Source: Ministry of Primary Industries OIA 4/12/18.

Table C1: Total greenweight (kg) of species catches during 2010-2018 inc., in an area centred on the proposed farm site. Source: Ministry of Primary Industries.

Common Name	Species Code	Greenweight (kg)
Barracouta	BAR	95,463
Blue cod	BCO	119
Butterfly perch	BPE	1
Banded wrasse	BPF	239
Short-tailed black ray	BRA	130
Northern bastard cod	BRC	2
Butterfish	BUT	22,380
Carpet shark	CAR	26,021
Capro dory	CDO	11,470
Conger eel	CON	354
Eagle ray	EGR	5,221
Elephant fish	ELE	7,089
Electric ray	ERA	80
Flatfish	FLA	16,269
Frostfish	FRO	5,065
Ghost shark	GSH	26,101
Marblefish	GTR	423
Gurnard	GUR	158,863
Hapuku	HAP	13,345
Hoki	HOK	3,542
Hapuku & Bass	HPB	86,096
John dory	JDO	111,299
Jack mackerel	JMA	153,023
Kahawai	KAH	25
Leatherjacket	LEA	26,759
Ling	LIN	2
Lemon sole	LSO	1,157
Blue moki	MOK	24,596
Porcupine fish	POP	1,075
Rattails	RAT	197,389
Red cod	RCO	215,121
Common roughy	RHY	1,000
Rough skate	RSK	68
School shark	SCH	272,724
Sand flounder	SFL	2,073
Gemfish	SKI	1,050
Snapper	SNA	68,928
Spiny dogfish	SPD	193,929
Sea perch	SPE	128
Rig	SPO	42,901
Spotted stargazer	SPZ	473
Giant stargazer	STA	4,660
Stingray (Unspecified)	STR	11

Table C1: continued		
Common Name	Species Code	Greenweight (kg)
Tarakihi	TAR	180,912
Trevally	TRE	3,987
Common warehou	WAR	75,034
Wrasses	WSE	304
All other species		221,415
Grand Total		2,278,316

APPENDIX D: Policy 11 of The New Zealand Coastal Policy Statement (NZCPS)

To protect indigenous biological diversity in the coastal environment

(a) avoid adverse effects of activities on:

(i) indigenous taxa that are listed as threatened or at risk in the New Zealand Threat Classification System lists;
(ii) taxa that are listed by the International Union for Conservation of Nature and Natural Resources as threatened;
(iii) indigenous ecosystems and vegetation types that are threatened in the coastal environment, or are naturally rare;
(iv) habitats of indigenous species where the species are at the limit of their natural range, or are naturally rare;
(v) areas containing nationally significant examples of indigenous community types; and
(vi) areas set aside for full or partial protection of indigenous biological diversity under other legislation; and

(b) avoid significant adverse effects and avoid, remedy or mitigate other adverse effects of activities on:

(i) areas of predominantly indigenous vegetation in the coastal environment;
(ii) habitats in the coastal environment that are important during the vulnerable life stages of indigenous species;
(iii) indigenous ecosystems and habitats that are only found in the coastal environment and are particularly vulnerable to modification, including estuaries, lagoons, coastal wetlands, dunelands, intertidal zones, rocky reef systems, eelgrass and saltmarsh;
(iv) habitats of indigenous species in the coastal environment that are important for recreational, commercial, traditional or cultural purposes;
(v) habitats, including areas and routes, important to migratory species; and
(vi) ecological corridors, and areas important for linking or maintaining biological values identified under this policy.

Naturally rare: Originally rare — rare before the arrival of humans in New Zealand.
Examples of taxa listed as threatened are: Maui’s dolphin, Hector’s dolphin, New Zealand fairy tern, Southern New Zealand dotterel.

APPENDIX E: Predicted rocky reef species in 10 areas of the Marlborough Sounds

Table E1: Species predicted as present in the Marlborough Sounds using boosted regression tree modelling of dive survey data, sorted by Family; see text for further explanation. Source: Smith et al (2013)

Family	Species	Common name	Admiralty Bay	Waitata to Tennyson	Pelorus Sound	Chetwodes to Alligator	Port Gore	Long Island	Outer QC*	Inner QC*	Tory Channel	Port Under-wood
Aplodactylidae	*Aplodactylus arctidens*	Marblefish				✓	✓	✓				✓
Carangidae	*Seriola lalandi*	Kingfish				✓		✓				
Cheilodactylidae	*Cheilodactylus spectabilis*	Red moki	✓			✓	✓	✓				✓
Cheilodactylidae	*Nemadactylus macropterus*	Tarakihi	✓			✓	✓	✓	✓	✓	✓	✓
Congridae	*Conger verreauxi*	Common conger eel	✓			✓	✓	✓	✓	✓	✓	✓
Kyphosidae	*Scorpis lineolatus*	Sweep						✓				
Labridae	*Notolabrus celidotus*	Spotty	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Labridae	*Notolabrus cinctus*	Girdled wrasse						✓				
Labridae	*Notolabrus fucicola*	Banded wrasse	✓	✓		✓	✓	✓	✓	✓	✓	✓
Labridae	*Pseudolabrus miles*	Scarlet wrasse	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Latridae	*Latridopsis ciliaris*	Blue moki				✓	✓	✓	✓	✓	✓	✓
Latridae	*Mendosoma lineatum*	Telescopefish						✓				
Monacanthidae	*Parika scaber*	Leatherjacket	✓	✓	✓	✓	✓		✓	✓	✓	✓
Moridae	*Lotella rhacina*	Rock cod	✓	✓	✓	✓	✓		✓	✓	✓	✓
Moridae	*Pseudophycis barbata*	Southern bastard cod	✓			✓	✓	✓				✓
Mugilidae	*Aldrichetta forsteri*	Yellow-eyed mullet	✓	✓	✓	✓	✓			✓	✓	✓
Mullidae	*Upeneichthys lineatus*	Goatfish	✓	✓	✓	✓		✓				
Odacidae	*Odax pullus*	Butterfish	✓	✓		✓	✓	✓	✓		✓	✓
Pinguipedidae	*Parapercis colias*	Blue cod	✓	✓	✓	✓	✓		✓	✓	✓	✓
Scorpaenidae	*Helicolenus percoides*	Sea perch			✓	✓	✓	✓	✓	✓	✓	
Scorpaenidae	*Scorpaena papillosus*	Dwarf scorpionfish	✓			✓	✓	✓			✓	✓
Serranidae	*Caesioperca lepidoptera*	Butterfly perch	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Serranidae	*Hypoplectrodes huntii*	Red-banded perch	✓			✓	✓	✓	✓	✓	✓	✓
Trachichthyidae	*Optivus elongatus*	Slender roughy	✓	✓		✓	✓	✓	✓		✓	

Table E1: *continued*

Trachichthyidae	*Paratrachichthys trailli*	Common roughy	✓			✓	✓	✓	✓		✓	✓
Tripterygiidae	*Forsterygion flavonigrum*	Yellow-black triplefin	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	*Forsterygion lapillum*	Common triplefin	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	*Forsterygion malcolmi*	Banded triplefin	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	*Forsterygion varium*	Variable triplefin	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	*Grahamina gymnota*	Robust triplefin		✓	✓					✓		
Tripterygiidae	*Karalepis stewarti*	Scaly-headed triplefin	✓			✓	✓	✓			✓	✓
Tripterygiidae	*Notoclinops caerulepunctus*	Blue dot triplefin	✓	✓		✓	✓	✓				
Tripterygiidae	*Notoclinops segmentatus*	Blue-eyed triplefin	✓	✓		✓	✓	✓	✓	✓	✓	✓
Tripterygiidae	*Notoclinops yaldwyni*	Yaldwyn’s triplefin	✓			✓	✓	✓	✓			
Tripterygiidae	*Obliquichthys maryannae*	Oblique-swimming triplefin	✓	✓		✓	✓	✓	✓		✓	✓
Tripterygiidae	*Ruanoho whero*	Spectacled triplefin	✓	✓		✓	✓	✓	✓	✓	✓	✓

*QC: Queen Charlotte Sound.

APPENDIX F: Proposed Farm Site in north western Cook Strait

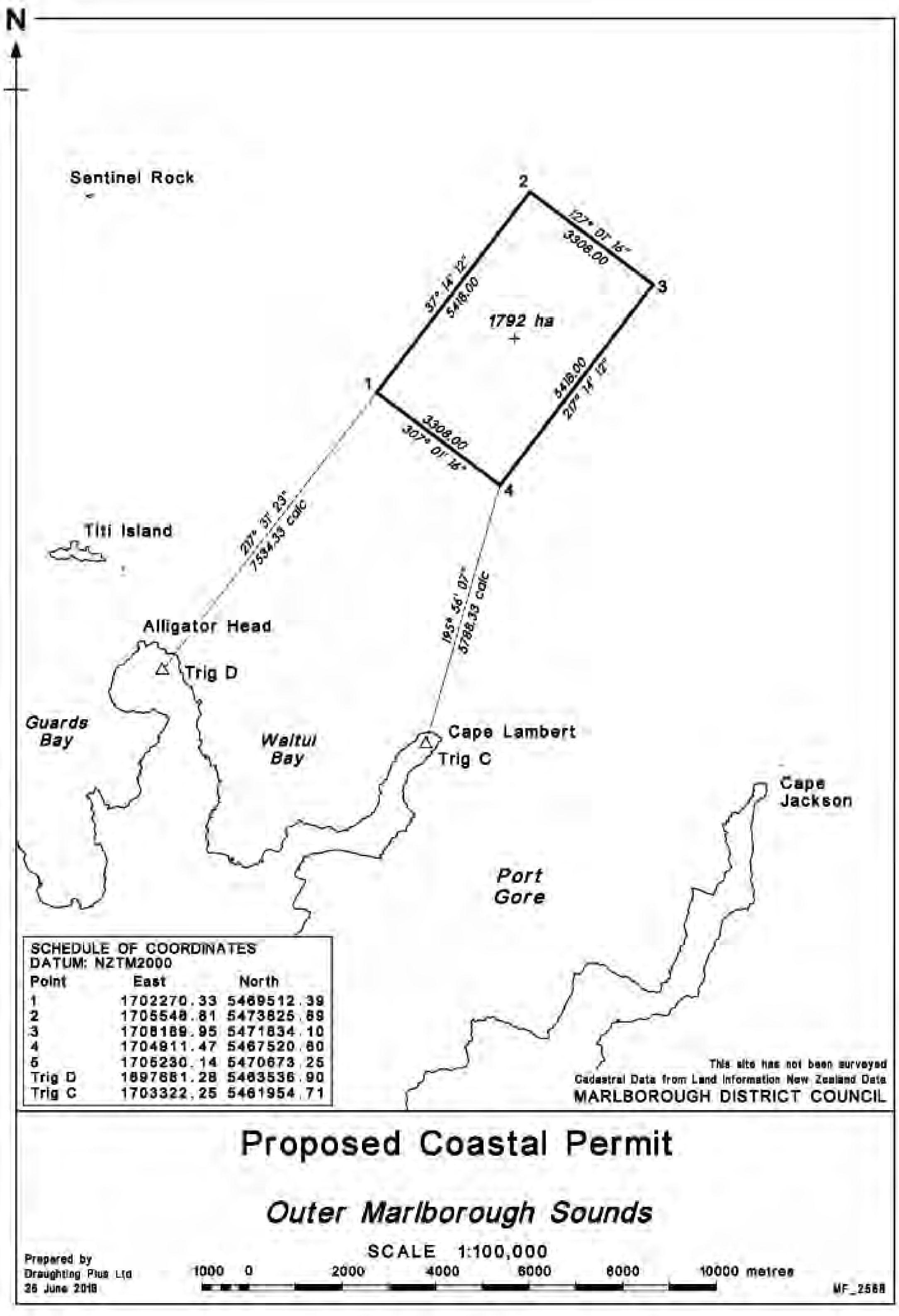


Figure F1. Position and spatial details of the farm site proposed by NZ King Salmon in north western Cook Strait.

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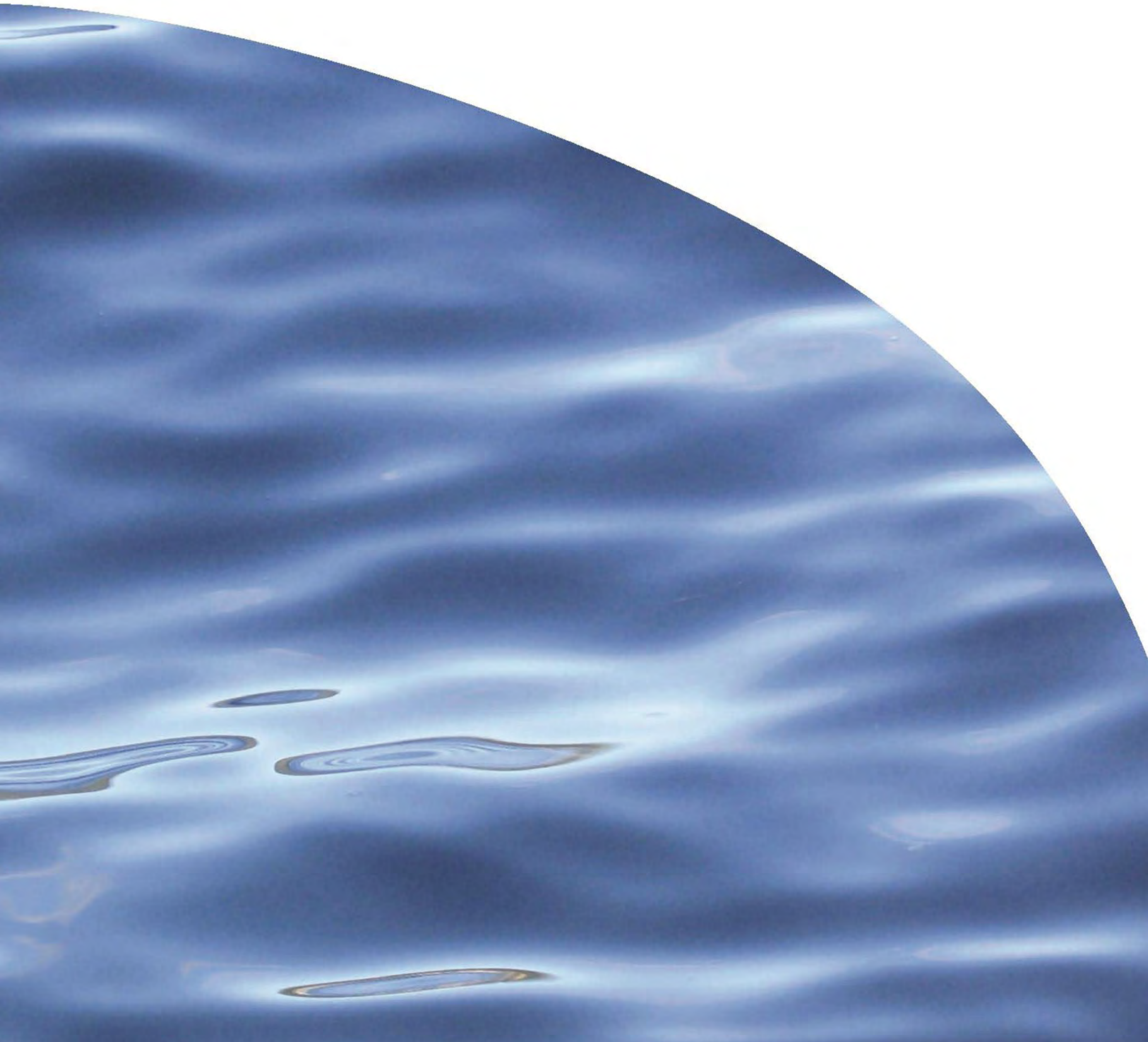
APPENDIX K: Biosecurity Report

REPORT NO. 3222

NEW ZEALAND KING SALMON COMPANY LIMITED: OPEN OCEAN FARM ASSESSMENT OF ENVIRONMENTAL EFFECTS - BIOSECURITY



NEW ZEALAND KING SALMON COMPANY LIMITED: OPEN OCEAN FARM ASSESSMENT OF ENVIRONMENTAL EFFECTS - BIOSECURITY

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EXECUTIVE SUMMARY

The New Zealand King Salmon Company (NZ King Salmon) proposes the development of an ~1,800 ha open ocean farm site on the northern edge of the Marlborough Sounds. The operational details of the farm (e.g. number and type of pen structures) are not confirmed at this point, however it is likely to represent a considerable increase in the scale of finfish farming operations for the region. As part of the assessment of environmental effects (AEE) for this proposal, Cawthron Institute was asked to undertake an assessment of biosecurity-related risks to the marine environment associated with the proposed development, including the potential for marine pest species to be introduced to, and/or spread within, the wider Marlborough region. Recommendations for practical mitigation of pathway risk and on-farm management are also discussed.

Biosecurity risks associated with the proposed development

As the proposed NZ King Salmon open ocean farm development is the first of its kind in New Zealand, at this stage the specific operational details are being developed. However, the associated additional vessel, gear and stock movements, plus the provision of novel habitat, are expected to present a minor incremental biosecurity risk to the region. Considering the amount of vessel traffic that already occurs in the area and the management practices already in place for existing company vessels, biosecurity risk associated with vessel movements is expected to be minor. An exception arises in the case of specialised service vessels (e.g. anchor installation, freight barges) from outside the region or overseas, whereby the biosecurity risk could be considered comparatively high depending on the region of origin. The risk from these vessels can be expected to be effectively managed through adhering to national regulations regarding hull biofouling and ballast water discharges. As the farm is expected to be developed using all new materials, there is no risk of marine pest introduction at the construction stage through use of previously-used materials. Movement of equipment/gear during the operational phase is likely to be regionally-restricted and relatively infrequent and is not expected to give rise to biosecurity risk that is considerably greater than existing sources. Similarly, the current methods for transport of fish, harvesting, and management of mortalities under containment will minimise any biosecurity risk associated with stock movements.

It has been suggested that nutrient enrichment from finfish farms could lead to algal pests being more widespread and abundant. However, there appears to be no evidence for such effects at existing salmon farms in the region, so this is not expected to be relevant. Physical disturbance and alteration of the seabed can lead to increased abundances of non-indigenous soft-sediment species. However, given the level of historic disturbance within the region (e.g. enrichment from other activities, commercial fishing), the benthic habitat affected in this way will be relatively minor by comparison. In addition, it is expected that the dispersive nature of the proposed farm site will minimise this risk to some degree.

Submerged infrastructure will provide novel artificial habitat in the area which may be colonised by pest species, thereby acting as a population reservoir. However, from a regional

perspective, there are already substantial amounts of artificial habitat along most areas of coastline which provide a sizeable surface area on which populations of marine biofouling species can and do establish. A potential advantage of open ocean aquaculture is that sites may be less vulnerable to colonisation by short-dispersing species (e.g. ascidians, bryozoans), as these taxa are unable to incrementally disperse across the kilometres of soft-sediment benthic habitat that typically isolate open ocean sites from coastal source populations. The risk associated with any species that do establish is also likely to be mitigated to some degree by an operational need to maintain a low level of fouling on nets and farm structures.

Existing regional biosecurity risks

When considering the risks associated with the proposed development, it is important to place risks in the context of those that already exist. Biosecurity risks can arise from sources unrelated to salmon farming, including through natural dispersal from pest populations already established in the region, introduction via other marine farming activities or via non-industry vectors (e.g. vessel movements, coastal developments). In addition to existing salmon farming operations, there are estimated to be c. 600 other marine farms in the region. These farms are highly connected at local and regional scales by vector activities and also provide large areas of habitat for populations of biofouling species. The proposed open ocean farm site is also near significant shipping routes, which exposes the site to colonisation through pathways that are unrelated to aquaculture activities. Legislative regulations regarding hull fouling and ballast water discharges are expected to minimise the risk posed by international vessels transiting near the site. However, there is currently no established, coordinated system in New Zealand to manage biosecurity risks posed by domestic vessel traffic.

Recommended mitigation measures

Despite the biosecurity risk being relatively minor and incremental, effective management of human-mediated pathways of spread is critical as these linkages have the potential to undermine the biosecurity protection afforded by the geographical isolation of the site. If the farm is consented, a range of best management practices regarding the set up and operation of marine farms can be applied to reduce biosecurity risks. In summary, key mitigation measures that should be adhered to include:

- any vessels arriving from other regions should aim to comply with the national-level hull biofouling and ballast water legislation, and ideally operate under a biosecurity management plan (BMP) specific to the vessel
- vessels associated with day-to-day operations of the farm should be properly maintained to prevent the growth of biofouling or the accumulation of sediment or debris
- all previously-used equipment or gear should be thoroughly cleaned, and appropriate treatments applied if necessary (e.g. disinfection), before moving between farm sites
- standard operating procedures that incorporate industry best-practice should be developed and adhered to for transporting stock

- farm personnel should be familiar with, remain vigilant for, and report pest organisms or those that exhibit unusual patterns of population growth
- farm infrastructure (e.g. pontoons, nets) should be maintained appropriately to prevent the establishment of large populations of pest species
- accurate records of all vessel, equipment, gear and stock movements to, from and within the open ocean farm site should be maintained.

These measures are largely straightforward and should not unduly interfere with the normal operation of the farm. In addition to the measures outlined above, NZ King Salmon personnel should maintain awareness of any new biosecurity guidance or requirements issued by the Ministry for Primary Industries (MPI) or Aquaculture New Zealand (AQNZ). It is recommended that a BMP tailored to the site be developed by a suitably qualified person to address both marine pest and disease risk. Appropriate requirements regarding review and auditing of this document will aid in its effectiveness. If the proposed mitigation measures are implemented appropriately, the residual biosecurity risk is expected to be negligible.

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1. BACKGROUND AND SCOPE

1.1. Proposed open ocean salmon farm

The New Zealand King Salmon Company Ltd (NZ King Salmon) proposes the development of an open ocean farm site on the northern edge of the Marlborough Sounds, due north of Cape Lambert and roughly east of the Chetwode Islands (Figure 1). The proposal is for an ~1,800 ha area to farm king salmon (*Oncorhynchus tshawytscha*). The operational details of the farm (e.g. number and type of pen structures) are not confirmed at this point. Options include, but are not limited to, flexible circular pens serviced by barge systems as well as enclosed pens that can be submerged to afford protection from unfavourable oceanic conditions. Pens are likely to be individually moored using a series of screw anchors. Water depth at the site is generally between 60 to 100 m. At full development, the proposed open ocean site represents a considerable increase in the scale of finfish farming operations for the Marlborough region.

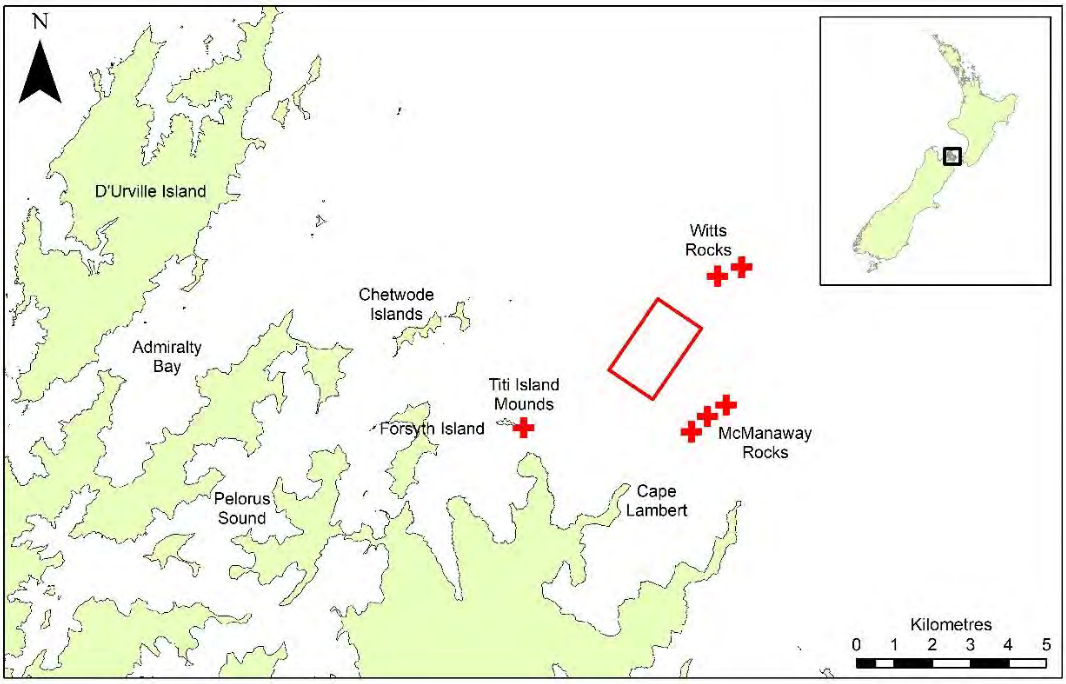

Figure 1. Proposed location of the open ocean farm development (~1,800 ha; red box). Areas recognised as ecologically significant marine sites (red crosses; from Davidson et al. 2011) are also indicated.

1.2. Report scope and structure

This report provides an overview of marine biosecurity issues relevant to finfish aquaculture in New Zealand, with specific consideration of biosecurity risks associated with the proposed open ocean farm site.

The report is structured into five main sections:

- overview of biosecurity risks associated with finfish aquaculture in New Zealand
- identification of existing biosecurity risks within the Marlborough region
- identification of biosecurity risks associated with the proposed open ocean salmon farm development, including both the construction and operational phases
- recommendations for mitigating risks associated with the proposed open ocean salmon farm development based on accepted best-practice
- assessment of residual risk if mitigation options are appropriately applied.

The focus of the report is on risks from macroscopic species (i.e. generally those that are conspicuous or at least visible to the naked eye). Several other groups of organisms associated with aquaculture can also be problematic in certain situations, including pathogens and parasites and biotoxin-producing microalgae associated with harmful algal blooms (HAB). These additional groups and their associated risks are discussed in other reports commissioned by NZ King Salmon.

2. BIOSECURITY RISKS AND FINFISH AQUACULTURE

2.1. Overview of marine biosecurity

Biosecurity is the protection of key values, including environmental, economic, human health and social/cultural values, from risks posed by introduced (i.e. non-indigenous) species. At least 330 non-indigenous species (NIS) have been introduced to New Zealand's marine environment (MPI 2015), most into areas of high boating activity such as commercial shipping ports and marinas (Hayden et al. 2009). Approximately half of these species are now recognised as *established* in New Zealand, meaning they have developed a viable self-sustaining population or populations. Marine NIS can undergo subsequent domestic spread by natural dispersal or via anthropogenic transport pathways[1] such as vessel movements and stock or equipment transfers (Sinner et al. 2013).

Some species can proliferate in their new environments and may cause, or be perceived to cause, adverse effects. In New Zealand, marine NIS species have negatively impacted fisheries, aquaculture industries, and the environment more generally, as well as presenting a nuisance to a wide range of recreational or customary users and marine industries. Often described as marine 'pests', it is these species that typically gain public attention (Falk-Petersen et al. 2006). This is especially the case for conspicuous organisms that affect areas of high conservation value or economically important sectors.

Effective management of marine pests after they have established in a location is often challenging and expensive. Generally, any management programmes initiated to deal with such incursions need to have a high likelihood of success due to competing funding priorities (Forrest & Hopkins 2013). Due to these difficulties, a key priority for effective marine biosecurity is to prevent the initial introduction and spread of these organisms. Managing human-mediated vectors[2] is recognised as the most effective strategy (Sinner et al. 2013). A thorough understanding of all transport pathways and mechanisms of spread is therefore critical, as unmanaged vectors have the potential to compromise the overall effectiveness of other biosecurity initiatives.

[1] There are a number of human activities in the marine space that may, intentionally or unintentionally, move marine pests from one place to another. These activities are generally called 'pathways', and include a range of industries operating within the marine environment (e.g. commercial shipping, aquaculture, etc.).

[2] Associated with pathways are the physical means by which the organism is transported, referred to as 'vectors'. Vectors include vessels and moveable structures (e.g. finfish farm pen structures, oil rigs) or equipment (e.g. fishing gear) that move among different geographic locations (both within and outside a region), which could exacerbate the spread of marine pests.

2.2. Regional and national biosecurity threats and management

2.2.1. Potentially high-risk marine pests

The present focus for central and local government in New Zealand is on marine NIS that have been identified as high-risk, and subsequently classified as 'unwanted organisms' under the Biosecurity Act 1993 and other legislation. At the time of writing, eight marine pest species are specified (Table 1). Each species has a prior history of invasion outside New Zealand, is known to have significant impacts on native ecosystems or economic values in the regions it has invaded, and is capable of surviving in New Zealand coastal waters (Wotton & Hewitt 2004). Three of these species are now established in New Zealand (the Asian kelp *Undaria pinnatifida*, the clubbed tunicate *Styela clava* and the Mediterranean fanworm *Sabella spallanzanii*), with all three recorded within the top of the South Island (includes coastal regions within the Tasman, Nelson and Marlborough jurisdictions). *Undaria* is now widespread throughout the region, and therefore no pest management strategy is in place. However, populations of *Styela* and *Sabella* remain regionally isolated. Within the Marlborough region, *Styela* is established within the marinas at both Waikawa and Picton, as well as isolated populations within the Pelorus Sound where it has been observed to be growing on mussel infrastructure and natural habitats. *Sabella* has been found and subsequently removed from boats outside Waikawa marina; however, it has not been observed within the marina itself. There have been isolated *Sabella* incursions within Picton marina over the past 2-3 years and population suppression (a joint initiative between MDC, Tasman District Council and Nelson City Council) is ongoing in this location.

There are several other high-profile marine pest species currently present in New Zealand that have, for various reasons, not been formally designated unwanted organisms. Species of particular concern include the Asian paddle crab (*Charybdis japonica*), droplet tunicate (*Eudistoma elongatum*), Asian date mussel (*Arcuatula senhousia*), Australian 'cunjevoi' tunicate (*Pyura doppelgangera*), vase tunicate (*Ciona robusta* (*intestinalis*)), and carpet tunicate (*Didemnum vexillum*). Of these, only the latter two species are currently present within the top of the South Island.

Table 1. Non-indigenous species designated 'unwanted organisms' under the Biosecurity Act 1993. Their recorded distribution in New Zealand is given and locations in or near the top of the South Island region are in bold. Modified from Piola and Forrest (2009).

Scientific and common name	New Zealand distribution	Example
Asterias amurensis Northern Pacific sea star	Not recorded	
Carcinus maenas European shore crab	Not recorded	
Caulerpa taxifolia Green aquarium weed	Not recorded	
Eriocheir sinensis Chinese mitten crab	Not recorded	
Potamocorbula amurensis Asian clam	Not recorded	
Sabella spallanzanii Mediterranean fanworm	Northland, Hauraki Gulf and Firth of Thames, Tauranga, Wellington, **Picton**, **Nelson**, **Golden Bay**, Lyttelton	
Styela clava Clubbed tunicate	Northland, Hauraki Gulf and Firth of Thames, Tauranga, Wellington, **Picton**, **Nelson**, **Golden Bay**, Lyttelton, Dunedin	
Undaria pinnatifida Asian kelp	Widespread in harbours between Stewart Island and Auckland, including in the **Marlborough region**	

2.2.2. Biosecurity management in New Zealand

In New Zealand, biosecurity management is administrated by the Ministry for Primary Industries (MPI) who implement the Biosecurity Act 1993. MPI are primarily concerned with the prevention of pest establishment in New Zealand and managing risk to any national or regional value associated with inter-regional vector movement. This includes border and pre-border management of risk vectors, surveillance at high risk points of entry (shipping ports) to facilitate early detection of high-risk NIS, response to new NIS incursions, national management of domestic vectors to limit spread, control programmes for priority pests, and related communications, for example to educate and raise awareness (see Sinner et al. 2012).

The 2010 New Zealand Coastal Policy Statement (NZCPS) also provides guidance on biological risk management with a marine focus. Under Policy 12 of the NZCPS, regional councils are required to manage risks to marine biosecurity from harmful aquatic organisms. In the Marlborough region this is achieved through a Regional Pest Management Plan (RPMP), produced by Marlborough District Council (MDC), which provides the framework to manage specified organisms in the Marlborough region. At the time of writing the only marine species identified as a pest under the RPMP is the Mediterranean fanworm *Sabella spallanzanii*. In addition, MDC is involved in the Top of the South Marine Biosecurity Partnership (TOSMBP), which co-ordinates efforts to prevent and manage marine pest invasions across the three regional jurisdictions. The Partnership also includes Tasman District Council, Nelson City Council, MPI, Department of Conservation, the aquaculture industry, port companies, local tangata whenua and other stakeholders. Amendments to the Biosecurity Act in 2012 allowed for the creation of regional pathway management plans to reduce the spread of pests and diseases that are already present in New Zealand, but not yet widespread. Several regional council authorities around New Zealand (e.g. Environment Southland, Northland Regional Council) have now developed or are developing plans that include practical measures to reduce the risks of transport of marine pests.

2.3. Transport vectors with reference to finfish aquaculture

Aquaculture operations present vector risks that can lead to marine pests being translocated within or between growing regions. Vessels, equipment/gear and stock can all harbour pests that ‘hitch-hike’ when transfers are made between farms, or between farms and other areas (e.g. ports and marinas). Controlling these vector risks, which are discussed in detail below, is a critical step in effective biosecurity management (Hewitt & Campbell 2007; Campbell 2009).

2.3.1. Movements of vessels or structures

Vessel or structure movements are generally considered the most important anthropogenic pathway for NIS spread (Ruiz et al. 1997; Molnar et al. 2008; Seebens et al. 2013). Vessels can transport marine organisms in ballast water, within entrained water or debris, or as part of biofouling[3] communities on the hull (including sea chests[4] and other internal seawater systems). Ballast water is not directly relevant to salmon aquaculture in New Zealand given the comparatively small size of the vessels in this industry (i.e. the vessels are too small to require ballasting). These vessels do however often take on seawater and debris as part of normal operations, which then accumulates on or in the deck or bilge spaces. Depending on the source, this water may contain potentially harmful pest species as adults or as their dispersive life-stages. Examples include:

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

If this water is subsequently discharged at another location, any associated pests may be transferred. A recent survey of 30 small vessels operating within the top of the South Island region identified 118 distinct taxa within the bilge water on board (Fletcher et al. 2017). Bilge water is not commonly treated prior to discharge to sea, so it is conceivable that these organisms and propagules may be viable at the time of discharge. In one study, larvae and fragments of three common biofouling species were able to pass through a bilge pump system relatively unharmed (Fletcher et al. 2017).

The dispersal of NIS as part of hull biofouling assemblages is reasonably well-understood, and recognised as a major biosecurity threat (Coutts & Taylor 2004; Hewitt et al. 2009; Hopkins & Forrest 2010b). Many of the better-known pest species are biofouling organisms, plus biofouling can provide habitat for mobile pest species such as crabs (e.g. Davidson et al. 2008). As well as industry vessels, risks can arise from non-industry vessels performing specific tasks on farms (e.g. installation of farm anchors) or passing near farms. The risk of pest spread increases for vessels that travel at speeds slow enough (< 10 knots; e.g. barges, towed structures) to enable the survival of associated fouling organisms (Coutts et al. 2010; Hopkins & Forrest 2010a).

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[3] Biofouling refers to the gradual accumulation of organisms and biogenic structures on artificial surfaces submerged in marine or freshwater environments. These assemblages can vary greatly in complexity and composition but may typically include microbial organisms, sessile algae and invertebrates (e.g. mussels, bryozoans, sponges, etc.).

[4] Sea chests are water intake chambers that are recessed into the side of the hull of large vessels.

2.3.2. Movements of equipment or gear

A wide variety of equipment or gear is used in association with the marine environment, for example, dive gear, fishing gear, ropes and chains, anchors and other ground tackle and marine farming lines (Sinner et al. 2013). Movement of these items can transport marine pests within associated water or sediments. As with vessel hulls, biofouling organisms can accumulate on any gear or equipment that has spent an extended period in the water. In addition, with some types of equipment (e.g. anchors, fishing nets, scallop dredges, etc.) it is common for marine organisms to become entangled during routine operations. These organisms can then be transported to new areas or regions along with the gear or equipment being moved.

Biofouling assemblages develop relatively quickly on marine farm infrastructure (e.g. Woods et al. 2012), and if this biomass is not removed or rendered inert before movement of farm equipment or gear to another location the associated biosecurity risk is high (Hewitt et al. 2004). A relevant local example of this occurring is the regional spread of the colonial ascidian *Didemnum vexillum*. The spread of *D. vexillum* from the initial incursion within Shakespeare Bay (near Picton) was precipitated by the transfer of forestry and marine farming equipment, including a salmon farm pen structure. Subsequent spread was greatly exacerbated by multiple transfers of infected mussel seed-stock and equipment (Forrest & Hopkins 2013), highlighting a key role of human activities in the domestic spread of this species.

2.3.3. Movements of livestock

The transfer of finfish stock (e.g. smolt, harvested fish, mortalities) between areas or regions can lead to the transfer of associated marine pests as well as pathogens and parasites (Sinner et al. 2013). The potential for stock-related transport of marine pests with regards to finfish aquaculture largely occurs from the water in which the fish are transferred (Forrest et al. 2011). As with vessel bilge water risks described above, the water in which fish are transferred may contain both juvenile (e.g. larvae, algal spores) and adult life stages (including fragments capable of asexual reproduction) of a range of organisms. There are additional risks with regards to the transport of pathogens and parasites, however these are outside the scope of the current report.

2.4. Farm-scale biosecurity risks

In addition to aiding the dispersal of pests and diseases, aquaculture operations physically impact the environment within the farm area. In the case of finfish aquaculture, farm infrastructure (e.g. pontoons, accommodation/feed barges, pen and predator nets) provide extensive areas of new habitat that can be colonised by marine pest species (see Fitridge et al. 2012). Once a pest species has established within a farm site it has the potential to spread more widely, with the farm acting as a reservoir for reproductive life stages (Bloecher et al. 2015). Nearby habitats are most at risk, including other artificial structures (e.g. mussel farms, jetties, moorings) and a range of natural habitats, such as rocky reef or cobble, and soft sediments that have biogenic (e.g. shell, hydroid trees, finger sponges, seaweed beds) structure available for colonisation. The spatial scale at which these habitats are affected depends on factors such as hydrodynamics, the competency period of propagules in the water column, and the abundance of such propagules (see Forrest 2011).

Aquaculture activities can also impact the immediate environment outside of the farm itself. Day-to-day farm operations can create environmental conditions that facilitate or exacerbate pest establishment. For example, altered nutrient cycling or water movement patterns can lead to more widespread and abundant populations of non-indigenous macroalgae species (see Kelly 2008). Similarly, deposition of fish faeces and uneaten feed may cause changes to the seabed beneath farms. Waste deposition can lead to organic enrichment of sediments, which can decrease oxygen levels and may lead to changes to the biodiversity of the area (Forrest et al. 2007). These alterations to the seabed may favour the establishment of invasive benthic species (e.g. Forrest & Creese 2006; Keeley et al. 2012). Impacts to natural environments from farm activities can occur at a variety of spatial scales and are again driven largely by hydrodynamics of the associated area.

3. EXISTING REGIONAL BIOSECURITY RISKS

When considering the risks associated with a specific activity, it is important to place these risks in the context of those that already exist. Biosecurity management in the marine environment is challenging; as such, the most realistic outcome is generally risk reduction to acceptable levels rather than total prevention (Forrest et al. 2009). Biosecurity hazards can initially arise from sources unrelated to salmon farming, including introduction via non-industry vessels as well as long-distance dispersal from established populations. It is disproportionate to impose particularly strict restrictions on a given farming operation if other activities exist in the area that undermine specific management efforts. Therefore, the biosecurity risks already apparent for the wider Marlborough region are discussed below.

3.1. Existing populations of non-indigenous species

A baseline biological survey of the Port of Picton undertaken in January 2005 recorded a total of 249 species or higher taxa, including 167 native species, 11 NIS, 36 cryptogenic species[5] and 35 organisms that could not be identified to species level (Inglis et al. 2008). The 11 NIS comprised one annelid worm (*Spirobranchus polytrema*), five species of bryozoan (*Bugula flabellata*, *B. neritina*, *Tricellaria inopinata*, *Cryptosula pallasiana* and *Watersipora subtorquata*), one hydroid (*Eudendrium generale*), one mollusc (*Theora lubrica*), two seaweeds (*Griffithsia crassiuscula* and *Undaria pinnatifida*) and one sponge (*Halisarca dujardini*). In addition, two non-indigenous annelid worms had been described in an earlier baseline survey of the same sampling locations (*Dipolydora armata* and *Polydora hoplura*, Inglis et al. 2006). Most of the NIS recorded are likely to have been introduced to New Zealand accidentally by international shipping or spread from other regions through domestic transport vectors.

The 36 cryptogenic species included 11 Category 1 and 25 Category 2 species[6]. These included 8 annelid worms, 1 bryozoan, 1 crustacean, 2 molluscs, 20 sponges and 4 ascidian species (Inglis et al. 2008). Three additional cryptogenic species had been described in the earlier baseline survey, including another bryozoan, a hydroid and an amphipod species (Inglis et al. 2006). Several of the Category 1 cryptogenic species (e.g. the ascidians *Asterocarpa cerea*, *Botrylloides leachii* and *Corella eumyota*) have been present in New Zealand for more than 100 years but have distributions outside New Zealand that suggest non-native origins (Cranfield et al. 1998).

[5] Organisms whose geographic origins (i.e. whether they are native or non-indigenous) are uncertain.

[6] Category 1 cryptogenic species includes species that may have been introduced to New Zealand before scientific records began and newly-described species exhibiting invasive behaviour in New Zealand but for which there are no known records outside the New Zealand region. Category 2 cryptogenic species are those newly-discovered species for which there is insufficient information to determine whether New Zealand lies within their native distribution.

A comprehensive review of marine NIS in the top of the South Island as at May 2008 described an additional 21 species known to be present in the region (Morrisey & Miller 2008). These include species that can reach high abundances and hence have the potential to cause adverse effects. Since late 2005, Picton Harbour (including sites within the Port of Picton, Shakespeare Bay, Picton marina and Waikawa marina) and Havelock marina have been included in the MPI-funded national Marine High Risk Site Surveillance (MHRSS) programme. This programme includes six-monthly surveys for a selected suite of target NIS at high-risk sites around the country, implemented since 2002. Since the more intensive baseline surveys were completed, two secondary target species[7] have been documented through MHRSS surveys within Picton Harbour (*Sabella spallanzanii* and *Styela clava*). In addition, three non-target NIS have been recorded (the ascidians *Ciona savignyi* and *Clavelina lepadiformis*, and the hydroid *Ectopleura* spp.). Several of the species described in the above surveys are considered fouling organisms and could conceivably colonise salmon aquaculture structures. In particular, hydroids are recognised as one of the dominant taxa of nuisance biofouling species in global fish aquaculture (see Floerl et al. 2016).

Changes in the distribution of NIS currently present in Picton Harbour and Havelock marina, as well as the arrival of new species, can be detected through the MHRSS programme. In contrast, incursions of NIS outside these high-risk sites are only likely to be detected opportunistically. Many of the NIS detected during these surveys have the capacity to spread naturally to surrounding areas (e.g. by larval dispersal in water currents), including within the wider Marlborough Sounds region, and some may have done so but have not yet been detected.

3.2. Existing aquaculture activities in the Marlborough region

The current marine farming activities within the wider Marlborough region present several potential sources of biosecurity risk. As at March 2019, there are 1058 active resource consents for marine farming in the Marlborough region (includes farm extensions, estimated to be c. 600 farms; Figure 2). Species cultivated include salmon, green-lipped mussels, Pacific oysters, pāua and seaweed. Marine farming in Marlborough produces approximately 80% of all commercially grown seafood in New Zealand. On average 65,000 tonnes of mussels and about 6,000 tonnes of salmon are harvested each year in Marlborough, together earning more than $NZD300 million in exports (MDC 2019). In terms of regional biosecurity risk, other marine farms within the region, and their associated activities, have a functional role that is qualitatively similar to the NZ King Salmon proposal. However, until the exact size and design of the proposed salmon farming operation is known it is not possible to make statements about the comparative magnitude of biosecurity risk.

[7] Includes non-indigenous or cryptogenic organisms which are known to be established in New Zealand coastal waters to enable detection of range extensions.

NZ King Salmon is the only large-scale finfish company operating in the Marlborough region[8]. The company has 11 farm sites in the region (see Figure 2), representing ~17 ha of surface structures and ~140 ha of total water space. Nine of these sites are presently stocked with fish and two sites are vacant. Active farms are in the outer Pelorus Sound as well as within Tory Channel, Ruakaka Bay, and Otanerau Bay in the wider Queen Charlotte Sound area. NZ King Salmon obtain smolt from land-based hatcheries at Tentburn, Waiau (Canterbury) and Takaka (Tasman). The fact that NZ King Salmon are the only large-scale finfish farming company in the region presents benefits from a biosecurity perspective. Only one company operating with overarching biosecurity policies enables more effective mitigation of biosecurity risks, especially with regards to operating biosecure units through area-based management principles.

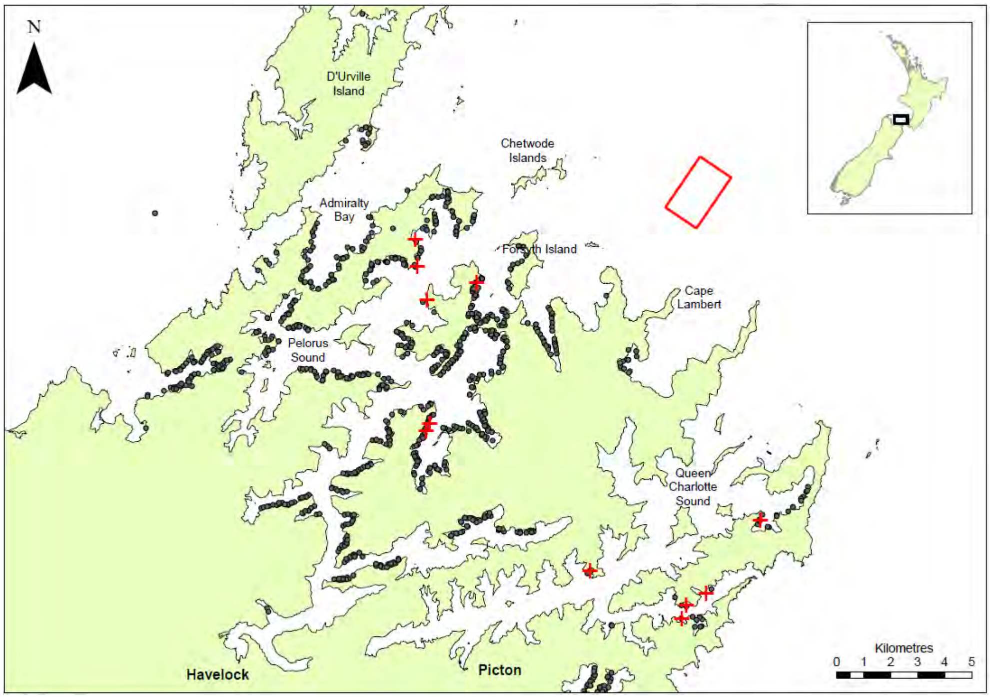

Figure 2. Location of the NZ King Salmon consented farm sites (red crosses), and active resource consents for other marine farms (black dots) within the Marlborough Sounds region. The location of the proposed open ocean farm site is indicated (red box). Based on Marlborough District Council data current to March 2019.

In addition to the nine active salmon farms, there are c. 600 other marine farms in the Marlborough region (mainly mussel farms), all of which have associated vessel, equipment and stock movements. Most aquaculture service vessels tend to operate within a single farming region (Forrest & Blakemore 2002). However, inter-regional movements can occur, particularly for harvesting purposes. Gust et al. (2008) described two mussel harvesting vessels that frequented the Port of Lyttelton, but

[8] Ngāi Tahu Seafood Resources Ltd have a consent for an experimental finfish site in Beatrix Bay, within the Pelorus Sound region. It has previously been used to trial farming snapper and kingfish.

which also serviced farms in the Marlborough Sounds. Similarly, Sanford Ltd has a number of aquaculture vessels that work in different areas within the top of the South Island region, as well as other regions. Transfer of marine farm equipment and gear (e.g. mussel ropes or floats) between farms, and between growing regions, is not particularly common but it does occur. If previously-used equipment or gear is not thoroughly cleaned and treated appropriately (e.g. disinfection), there is the potential to translocate any associated biofouling pests.

Juvenile mussel stock is frequently transferred among farms and regions, as well as from hatcheries, with associated biosecurity risk. The Marlborough mussel industry mostly uses 'Kaitaia' spat which is harvested attached to beach-cast seaweed along Northland's Ninety Mile Beach. Along with spat sourced from Kaitaia, the Marlborough mussel industry also utilises some locally caught spat (from selected bays in Marlborough and Golden Bay) as well as spat bred in the commercial hatchery based at the Cawthron Aquaculture Park in Nelson (SPATnz). In addition to spat transfers, movement of larger (~30 to 50 mm) 'seed' mussels, also occurs. From a biosecurity perspective, transfers of mussel spat and seed between collection and on-growing areas are reasonably significant. The biosecurity risk from transfers of seed mussels between the three geographic mussel farming zones[9] is managed through a voluntary code of practice.

3.3. Activities unrelated to aquaculture (commercial and recreational)

The proposed open ocean farm site could become infected via pathways that are unrelated to aquaculture activities. These pathways include movements of local, regional and international vessels and the spread of risk species from existing local sources, including both natural and artificial habitats.

3.3.1. Vessel movements

A wide range of vessels move into and within the Marlborough region, for both recreational and commercial purposes, with the proposed open ocean farm development in close proximity to domestic and international shipping routes (see Figure 3). Vessels entering New Zealand waters from overseas are required by national and international regulations to manage the risk of introducing NIS via hull fouling (through MPI's Craft Risk Management Standard for Vessel Biofouling; CRMS) and ballast water (under the International Convention for the Control and Management of Ships' Ballast Water and Sediments; BWM Convention). The combined requirements are expected to minimise the risk of introductions of NIS from international vessels passing near to the proposed open ocean farm site.

[9] The three zones are: northern New Zealand (north of Mahia Peninsula including the Firth of Thames and Coromandel); southern New Zealand (south of Kaikoura); and a central zone between these two (which includes the Marlborough Sounds and Golden/Tasman bays).

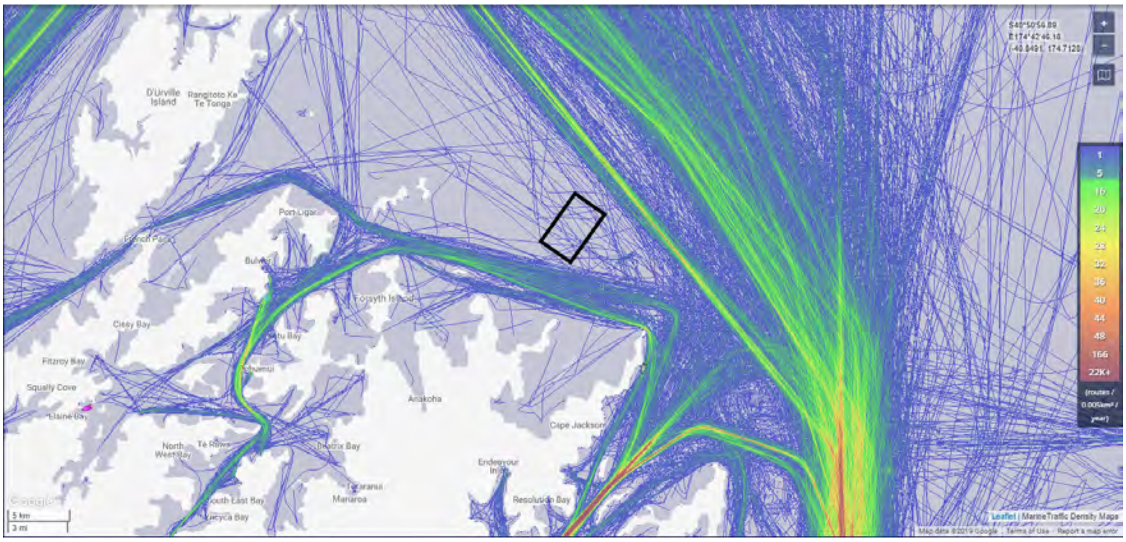

Figure 3. Vessel movements during 2017 in the vicinity of the proposed open ocean farm development (approximate location indicated by black box). Lines indicate density of movements (routes/0.005 km^2/year), with red colouration indicating the highest vessel traffic. Movement data is collected only for vessels fitted with an Automatic Identification System (AIS), which generally includes all cargo vessels > 500 gross tonnage, all international vessels > 300 gross tonnage, and all commercial passenger ships. Source: MarineTraffic.

Currently there is no established, coordinated system in New Zealand to manage biosecurity risks posed by domestic vessel traffic. Small commercial and recreational vessels pose a significant biosecurity risk as they often operate at a range of geographical scales (i.e. local, region and international) and their movement is largely unregulated. For recreational vessels in particular, other risk factors include being typically slow moving, numerous, idle for long periods, and frequenting high-value areas (e.g. marine reserves) as well as transport hubs (e.g. marinas). While generally being more geographically constrained, the consistent nature of small commercial vessel movements may also lead to increased risk with regards to transport of marine pests.

Port Marlborough, located at the head of Picton Harbour, is the most significant commercial shipping port in the region. The main cargoes transported through the port are logs, salt, cement and fish. The total number of vessel visits (≥ 500 gross tonnes) to Port Marlborough during the 2017–2018 financial year was 3,363 (PML 2018). Excluding the interisland ferry movements, there were 207 other vessel arrivals including 41 cruise ships. There are a number of barging companies who operate out of Picton, servicing the outer regions of the Queen Charlotte Sound (e.g. construction of fixed structures, mooring installations, freight transport) (Floerl et al. 2015). The commercial port at Havelock, located at the south-western edge of the Pelorus Sound, is the centre for much of the New Zealand green-lipped mussel industry. As such the port is the base for a number of vessels servicing this industry, as well as the salmon farms that operate within the Pelorus Sound. The port also houses several water taxis, small tourism vessels and fishing boats. Traffic movements are largely restricted to domestic vessels returning to the port each day. There are not believed to be many visits from vessels from other regions in New Zealand. The port does not have customs clearance for direct international arrivals (Floerl et al. 2015).

The number of recreational vessels based in the Marlborough region is not known accurately because there is no required registration of non-commercial craft. Approximately 60 vessels are believed to visit Picton marina from other regions in New Zealand or from overseas each year (Floerl et al. 2015). The marina itself does not have customs clearance so any recreational craft visiting from overseas will have entered New Zealand at a different location, or will clear customs in the port area. The marina at Havelock accommodates a mix of both recreational and commercial vessels including charter boats and marine farming vessels. The marina does not have customs clearance and does not get many visits from vessels outside of the top of the South Island region (Floerl et al. 2015). The exposed nature of the proposed open ocean farm site means that it is unlikely to be a particularly high-use area with regards to locally-based recreational vessels.

3.3.2. Other coastal structures

The Marlborough region contains around one-fifth of New Zealand's coastline[10], with a considerable number of coastal structures located within these areas (e.g. marinas, boat ramps, jetties, seawalls, moorings, etc.). As at March 2019 there were active resource consents for 1268 structures and 2802 moorings within the region[11] (Figure 4 and Figure 5). Marine pest species can have a preference for colonising artificial over natural substrata (Glasby et al. 2007; Bulleri & Chapman 2010). As such, the replacement of natural, often sedimentary, substrata with hard substrata can alter the distribution of species, particularly NIS. Once established, the proliferation of pests within or adjacent to the new substrata creates a source of planktonic propagules.

Due to the relative importance of shipping for human-mediated spread of marine pests, ports and marina facilities are often the sites where NIS become first established (Inglis 2001; Hayes et al. 2005). In particular, swing moorings and their associated vessels have been identified as particularly high-risk with regards to marine pest transfers (see Piola & Forrest 2009). Intensive development of coastal margins can also facilitate the spread of pest species through a 'stepping stone' process, whereby species are able to colonise adjacent structures and overcome natural barriers to their dispersal or establishment (see Forrest et al. 2009). As with other marine farming activities, the numerous structures and moorings in the region have a functional role similar to that of the open ocean farm development (e.g.

[10] https://www.marlborough.govt.nz/about-marlborough/marlborough-land-and-water-areas
[11] https://data-marlborough.opendata.arcgis.com/datasets/772cac1f5aa7425d9de27cf132aac48d_5

creation of novel habitat); however, quantitatively their role is likely of far greater magnitude.

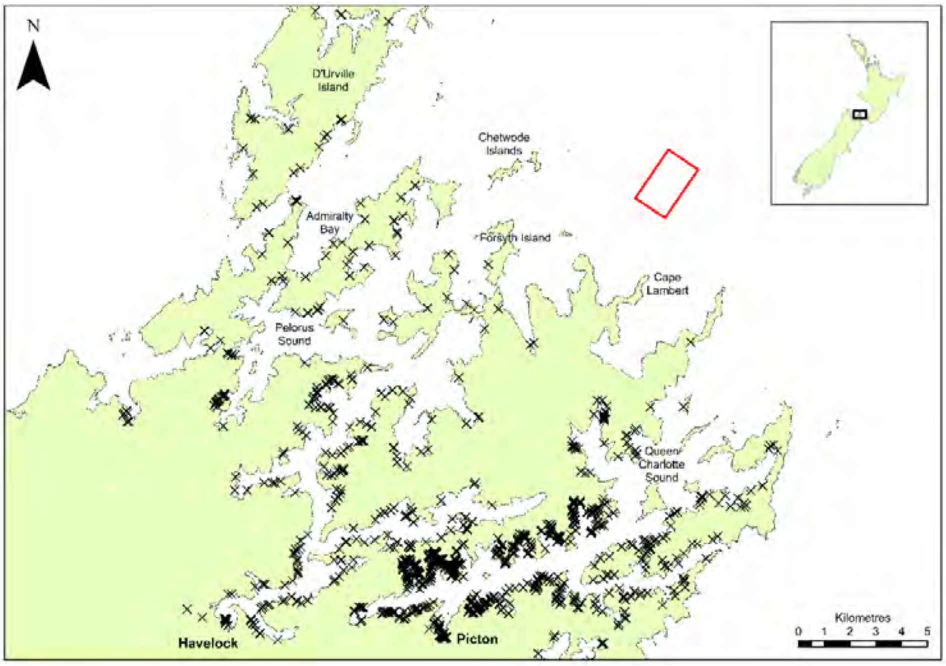

Figure 4. Location of coastal structures (e.g. marinas, jetties, boat ramps; black crosses) within the Marlborough Sounds region. The location of the proposed open ocean farm site is also indicated (red box). Based on Marlborough District Council data current to March 2019.

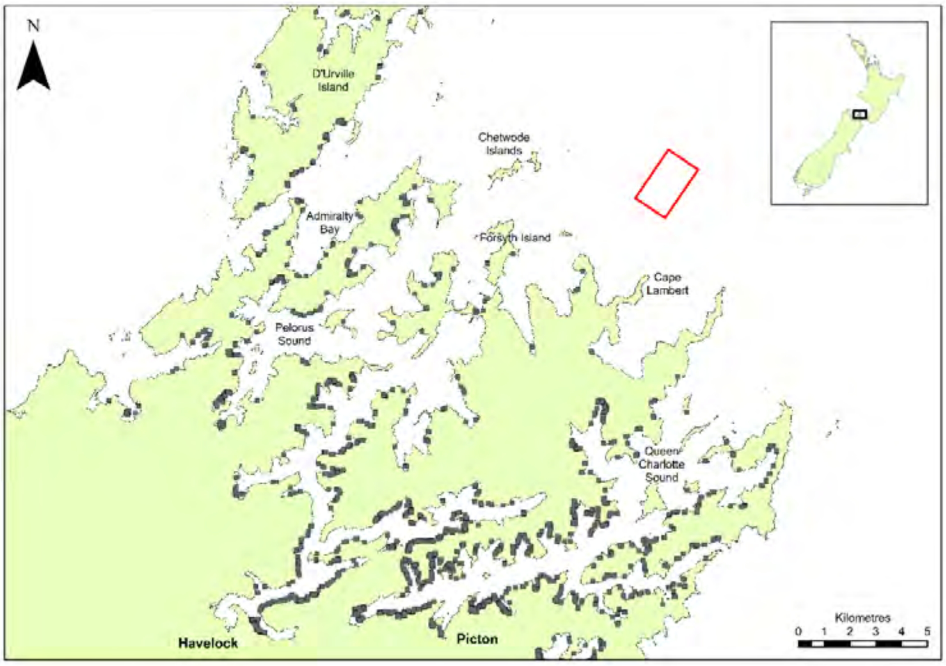

Figure 5. Location of coastal moorings with active resource consents (grey dots) within the Marlborough Sounds region. The location of the proposed open ocean farm site is also indicated (red box). Based on Marlborough District Council data current to March 2019.

4. RISKS FROM THE PROPOSED OPEN OCEAN SALMON FARM

As the proposed NZ King Salmon open ocean farm development is the first of its kind in New Zealand, at this stage the specific operational details are being developed. This pertains to the construction process as well as to the subsequent operation of the farm. As a result, we do not have the necessary information to understand pathway risk to the site in its entirety. We can, however, identify situations where the potential for risk is greatest, and these should be considered at the consent application stage (see Forrest et al. 2011). These are farm-related activities that involve:

- international source regions, or domestic source regions known to be infected by recognised high-risk pests, especially pest species that do not already occur in the Marlborough region
- methods of transfer that do not already occur as a result of other human activities in the Marlborough region
- methods of transfer that are considerably more frequent than other human-mediated pathways unrelated to salmon culture
- methods of transfer that lead to farm infection risk that is considerably greater than posed by natural pest dispersal from existing source populations (e.g. in adjacent natural or artificial habitats).

Biosecurity risk in the context of the proposed open ocean development should be considered from a regional perspective, including the likely importance of associated risk mechanisms in the context of other controlled and uncontrolled activities in the region. This is done in the sections below, with effects structured into biosecurity risks associated with (1) farm construction and (2) farm operation where relevant, and summarised in Table 2.

4.1. Transfer of marine pests via vessel and structure movements

4.1.1. Construction phase

In the construction of the farm, it is possible that NZ King Salmon will contract specialised service vessels (e.g. for anchor installation, freight barges) from outside the region or from overseas that could pose a biosecurity risk. Given the scope of development, such vessels may operate within the Marlborough region for a considerable period (weeks to months). Some aspects of biosecurity risk will relate to maintenance and voyage history and are very specific to the vessel contracted for the activity. For example, barges are typically slow-moving, and their travel history is characterised by long residency periods at previous destination ports. Slow-moving vessels can become heavily fouled, and a slow voyage speed (< 10 knots) is generally considered to favour the survival of associated biofouling species. These vessels also typically operate for a long duration (e.g. a few months) in any one location, which leads to a greater biosecurity risk than a short-stay vessel (e.g. a merchant ship with a turn-around time of 2-3 days), assuming that the risk of organism release increases over time (Coutts et al. 2010; Hopkins & Forrest 2010a).

These types of specialised vessels also tend to have a large number of 'niche areas', which may pose a higher level of biosecurity risk than vessels with a more general hull design. Some niche areas do not receive antifouling treatments during dry-docking, or the antifouling coating is subjected to excessive wear, and will subsequently accumulate large amounts of biofouling growth. Some niche areas also provide relatively sheltered environments for marine growth (e.g. sea chests, other internal seawater systems), and can contain considerable biofouling and mobile organisms such as crabs, fish and sea stars (Coutts & Dodgshun 2007; Frey et al. 2014).

The risks from these vessels will be dependent upon where the vessel has originated from, whether the region of origin has established populations of marine pests not currently present within the Marlborough region, and what risk mitigation measures have been undertaken for these vessels prior to their passage to the proposed site. The movement of a single vessel into the region may appear at face value to be of limited concern give the high volume of other traffic. However, there are a number of instances where similar one-off events have been implicated in the introduction of NIS to New Zealand, for example the international movements of barges. It is expected that the risks from these vessels can be appropriately mitigated through adhering to national-level guidelines regarding vessel maintenance, in particular acceptable levels of hull fouling (see Section 5.1.1).

4.1.2. Operational phase

Exact vessel movements for the proposed development are not known at this stage. However, it is expected that visits to the open ocean site will be fewer than those to existing farming operations in the region due to the location and requirement for suitably specified vessels (pers. comm. M. Gillard, NZ King Salmon, 15 March 2019). Vessel movements are likely to include bulk feed deliveries on an infrequent basis, visits from a harvest barge and harvest crew vessel, as well as from servicing vessels to carry out other logistical work (e.g. net cleaning). While pen structures are occasionally moved between current farm sites, this is not expected to occur as part of the current development. Vessel movements associated with the proposed development are expected to occur predominantly within the Marlborough region.

Risks posed by vessels used during day-to-day operation of the open ocean farm will be common to existing vectors within the region. Existing sources of biosecurity risk include international vessel arrivals into the Port of Marlborough and domestic vessel movements into the region (e.g. recreational vessels, fishing boats, tourism operators, barges, merchant ships). Vessel movements associated with the open ocean farm development will therefore represent a very small subset of biosecurity risk pathways that already exist in the region. Considering the amount of vessel traffic that already occurs in the area, the level of risk is expected to be relatively minor compared to other sources. That being so, the number of movements in and around the proposed site will increase with an associated increased risk of NIS transfer to the site, as well as from the site to other locations.

4.2. Transfer of marine pests via equipment/gear movements

4.2.1. Construction phase

As with any coastal development, there is a risk of inadvertently introducing pest species associated with 'second hand' materials that might be used for construction. For example, leased pontoon transfers around Waitemata Harbour possibly contributed to the initial spread of the sea squirt *Styela clava* in that region (see Gust et al. 2008). The proposed open ocean farm site is expected to be developed using all new materials (pers. comm. M. Gillard, NZ King Salmon, 15 March 2019). This removes the risk of a marine pest introduction at the construction stage due to use of previously-used infrastructure.

4.2.2. Operational phase

Movement of farm-related equipment or gear during the operational phase is not expected to give rise to biosecurity risk that is considerably greater than that for existing sources of biosecurity risk in the region. Any movement of equipment or gear is likely to be regionally-restricted and will be relatively infrequent. Risk mechanisms associated with these movements (i.e. water and sediments, fouling, entanglement) will be common to existing vectors within the region (e.g. movement of mussel farming equipment, movement of recreational vessels). In the context of other activities in the Marlborough region, risks posed by farm-related equipment or gear movements are expected to be relatively minor.

4.3. Transfer of marine pests via stock movements

NZ King Salmon stock is sourced from freshwater hatcheries, so pathway risks related to the transfer of smolt to sea farms are not relevant to the current proposal (i.e. they are transferred in fresh water). At this stage it is not known whether smolt will be transferred directly to the proposed open ocean farm site or held at an existing farm site initially. Once transferred to the open ocean site, it is not expected that grow-out fish will be moved from the farm during the production phase. Based on current operations, harvesting of stock is expected to be carried out on site using a harvest vessel with fish transported in closed containers to prevent discharge of water or blood to the environment. Processing will be shore-based, with residual water and blood disposed of using appropriate wastewater treatment facilities. On-farm mortalities will be stored in non-leaking bins with sealable lids. Dead stock will be transported to shore in closed containers, with no discharge of associated water or waste material to the environment. In the context of existing finfish farming activities in the Marlborough region, and with reference to marine pests only, biosecurity risks posed by stock movements to and from the proposed open ocean site are expected to be minor.

4.4. Facilitation of marine pest establishment through changes to the local environment

4.4.1. Construction phase

Physical disturbance and alteration of the seabed as a result of construction activities (e.g. installation of farm anchors) may increase the susceptibility of seabed habitats to colonisation by marine pests. The anchor itself does not damage seabed substantially; however, associated ‘clump weights’ required for installation do cause disturbance either side of the anchor point (pers. comm. B. Lines, Diving Services New Zealand, 3 April 2019). These weights have a very small footprint (< 0.5 m circumference) and the level of disturbance is highly localised. Given the level of historic disturbance within the region (e.g. commercial fishing), the benthic habitat affected in this way will be minor by comparison.

4.4.2. Operational phase

Day-to-day farm operations at the proposed open ocean site may also alter the local environment (e.g. change water or sediment quality) and create conditions that facilitate or increase biosecurity risks. Organic enrichment of the seabed as a result of farming activities may also increase the susceptibility of seabed habitats to colonisation by disturbance-tolerant pest species. For example, the non-indigenous soft-sediment bivalve *Theora lubrica* is known to occur at enhanced abundances (e.g. 5-10 times greater than reference site densities) in disturbed areas including around salmon farm pens (Forrest 2011). This species is regionally and nationally common however, and as such is not considered a specific biosecurity threat. It is also acknowledged that the exposed nature of the proposed site will offset this risk to some degree, with increased water movement likely to disperse waste material.

Increases in nutrient concentrations (i.e. high dissolved inorganic nitrogen loads) in the farm vicinity can theoretically promote the productivity of macroalgal species, including pest species such as *Undaria*. This does not appear to be relevant in the wider Marlborough region, with changes in macroalgal cover at existing salmon farm sites believed to be related to natural fluctuations in abundances, rather than due to farm-related effects (e.g. Dunmore 2018). Invasiveness in both artificial and natural habitats in other regions has also been shown to vary considerably both spatially and temporally irrespective of anthropogenic influences (see Forrest & Taylor 2002; Forrest & Hopkins 2013).

4.5. Increased abundance and spread of marine pests from the creation of novel habitat

Submerged structures (e.g. pens, nets, anchors and mooring lines) associated with the proposed open ocean development will provide locally novel habitat for colonisation by fouling organisms and associated biota. The proposed location ~6 km from the nearest coastline means the site is considerably less vulnerable to colonisation by short-dispersing species such as ascidians and bryozoans (see Mohammed 1998; Atalah et al. 2016). Species with extended planktonic larval durations (i.e. days to weeks; includes barnacles, mussels, cnidarians) are more likely to colonise the farm structures through natural dispersal, however, this will be dependent on hydrodynamics and environmental conditions of the associated area.

As the farm is a semi-permanent structure, it will act as a population reservoir for any marine pests that do successfully establish. There are several processes by which the farm may act as reservoir, including through dispersal of planktonic life-stages of established fouling organisms and deposition of fouling to the seabed (e.g. deliberate defouling during farm maintenance). Secondary spread from the farm will be dependent on habitat requirements of pest species. Species like the kelp *Undaria* and sea squirt *Didemnum* are primarily a threat on hard substratum habitats, such as artificial structures and rocky reef. Their capacity to occupy soft-sediment habitats, such as in the vicinity of the proposed open ocean farm development, is likely to be minimal[12] or non-existent. There are areas of significant hard substrate nearby (i.e. McManaway Rocks and Witts Rocks; see Figure 1); however, it should be noted that many species that are invasive on artificial structures are often not prevalent in adjacent natural habitats (see Hopkins et al. 2011; Forrest et al. 2013).

As discussed in Forrest et al. (2011), at the scale of an individual finfish farm, the incremental reservoir risk is likely to be relatively minor. However, at full development over the 1,800-ha area, the surface area of artificial structures (hence the propagule reservoir) at the site will be considerably increased. If a pest population did establish on the farm, it might reach a very large size given the extent of available habitat. This risk will be mitigated to some degree by an operational need to maintain a low level of fouling on nets and some farm structures (i.e. to prevent restriction of water flow or excessive weight). In addition, the relative isolation of the site will mean that farm structures are less likely to act as a 'stepping stone' in the regional spread of pest species, as is the case with inshore structures.

[12] Several high-risk species can colonise small areas of hard substrate within predominantly soft-sediment habitats (e.g. the fanworm *Sabella spallanzanii* and the clubbed tunicate *Styela clava* have been shown to establish on pieces of shell material within the Hauraki Gulf and Firth of Thames regions).

Table 2. Summary of potential effects resulting from the NZ King Salmon open ocean farm proposal. Recommended mitigation actions are also provided.

Issue	Potential effect	Significance of effect	Mitigation actions
Transfer of marine pests via vessel and structure movements	Vessels from outside of the Marlborough region or from overseas introduce pest species that do not already occur in the region	Minor incremental effect: Dependent upon region of origin and level of risk mitigation undertaken prior to arrival	• Comply with national-level hull biofouling and ballast water legislation, operate under a BMP specific to the vessel
	Day-to-day vessel movements lead to infection of farm site or transfer of pests from farm site to other locations with associated values (e.g. natural character, other commercial industries) adversely affected	Minor incremental effect: Farm site may become infected by pest species as a result of other unmanaged vectors, or by natural dispersal from established local populations. Farm-related vessel movements will represent a very small subset of vessel movements that already occur in the region	• Adhere to good maintenance practices to prevent growth of biofouling and accumulation of sediment or debris
Transfer of marine pests via equipment/gear movements	Introduction of pest species to the site via previously-used infrastructure at the construction stage	Not applicable: Farm site is expected to be developed using all new materials	• Use of new equipment or gear for development of farm
	Movement of equipment/gear used in day-to-day operation of farm leads to infection of farm site or transfer of pests from farm site to other locations with associated values (e.g. natural character, other commercial industries) adversely affected	Minor incremental effect: Farm site may become infected by pest species as a result of other unmanaged vectors, or by natural dispersal from established local populations. Movements are likely to be regionally restricted and relatively infrequent. Associated risk likely to be common to existing vectors in the region	• All previously-used equipment/gear thoroughly cleaned, and appropriate treatments applied if necessary (e.g. disinfection), before moving between farm sites
Transfer of marine pests via stock movements	Stock movements lead to infection of farm site or transfer of pests from farm site to other locations with associated values (e.g. natural character, other commercial industries) adversely affected	Minor incremental effect: Farm site may become infected by pest species as a result of other unmanaged vectors, or by natural dispersal from established local populations. Stock movements from outside the region (i.e. smolt transfer) are in fresh water so not relevant for marine pest transfer. Risk common to existing finfish farming activities in the region	• Development of standard operating procedures that incorporate industry best practice
Facilitation of marine pest establishment through changes to the local environment	Physical disturbance of the seabed (i.e. installation of anchoring systems, organic enrichment) leads to increased susceptibility to colonisation by disturbance-tolerant pest species	Minor incremental effect: Will depend on level of disturbance and propagule transfer. Exposed nature of site may offset risk to some degree through increased water movement	• Manage the farm within acceptable environmental limits with regards to seabed enrichment
	Nutrient enrichment leads to increased productivity of macroalgal species, including pest species (e.g. the kelp *Undaria pinnatifida*)	Minor incremental effect: *Undaria pinnatifida* is widespread in the region, abundance does not appear to be exacerbated by point source nutrient enrichment	• Manage the farm within acceptable environmental limits with regards to nutrient enrichment
Increased abundance and spread of marine pests from the creation of novel habitat	Farm becomes a reservoir for the subsequent spread of pests to nearby natural habitats with associated values (e.g. natural character, other commercial industries) adversely affected	Minor incremental effect: Secondary spread from farm structures dependent on habitat requirements of pest species. Will be limited for some species due to predominantly soft-sediment substrate in the immediate area	• Surveillance within the farm to enable timely detection of known and unknown pest species • Regular defouling of farm infrastructure (e.g. pontoons, nets) to prevent establishment of large populations of pest species

5. RECOMMENDED MITIGATION MEASURES

Due to the difficulties in managing established marine pests, preventing incursions through the management of high-risk vectors is a critical aspect of marine biosecurity in New Zealand. There are potential biosecurity risks associated with both the construction and operation of the proposed open ocean farm, with some of these risks occurring against a background of existing biosecurity risk in the region. Mitigation of risk pathways and vectors associated with farming activities will contribute to risk reduction. To ensure that the most appropriate measures are in place, it is suggested that a Biosecurity Management Plan (BMP) tailored to the site be developed by a suitably qualified person to address both marine pest and disease risk. NZ King Salmon have a BMP in place for the current inshore sites (NZKS 2018); this document could provide a starting point for a BMP for the open ocean site.

If the farm is consented, there are a range of best management practices regarding the set up and operation of marine farms that can help reduce biosecurity risks. AQNZ's 'Sustainable Management Framework' (SMF) document for salmon[13] outlines threats common to finfish farming operations in New Zealand along with a set of voluntary guidelines to minimise biosecurity risks. In addition, AQNZ and MPI have jointly produced the 'Aquaculture Biosecurity Handbook'[14] and an associated technical document, which provides marine farmers with guidance to strengthen on-farm biosecurity management. The guidelines represent industry best practice and, when implemented, should reduce risk to a level that is acceptable in light of current activities. The specific mitigation options proposed below are largely based on the Biosecurity Management Objectives and Recommended Practices of the handbook and the best-practice Operational Procedures described in Appendix 2 of the SMF.

5.1. Vessel and gear movements

5.1.1. Construction phase

Biosecurity risks from overseas vessels will be minimised by following the recently implemented Craft Risk Management Standard for Vessel Biofouling (CRMS) governing levels of acceptable hull biofouling, as well as legislation governing the discharge of ballast water and associated sediments (BWM Convention). Under the MDC Regional Pest Management Plan 2018, domestic vessels entering Marlborough waters must not have more than a light slime layer on their hull[15]. Exceptions to this rule are available if the vessel is entering Marlborough for the purpose of haul out or due to emergency situations. To aid in compliance with this rule, it is recommended that vessels associated with the construction of the farm that are entering

[13] Available from: https://www.aplusaquaculture.nz/#frameworks
[14] Available from: https://www.mpi.govt.nz/dmsdocument/13293-aquaculture-biosecurity-handbook-assisting-new-zealands-commercial-and-non-commercial-aquaculture-to-minimise-on-farm-biosecurity-risk/sitemap
[15] For more information, see: www.marlborough.govt.nz/environment/biosecurity/marine-biosecurity

Marlborough from other regions aim to comply with the CRMS and BWM Convention legislation. The most straightforward way to meet these requirements, thus ensuring that the biosecurity risk is acceptable, is to develop a BMP specific to the vessel in question. Guidance material regarding the development of BMPs for vessels is available online[16].

5.1.2. Operational phase

Biosecurity risks tend to be most significant on poorly maintained vessels. As such, vector risks associated with farm vessels can be mitigated via good maintenance practices as follows:

- ensure all vessels have up-to-date and vessel-appropriate antifouling systems that cover both general submerged hull areas and niche areas; record paint types used and expected service life and schedule hull maintenance and coating renewal accordingly
- regularly inspect hulls for conspicuous fouling or notifiable pests, especially before leaving one area for another; careful attention should be given to niche areas that are not typically antifouled (e.g. bottom of keel, pipe intake/outlets, rubbers, hard-stand support strips) as these are particularly prone to biofouling
- wash or purge water and debris from decks and bilge before leaving one area for another
- become familiar with, and display on all vessels, MPI's 'New Zealand's Marine Pest Identification Guide'
- report suspected marine pest or pathogen detections to the MPI Exotic Pest and Disease Hotline (0800 80 99 66).

Note that, as well as being consistent with industry best practice, these measures are also largely consistent with those being proposed for domestic vessels in general by regional authorities and MPI. The measures proposed are largely straightforward and should not unduly interfere with the normal operation of farm vessels.

If transfers of previously-used equipment or gear (i.e. harvesting equipment, net cleaning machines) between farm sites is required as part of ongoing operations, all equipment should be thoroughly cleaned, and appropriate treatments applied if necessary (e.g. disinfection). Records should be maintained for movements of vessels, equipment or gear between established farms and the proposed open ocean farm development, as well as associated cleaning and disinfection of structures, equipment and vessels.

[16] https://www.mpi.govt.nz/importing/border-clearance/vessels/arrival-process-steps/biofouling/commercial-vessels/

5.2. Stock movements

Fish transport should responsibly and safely transfer fish, while ensuring the environment is protected against biosecurity risks. It is recommended that standard operating procedures should be written and adhered to for transporting stock, with particular reference to discharge of transport water and other organic waste. Comprehensive guidelines regarding stock transfers are provided in the MPI and AQNZ-produced technical document accompanying the Aquaculture Biosecurity Handbook (Georgiades et al. 2016).

Vehicles, vessels and equipment used for transport, whether on land or water, should be designed and maintained to safely load, hold, and transport stock, and ensure containment of transport water and stock. They should be equipped with suitable monitoring equipment to maintain water quality and biosecurity standards during transport (Georgiades et al. 2016). Where contract services are used, it is important that transport companies are aware of the biosecurity issues surrounding transport of stock and are actively involved in the maintenance of high standards of biosecurity. In addition, accurate records of all stock movements to, from and within the farm should be maintained. These measures are expected to be highly effective at mitigating biosecurity risk.

5.3. On-farm management measures

Surveillance within the farm to enable early detection of known and unknown pest species is also recommended. Surveillance can either be ‘passive’ or ‘active’. Passive surveillance relies on opportunistic detection of unusual organisms by farm staff, so NZ King Salmon personnel should become familiar with, as a minimum, MPI’s ‘New Zealand’s Marine Pest Identification Guide’. Active surveillance involves regular surveys, usually for a suite of target species but also for any organisms that farm staff have not seen on the farm structure before or that exhibit unusual patterns of population growth. It is critical that in the design of surveillance plans, clear goals and performance criteria are specified.

Aside from marine pest control for biosecurity reasons, some level of general biofouling control will be required on finfish farms for operational reasons. Defouling infrastructure (e.g. pens, feed barges) is necessary to reduce weight and drag and will also help prevent the establishment of marine pests at the site. Other benefits include maintaining water flow and quality, reducing parasite reservoirs and reducing stress on farmed fish. Any cleaning of farm infrastructure should ideally be undertaken on site. Cleaning on site ensures biofouling and sediment are released within the permitted area and helps prevent the transfer of species between areas. Where land-based cleaning is undertaken (e.g. for equipment that can be removed), debris should be collected and disposed of at a suitable landfill or in such a way that no viable organisms (or their reproductive material) are returned to coastal marine areas.

From a wider environmental perspective, control of pest populations on structures will reduce propagule pressure[17] for spread to other habitats (including other artificial structures as well as natural habitats) or other vectors (e.g. vessels). There may also be circumstances in which it is worthwhile responding to new high-risk species detected on a finfish farm (e.g. attempting to eradicate), but assessment of efficacy will require consideration of other sources of risk (e.g. background risk and re-infection potential). Any control or eradication programmes should involve the capture of waste material for appropriate disposal and be undertaken in consultation with regulatory authorities and scientific experts.

[17] The term propagule pressure describes the measure of propagule delivery, including the magnitude and frequency, to a recipient area from established pest populations or transport vectors.

6. SUMMARY AND CONCLUSIONS

The proposed open ocean farm development at the northern edge of the Marlborough Sounds is likely to present a minor incremental biosecurity risk as a result of additional vessel, gear and stock movements, plus the provision of additional habitat for potential pest organisms. Any farm-related vessels arriving from outside the region (i.e. for farm construction) are likely to be the most important biosecurity risk associated with the development. In the context of other controlled and uncontrolled activities that give rise to biosecurity risk, vector movements associated with day-to-day farm operations are not likely to pose an unacceptably high level of risk. Similarly, while the proposed development will lead to the creation of substantial novel habitat, from a regional perspective there are already substantial amounts of artificial habitats along most areas of coastline which provide a sizeable surface area on which populations of marine biofouling pests can and do establish. The dispersive nature of the proposed farm site will minimise the accumulation of organic waste on the seabed beneath and of nutrients in the water column around the farm. This will to some degree minimise the risk of creating conditions favourable to NIS.

A potential advantage of open ocean aquaculture is that sites may be less vulnerable to the spread of short-dispersing species, as a result of relatively low connectivity with coastal source populations on hard substrata (e.g. artificial structures and natural rocky habitats; see Mohammed 1998; Atalah et al. 2016). In particular, open ocean sites are less likely to be colonised by operationally significant biofouling groups such as ascidians and bryozoans, which generally have a limited planktonic dispersal range (< 1 day larval duration; see Fitridge et al. 2012). A short larval duration will mean these groups of taxa are unable to incrementally disperse across the kilometres of soft-sediment benthic habitat that typically isolate open ocean aquaculture from coastal source populations (see Atalah et al. 2016). Due to the exposed location, open ocean sites are also likely to have relatively low exposure to non-farming related vectors such as recreational vessels.

Despite the biosecurity risk being relatively minor and incremental, effective management of human-mediated pathways of spread to the site is critical to ensure the environment and farm itself are protected. These linkages have the potential to undermine the biosecurity protection afforded by the geographical isolation of open ocean sites (see Morrisey et al. 2011). In summary, key mitigation measures that should be adhered to include:

- vessels associated with the farm development that are entering Marlborough from other regions should aim to comply with the national-level hull biofouling and ballast water legislation, and ideally operate under a BMP specific to the vessel in question

- vessels associated with day-to-day operations of the farm should be properly maintained to prevent the growth of biofouling or the accumulation of sediment or debris
- all previously-used equipment or gear should be thoroughly cleaned, and appropriate treatments applied if necessary (e.g. disinfection), before moving between farm sites
- standard operating procedures that incorporate industry best-practice should be developed and adhered to for transporting stock
- farm personnel should be familiar with, remain vigilant for, and report pest organisms or those that exhibit unusual patterns of population growth
- farm infrastructure (e.g. pontoons, nets) should be maintained appropriately to prevent the establishment of large populations of pest species
- accurate records of all vessel, equipment, gear and stock movements to, from and within the open ocean farm site should be maintained.

These measures are largely straightforward and should not unduly interfere with the normal operation of the farm. In addition to the measures outlined above, NZ King Salmon personnel should maintain awareness of any new biosecurity guidance or requirements issued by MPI or AQNZ and it is recommended that a BMP tailored to the site be developed by a suitably qualified person to address both marine pest and disease risk. Appropriate requirements regarding review and auditing of this document will greatly aid in its effectiveness. If the proposed mitigation measures are implemented appropriately, the residual biosecurity risk is expected to be negligible.

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APPENDIX L: Fish Disease Report

DISEASE RISK ASSESSMENT REPORT – OPEN OCEAN SALMON FARMS NEAR MARLBOROUGH SOUNDS, NEW ZEALAND

DIGSFISH SERVICES

DigsFish Services Report: DF 19-01
20 February 2019

DISEASE RISK ASSESSMENT REPORT – OPEN OCEAN SALMON FARMS NEAR MARLBOROUGH SOUNDS, NEW ZEALAND

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Contents

Abbreviations and Acronyms

AEE	Assessment of environmental effects
AGD	Amoebic gill disease
ALOP	Appropriate level of protection
CAN	Controlled area notice
DPIPWE	Department of Primary Industries water and the Environment (Tasmania)
EIBS	Erythrocytic inclusion body syndrome
ERM	Enteric redmouth disease
EUS	Epizootic ulcerative syndrome
GDAS	Gastric dilation and air sacculitis
HSMI	Heart and skeletal muscle inflammation
IHN	Infectious Haematopoietic Necrosis
IHNV	Infectious Haematopoietic Necrosis Virus
IPN	Infectious Pancreatic Necrosis
IPNV	Infectious Pancreatic Necrosis Virus
ISA	Infectious Salmon Anaemia
ISAV	Infectious Salmon Anaemia Virus
MPI	Ministry for Primary Industries
NZKS	New Zealand King Salmon Company Ltd
NZ-RLO	New Zealand rickettsia-like agent, 3 known genotypes of PLB including one closely related to *Piscirickettsia salmonis*
OIE	World Organisation for Animal Health (formerly Office International des Epizooties).
PHV	Pilchard herpesvirus
PLB	*Piscirickettsia*-like bacteria
POMV	Pilchard orthomyxovirus
PRV	Piscine orthoreovirus
RA	Risk analysis
RLO	Rickettsia-like organism
SAV	Salmonid alphavirus
SD	Sleeping disease
SPD	Salmon pancreas disease
TAB	Tasmanian aquabirnavirus
$TCID_{50}$	Tissue culture infectious dose 50% endpoint
TSRV	Tasmanian salmonid reovirus
VEN	Viral erythrocytic necrosis
VHS	Viral Haemorrhagic Septicaemia
VHSV	Viral Haemorrhagic Septicaemia Virus

Version control

First draft:	18 December 2018
Final report:	20 February 2019

Disclaimer:

DigsFish Services have taken all reasonable care and diligence to ensure the information contained in this report is accurate at the time of publication. However this report is offered as general advice only, we do not warrant the accuracy of the information contained within and accept no liability for any loss or damage that may result from reliance on this information.

Executive Summary

This report was undertaken to assess potential changes to disease risks associated with a proposal to locate a new salmon farming site offshore in deep water outside the Marlborough Sounds in the southern Cook Strait, New Zealand to accommodate 6-10 offshore salmon seacages producing 1000 metric tonnes of chinook salmon (*Oncorhynchus tshawytscha*) each per annum. A review of the disease status of *O. tshawytscha* in New Zealand revealed a few minor changes to the hazards identified previously (Diggles 2016), identifying 25 infectious agents and 12 non-infectious diseases of cultured salmon in New Zealand. The most problematic disease issue for the industry in recent years remains the emergence of a *Piscirickettsia salmonis*-like bacterial disease agent (NZ-RLO) which has been particularly problematic at inshore farming sites with suboptimal low current flow conditions.

This risk assessment found that the proposed location of salmon farming cages offshore in the southern Cook Strait follows worlds best practice for establishment of a new independent farm management area separated by an ideal buffer zone that exceeds 16 km, a distance that has been empirically proven to effectively mitigate risks of spread of viruses and bacterial disease agents. The proposal to expand the industry offshore into deeper areas with higher water flow would improve the environmental conditions to which cultured salmon are exposed. This would reduce the risk of outbreaks of not only non-infectious diseases, but would also mitigate significant risk factors for emergence of infectious diseases like the NZ-RLO which can occur at suboptimal sites. The present proposal would therefore allow the salmon farming industry in the Marlborough Sounds to expand while moving towards world's best practice biosecurity area management arrangements by establishment of three independent farm management areas separated by epidemiologically proven buffer zones. It is recognised that an unquantifiable risk remains that biosecurity leaks could allow exotic diseases to be introduced, and/or new endemic diseases could emerge in salmon aquaculture in New Zealand at some time in the future. Because of this, it is important that planning arrangements allow biosecurity management to continue to migrate towards world's best practice.

The farms in the Tory Channel area (Clay Point, Te Pangu, and Ngamahau and Otanerau Bay) should be managed as one farm management area (Queen Charlotte Sound Management Area). The farms in the Pelorus Sound (Kopaua, Waitata, Waitata Reach, Forsyth Bay, and Waihinau Bay) should be managed as a second farm management area (Pelorus Sound Management Area), while the proposed offshore farms could be managed as a third independent Offshore Management Area.

Based on conclusions from this risk analysis, I consider the proposed location of the offshore salmon farming area to be appropriate as it reduces proximity to shipping, maintains a minimum 16 km on-water buffer zone that has been epidemiologically proven to allow independent management of all three farm areas, while the increased water depth and improved water quality (relatively high dissolved oxygen, relatively low water temperature, increased distance to bottom dwelling fishes compared to inshore sites) will reduce risks of outbreaks of NZ-RLO and other infectious and non-infectious diseases. In view of current global warming trends which are likely to increase disease risks to the industry over time, the ideal situation of 3 sufficiently large independent farm management areas with regular synchronised fallowing of each area should be considered the ultimate goal for future planning arrangements for the industry in the Marlborough Sounds region.

Objectives of this document

Salmon farming in the Marlborough Sounds is undertaken under the scrutiny of the Ministry for Primary Industries and the Marlborough District Council who implement the Best Management Practice Guidelines for Salmon Farms in the Marlborough Sounds (Benthic Standards Working Group 2014).

The New Zealand King Salmon Co. Limited (NZKS) is applying for resource consent to occupy a portion of the coastal marine area in Cook Strait for the purposes of seacage salmon farming. The proposed area of occupation is broadly between Sentinel Rock, Witts Rock and McManaway Rock, north of the Marlborough Sounds (Figure 1). This proposal has arisen to allow the industry to potentially expand in the future into offshore waters while ensuring that the environmental requirements outlined in the best management practice guidelines for salmon farms in the Marlborough Sounds (Benthic Standards Working Group 2014) can be met. An important component of the application process is the Assessment of Environmental Affects (AEE). One component of the AEE process is to provide a disease risk assessment report that identifies any potential issues for salmon health that may arise as a result of the proposed changes.

The objective of this document is therefore to review and update previous disease risk assessment reports (Diggles 2011, 2016, 2018) and develop a disease risk assessment report that identifies any potential changes to the disease status of salmon cultured by NZKS that may arise as a result of the proposed changes.

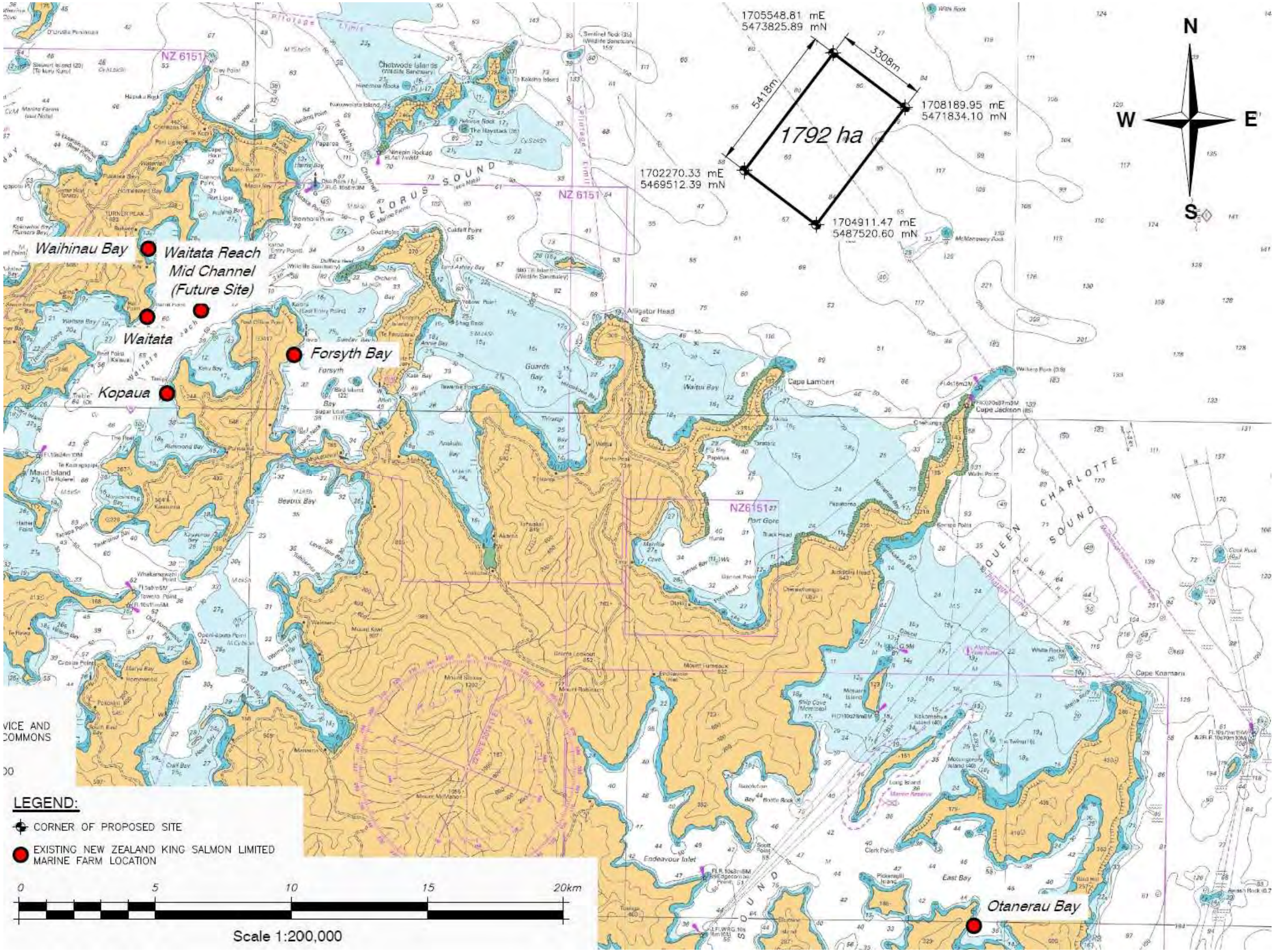

Figure 1. Map showing location of existing or proposed NZKS farming sites (excluding Richmond Bay South) and location of the proposed offshore site.

1.0 Introduction

The aquaculture industry is of national significance to New Zealand, providing jobs, wealth through export income and food security for New Zealanders. By virtue of its geographic isolation, New Zealand is in a unique position to further develop a sustainable salmon farming industry that is free from many of the problems that have emerged in salmon farming elsewhere. The geographic isolation of the country, world leading biosecurity arrangements and the absence of native salmonids means that New Zealand is free from many important diseases of salmonids at this time (Boustead 1989, Diggles et al. 2002, Diggles 2011, 2016).

Chinook salmon *Oncorhynchus tshawytscha* (also known as quinnat or king salmon) were introduced into New Zealand by acclimatization societies as ova only between 1875 and 1907 (McDowall 1978, 1994), virtually eliminating the risk of introduction of many diseases that have emerged in northern hemisphere salmon in recent years and spread with salmonid farming (Costello 2006, Kibenge et al. 2009, Snow 2011, Murray et al. 2016). Chinook salmon are the only salmonid species cultured by NZKS, mainly because they appear innately resistant to some of the key disease agents that have been problematic in salmon culture overseas (Boustead 1989, Johnson and Albright 1992a, Rolland and Winton 2003, Gottesfeld et al. 2009, Murray et al. 2016). Because of these and other reasons, NZKS has become a successful company with around 480 staff and consent for eleven salmon farms utilizing seacages located within the Marlborough Sounds which produce approximately 8,000 tonnes of King salmon per annum (around 50% of the world production for this species). The annual revenue of NZKS is around $160 million NZD and as such the industry generates not only food security, but also various other regional and national economic benefits for New Zealand.

However, there is no room for complacency when implementing a successful salmonid aquaculture industry (Wilson et al. 2009). New diseases continue to emerge in aquaculture (Murray and Peeler 2005, Asche et al. 2010, Thrush et al. 2011, Snow 2011, Blaylock and Bullard 2014) and the dynamics of infectious diseases are often related to the density of host populations (Grenfell and Dobson 1995, Krkosek 2010). Furthermore, even world leading biosecurity policy arrangements are not perfect, as demonstrated by biosecurity leaks that have resulted in the introduction and establishment of several aquatic pests and diseases in New Zealand waters such as the seaweed *Undaria pinnatifida* in 1987 (see Stuart 2004), swimming crab *Charybdis japonica* in 2000 (Smith et al. 2003), the diatom *Didymosphenia geminate* in 2004 (Kilroy et al. 2009) and *Bonamia ostreae* (see Lane et al. 2016). Because of this, it is important to ensure that the salmon industry in New Zealand is well managed in order to firstly avoid disease problems, and in a worse case scenario, to be able to effectively manage any new problems that may emerge (Munro et al. 2003, Murray and Peeler 2005, Gustafson et al. 2005, 2007, Marine Harvest 2008, Kibenge et al. 2009, Mardones et al. 2009, Blaylock and Bullard 2014).

This environmental assessment report has been undertaken to assess the disease risks associated with a proposal to establish a new offshore salmon farming area in the Cook Strait outside the Marlborough Sounds. This report will update previous reports (Diggles 2011, 2016) and will start by examining the location of the proposed new site, followed by a brief review of the diseases in seacage farming of salmon in an international context, to identify the various types of significant diseases in chinook salmon overseas, summarise their environmental impacts (if any), and identify the best practice management measures currently used for their avoidance and control. To describe the existing environment, the known diseases of salmon in New Zealand will be reviewed and their current environmental impacts (if any) will be assessed. An assessment of environmental effects that may result from the proposed offshore salmon farm site will then be undertaken. This assessment will include a qualitative risk analysis of the likelihood of any changes to the existing disease status of chinook salmon, native fishes and other aquatic animals within the Marlborough Sounds region and assess the consequences of disease spread (should it occur). Recommendations will then be made to help ensure that the outcomes from the proposed development, if it goes ahead, will remain consistent with the industries migration towards current world's best practice for seacage aquaculture farm management, in order to minimise risks to the environment and industry development from disease agents of salmon.

2.0 Site location

The proposal to establish a new offshore salmon farming area in the Cook Strait is centred around a 1792 hectare area between Sentinel Rock, Witts Rock and McManaway Rock, north of the Marlborough Sounds (Figure 1). The proposed location is in an area which is a minimum 5.5 km from the nearest land with a water depth of approximately 70–100 meters, modelled significant wave height of 1-1.5 meters (maximum 7 meters) (NZKS 2018) and average water currents that are likely to exceed 0.4 meters/sec (Figure 2). The oceanic water quality expected at this offshore location will have relatively high dissolved oxygen and relatively low water temperature and particulates compared to inshore locations, while the deeper water will further distance the cultured fish from potential reservoirs of infection such as bottom dwelling invertebrates and flatfish (Wallace et al. 2008, Kirchhoff et al. 2011, Bruno et al. 2014, see also Section 6.4.5). Because of these reasons, the proposed location is likely to be more suitable for salmon farming than other inshore locations within the Marlborough Sounds (Gillespie et al. 2011, Figure 2). Attainment of the highest possible water quality is a fundamental requirement underpinning fish health and welfare in any aquaculture venture, hence this site planning decision is likely to represent a positive development for the industry if it can overcome the technical difficulties of operating seacages in such water depths. Another potential benefit of the proposed site is the reduced proximity to vessel traffic compared to existing farm sites within the Marlborough Sounds (Figure 3). It is well known that pests and diseases can be translocated by shipping as well as organisms carried in the ballast water and biofouling of shipping (Murray et al. 2002, Bain et al. 2010), hence moving seacage farm sites further away from shipping routes will help reduce disease incursion risk.

The incorporation of epidemiologically proven salmon farming-free buffer zones between different salmon farming sites has become an important component of best practice integrated management of salmon aquaculture industries worldwide (Brooks 2009, Sitjá-Bobadilla and Oidtmann 2017). Buffer zones are extremely useful because they ensure the epidemiological independence of different salmon farming areas. If a buffer zone is not sufficiently large enough to break the lifecycle of a pathogen, different farming sites become interconnected, allowing horizontal spread of diseases through movements of water, shipping and other potential vectors such as wild fishes (Dempster et al. 2009, Uglem et al. 2009). Buffer zones also allow integrated pest and disease management strategies to be successfully implemented in each independent farm management area during disease outbreaks (McClure et al. 2005, Chambers and Ernst 2005, Gustafson et al. 2007).

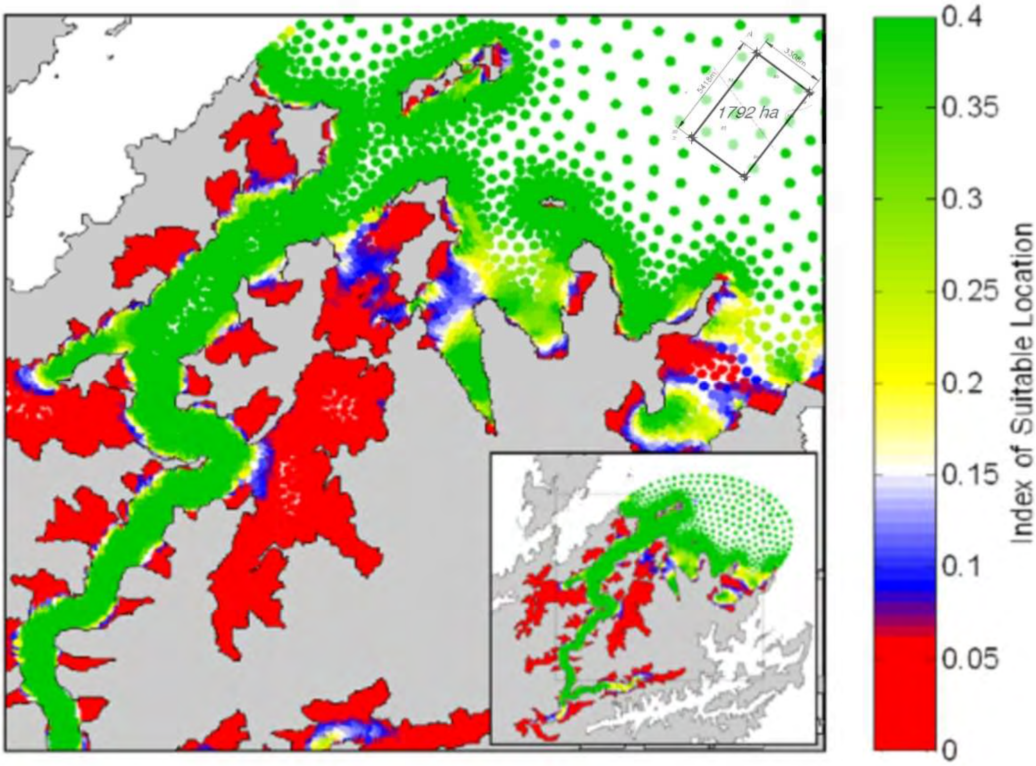

Figure 2. Current data (meters/sec, scale on right) is one variable used to define the suitable salmon farming sites (green colour) in the Marlborough Sounds during site planning. Red regions depict poor site characteristics (depth averaged current flow less than 0.1 m/s). The proposed new area (rectangle) is in a high current zone outside the Marlborough Sounds. Figures from Gillespie et al. (2011).

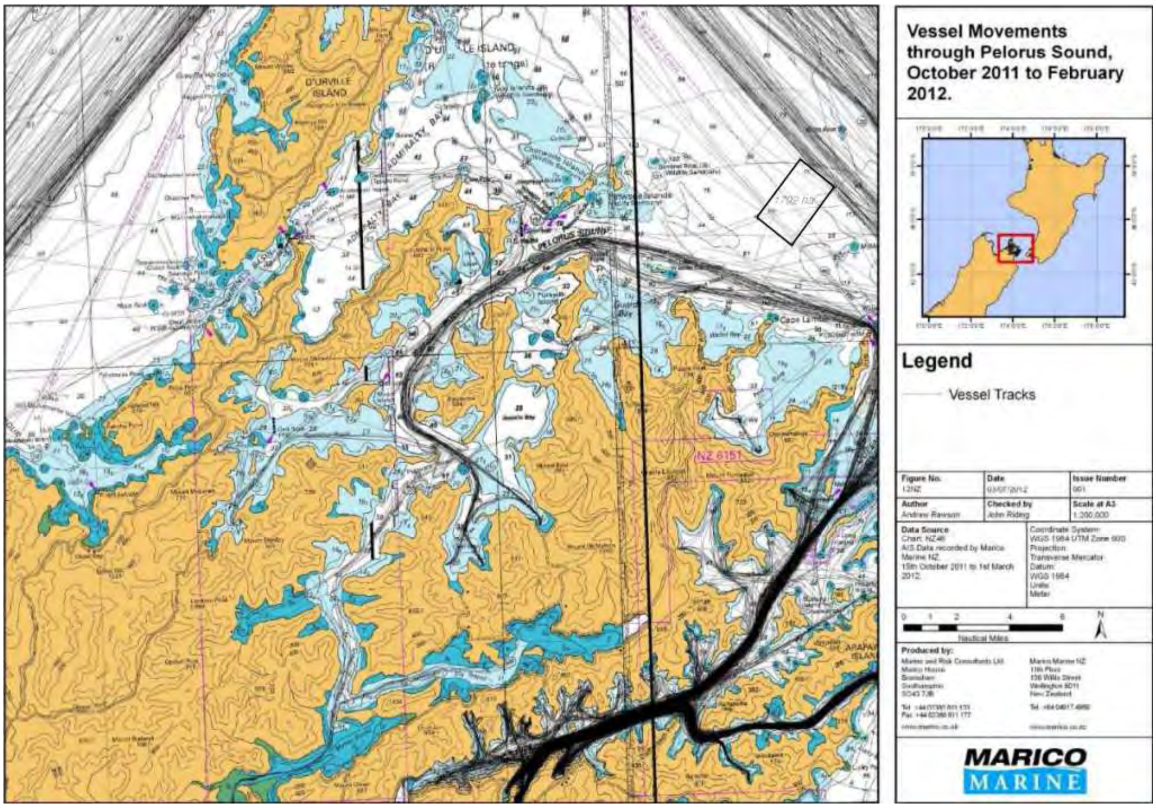

Figure 3. Position of the proposed offshore site (rectangle) in relation to shipping movements.

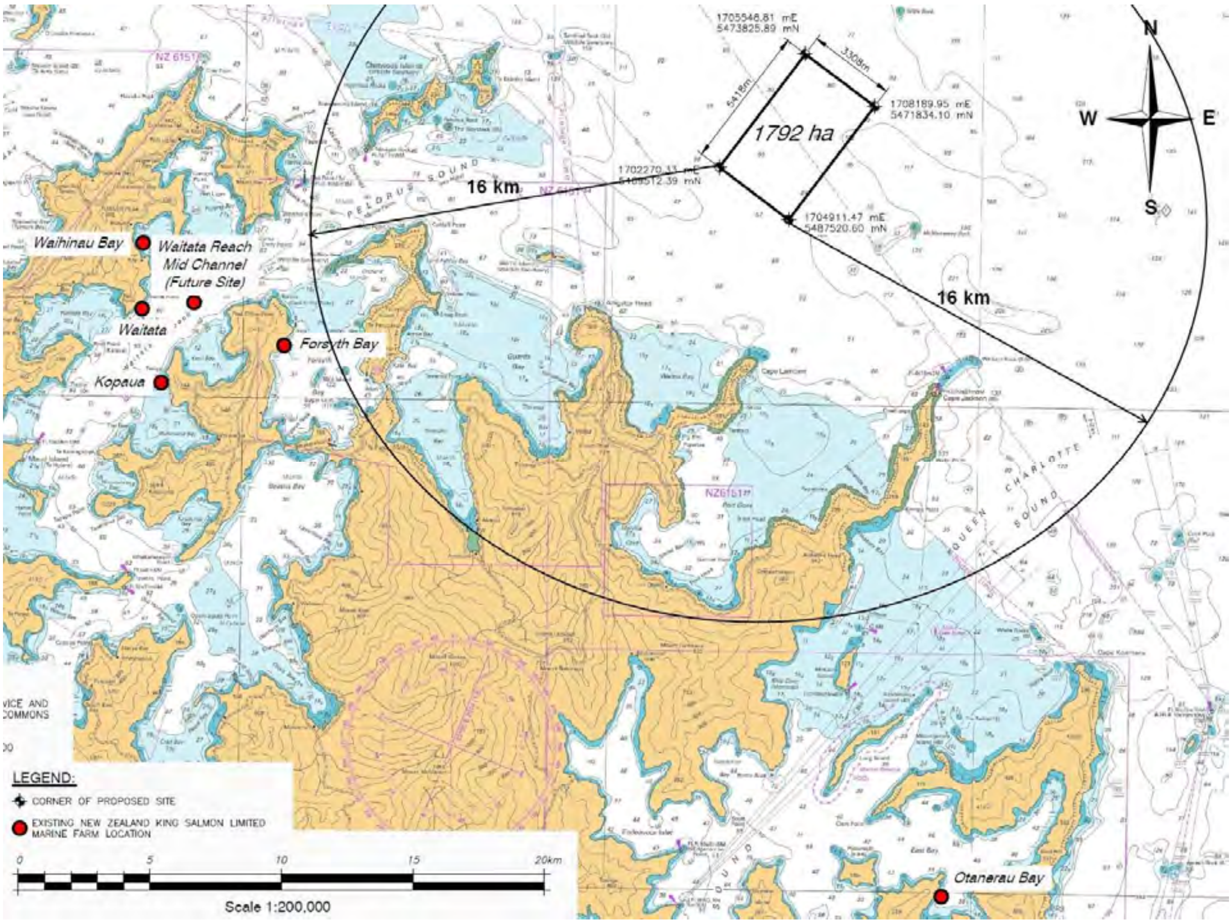

Figure 4. No existing or proposed NZKS farming sites are within a 16 km radius from the proposed offshore site. NOTE: this map does not show the proposed site at Richmond Bay South.

The width of an ideal buffer zone for any given cultured aquacultured species is defined based on epidemiological criteria, particularly those relating to movements of water (e.g. tidal excursion) and the dispersal dynamics (particularly the longevity of infective stages) of the disease agents of concern (Chambers and Ernst 2005, Gustafson et al. 2007). In the case of salmon aquaculture, the dispersal dynamics of viruses (e.g. ISA, IPN), bacteria (e.g. *Piscirickettsia*) and parasites (e.g. sea lice) appear particularly important as these disease agents have proven to be problematic overseas (Scheel et al. 2007, Wallace et al. 2008, Brooks 2009, Rees et al. 2014) and could therefore emerge in New Zealand salmonid culture at some stage in the future.

Empirical evidence and earlier modelling from the northern hemisphere showed that for viruses such as infectious pancreatic necrosis virus (IPNV) and infectious salmon anaemia virus (ISAV), infection pressures return to baseline levels between 0.5 and 8 km from infected sites, depending on several variables (Diggles 2018). However, more recent data for IPNV, ISAV and the bacteria *Piscirickettsia salmonis* from areas of high intensity salmon farming in Chile, suggest a more conservative ideal buffer zone of up to 15 km may be worth consideration for these disease agents (Diggles 2018). Figure 4 shows that no existing or proposed salmon farming sites occur within a radius of 16 km from the proposed new offshore site. The review of the scientific literature by Diggles (2018) suggested that the width of an ideal on-water buffer zone ("as the fish swims", not "as the crow flies") to ensure true independence of salmon farming management areas in New Zealand under its current disease status (in which sea lice (*Caligus* spp., *Lepeophtheirus* spp.) infections are not problematic for the resistant chinook salmon) would be somewhere around 15 km. In other parts of the world, sea lice infections are problematic for salmon farming because they farm a susceptible host species (Atlantic salmon, *Salmo salar*) in areas where wild populations of *S. salar* act as reservoirs of sea lice and other diseases (Jackson et al. 2018). Furthermore, sea lice have a non-infective nauplius stage which moults after a week or two (depending on water temperature) into a reasonably robust infective copepodid, and theoretically a single copepodid is sufficient to cause reinfection. Because of this, the distance at which sea lice infection pressure remains significantly higher than normal background levels depends on various factors, but appears to be over 8-12 km and less than 30-45 km from a source farm (Diggles 2018). Hence, if for some unknown reason at some stage in the future sea lice outbreaks became problematic in New Zealand, consideration may be required to increase the size of an ideal buffer zone, however the actual minimum distance would depend on many factors and require detailed modelling (MAF Biosecurity 2011a, Diggles 2018). A more detailed review of this subject for the various different disease agents (viruses, bacteria, metazoan parasites) can be found in Section 7.3.

3.0 Review of Disease Agents in Global Salmon Seacage Culture

Seacage culture of salmon can be associated with a range of infectious disease agents, including microparasites such as viruses, bacteria and protozoa, metazoan macroparasites such as monogeneans and crustaceans, as well as several non-infectious diseases (Kent and Poppe 1998, Kent 2000, Murray et al. 2016). The potential for diseases of seacage aquacultured salmon to impact the marine environment has attracted much scientific study. It is also a controversial issue in some parts of the world due to the activities of anti-salmon farming activists (e.g. see Gustafson et al. 2018), hence it is important that decision making in this area is based on the best available peer reviewed scientific data. In this section the major types of diseases in seacage farming of salmon in the international context are again reviewed. This has been done firstly to identify the significant diseases that have occurred overseas, to summarise their environmental impacts (if any), and identify the best practice management measures currently used for their avoidance and control.

3.1 Viral diseases

Overview

Several viral diseases have caused problems in seacage aquaculture of salmonids in the northern hemisphere, including infectious haematopoietic necrosis (IHN), birnaviruses including infectious pancreatic necrosis (IPN), infectious salmon anaemia (ISA), viral haemorrhagic septicaemia (VHS), infection with salmonid alphavirus (SAV), viral erythrocytic necrosis (VEN), erythrocytic inclusion body syndrome (EIBS) and heart and skeletal muscle inflammation (HSMI) caused by piscine orthoreoviruses (PRV), and salmonid herpes virus 2 infections (including *Oncorhynchus masou* virus) (see Kent and Poppe 1998, Murray et al 2016, Takano et al. 2016, Deperasińska et al. 2018). In the southern hemisphere, viral diseases in cultured salmon have been caused by IPN, ISA and PRV in Chile (Mardones et al. 2009, Bohle et al. 2018, Escobar-Doderoa et al. 2018), and in Tasmania other orthomyxoviruses such as Pilchard orthomyxovirus (POMV) and the Tasmanian salmonid reovirus (TSRV) (Zainathan 2012, DPIPWE 2015). Of these, the viral diseases which have caused the most significant problems in seacaged salmonids are IPN and ISA (Murray et al. 2005, 2016), though SAV is an emerging disease of Atlantic salmon, rainbow trout and Arctic char cultured in freshwater and the first year at sea (Graham et al. 2010, Deperasińska et al. 2018, Lewisch et al. 2018). VHS was once known only from salmonids cultured in freshwater, but is now known to occur naturally in wild marine and freshwater non-salmonid fish and has also emerged and caused disease in seawater farmed rainbow trout in Norway (Dale et al. 2009). Various strains of birnaviruses have been described from at least 65 species of fish in 20 families (McAllister 1993), and also from bivalve molluscs and crustaceans (Reno 1999). Isolates of IPNV-like birnaviruses from returning chinook salmon in New Zealand were identified as belonging to IPNV Genogroup 5 (Davies et al. 2010) and appear non pathogenic to salmonids (Diggles et al. 2002, McColl et al. 2010). VHSV has been recorded from at least 82 species of marine and freshwater fish (including chinook salmon) at water temperatures of 18°C or less, but VHSV has not been recorded from the southern hemisphere at this time (Diggles and Landos 2010, OIE 2018a). ISA has been reported in Europe, Canada, USA, Faroe Islands and Chile, but not New Zealand or Australia, but it appears that chinook salmon are resistant to ISAV and show no clinical signs of disease (Rolland and Winton 2003, OIE 2018b). In western Canada, some research groups suggested that there may be evidence of genetic material similar to benign ISA-like variants in less than 2% (2 "non-negatives" from 102 fish examined) of healthy chinook salmon sampled from the wild (Kibenge et al. 2016). However, there is debate about the meaning of these "non-negative" results as the presence of ISAV has never been confirmed in the Pacific North America region despite over 36,000 Pacific salmon (including O. *tshawytscha*) being tested since July 2010 using cell culture methods and over 4900 sampled using molecular tests (Amos et al. 2014. Gustafson et al. 2018), suggesting the "non-negative" results of Kibenge et al. (2016) are erroneous false positive laboratory artefacts due to a decoupling of modern vs traditional diagnostic methods (Burge et al. 2016). Cultured chinook salmon are also known to be susceptible to IHNV, and VEN but these disease agents have not been recorded from the southern hemisphere (Kent and Poppe 1998, OIE 2018c). More recently, different strains of piscine orthoreoviruses (PRV) have been found to be associated with various chronic disease syndromes including EIBS in coho salmon (*Oncorhynchus kisutch*) and chinook salmon in the USA and Japan (Takano et al. 2016), heart and skeletal muscle inflammation in cultured Atlantic salmon in Norway (Godoy et al. 2016, Wessel et al. 2017), and jaundice syndrome in coho salmon in Chile (Bohle et al. 2018), and in chinook salmon in British Columbia (Miller et al. 2017, Di Cicco et al. 2018). Of the remaining viruses infecting salmon in the southern hemisphere, the Pilchard orthomyxovirus (POMV) has caused mortalities in Atlantic salmon in Tasmania (where it is vectored by wild pilchards), while Tasmanian salmonid reovirus (TSRV) has occasionally been associated with mortalities of salmon exposed to *Piscirickettsia*-like bacteria or certain adverse environmental conditions (Zainathan 2012, DPIPWE 2015).

Environmental impacts

Viruses originating from cultured salmonids appear to have minimal impact on wild populations of finfish. Wallace et al. (2008) found a significantly higher prevalence of IPNV (0.32%) in wild marine fish caught at a distance less than 5 km from salmon aquaculture sites, than from wild marine fish caught at a distance greater than 5 km from fish farms (0.03%). This suggests that fish farms may act as a localized source of "backspill" IPNV infection to local wild fish, rather than wild reservoirs of infection posing a high risk to farmed fish (Wallace et al. 2008). However, Wallace et al. (2008) also reported that IPNV is also endemic in wild marine fish, (particularly bottom dwelling flatfish) at low prevalences (overall prevalence in 30627 fish was 0.15%), with maximum prevalence in flatfish being 12.5% in flounder (*Platichthys flesus*), while for roundfish maximum prevalence of IPNV was 1.1% in saithe (*Pollachius virens*). Indeed, it appears that IPNV and IPNV-like aquabirnaviruses and other viruses such as VHSV are naturally widespread and persistent in the marine environment in many parts of the world (Skall et al. 2005a, 2005b, Wallace et al. 2008, Davies et al. 2010). No clinical signs of IPN disease have been observed in any of the wild fish sampled from Scotland, Australia or NZ, however outbreaks of VHS due to various different genotypes of VHSV have been recorded in wild fishes in both freshwater and marine areas of the northern hemisphere (Lumsden et al. 2007, Bain et al. 2008). These outbreaks of VHS in wild fishes have not been associated with aquaculture activities, but have been variously associated with stressors due to spawning, pollution or other environmental factors (Elston and Myers 2009), including introduction of virus into naïve populations of fish via natural or anthropogenic movements of live fishes or ballast water (Bain et al. 2010, Diggles and Landos 2010). Disease outbreaks of other viruses such as IHNV have been associated with immunosuppression of wild salmon due to reduced water quality (Clifford et al. 2005). Infection with salmonid alphavirus (SAV) has been reported from some wild species of flatfish and wrasses which act as reservoirs for the disease (Snow et al. 2010, Bruno et al. 2014, Deperasińska et al. 2018), but the presence of the virus has not been associated with disease or any detectable changes in population status of infected flatfish or wrasses (Bruno et al. 2014, Jones et al. 2015), nor have alphaviruses been found in wild salmonids (Snow 2011, Jones et al. 2015, Deperasińska et al. 2018). Piscine orthoreoviruses have been known for several decades to occur naturally in wild salmonids, even in remote regions including chinook salmon in Alaska (Purcell et al. 2018). One particular strain of orthomyxovirus (PRV2) has recently been shown to cause EIBS and low level mortalities in coho and chinook salmon in the northern hemisphere (Takano et al. 2016). Another strain (PRV1) causes HSMI in cultured Atlantic salmon in Norway (Wessel et al. 2017) and other parts of Europe, and a PRV3 strain causes HMSI-like symptoms in coho salmon cultured in Chile (Godoy et al. 2016). In contrast, a Pacific coast strain of PRV1 from Canada, while transmissible, did not cause disease in Atlantic salmon, chinook salmon and sockeye salmon (Garver et al. 2016b, Di Cicco et al. 2017). It appears that while these other strains of PRV1 may be able to infect chinook salmon in the laboratory (e.g. Garver et al. 2016a), suggestions by some authors that they may cause disease in wild chinook salmon (Morton et al. 2017) remain purely speculative (Garver et al. 2016a, 2016b). Indeed, these viruses commonly occur in healthy wild fishes at low prevalences (c. 3-10%) that may vary seasonally (Bass et al. 2017, Miller et al. 2017, Purcell et al. 2018, Tucker et al. 2018) and have never been associated with disease in wild fishes. Furthermore, even in cultured chinook salmon a causal relationship between the presence of PRV1 strains and jaundice disease has not been demonstrated experimentally (Garver et al. 2016a, 2016b, De Cicco et al. 2017, 2018), as large numbers of healthy fish test positive for PRV at prevalences approaching 100%, although PRV tends to occur at higher levels in all jaundiced fish, often in mixed infections with other disease agents (Miller et al. 2017, Di Cicco et al. 2018). At this time there appears to be sufficient information to suggest that high levels of PRV1 are associated with jaundice and low level mortalities (<5%) in cultured chinook salmon, but there is no evidence that suggests the health of wild chinook salmon is affected in any way by piscine orthoreoviruses.

An orthomyxovirus that was first reported from farmed Atlantic salmon in Tasmania in 2006 was identical to pilchard orthomyxovirus (POMV) that was originally identified from wild pilchards

(*Sardinops sagax-neopilchardus*) in South Australia in 1998 (SCAHH 2015). Outbreaks of disease due to POMV in cultured Atlantic salmon have occurred in Tasmania since 2012 and are associated with sub-clinically infected wild pilchards schooling around salmon sea cages (SCAHH 2015). Given their apparent resistance to other orthomyxoviruses such as ISA, it is not known whether chinook salmon are susceptible to POMV, and at this time there is no evidence that POMV occurs in pilchards in New Zealand. However in recent POMV outbreaks in Macquarie Harbour in Tasmania, only cultured Atlantic salmon were affected, with no disease recorded in either cultured rainbow trout, or wild pilchards[1]. This suggests that POMV has a narrow host specificity, increasing the likelihood that chinook salmon are potentially resistant to infection with POMV. In 1995, widespread mortalities of pilchards infected by the first outbreak of pilchard herpesvirus (PHV) were observed in New Zealand, after PHV disease spread throughout populations of pilchards in Australia (Whittington et al. 2008). It appears the herpesvirus was introduced into New Zealand in 1995 via infected frozen pilchards used as bait 4 weeks after a shipment of infected pilchards was received in New Zealand from Bremer Bay, Western Australia (Hine 1995, Fletcher et al. 1997, Crockford 2007, P.M Hine, personal communication). However in 1998-99 a second epizootic due to PHV in Australia did not reach New Zealand, probably due to immediate implementation of a temporary ban on movements of frozen pilchards from Australia to New Zealand during the entire course of the second event (P.M. Hine and B.K Diggles, personal observation). Taking these factors into consideration, it is considered extremely unlikely that POMV infected pilchards from Australia would be able to naturally reach New Zealand and precipitate a disease outbreak in cultured chinook salmon.

Best practice management

Because salmon farming is done in seacages in regions where wild fishes occur, it is impossible to fully control the presence of viral disease agents in the rearing environment. There are no effective treatments for viral diseases and prevention is the key form of management. Screening of broodstock for key viruses and vaccination of seedstock can be highly effective in controlling the spread of viral diseases (Nylund et al. 2007, Munro et al. 2010, Dadar et al. 2017, Wessel et al. 2018). Maximising water quality and reducing or eliminating exposure to pollutants such as pesticides can also assist in maximizing immune competence of cultured fish, which can reduce the prevalence and severity of viral diseases (Clifford et al. 2005). Good husbandry that includes prevention of fish escapes, frequent removal of sick or dead fish, optimising fish nutrition, control of potential vectors, and implementation of effective on farm biosecurity controls (e.g. disinfection) at critical areas such as personnel entry points are also useful preventative measures. Biosecurity strategies that have also been used at an industry planning level to minimize the risk of outbreaks of important viral diseases such as ISA have included use of independent farm management areas where production from several farming sites can be co-ordinated and synchronised using single year classes of fish, and where integrated disease management procedures that include site fallowing can be implemented if necessary (Munro et al. 2003, Chang et al. 2007, Marine Harvest 2008, Brooks 2009, Jones et al. 2015, Oidtmann et al. 2017). Separation of the farm management areas by buffer zones of sufficient distance to reduce the risk of horizontal disease transmission via movements of water and wild fishes is also useful to avoid and/or control outbreaks of viral disease (Scheel et al. 2007). When best practice disease management methods

[1] https://www.abc.net.au/news/2018-05-29/salmon-deaths-in-macquarie-harbour-top-one-million-epa-says/9810720

such as those mentioned above are utilized, risks of viral pathogen transmission to wild fish populations are effectively mitigated (Jones et al. 2015).

3.2 Bacterial diseases

Overview

All fish have a "normal" bacterial flora (also known as bacterial biota, see Tarnecki et al. 2018) that changes seasonally (Bisset 1948) and which is moved with the fish whenever the host is translocated. There are also facultative bacterial pathogens such as those in the *Flavobacterium*/*Cytophaga*/*Tenacibaculum* group (including *Tenacibaculum maritimum*), *Vibrio* sp. groups and *Nocardia* sp. groups that are considered to be ubiquitous in aquatic environments (Austin and Austin 2007), including in New Zealand (Diggles et al. 2002, Brosnahan et al. 2017b, 2018), but certain strains of which can cause disease and mortalities in a wide range of aquatic animals that are stressed, injured and/or exposed to adverse environmental conditions. However there are also specific bacterial pathogens that are not considered to be ubiquitous and which are limited in their distribution (Toranzo et al. 2005). The latter include typical strains of *Aeromonas salmonicida,* which can cause Furunculosis (*A. salmonicida* subsp. salmonicida), and atypical strains of *A. salmonicida* which can cause other diseases such as goldfish ulcer disease. Both typical and atypical strains of *A. salmonicida* are highly pathogenic for salmonids and have been translocated to new areas with movements of live, dead and frozen fish (Ostland et al. 1987, Whittington et al. 1987). Typical strains of *A. salmonicida* have not been recorded from Australia or New Zealand to date (Diggles et al. 2002, McIntyre et al. 2010), however atypical strains of *A. salmonicida* cause goldfish ulcer disease in Australia and Atlantic salmon *(Salmo salar)* in that country were shown to be extremely vulnerable to infection (Whittington and Cullis 1988). In New Zealand, wild lampreys (Kanakana, *Geotria australis*) were reported with haemorrhagic external lesions in several river systems in Southland in the spring of 2011. Testing by MAF Biosecurity confirmed that an uncharacterized, unculturable atypical strain of *A. salmonicida* was associated with the lesions but was not acting as a primary pathogen (MAF Biosecurity 2011b, Brian Jones, personal communication 29 May 2016).

Another important bacterium *Yersinia ruckeri* occurs in freshwater, and is the causative agent of enteric redmouth disease (ERM), which was first described in rainbow trout from the Hagerman Valley, in Idaho, USA in the 1950s (Rucker 1966). ERM was reported for the first time in Europe in the 1980's, with the bacterium possibly being introduced through movements of live baitfish from the USA (Michel et al. 1986, Davies 1990). A different strain of *Y. ruckeri* occurs in New Zealand, where it occasionally infects juvenile chinook salmon reared in freshwater causing the milder disease yersinosis (Diggles et al. 2002). Bacterial kidney disease caused by *Renibacterium salmoninarum* causes chronic mortality in seacage cultured chinook and coho salmon in Europe and British Columbia (Kent and Poppe 1998), however this bacterium has not been recorded from Australia or New Zealand. *Piscirickettsia*, *Francisella*, and other rickettsia-like organisms (RLOs) have been problematic in the culture of salmon in several regions of the world (Corbeil et al. 2005, Colquhoun and Duodu 2011), including Atlantic salmon in Europe and Chile (Rees et al. 2014), chinook salmon in British Columbia (Kent and Poppe 1998), Atlantic salmon in Australia (Corbeil et al. 2005, Corbeil and Crane 2009), and most recently in chinook salmon in New Zealand (MPI 2015, 2016, Brosnahan et al. 2017a, 2018, Gias et al. 2018). The onset of piscirickettsial disease in salmonids usually occurs after transfer of fish from freshwater to seawater net pens and naturally infected, apparently healthy wild marine fish are likely sources of *Piscirickettsia*-like bacteria (PLB) (Mauel and Miller 2002, Colquhoun and Duodu 2011).

Environmental impacts

Bacteria originating from cultured salmonids generally have minimal impact on wild populations of finfish or other aquatic animals. Optimisation of the rearing environment and elimination of stressors such as low oxygen, high water temperatures or overstocking, and incorporation of routine fish health management procedures (Jones et al. 2015, and see below) are usually sufficient to prevent most bacterial infections from reaching intensities that could promote "backspill" infection of wild fish stocks. Consequently, there is little evidence that most types of bacteria harboured by cultured fish can cause clinical disease in wild fish, however spread of furunculosis from cultured salmonids in Norway into naïve populations of wild salmonids has been observed (Johnsen and Jensen 1994), with potentially detrimental impacts on wild salmonids being noted by those authors. On the other hand, it is well established that wild fish act as reservoirs of infection of aquacultured fish with many bacterial disease agents (Kent and Poppe 1998), and the vast majority of detections of significant bacteria such as *A. salmonicida* in wild fishes are from asymptomatic carrier fish (Nomura et al. 1993).

Best practice management

Best practice management of bacterial diseases includes many of the management methods used to minimize spread of viral disease agents, particularly vaccination. As bacterial disease agents are usually opportunistic pathogens, good husbandry that reduces/eliminates physical handling of fish to avoid damage to skin and fins, optimising fish nutrition, maximising water quality to maximize immune competence (including maintaining dissolved oxygen levels above 6 mg/L, reducing temperature and salinity fluctuations, avoiding temperature extremes (>17°C) and exposure to pollutants [Ellard 2015, Brosnahan et al. 2018]), and prompt removal of moribund or dead fish can markedly reduce the prevalence and severity of bacterial diseases (Kent and Poppe 1998). Many bacteria are susceptible to antibiotic treatment which is usually administered in-feed (Kent and Poppe 1998), however resistance to antimicrobials can develop, and vaccination is now commonly used to reduce or eliminate bacterial diseases in seacage growout of salmonids and other marine fishes (Håstein et al. 2005, Dadar et al. 2017).

3.3 Fungal diseases

Overview

Several types of fungi are considered to be ubiquitous opportunistic saprobes which can overwhelm the innate immune system and infect aquatic animals that are injured, stressed or immunocompromised by exposure to suboptimal conditions, such as pollutants or rapid drops in water temperature (Roberts 2001). Examples include oomycete water moulds such as *Saprolegnia* which are well known opportunistic invaders of compromised salmonids or their eggs in freshwater areas (Roberts 2001), and *Exophiala* spp. which have caused disease in salmonids cultured in seacages (Kent and Poppe 1998). However there are also other fungus-like pathogens of salmonids that are not considered to be ubiquitous in their distribution, such as *Ichthyophonus hoferi* which is a fungus-like protistan that has caused disease in salmonids reared in seawater (Kent and Poppe 1998). *Icthyophonus hoferi* has low host specificity, infecting at least 70 species of fish (Zubchenko and Karaseva 2002), including brown trout, rainbow trout and Atlantic salmon in Tasmania (Slocombe 1980, Ellard 2015), however *I. hoferi* has not been recorded in New Zealand. The closely related rosette agent is considered to be an obligate intracellular parasite of chinook salmon that was identified as *Spaerothecum destruens* by Arkush et al. (2003), and which has been placed with *Ichthyophonus* in the Ichthyosporea within the clade Mesomycetozoa (Sina et al. 2005, Gozlan et al. 2009). Another fungus-like pathogen found in wild chinook salmon in North America is *Dermocystidium salmonis*, which has caused disease in wild prespawning fish in some years (Bass et al. 2017). Both the fungus-like rosette agent and *D. salmonis* have never been recorded in the southern hemisphere.

Environmental impacts

There is no evidence that fungi harboured by cultured salmonids can cause increased disease in wild fish. Optimisation of the rearing environment and reduction of stressors are usually sufficient to prevent most fungal infections from progressing. On the other hand, it is well established that wild fish can act as reservoirs of infection of aquacultured fish with many fungal disease agents (Kent and Poppe 1998), and indeed, *Ichthyophonus hoferi* is well known to naturally cause disease, morbidity and even mass mortality in wild fishes (Zubchenko and Karaseva 2002), as well as in cultured fishes fed *I. hoferi* infected wild fishes (Slocombe 1980).

Best practice management

Best practice management of fungal diseases include many of the management methods used to minimize spread of viral and bacterial disease agents. As many fungal disease agents are ubiquitous opportunistic pathogens that usually secondarily invade damaged tissues, good husbandry that reduces/eliminates physical handling of fish to avoid damage to skin and fins, optimising fish nutrition, maximising water quality, including maintaining dissolved oxygen levels above 6 mg/L, reducing temperature and salinity fluctuations and avoiding temperature extremes and exposure to pollutants to maximize immune competence can reduce the prevalence and severity of fungal diseases. Vaccination may also be a useful approach in some cases (Dadar et al. 2017). Use of formulated pellet diets and avoidance of natural feeds may be useful methods of avoiding infection with *Ichthyophonus hoferi* and *Spaerothecum destruens*, which may be transmitted orally through consumption of infected fish (Slocombe 1980, Kent and Poppe 1998). Use of hydrogen peroxide or iodophores can reduce water mould infections of eggs, however treatment of growout fish with other fungicidal drugs is usually problematic due to the potential for residues that conflict with strict food safety requirements (Kent and Poppe 1998).

3.4 Protozoal diseases

Overview

A variety of diseases caused by protozoan agents have been recorded from salmonids cultured in seacages, including infections by amoebae, microsporidians, flagellates and ciliates (Kent and Poppe 1998). Cultured salmonids in many parts of the world are adversely affected by amoebic gill disease (AGD), which is caused by infection of the gills with free living amoebae, predominantly *Neoparamoeba perurans* (see Young et al. 2007, Young et al. 2008, Crosbie et al. 2012). *Neoparamoeba perurans* has been recorded in chinook salmon in New Zealand in the absence of disease (Young et al. 2008), and chinook salmon appear relatively resistant to this disease agent (Munday et al. 2001). Microsporidians are obligate, intracellular parasites that infect arthropods, fish, and mammals (Lom and Dykova 1992). In fish, microsporidian infections can be widespread in various tissues or concentrated into cysts that are often grossly visible. The lifecycle is usually direct, but can include an intermediate host (Vossbrinck et al. 1998). The microsporidian *Loma salmonae* infects the gills and other vascularized tissues of wild and hatchery-reared salmonids in fresh water throughout the Pacific Northwest (Kent et al. 1995). Severe gill infections have been reported in cultured rainbow trout (*Oncorhynchus mykiss*) and kokanee salmon (*O. nerka*), while systemic infections by *L. salmonae* have also been reported in cultured chinook salmon. The susceptibility of various salmonid species to *Loma* was investigated by Ramsay et al. (2002), and chinook salmon was shown to be the most susceptible species. Although the gill is the primary site of infection, the route of initial infection is via the gut and parasites and associated lesions can occur elsewhere, including the heart, spleen, kidney, and pseudobranch (Kent and Speare 2005, Becker and Speare 2007). *Loma salmonae* is considered to be a freshwater parasite, but infections can persist after fish are transferred to seawater (Kent and Poppe 1998). Microsporidians with possible affinities with *L. salmonae* have been recorded in chinook salmon cultured at farming sites in Kopaua and Otanerau in the Marlborough Sounds (Cesar Lopez, NZKS veterinarian, personal communication). Other microsporidians known to infect cultured salmon include *Desmozoon lepeophtherii* (syn. *Paranucleospora theridion*) which infects both sea lice and Atlantic salmon in Europe (Nylund et al. 2010), contributing to proliferative gill inflammation (Nylund et al. 2011, Matthews et al. 2013). A range of other microsporidians are known to naturally infect wild chinook salmon during the marine stage of their lifecycle, including *Facilospora margolisi* (see Bass et al. 2017). The flagellates *Ichthyobodo*, *Hexamita* and *Cryptobia* have caused mortality in a range of species of seacaged salmonids in the northern hemisphere (Kent and Poppe 1998). *Hexamita salmonis* is normally a parasite of the intestinal tract of salmon in freshwater, but it persisted after transfer of fish to marine sites and caused severe disease and up to 50% mortalities in seacage cultured chinook salmon in British Columbia (Kent and Poppe 1998). *Ichthyobodo necator* and *Cryptobia salmositica* are other flagellate parasites of freshwater fishes that can persist on salmonids after transfer into seawater, causing disease in chinook salmon (Kent and Poppe 1998). The ciliate *Ichthyophthirius multifiliis* is a ubiquitous parasite that is responsible for white spot disease in freshwater fish (Matthews 2005). *Ichthyophthirius multifiliis* can infect salmonids during the freshwater stages of the production cycle, but the parasite cannot complete its lifecycle in seawater. Ciliates that have been recognised to cause disease in seacaged salmon are *Trichodina* spp., which can occur on the skin and gills (Kent and Poppe 1998).

Environmental impacts

There is no evidence that protozoans harboured by cultured salmonids can cause increased disease in wild fish. Amoebae responsible for AGD are ubiquitous and free living in the environment (Bridle et al. 2010, Crosbie et al. 2012) and only proliferate on the gills and cause disease in fish cultured under certain stressful situations (Kent et al. 1988, Wright et al. 2017a,b). Although common in wild salmon, *L. salmonae* is not usually considered a severe pathogen in wild salmon (Kent 2000), though occasional heavily infected fish may be recorded due to the typical overdispersed distribution of parasitic infections in wild fish (Kent et al. 1998). In contrast, wild fish are recognized as reservoirs of infection of many parasitic protozoans, including flagellates and ciliates that only become problematic in aquacultured fish held at high densities (Kent et al. 1998).

Best practice management

Best practice management of protozoan diseases include many of the management methods used to minimize spread of viral, bacterial and fungal disease agents. Good husbandry that reduces/eliminates physical handling of fish to avoid damage to skin and fins, optimising fish nutrition, frequent net cage cleaning, maximising water quality, including maintaining dissolved oxygen levels above 6 mg/L, reducing temperature and salinity fluctuations and avoiding temperature extremes and exposure to pollutants to maximize immune competence can reduce the prevalence of protozoan diseases. Proliferation of protozoan parasites is encouraged by high stocking densities (Crosbie et al. 2010), hence use of moderate stocking densities (<15 kg/m^2) is recommended. Protozoan infections can often be reduced by frequent net cleaning (this interrupts life cycles of some protozoans), bathing seacaged fish in freshwater, or hydrogen peroxide baths (Martinsen et al. 2018), though this is a laborious process that is stressful to fish and increases production costs, a problem which has increased interest in innovative alternative therapies such as “snorkel” sea cage designs that reduce amoebic infections (Wright et al. 2017a, Sitjá-Bobadilla and Oidtmann 2017). Fish can recover from protozoan infections under appropriately favourable environmental conditions, and in these cases may mount robust immune responses (e.g. Kent and Speare 2005), suggesting that vaccination may also represent a promising method for disease control for the most problematic protozoan diseases.

3.5 Metazoan diseases

Overview

Salmonids in seacages can be infected by a wide range of metazoan disease agents, including myxosporeans, copepods, monogeneans, digeneans, cestodes, and nematodes (Kent and Poppe 1998, Kent 2000). Some metazoan parasites have complicated multi-host lifecycles (Rohde 1984), while others (particularly ectoparasitic monogeneans and crustaceans) have direct lifecycles which can be readily completed when fish are confined at high densities in seacages. Several species of myxosporean parasites have been recorded in seacage cultured salmonids, including *Kudoa thyrsites*, *Ceratonova* (*Ceratomyxa*) *shasta*, *Chloromyxum truttae*, *Myxobolus* spp., *Parvicapsula* sp. and *Tetracapsuloides bryosalmonae* (see Kent and Poppe 1998, Bass et al. 2017). The lifecycle of many myxosporeans requires invertebrate intermediate hosts (Markiw and Wolf 1983, Wolf and Markiw 1984), though it appears that some myxosporeans can be transmitted directly (Diamant 1997, Swearer and Robertson. 1999, Yasuda 2002). Species such as *K. thyrsites* which causes muscle liquefaction, appear ubiquitous (Moran and Kent 1999, Moran et al. 1999a, Whipps et al. 2003). While *Kudoa* spp. have been recorded from New Zealand fishes (Hine et al. 2000), *K. thyrsites* has not been officially recorded (Hine et al. 2000), though known hosts (barracouta, *Thyrsites atun*) are present in New Zealand and indeed juvenile *T. atun* have been observed in seacages with cultured salmon (B. Diggles, personal observations). Attempts to transfer *K. thyrsites* infection by feeding spores to Atlantic salmon failed to transmit infection, however Atlantic salmon held in seacages in marine waters where *K. thyrsites* was enzootic became infected within 2 weeks (Moran et al. 1999b). This suggests that fish in seacages may become infected indirectly through contact with infective stages (actinospores) released by intermediate hosts, directly by eating presporogonic stages excreted by other infected fishes (or via cannibalism), or even by obtaining presporogonic stages via blood transferred by blood feeding vectors such as copepods or leeches (Moran et al. 1999b).

Crustacean ectoparasites of fish invade the fins, gills, skin and other body cavities (Kabata 1979, 1984). Their lifecycles are direct with fish being infected by planktonic copepodid larval stages that hatch from eggs deposited by adult copepods (Kabata 1984). Several types of crustaceans have been recorded from salmonids cultured in seacages. These include members of the families Caligidae (Sea lice), Ergasilidae, Penellidae, isopods and branchiurans (Kent and Poppe 1998). Wild salmonids and other marine fish are the usual reservoirs for crustacean parasites that affect cultured salmonids (Brooks 2009, Gottesfeld et al. 2009, Penston et al. 2011, Molinet et al. 2011). Of the various groups of crustacean ectoparasites, sea lice infections are responsible for the majority of problems in seacage culture of salmonids in the Northern hemisphere and Chile (Krkosek et al. 2005, Costello 2006, 2009, Todd 2007, Molinet et al. 2011, Murray et al. 2016, Wright et al. 2017a), while deaths due to consumption of free living isopods by seacaged fish has been recorded in salmon culture in New Zealand (Boustead 1989).

Monogeneans are ectoparasitic helminths with direct lifecycles that are occasionally seen in cultured salmonids in the northern hemisphere, but are seldom problematic (Kent and Poppe 1998). Digeneans, cestodes and nematodes are endoparasitic helminths that live in the gastrointestinal tract of fishes and other vertebrates. The digenean lifecycle requires a molluscan first intermediate host with plankton eating fishes as final hosts, or second intermediate hosts in some lifecycles where final hosts include larger fishes, birds and mammals. The cestode lifecycle generally requires crustaceans (e.g. copepods) as the first intermediate host with plankton eating fishes as final hosts, or second intermediate hosts in some lifecycles where final hosts include larger fishes, sharks, birds or mammals (Rohde 1984, Noga 2010). The lifecycle of nematodes requires crustaceans (e.g. copepods) as the first intermediate host with plankton eating fishes as final hosts, or second intermediate hosts in some lifecycles where final hosts include larger fishes, birds or mammals (Rohde 1984). Salmonids in seacages worldwide can be infected by several species of digeneans, cestodes and nematodes if the fish consume natural prey items such as molluscan or crustacean intermediate hosts (Kent and Poppe 1998), but these helminth infections naturally occur in wild fishes and seldom, if ever, cause disease.

Environmental impacts

The environmental impacts of the majority of metazoan disease agents of cultured salmonids are negligible, however there is evidence in some regions of the world where intensive salmon farming occurs in seacages and salmonids are native fishes that occur naturally in the wild, that large populations of farmed salmon can act as reservoirs of sea lice (mainly *Lepeophtheirus salmonis*, but also other species including *Caligus elongatus*, *C. rogercresseyi* or *C. clemensi*) which can result in increased "spillback" infection of wild salmonids that must swim past seacage sites during their migrations (Krkosek et al. 2005, Costello 2006, 2009, Todd 2007, Amundrud and Murray 2009, Jones et al. 2015). The additional infection pressure exerted by large numbers of salmon farms can increase sea lice burdens on wild fish, potentially resulting in increased morbidity or even mortality in juveniles leaving salmon rivers or early river entry in adult fish returning to rivers to spawn (Krkosek et al. 2005, Wells et al. 2007, Todd 2007, Costello 2009, Moore et al. 2018). Experimental treatment of wild salmon to remove sea lice increased salmon survival by odds ratios of 1.14 – 1.17 in Irish and Norwegian studies, respectively, although meta-analyses by other authors conclude sea lice treatments improve wild salmon survival even more (Jones et al. 2015). Nevertheless the relationship between salmon farms and sea lice infections on wild fish is complex (Moore et al. 2018), and the ongoing scientific debate regarding the quantitative effect of sea lice infection on wild salmonids emphasises the challenges associated with attempting to quantify the incremental impact of these parasites within wild fish populations already experiencing >95% natural mortality (Jones et al. 2015).

Best practice management

Best practice management of metazoan diseases include many of the management methods used to minimize spread of viral, bacterial, fungal and protozoan disease agents. Good husbandry that optimises fish nutrition, frequent cleaning of cage netting to interrupt parasite lifecycles, and ensuring the best possible water quality will maximize immune competence and potentially reduce the prevalence of some metazoan disease agents. Proliferation of metazoan parasites is encouraged by high stocking densities, hence use of moderate stocking densities (<15 kg/m^2) is indicated. Biosecurity strategies that have also been used at an industry planning level to minimize the risk of sea lice outbreaks include use of independent farm management areas where production from several farming sites can be co-ordinated and synchronised, and where integrated disease management procedures that can include site fallowing can be implemented if necessary (Chang et al. 2007, Brooks 2009). Separation of the farm management areas by buffer zones of sufficient distance to reduce the risk of horizontal disease transmission via water movements is also useful to avoid and/or control outbreaks of disease caused by sea lice (Brooks 2009, Sobrazo et al. 2018, see also Section 7.3). Sea lice have been controlled in salmon cultured in the northern hemisphere through oral administration of drugs such as emamectin benzoate (SLICE), though development of drug resistant strains of parasites has been noted in some areas (Sitjá-Bobadilla and Oidtmann 2017). Because of this, recent research has investigated innovative alternative therapies such as "snorkel" sea cage designs (Wright et al. 2017a) and thermal delicing through exposure to warm freshwater baths (Grøntvedt et al. 2015). There are no drugs commercially available to control myxosporean infections, however regular cleaning of nets may help remove a range of invertebrates that are potential intermediate hosts for myxosporeans such as *K. thyrsites*. Most helminth infections can be reduced by oral treatment with anthelmintics, while many types of ectoparasitic metazoans can also be managed by bathing seacaged fish in freshwater, formalin or hydrogen peroxide baths (Martinsen et al. 2018), though this is a laborious process that increases production costs and stresses fish.

4.0 Description of the existing environment - Disease Agents in New Zealand Salmon

A comprehensive review of the literature relating to the diseases and parasites of salmon (*Oncorhynchus tshawytscha*, *O. nerka*) in New Zealand was conducted, including key references such as Boustead (1982, 1989), Anderson (1995, 1996, 1998), Hine et al. (2000), Diggles et al. (2002), McIntyre et al. (2010) and the references cited therein. Information compiled since a previous risk assessment Diggles (2016) was also updated by contacting fish health experts within the NZ Ministry for Primary Industries (MPI), as well as searching multiple electronic databases including Cambridge Scientific Abstracts, Scirius, Scopus and Web of Knowledge with keywords salmon and New Zealand. Unpublished data relating to the infectious and non-infectious diseases of chinook salmon encountered by NZKS veterinarians was also included. A list of the known diseases and parasites of wild and cultured salmon in New Zealand is contained in Table 1. The list contains 25 infectious disease agents of wild and cultured salmon, including 1 virus (aquatic birnavirus), 7 bacterial diseases, 1 fungal disease, 4 protozoan disease agents and 12 metazoan disease agents (Table 1). The list also contained 12 non-infectious diseases that have been reported mainly from cultured salmon (Table 1).

Table 1. List of the known infectious and non-infectious diseases and parasites recorded from wild and cultured salmon (*Oncorhynchus tshawytscha, O. nerka*) in New Zealand.

Disease	Under official control	Occurs in cultured salmon in NZ	May cause significant disease in wild marine fish	May cause significant disease in seacaged fish
INFECTIOUS AGENTS				
VIRUSES				
Aquatic Birnavirus (IPNV Genogroup 5)	Yes	No	No	Yes
BACTERIA				
Flexibacter spp./ *Tenacibaculum* spp.	No	Yes	No	Yes
Bacterial gill disease	No	Yes	No	No
Mycobacterium spp.	No	Yes	No	No
Nocardia spp. (Nocardiosis)	No	Yes	No	No
Piscirickettsia-like bacteria (NZ-RLO)	Yes	Yes	No	Yes
Vibrio spp.	No	Yes	No	Yes
Yersinia ruckeri (Yersinosis)	No	Yes	No	No
FUNGI				
Saprolegnia spp.	No	Yes	No	No
PROTOZOA				
Chilodonella spp., *Trichodina* spp.	No	Yes	No	No
Ichthyophthirius multifiliis	No	Yes	No	No
Microsporidia	No	Yes	No	No
Neoparamoeba perurans / Cochliopodida sp.	No	Yes	No	Yes
METAZOA				
Digenea				
Derogenes varicus	No	No	No	No
Lecithocladium seriolellae	No	No	No	No
Parahemiurus sp.	No	No	No	No
Tubovesicula angusticauda	No	No	No	No
Cestoda				
Hepatoxylin trichiuri	No	No	No	No
Phyllobothrium sp.	No	No	No	No
Nematoda				
Heduris spinigera	No	No	No	No
Hysterothylacium sp.	No	Yes	No	No
Crustacea				
Caligus spp.	No	Yes	No	Yes
Cirolana sp.	No	Yes	No	No
Paeonodes nemaformis	No	No	No	No
Myxozoa				
Myxobolus cerebralis	Yes	Yes	No	No
NON-INFECTIOUS AGENTS				
Algal blooms	No	Yes	Yes	Yes
Cardiomyopathy	No	Yes	No	No
Gas Bubble Disease	No	Yes	No	No
Gastric Dilation and Air Sacculitis (GDAS)	No	Yes	No	Yes
Isopod invasion	No	Yes	No	Yes
Jellyfish strike	No	Yes	No	Yes
Neoplasia	No	Yes	No	No
Nephrocalcinosis	No	Yes	No	No
Pinhead syndrome, Runting	No	Yes	No	No
Seal predation	No	Yes	No	No
Skin lesions/sunburn	No	Yes	No	No
Spinal deformity	No	Yes	No	Yes

5.0 Assessment of Environmental Effects

After defining the known diseases of salmon in New Zealand (Table 1), the next step in the assessment of environmental effects is to identify those diseases that represent potential hazards to the environment. For the remainder of this risk assessment, the commodity being considered will be chinook salmon (*O. tshawytscha*) reared in sea cages at a new offshore salmon farming area in the Cook Strait north of the Marlborough Sounds.

5.1 Hazard Identification

To determine which diseases are likely to represent hazards to the environment, the criteria for consideration during the hazard identification process were as follows:

For each disease agent in the initial list, the following questions were considered:

1. Is the disease agent infectious?, and;

2. Whether chinook salmon cultured in seacages could potentially be infected by the disease agent.

For any disease agent, if the answers to both questions 1 and 2 was 'yes', it was classified as a potential hazard (Figure 5). For all potential hazards, any of those considered likely to cause detrimental impacts to the environment based on one or more of the following criteria were classed as diseases of concern that required detailed risk assessment. The criteria used included whether:

- If the disease agent is "under official control", by its listing in New Zealand's national list of reportable diseases of aquatic animals (Table 2); and/or

- it would be expected to cause a distinct pathological effect in an infected population; and/or

- it would be expected to cause economic harm (e.g. increased mortality, reduced growth rates, decreased product quality, loss of market access, increased costs); and/or

- it would be expected to cause damage to the environment and/or endemic species (defined as either native species that occur naturally in New Zealand's waters, or species that were introduced into New Zealand and are now considered to be acclimatised).

The process used for decision making in relation to the hazard identification process is summarised in Figure 5. Non-infectious diseases and infectious disease agents that are not considered likely to cause a distinct pathological effect in affected populations, and/or economic harm, and/or damage to the environment were considered to represent a negligible risk, and were excluded from further assessment. The reasons why these other infectious disease agents were excluded from detailed risk assessment are elaborated upon in more detail in the following section.

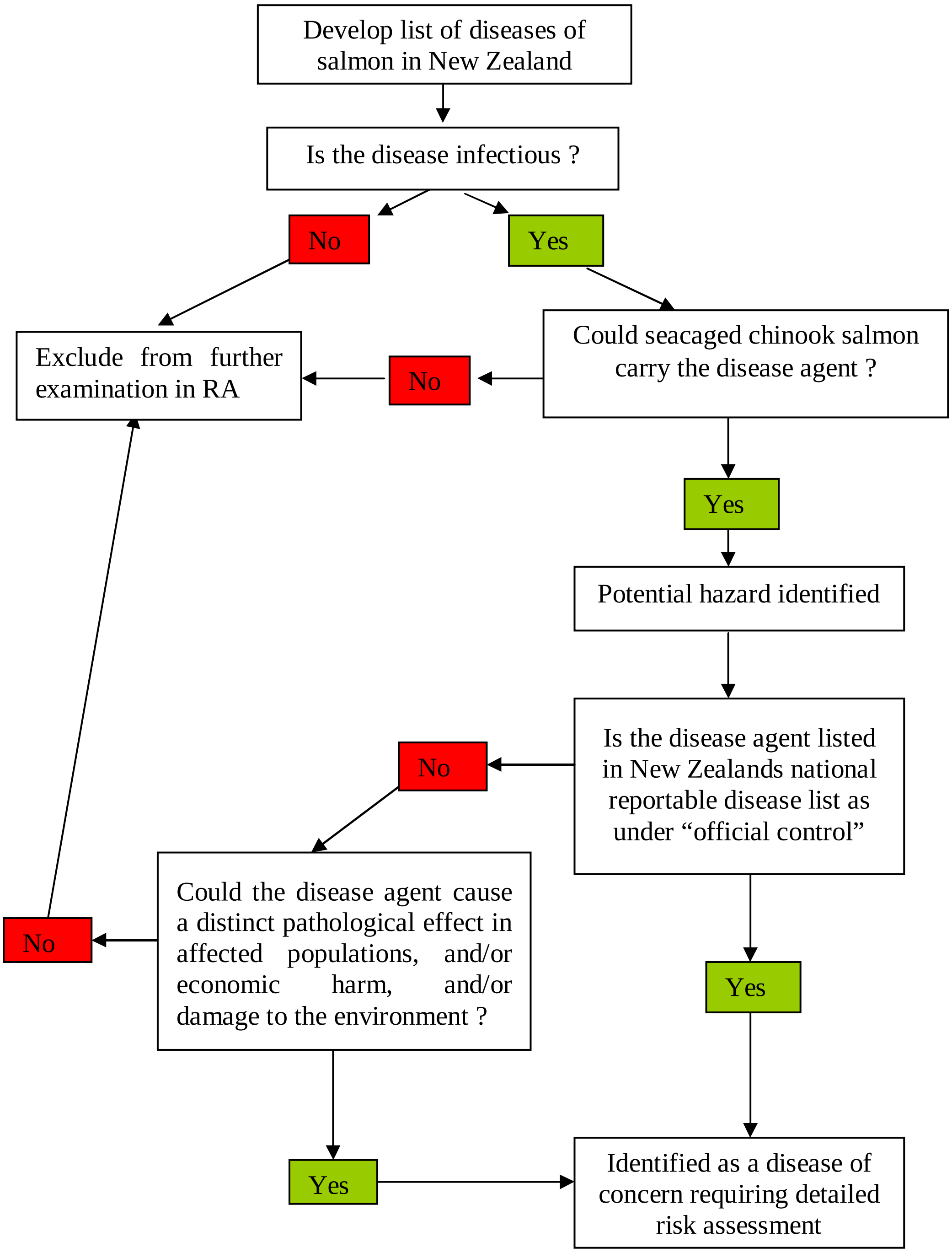

Figure 5. Flow chart showing the decision making process used to identify diseases of concern in the hazard identification step.

Table 2. New Zealand's national list of notifiable diseases of finfish (i.e. diseases under official control). (https://www.mpi.govt.nz/protection-and-response/finding-and-reporting-pests-and-diseases/registers-and-lists/)

New Zealand's National List of Notifiable Diseases of Finfish (as of Dec 2018)	Listed in the OIE *Aquatic Animal Health Code (2018)**	Exotic to New Zealand	Found in salmon in New Zealand
1. Bacterial kidney disease (*Renibacterium salmoninarum*)		✓	
2. *Yersinia ruckeri* (Exotic strains)		✓	
3. Epizootic haematopoietic necrosis – EHN virus	✓	✓	
4. Infection with *Aphanomyces invadans* (EUS)	✓	✓	
5. Furunculosis (*Aeromonas salmonicida* subsp. *salmonicida*)		✓	
6. Gyrodactylosis (*Gyrodactylus salaris*)	✓	✓	
7. Infectious haematopoietic necrosis – IHN virus	✓	✓	
8. Infectious pancreatic necrosis virus (IPN virus, exotic strains)			✓**
9. Infection with infectious salmon anaemia virus (ISA)	✓	✓	
10. Infection with Koi herpesvirus (KHV)	✓	✓	
11. *Oncorhynchus masou* virus		✓	
12. Red sea bream iridoviral disease	✓	✓	
13. Spring viraemia of carp – SVC virus	✓	✓	
14. Viral haemorrhagic septicaemia – VHS virus	✓	✓	
15. Infection with *Myxobolus cerebralis* (Whirling Disease)			✓
16. Infection with New Zealand *Rickettsiaceae* species			✓***

* (see OIE 2018d).

** A birnavirus (IPNV Genogroup 5) occurs in returning sea run salmon in New Zealand (Davies et al. 2010).

*** declared unwanted organisms under section 131 of the Biosecurity Act 1993 on 20 April 2016.

5.2 Elimination of insignificant diseases

5.2.1 Non-infectious diseases

As a general rule, all of the non-infectious diseases of salmon do not pose a threat to the natural environment, as by definition they are non-infectious and cannot be transmitted to other marine fishes or other aquatic animals. However, one exception to this rule is algal blooms, which represent a risk to not only cultured salmon, but also other aquatic animals and the wider environment (Chang et al. 1990, 2001). Increased risk of algal blooms can sometimes be linked to increased nutrient loads from seacage aquaculture in regions where flushing of nutrients is insufficient (Buschmann et al. 2006, San-Diego et al. 2008), however a range of other environmental conditions are also usually required before conditions are suitable for algal blooms to occur (Diggles et al. 2002). Evaluation of the potential environmental effects in relation to nutrient loading due to the proposed planning changes are outside the scope of this document, and will be covered elsewhere in the planning documents. The reasons why some other infectious disease agents were excluded from detailed risk assessment are elaborated upon below.

5.2.2 Bacteria

Bacterial gill disease, coldwater disease including *Flexibacter* spp./*Tenacibaculum* spp.,

Flavobacteria including members of the genera *Flexibacter*, *Tenacibaculum*, *Flavobacterium*, and *Cytophaga* are ubiquitous in aquatic environments (Austin and Austin 2007, Pulkkinen et al. 2010, Brosnahan et al. 2018), but some strains are facultative pathogens that can cause disease (for example, columnaris, bacterial gill disease, fin rot, gill rot) and mortalities in freshwater and marine fish that are stressed, injured and/or exposed to adverse environmental conditions (Mitchell and Rodger 2011). Freshwater genera include *Flavobacterium columnare* (agent of columnaris disease), *F. psychrophilum* (agent of cold water disease) and *F. branchiophilium* (agent of bacterial gill disease), while the marine equivalent is *Tenacibaculum maritimum* (formerly *Flexibacter maritimus*, see Diggles et al. 2002, Brosnahan et al. 2018). The freshwater flavobacteria found on salmon in New Zealand (Boustead 1989), including *F. psychrophilum* which has been isolated from trout (B. Jones, personal communication, 29 May 2016), do not grow at marine salinities and hence they do not affect marine fish. On the other hand, *Tenacibaculum maritimum* can cause disease in marine fish, but the bacterium is already ubiquitous in the New Zealand marine environment and has been previously identified from several species including snapper (*Pagrus auratus*) and blue cod (*Parapercis colias*) (Diggles et al. 2002, B.K. Diggles, personal obs.) as well as more recently in cultured chinook salmon (MPI 2015, Brosnahan et al. 2018). Good husbandry methods such as conservative stocking densities (<15 kg/m^2), avoidance of temperature extremes, avoiding damage to fish during handling, maintenance of high water quality and prompt removal of dead fish from tanks and cages can significantly limit the proliferation of these bacteria in cultured fish (Boustead 1989, Diggles et al. 2002, Pulkkinen et al. 2010). *Tenacibaculum maritimum* occurs naturally on wild fish and other aquatic animals throughout New Zealand, often in the absence of disease (Fischer and Appleby 2017, Brosnahan et al. 2018). The strain of *T. maritimum* in New Zealand was shown to be identical to strains detected in Tasmania (Brosnahan et al. 2018). This is not surprising given the ubiquitous nature of the disease agent and the fact that *T. maritimum* has also been found in large numbers on jellyfish, which may act as vectors for *T. maritimum* infections of seacage cultured salmon if the salmon are damaged by contact with jellyfish tentacles (Ferguson et al. 2010). Because these disease agents are already ubiquitous in the marine environment and only cause disease in captive fish cultured in stressful conditions at high densities, these bacteria are unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and thus they do not need to be considered further.

***Mycobacterium* spp. and Nocardiosis**

Species of *Mycobacterium* are acid fast, gram positive bacteria that are commonly found in the aquatic environment and may cause chronic granulomatous disease in freshwater fishes, including cultured salmon (Ashburner 1977, Whipps et al. 2007). Three *Mycobacterium* spp. (*M. marinum, M. fortuitum, M. chelonae*) are common causes of mycobacteriosis in ornamental fish, are ubiquitous in ornamental fishes in New Zealand (Diggles et al. 2002), and can infect chinook salmon (Brosnahan et al. 2017b). Infection with *Mycobacterium marinum* in humans is known as 'fish tank granuloma' and can lead to severe skin infections, whose treatment may last for over a year and frequently involves surgery (Aubry et al. 2002, Lahey 2003). Nocardiosis is a systemic bacterial disease caused by weakly gram-positive, partially acid-fast, aerobic, filamentous rod shaped bacteria of the genus *Nocardia* (see Bransden et al. 2000, Labrie et al. 2008). Nocardiosis caused by *Nocardia salmonicida* was first reported in sockeye salmon (*Oncorhynchus nerka*) by Rucker (1949), but since then outbreaks of this disease in fishes have also been associated with other species of *Nocardia*, including *N. asteroides*, and *N. seriolae* (see Labrie et al. 2008). Typical signs of nocardiosis in fish include development of granulomatous nodules in gills, spleen, kidney and liver with or without multiple skin ulcers/nodules (Labrie et al. 2008). This genus of bacteria has a global distribution and is ubiquitous in soil, fresh and saltwater environments (Brown-Elliot et al. 2006). Besides *N. salmonicida*, various other species of *Nocardia* are known to infect salmon, including an unidentified *Nocardia* spp. infecting Atlantic salmon cultured in freshwater in Tasmania at a prevalence of 3% (Bransden et al. 2000, Ellard 2015), while a novel *Nocardia* spp. was isolated from boil-like lesions in the skin of chinook salmon cultured in freshwater in New Zealand (Brosnahan et al. 2017b). In the latter case, the presence of *Nocardia* spp. was associated with mortalities of 3.5% in fish which may have been exposed to water containing excessive sediment (Brosnahan et al. 2017b). Because both *Mycobacterium* spp. and *Nocardia* spp. are already ubiquitous in the aquatic environment, and only cause limited disease in cultured fish held in stressful conditions at high densities in freshwater sites, these bacteria are extremely unlikely to pose a threat to wild marine fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and thus they do not need to be considered further.

***Vibrio* spp.**

Bacteria of the genus *Vibrio* are ubiquitous in marine environments (Egidus 1987, Austin and Austin 2007), and several species within the genus are facultative pathogens that can cause disease and mortalities in marine fish that are stressed, injured and/or exposed to adverse environmental conditions (Austin and Austin 2007). At least two species of *Vibrio* have been recorded from salmon in New Zealand, including *Vibrio anguillarum* and *V. ordalii* (see Boustead 1989, Diggles et al. 2002), but *Vibrio* spp. including *V. parahaemolyticus* isolated from snapper (B. Jones, personal communication, 29 May 2016) are ubiquitous and can infect damaged fish anywhere in the New Zealand marine environment (Diggles et al. 2002). Good husbandry methods such as conservative stocking densities (<15 kg/m^2), avoidance of damage to fish during handling, maintenance of high water quality and prompt removal of dead fish from tanks and cages can significantly limit the proliferation of these bacteria in cultured fish (Boustead 1989, Diggles et al. 2002). Because these disease agents are already ubiquitous in the marine environment and only cause disease in cultured fish that are damaged or held in suboptimal conditions, these bacteria are unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and thus they do not need to be considered further.

***Yersinia ruckeri* (Yersinosis)**

The bacterium *Yersinia ruckeri* is a member of the family *Enterobacteriaceae*, and has a worldwide distribution (Carson and Wilson 2009). This bacterium has been associated with disease in cultured freshwater fishes, mainly salmonids, but also eels, goldfish, carp and others (Tobback et al. 2007, Carson and Wilson 2009). In New Zealand, *Y. ruckeri* has been isolated in salmon from freshwater hatcheries on the east coast of the South Island (Anderson et al. 1994, Anderson 1995, Diggles et al. 2002), but given its ubiquitous distribution worldwide, it is likely that the bacterium is enzootic in the New Zealand environment (Diggles et al. 2002), though it has only been detected at salmonid hatcheries (Anderson et al. 1994). Infection with *Y. ruckeri* results in bacterial septicaemia and disease is most commonly detected due to exophthalmos and blood spots in the eye (Anderson et al. 1994). The severity of the disease is dependant upon the virulence of the variant of the bacterium involved and environmental conditions, being most problematic at higher water temperatures and high stocking densities (Tobback et al. 2007). Acute infections in trout with the 'Hagerman' strain are referred to as enteric red mouth (ERM), however in New Zealand the 'Hagerman' strain is considered exotic (Carson and Wilson 2009), and a milder form of the disease that occurs in salmon is termed yersinosis.

Yersinia ruckeri is considered an opportunistic pathogen that rarely causes disease in healthy unstressed fish. Disease outbreaks associated with *Y. ruckeri* in cultured salmon occur almost exclusively in freshwater hatcheries when they are injured or held in high densities under poor conditions (Anderson et al. 1994, Anderson 1997, Carson and Wilson 2009), though smolts previously exposed to the bacterium in freshwater may become diseased if they become stressed after transfer to saltwater (Sparboe et al. 1986). The risk of outbreaks of marine yersinosis in cultured salmon is greatly reduced through maximising water quality during the freshwater hatchery phase and vaccination prior to seawater transfer (Ellard 2015). The survival of the bacterium is greatly reduced in seawater (Thorsen et al. 1992), and adhesion of the bacterium to fish is inhibited at higher salinities, preventing entry (Altinok 2004), hence the disease does not affect obligate marine fish (Tobback et al. 2007). Because of this, *Y. ruckeri* is unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and thus this disease agent does not need to be considered further.

5.2.3 Fungi

***Saprolegnia* spp.**

Water moulds (Class Oomycetes) of the genus *Saprolegnia* (Family Saprolegniales) are ubiquitous in freshwater environments worldwide (Noga 2010). *Saprolegnia* spp. are common opportunistic saprophytes which are associated with disease in freshwater only when the host fish is compromised or stressed (Roberts 2001). These fungi can infect all species of freshwater finfish in New Zealand, including salmon, trout, eels, and native species, as well as their eggs (Hine and Boustead 1974). Good husbandry methods such as avoidance of damage to eggs or fish during handling, maintenance of high water quality and avoidance of extremes in water temperature can significantly limit the proliferation of these fungi in cultured fish (Noga 2010). However, these fungi do not tolerate salt and they cannot survive in seawater (Noga 2010). Because of this, freshwater moulds and fungi are unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and thus they do not need to be considered further.

5.2.4 Protozoa

Chilodonella* spp., *Trichodina* spp. and *Ichthyophthirius multifiliis

Ciliate protozoans of the genera *Chilodonella*, *Trichodina* and *Ichthyophthirius multifiliis* infect a wide range of species of freshwater fishes worldwide, including both wild and captive freshwater fishes in New Zealand (Diggles et al. 2002). These parasites can infect salmon in New Zealand (Boustead 1989), and because their direct lifecycle includes multiplication by binary fission (*Chilodonella* spp., *Trichodina* spp.) or within the benthic encysted tomont stage (*I. multifiliis*), heavy infections can quickly lead to epizootics when fish are held at high densities and are left untreated. However, *Chilodonella* and *Ichthyophthirius multifiliis* do not tolerate salt (Selosse and Rowland 1990, Roberts 2001) and therefore they cannot survive in seawater, while *Trichodina* spp. are relatively harmless and are ubiquitous in the marine environment (Diggles et al. 2002). Because of this, they are unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and thus they do not need to be considered further.

Microsporidians

A microsporidian with possible affinities with *L. salmonae* has been recorded in the internal organs of chinook salmon cultured at farming sites in Kopaua and Otanerau in the Marlborough Sounds (Cesar Lopez, NZKS veterinarian, personal communication). The discovery of the parasite has been incidental and sporadic during routine health surveillance over many years. To date the parasite has not been associated with mortalities, and no evidence of grossly visible xenoma formation has been observed (Cesar Lopez, NZKS veterinarian, personal communication). The identity of the parasite remains undetermined. Several types of microsporidians are known to naturally infect fish in New Zealand (Hine et al. 2000, Diggles 2003) and it is possible that the cultured salmon are becoming infected after exposure to wild reservoir hosts while they are being reared in the seacages. Given the sporadic and incidental nature of these findings in apparently healthy fish, these microsporidians do not appear to be pathogenic and are considered at this time to be unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and thus they do not need to be considered further.

5.2.5 Metazoa

Digeneans

Digenean trematodes are endoparasitic helminths which have been recorded from a wide range of marine and freshwater fish species throughout New Zealand (Hine et al. 2000). Their indirect lifecycle requires a molluscan first intermediate host with plankton eating fishes as final hosts, or second intermediate hosts in some lifecycles where final hosts include larger fishes, birds and mammals. Under most circumstances, the multi host lifecycles of these parasites reduce the risk of their translocation, because additional hosts need to occur in the receiving environment in order to complete the life cycle. Four species of digeneans have been recorded from wild salmon in New Zealand (Table 1). All of these are parasites of endemic marine fishes (Hine et al. 2000) which have low host specificity and switched hosts to the introduced salmon during the oceanic stages of their lifecycle (Margolis and Boyce 1990). Salmon become infected with these parasites through consumption of intermediate hosts or natural exposure to infective stages in natural food items (Margolis and Boyce 1990). Because cultured salmon are fed artificial feeds, they are not regularly exposed to infective stages of digenean parasites via the diet, and hence they do not tend to pick up large numbers of these parasites during their time in seacages, though they can occasionally become infected by preying on natural prey items which may stray into the seacages. Because of these reasons, they are unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, hence these disease agents do not need to be considered further.

Nematodes and Cestodes

Nematodes and cestodes are endoparasitic helminths that live in the gastrointestinal tract of a wide variety of fishes in New Zealand (Hine et al. 2000). Their lifecycle generally requires crustaceans as the first intermediate host with plankton eating fishes as final hosts, or second intermediate hosts in some lifecycles where final hosts include larger fishes, sharks, birds or mammals (Rohde 1984, Noga 2010). Under most circumstances, the multi host lifecycles of these parasites reduce the risk of their translocation, because additional hosts need to occur in the receiving environment in order to complete the life cycle. Two species of cestodes and two species of nematodes have been recorded from wild salmon in New Zealand (Table 1). All of these are parasites of endemic marine fishes (Hine et al. 2000) which have low host specificity and switched hosts to the introduced salmon during the oceanic stages of their lifecycle (Margolis and Boyce 1990). The salmon become infected with these parasites through consumption of intermediate hosts or natural exposure to infective stages in natural food items (Boustead 1989, Margolis and Boyce 1990). Because cultured salmon are fed artificial feeds, they are not regularly exposed to infective stages of helminth parasites via the diet, and hence they do not tend to pick up large numbers of these parasites during their time in seacages, though they can occasionally become infected by preying on natural prey items which may stray into the seacages. Because of these reasons, they are unlikely to pose a threat to wild fishes or other aquatic animals in the Cook Strait north of the Marlborough Sounds, and hence these disease agents do not need to be considered further.

Crustaceans

Parasitic crustaceans, mainly isopods and copepods, live on the body surfaces, gills and in the musculature of a wide variety of marine and freshwater fishes (Hine et al. 2000). Their lifecycles are direct with fish being infected by planktonic copepodid larval stages that hatch from eggs deposited by adult copepods (Kabata 1984). In New Zealand, three species of crustaceans have been recorded from salmon. One of these is *Paenodes nemaformis*, a copepod that usually infects brown trout in freshwater, but there is also a single record of it infecting chinook salmon from Queenstown, also in freshwater (Boustead 1989). A species of isopod, *Cirolana* spp., was found in the mouth of returning sea run chinook salmon (Boustead 1982). Other free living isopods can sometimes be ingested by salmon in seacages, survive being swallowed and damage the stomach and internal organs, causing death (Boustead 1989). *Paenodes nemaformis* is a parasite of freshwater fishes only (Hewitt 1969), and does not occur on salmon in seacages. *Cirolana* sp. appears to be an example of opportunistic host switching in wild fishes, and salmon in seacages do not tend to pick up these parasites (Boustead 1989). Because of these reasons, these two parasites do not need to be considered further.

The third species of crustacean parasite that has been observed on salmon in New Zealand is *Caligus longicaudatus*, an ectoparasitic copepod that was found in small numbers in sockeye salmon (*Oncorhynchus nerka*) reared in seacages in New Zealand (Boustead 1989), while chinook salmon in nearby seacages were not affected (Boustead 1989). Members of the genus *Caligus* are known as "sea lice", and there are several species of *Caligus* that occur on marine fish in New Zealand waters (Hewitt 1963, Jones 1988, Hine et al. 2000). One species, namely *Caligus elongatus*, is a host generalist which has been problematic in salmonid aquaculture in the northern hemisphere, and could threaten a wide range of hosts in sea cage culture (Todd 2007) as it has been found on at least 60 host species (Jones 1988), though some of these may be misidentifications of *Caligus chiastos* (see Hayward et al. 2009). *Caligus elongatus* has been found in the South Island of NZ in the Heathcote Estuary, Christchurch on flounder *Rhombosolea* spp. (Jones 1988, Hine et al. 2000). Another species, namely *C. epidemicus*, is found on fishes in the North Island. It is another host generalist that has been associated with disease outbreaks on wild and cultured fishes in various locations (Hewitt 1971, Ho et al. 2004). Because of these reasons, Caligid copepods will be subjected to detailed risk assessment.

5.3 The diseases of concern requiring detailed risk assessment

After excluding the non-infectious diseases and the insignificant infectious diseases listed in Table 1 for the reasons outlined above, the diseases of salmon in New Zealand that will require detailed risk assessment are listed below in Table 3.

Table 3. List of the diseases of concern that will be subjected to detailed risk assessment.

Disease	Under official control	Occurs in cultured salmon in NZ	May cause significant disease in wild marine fish	May cause significant disease in seacage cultured fish
VIRUSES				
Aquatic Birnavirus	Yes	No	No	Yes
BACTERIA				
Piscirickettsia-like bacteria (NZ-RLO)	Yes	Yes	No	Yes
PROTOZOA				
Amoebic gill disease *(Neoparamoeba perurans / Cochliopodida* sp.)	No	Yes	No	Yes
METAZOA				
Crustacea				
Sea lice (*Caligus* spp.)	No	Yes	No	Yes
Myxozoa				
Whirling Disease (*Myxobolus cerebralis*)	Yes	Yes	No	No

6.0 Detailed Risk Assessment

6.1 Infection with Aquatic Birnavirus

6.1.1 Aetiologic agent: Non-enveloped viruses with a double-stranded RNA genome of the genus *Aquabirnavirus* within the Family Birnaviridae.

6.1.2 OIE List: No **Reportable disease in New Zealand:** Yes

6.1.3 New Zealand's status: An aquatic birnavirus strain (IPNV Genogroup 5) has been reported from returning chinook salmon in the South Island and cultured turbot in Wellington Harbour (Tisdall and Phipps 1987, B.K. Diggles, unpublished data, Davies et al. 2010).

6.1.4 Epidemiology

Aquatic birnaviruses have been isolated from a large number of marine and freshwater aquatic animals (McAllister 1993), to the extent that these viruses are considered to be ubiquitous in aquatic environments worldwide (Reno 1999). Various strains of birnavirus have been described from at least 65 species of fish in 20 families (McAllister 1993), and also from bivalve molluscs and crustaceans (Reno 1999). The type species for the genus *Aquabirnavirus* is Infectious Pancreatic Necrosis Virus (IPNV), which causes infectious pancreatic necrosis (IPN), a significant disease of salmonids (Wolf et al. 1960). The genus includes both virulent and avirulent viruses with the term 'infectious pancreatic necrosis' (IPN) virus being reserved for those isolates that are pathogenic for species within the Family Salmonidae (McColl et al. 2009). IPN disease has not been formally recorded in New Zealand, however an aquatic birnavirus was isolated from apparently healthy sea run chinook salmon (*O. tshawytscha*) returning up the Rakaia River (Tisdall and Phipps 1987), and the Hakataramea River (Anderson 1998), but this virus has never been associated with disease in these fishes. More recently, a birnavirus was found to be associated with a suspicious outbreak of bacterial disease in juvenile turbot (*Colistium nudipinnis*) in New Zealand (Diggles et al. 2000), with the virus being isolated from surviving fish several years after the epizootic (B.K. Diggles unpublished data, Davies et al. 2010, who incorrectly identified the host as *Psetta maxima*). New Zealand virus isolates were identified as belonging to IPNV Genogroup 5 (see Davies et al. 2010) and appear non pathogenic to salmonids (Diggles et al. 2002, McColl et al. 2010). However, it is possible that members of this genogroup may be pathogenic in non-salmonid hosts (such as flatfish, which are common carriers of the virus (Wallace et al. 2008)) or even to salmonids under different environmental or husbandry conditions (such as small juvenile fish in hatcheries) (Davies et al. 2010). The isolate from turbot showed a high level of sequence identity (97-99%) to birnavirus isolates from wild marine fish in Tasmania, suggesting that the Australian and New Zealand isolates originate from the same source, presumably wild marine species inhabiting the Southern Ocean. The isolate from returning chinook salmon was also very similar to the birnavirus isolates from wild marine fish in Tasmania (94-98% identity) (Crane et al. 2000, Davies et al. 2010) but quite different to a birnavirus that was associated with mortalities of rainbow trout in freshwater in Victoria during a period of high water temperatures (McCowan et al. 2015, Mohr et al. 2015).

In Japan aquatic birnaviruses cause some of the most important diseases of juvenile yellowtail (*Seriola quinqueradiata*), kingfish (*S. lalandi aureovittata*) and amberjack (*S. dumerili*) (see Isshiki and Kusuda 1987, Isshiki et al. 2001, Nakajima et al. 1998, Muroga 2001). This suggests that cultured kingfish in New Zealand may also be susceptible to aquatic birnaviruses. Aquatic birnaviruses are known to cause disease almost exclusively in juvenile fish (Novoa et al. 1993, Reno 1999), with yellowtail less than 10 grams being particularly susceptible in Japan, with moribund juveniles typically exhibiting anaemic gills, haemorrhaging in the liver, severe ascites, and pancreatic necrosis (Nakajima et al. 1998). Water-born birnaviruses accumulated by bivalves, crustaceans and birds can remain viable when excreted (Mortensen et al. 1992), and can be subsequently used to infect fish experimentally (Mortensen 1993), although viral replication does not appear to occur in other hosts, hence the main method of translocation remains live fish and eggs (Reno 1999).

6.1.5 Release assessment

Birnaviruses are isolated only rarely from marine fish in New Zealand, however wild marine fish must be considered a reservoir of infection. A comprehensive survey of wild marine fish for aquabirnavirus has not been undertaken in New Zealand, though surveys of thousands of cultured and returning chinook salmon over many years have shown the virus to be rare (Anderson 1995, 1996, 1998, McIntyre et al. 2010). Nevertheless, aquatic birnaviruses are known to occur in the marine waters adjacent to the South Island of New Zealand at low prevalences, and indeed they are considered likely to be present throughout the Southern Ocean (Davies et al. 2010, Mohr et al. 2015), though the required surveys have not been conducted to determine the range of host species or prevalence of infection.

Infection is direct via horizontal exposure to viral particles in the water, or by vertical transmission from infected gametes (McAllister 1993). Juvenile fish that survive infection can be lifelong carriers which shed the virus via the urine, faeces and sexual products (Reno 1999), however large juveniles and adults exposed to the virus for the first time may be refractory to infection or can spontaneously recover (Novoa et al. 1993). Aquabirnaviruses are very persistent in the environment, with minimal loss of infectivity after 10 weeks in filtered seawater at 4 and 10°C, and they are also very resistant to a broad range of disinfectants (Bovo et al. 2005). Aquatic birnavirus is not inactivated by passage through the bird digestive system and as such, the disease agent can also be spread naturally via mechanical vectors such as sea birds (Reno 1999).

The release of birnavirus into the environment from seacaged salmon requires the following pathway to occur. A chinook salmon that has become naturally and subclinically infected with birnavirus through contact with seawater is selected for use as broodstock. Viable aquabirnavirus must persist in the sexual fluids and survive surface treatments of the eggs (e.g. hydrogen peroxide and/or iodophor treatment), then subsequently persist in the larvae after fertilized eggs hatch. Larval and juvenile salmon reared in freshwater must then survive without being detected during routine surveillance of clinically healthy fishes for viruses, without outbreaks of clinical disease (because every disease outbreak is routinely investigated), and survive the stress of saltwater acclimation as smolts. Only after all of these conditions are met, would viable aquabirnavirus be present in cultured salmon and potentially be able to be released into the environment. Taking into account the extremely low prevalence of the disease agent in returning salmon, and the fact that the vast majority of broodstock chinook salmon used by NZKS are held over in freshwater for their entire lives, the likelihood estimations for the release of salmon infected by aquatic birnavirus into seacages in the Cook Strait north of the Marlborough Sounds is considered to be **Extremely Low**.

6.1.6 Exposure assessment

Marine teleosts and invertebrates in New Zealand are already at risk of exposure to the local strain of aquatic birnavirus, which probably occurs in turbot (*C. nudipinnis*) and other species of wild fishes, which act as a reservoir of infection for returning salmon broodstock to be exposed to the virus. Therefore, the most likely exposure pathway is via aquabirnavirus already in the environment near seacages (most likely from natural reservoir hosts such as bottom dwelling flatfish) which could infect salmon already held in seacages. However, the risk of exposure under this scenario would be much reduced given the greater dilution factors associated with proposed placement of seacages in the Cook Strait north of the Marlborough Sounds, as the greater water depth (70-100 meters) would greatly increase the distance between farmed salmon and potential aquabirnavirus reservoirs like bottom dwelling turbot or other flatfish.

Infection of farmed salmon or wild fish and bivalves would occur only if sufficient quantities of virus (i.e. an infective dose) was introduced into an area where susceptible hosts were present. Susceptible fish and bivalves can become infected with aquatic birnavirus via horizontal transmission through the water (immersion) and also by *per-os* exposure (Reno 1999). The infectious dose of birnavirus by the immersion pathway varies according to the strain of virus used and the species challenged (McAllister and Owens 1995), ranging from $>10^3$ $TCID_{50}$/mL for arctic char (McAllister et al. 2000), to $< 10^{-1}$ $TCID_{50}$/mL for Atlantic salmon post smolts exposed to pathogenic strains of IPNV (Urquhart et al. 2008). The infectious dose of birnavirus by *per-os* exposure also varies, with Mortensen (1993) requiring a dose of 10^6 $TCID_{50}$/g of IPNV obtained from scallops before successful transmission to brown trout was obtained. However Wechsler et al. (1987) reported successful transmission of IPNV to striped bass fed brook trout infected with between 2 x 10^2 and 2 x 10^5 $TCID_{50}$/g IPNV.

Clinically diseased fish infected with birnavirus can have very high viral titres in their internal organs (10^7 - 10^9 $TCID_{50}$/g,) as well as high viral shedding rates (Reno 1999, Sommer et al. 2004, Urquhart et al. 2008), however no fish with clinical disease caused by birnavirus infection have ever been formally recorded in New Zealand (Diggles et al. 2002, Davies et al. 2010, Mohr et al. 2015). The levels of birnavirus in sub-clinically infected fish can still be relatively high (10^2 - 10^6 $TCID_{50}$/g , see McAllister et al. 2000), but are usually lower and often around the limits of detection using cell culture techniques (c. 10^1 - 10^2 $TCID_{50}$/g, Wechsler et al. 1987, Roberts 2001). The likelihood that an infectious dose can be transmitted horizontally into a natural water body via its spread from seacaged salmon that are sub-clinically infected with aquatic birnavirus appears unlikely, however the likelihood would increase if the salmon became clinically diseased. Indeed, prevalence of IPNV was increased slightly above background levels (from 0.15% prevalence to 0.58% prevalence) in wild fishes within 5 km of salmon farms in Scotland that contained fish clinically diseased with IPN (Wallace et al. 2008). However, the birnavirus isolates recorded to date in New Zealand are not pathogenic to salmon (Diggles et al. 2002, Davies et al. 2010, Mohr et al. 2015) hence the risk of seacaged salmon becoming diseased appears extremely low. Nevertheless, given that there is a direct pathway for virus particles shed by seacaged salmon to enter the marine environment and infect wild fishes that may be attracted to seacages (Dempster et al. 2009, Uglem et al. 2009), and since the range of susceptible reservoir hosts may be broad, the risk of exposure and establishment is non-negligible, and the likelihood of exposure and establishment of aquatic birnavirus in wild fish and mollusc populations is considered to be **Very Low**.

6.1.7 Consequence assessment

When fish become infected with aquatic birnavirus, mortality is mainly restricted to larval and early juvenile stages, and disease does not necessarily occur in larger fish. Indeed, many fish experimentally infected with aquatic birnavirus can naturally resolve the infection provided they are healthy and remain unstressed (Reno 1999). However, others fish remain carriers for life, and risk spreading birnavirus to their progeny vertically via infected gametes. Given that aquabirnavirus is already present in some parts of New Zealand's environment, and these viruses only tend to occur at subclinical levels in juvenile and adult fish in the wild (Anderson 1995, 1996, 1998, Wallace et al. 2008, McIntyre et al. 2010), the consequences of localized slight increases in prevalence of birnaviruses in wild fish within 5 km of affected salmon farms (Wallace et al. 2008) appear related mainly to possible increased mortality of larval and early juvenile stages, which although never documented in wild fishes, if it occurs it could have some impact on wild fish at the population level. These viruses may also increase costs of production in marine finfish aquaculture hatcheries due to use of infected wild caught broodstock. These viruses are no longer listed by the OIE and hence their presence is unlikely to have adverse impacts on national or international trade, but aquabirnaviruses remain reportable in New Zealand. Considering all of these factors, establishment of the disease in cultured salmon would have mild biological consequences, which would be amenable to control, and would not cause any noticeable environmental effects. It is therefore estimated that the consequences of potential introduction of birnavirus strains into New Zealand's environment via salmon in sea cages in the Cook Strait north of the Marlborough Sounds would likely be **Very Low**.

6.1.8 Risk estimation

The unrestricted risk associated with aquatic birnavirus is determined by combining the likelihood of release and exposure (from Table 5) with the consequences of establishment (Tables 6, 7). The unrestricted risk estimate for aquatic birnavirus does not exceed the ALOP, suggesting that additional risk management for this disease agent is not required.

Risk estimate for infection with Aquatic Birnavirus

Commodity type	Sea caged salmon
Combined likelihood of release and exposure	Extremely Low
Consequences of establishment and spread	Very Low
Risk estimation	Negligible Risk

6.2 Infection with *Piscirickettsia*-like bacteria (NZ-RLO)

6.2.1 Aetiologic agent: Gram negative, obligate intracellular gamma proteobacteria of the genus *Piscirickettsia* within the Family *Piscirickettsiaceae*.

6.2.2 OIE List: No **Reportable disease in New Zealand:** Yes

6.2.3 New Zealand's status: Three strains of a rickettsia-like bacterium (the NZ-RLO) closely related to *Piscirickettsia salmonis* have been isolated from chinook salmon cultured in the outer Pelorus Sound and Queen Charlotte Sound (MPI 2015, 2016, Brosnahan et al. 2017a, 2018, Gias et al. 2018).

6.2.4 Epidemiology

Members of the genus *Piscirickettsia* are obligate intracellular bacterial disease agents which cause rickettsial septicaemias in fishes. *Piscirickettsia salmonis* was the first member of the group to be described following its involvement in outbreaks of piscirickettsiosis disease in coho salmon (*Oncorhynchus kisutch*) cultured in seawater net pens in Chile in the late 1980's (Fryer et al. 1990, 1992). Mortalities of up to 90% (more usually 20-30%) were recorded in affected farms eventually resulting in a shift to farming more *Piscirickettsia*-resistant species such as Atlantic salmon (Mauel and Miller 2002, Fryer and Hedrick 2003, Rees et al. 2014). Since then *P. salmonis* has been isolated from several species of salmonids throughout the northern hemisphere including Atlantic salmon (*Salmo salar*), chinook salmon (*O. tshawytscha*), rainbow trout (*O. mykiss*), Pink salmon (*O. gorbuscha*), cherry salmon (*O. masou*) as well as white sea bass (*Atactoscion noblis*), and European seabass (*Dicentrarchus labrax*), whilst closely related *P. salmonis*-like bacteria have also been isolated from grouper (*Epinephelus melanostigma*), muskellunge (*Esox masquinongy*) and tilapia (*Oreochromis* sp., *Tilapia* sp., *Sarotherodon* sp.), amongst others (Mauel and Miller 2002, DAFF 2013). In the southern hemisphere, besides infections of salmonids in Chile (Rees et al. 2014), a *P. salmonis*-like organism (Tas-RLO) was reported from Atlantic salmon in Tasmania (Corbeil et al. 2005, Corbeil and Crane 2009), and most recently 3 strains of a similar organism (NZ-RLO) has been identified from chinook salmon cultured in the Marlborough Sounds since 2012 (MPI 2015, 2016, Brosnahan et al. 2017a, 2018, Gias et al. 2018).

The discovery of the NZ-RLO occurred after investigations into the cause of unusually high mortalities of up to 66.5% of chinook salmon (2.2-3 kg weight) cultured at a low water flow site in Waihinau Bay in Pelorus Sound in February 2015 (Fischer and Appleby 2017). Retesting of historical tissue samples showed the NZ-RLO was present at the same site in 2012 when an unusual increase in mortality rate (21.8% cumulative mortalities) was noted without a definitive diagnosis as to the cause (MPI 2013, Fischer and Appleby 2017). Subsequently, a second NZ-RLO (NZ-RLO2) was detected at Waihinau Bay and other NZKS farms at Ruakaka Bay and Otanerau Bay in the Marlborough Sounds, and a third NZ-RLO (NZ-RLO3) was detected in apparently healthy fish at a farm in Akaroa Harbour (Fischer and Appleby 2017, Gias et al. 2018). NZ-RLO1 is of particular interest because it is listed as an unwanted organism under the Biosecurity Act 1993 and is sufficiently different from *Piscirickettsia salmonis* that the standard test recommended for *P. salmonis* was usually negative or indicated a weak positive (Fischer and Appleby 2017). NZ-RLO1 was most commonly cultured from the kidney in salmon from

Waihinau Bay, Clay Point and Ruakaka and has the highest genetic similarity (99.6%) to the *Piscirickettsia*-like organism from Tasmania (Tas-RLO); NZ-RLO2 was most commonly cultured from skin lesions in salmon from Waihinau, Ruakaka and Otanerau Bays and showed 100% genetic similarity to a *P. salmonis* strain from Ireland, while NZ-RLO3 in salmon from Akaroa Harbour was most commonly detected in the spleen and showed highest genetic similarity (99.2%) to a *P. salmonis* strain from Chile (Fischer and Appleby 2017, Brosnahan et al. 2018). In each case, the NZ-RLOs and *T. maritimum* were also detected in apparently healthy fish (Fischer and Appleby 2017, Brosnahan et al. 2017a). The fact that the RLO was only associated with disease and skin ulcers at the two farming sites with highest water temperatures, suggesting that the disease process was probably multifactorial and related to suboptimal environmental conditions (water temperatures > 16°C) at low water flow sites (Brosnahan et al. 2018, Gias et al. 2018).

The detection of three different strains of NZ-RLO that were not geographically present in all three regions could suggest the NZ-RLO has been present in New Zealand for a long enough period (possibly in native New Zealand fish which may act as reservoirs for the bacterium) to establish regional differences spreading naturally over time, or alternatively, they could have been introduced from three separate incursions (Brosnahan et al. 2018). In response to these disease outbreaks, MPI imposed controls on the movement of salmon, salmon products, and salmon farming-related equipment within the Marlborough Sounds in April 2016 using a Controlled Area and Notice of Movement Controls under section 131 of the Biosecurity Act ("Controlled Area Notice") with the intention of limiting the spread of NZ-RLOs to other marine salmon farming areas (MPI 2016).

The onset of piscirickettsiosis in cultured salmon usually follows the transfer of fish from freshwater hatcheries to marine sites where they are exposed to the bacterium via marine reservoir hosts or vectors such as ectoparasites (Kent and Poppe 1998). Horizontal transmission of the disease by cohabitation occurs readily in saltwater via the skin, gills or intestine (Corbeil and Crane 2009), however, there is evidence that the disease can also occur in brackish water or even in freshwater where horizontal transmission is limited by reduced survival of the disease agent, but the disease may nevertheless be vertically transmitted to juveniles from infected adult fish returning from the sea (Kent and Poppe 1998). Vertical transmission has been demonstrated under experimental conditions and *P. salmonis* has been detected in milt, eggs and coelomic fluid from infected broodstock (DAFF 2013). Larenas et al. (2003) estimated that 10% of eggs and fry originating from one or more infected broodstock were infected with *P. salmonis*. *Piscirickettsia salmonis* can adhere to the surface of eggs, can occur within the yolk of unfertilised eggs, and is capable of penetrating the ovum (Larenas et al. 2003). This has implications for the biosecurity of hatcheries, because the surface disinfection of fertilised eggs may not inactivate all *P. salmonis* bacteria (DAFF 2013).

Fish of all ages are susceptible to infection and outbreaks of disease usually follow periods of stress from various husbandry related factors including osmotic shock during smoltification, high water temperatures or rapid fluctuations in temperature, exposure to algal blooms, and co-infection with other disease agents (particularly viruses, see Zainathan 2012, DAFF 2013), all of which can increase susceptibility to infection (Fryer and Hedrick 2003). In Tasmania, salmon that tested positive for Tas-RLO without the presence of aquatic reovirus did not display signs of clinical disease and did not have increased mortality (DAFF 2013).

Gross signs of clinical piscirickettsiosis include darkening in colour, lethargy, swimming at the surface and inappetance. Erratic swimming and exophthalmos may occur in some fish where the bacteria can be isolated from the brain, while skin lesions which progress to shallow ulcers may also be present (Fryer and Hedrick 2003, Brosnahan et al. 2018). Internally, the liver and spleen may be enlarged and exhibit multifocal, grossly visible pale nodular granulomatous lesions and ascites fluid may be present. The optimal temperature for growth of *P. salmonis* in vitro is 15–18°C which corresponds with water temperatures reported during most disease outbreaks in salmonid culture, while growth is retarded above 20°C and below 10°C and ceases above 25°C (Fryer and Hedrick 2003). In contrast, outbreaks of piscirickettsiosis in non salmonids such as tilapias in Hawaii can occur at water temperatures as high as 26°C (Mauel et al. 2003). As for other bacterial diseases, vaccination is the first option to investigate to control the disease, while use of best practice husbandry methods to control known risk factors can reduce the likelihood of *Piscirickettsia* outbreaks, including maximizing water quality, using broodstock that have never been exposed to seawater, rearing fish at lower densities, allowing farms in a given region to fallow, controlling ectoparasites that may act as vectors, and avoiding horizontal transmission between year classes by holding single year classes of fish at any given site (Fryer and Hedrick 2003).

6.2.5 Release assessment

Piscirickettsia-like RLOs are known to occur in healthy and diseased chinook salmon cultured in the outer Pelorus Sound and Queen Charlotte Sound regions of the Marlborough Sounds, as well as in apparently healthy chinook salmon in Akaroa Harbour. A survey of cultured salmon elsewhere in New Zealand has shown that disease associated with the NZ-RLO does not occur outside the Marlborough Sounds and is most prominent in salmon farmed at low flow farm sites (MPI 2016, Fischer and Appleby 2017, Brosnahan et al. 2018), suggesting that environmental conditions at these sites are more permissive for infection to occur and disease to emerge, especially during summer when salmon may be stressed by high water temperatures exceeding 18°C at some locations (Fischer and Appleby 2017).

Infection is direct via horizontal exposure to bacteria in the water, or by vertical transmission from infected gametes. Given that *Piscirickettsia*-like disease agents are currently restricted to salmon held at certain sub-optimal seacage farm sites, this suggests that the onset of piscirickettsiosis in cultured salmon in New Zealand occurs due to horizontal transmission after the transfer of fish from freshwater hatcheries to certain marine sites where the fish are exposed to various different strains of the bacterium via marine reservoir hosts (or vectors) under certain environmental conditions that permit establishment of infection. Once an index case occurs, horizontal transmission of the disease from a clinically infected fish to other fish cohabiting the seacage can be expected via increased shedding of the bacterium via lesions, bile, faeces or urine and uptake in new hosts via skin, gills or intestine (Corbeil and Crane 2009, DAFF 2013). Hence once established on a farm and in the absence of disease mitigation efforts, the buildup of infectious stages is likely to result in increased shedding of the bacterium into the water column, increasing the risk of "backspill" infection of wild non-salmonid hosts. Taking into account that these disease agents are known to occur in the New Zealand environment and have been observed in diseased cultured chinook salmon in the Marlborough Sounds, the likelihood estimation for salmon infected by *Piscirickettsia*-like bacteria occurring in seacages in the Cook Strait north of the Marlborough Sounds is considered to be **High**.

6.2.6 Exposure assessment

Marine teleosts and invertebrates in New Zealand are already at risk of exposure to the local strain of *Piscirickettsia*-like bacteria, including as yet unidentified species of wild fishes or invertebrates which probably act as a reservoir of infection and/or vectors for cultured salmon. It is assumed susceptible hosts occur in the New Zealand environment, but "backspill" infection of these would occur only if sufficient quantities of bacteria (i.e. an infective dose) were introduced into an area where susceptible hosts were present close to salmon cages.

The virulence and infectious dose of *Piscirickettsia*-like bacteria by horizontal transmission varies according to the strain of bacteria and the species challenged. House et al. (1999) determined that coho salmon injected with $10^{2.6}$ $TCID_{50}$ of a less virulent Norwegian strain of *P. salmonis* had no increase in mortality rate compared to controls, but a similar dose of a virulent strain from Chile resulted in mortalities exceeding 50%. In contrast, minimum infective dose via the immersion route appears to be much higher. For example, Birbeck et al. (2004) studied a *P. salmonis* strain with an LD50 by injection into Atlantic salmon of < 200 $TCID_{50}$, which caused only 10% mortality when Atlantic salmon were exposed by immersion to 10^5 $TCID_{50}$/ml for 1 hour at 14°C.

Assuming New Zealand strains of *Piscirickettsia*-like bacteria are highly virulent (until proven otherwise), given that susceptible fish can be infected by immersion in virulent *P. salmonis* only at moderately high infective doses (Birbeck et al. 2004), it appears unlikely that an infectious dose can be transmitted horizontally into a natural water body via its spread from seacaged salmon that are sub-clinically infected with *Piscirickettsia*-like bacteria. This likelihood would be further reduced from the present baseline if seacages are located in the Cook Strait north of the Marlborough Sounds, due to the increased dilution factors from the increased water depth, and the reduced chances of disease outbreaks due to better water quality and lower average water temperatures in Cook Strait. Nevertheless, the likelihood of backspill infection occurring would increase if the salmon became clinically diseased. Given that there is a direct pathway for bacteria shed by seacaged salmon to enter the marine environment and infect wild fishes that may be attracted to seacages (Dempster et al. 2009, Uglem et al. 2009), and acknowledging that susceptible hosts are likely to be present in the vicinity of sea cages (due to attraction to feed inputs etc.), the risk of exposure and establishment is non-negligible, and the likelihood of exposure and establishment of *Piscirickettsia*-like bacteria in wild fish populations is considered to be **Low** if salmon are subclinically infected, and **Moderate** if they are clinically diseased.

6.2.7 Consequence assessment

When fish are infected with *Piscirickettsia*-like bacteria, mortality is observed almost exclusively in cultured fish that are stressed by other predisposing factors, and there are very few documented instances of mortalities occurring in wild fish. Possible exceptions to this include an outbreak of disease due to a *Piscirickettsia*-like bacteria in muskellunge and yellow perch in the USA (Thomas and Faisal 2009), and in tilapia in Hawaii, where diseased wild tilapia were observed and suspected to be the origin of the infection, but no other species were affected (Mauel et al. 2003). Both the latter examples are from freshwater and to date, *Piscirickettsia*-like bacteria have not been reported to cause disease or mortality in wild marine fish. However, if the risk of exposure of wild fish to the NZ-RLO is left unmitigated, its persistence in populations of cultured fish has the potential to adversely affect the productivity and profitability of the salmon culture industry in the Marlborough Sounds and Cook Strait. These bacteria are no longer listed by the OIE and hence their presence is unlikely to have adverse impacts on national or international trade, but the NZ-RLO remains reportable in New Zealand and is currently subject to a containment notice (MPI 2016). Considering all of these factors, establishment of the disease in cultured salmon is likely to have mild biological consequences, which would be amenable to control, and would be unlikely to cause any noticeable environmental effects. It is therefore estimated that the consequences of spillback introduction of *Piscirickettsia*-like bacteria into New Zealand's environment via salmon in sea cages in the Cook Strait north of the Marlborough Sounds would likely be **Low**.

6.2.8 Risk estimation

The unrestricted risk associated with *Piscirickettsia*-like bacteria is determined by combining the likelihood of release and exposure (from Table 5) with the consequences of establishment (Tables 6, 7). The unrestricted risk estimate for *Piscirickettsia*-like bacteria does not exceed the ALOP for subclinically diseased salmon, but does exceed the ALOP if salmon are clinically diseased, suggesting that additional risk management for this disease agent is required under such circumstances.

Risk estimate for infection with *Piscirickettsia*-like bacteria (NZ-RLO)

Commodity type	Sub-clinically diseased seacaged salmon	Clinically diseased seacaged salmon
Combined likelihood of release and exposure	Low	Moderate
Consequences of establishment and spread	Low	Low
Risk estimation	Very Low Risk	Low Risk

6.3 Amoebic/Nodular Gill Disease

6.3.1 Aetiologic agent: Amoebae including *Neoparamoeba perurans* and *Cochliopodia* spp.

6.3.2 OIE List: No **Reportable disease in New Zealand:** No

6.3.3 New Zealand's status: Amoebae such as *N. perurans* and *Cochliopodia* –like species are known to occur on cultured salmon in marine and freshwater environments, respectively.

6.3.4 Epidemiology

Amoebic gill disease (AGD) is an economically important disease of salmon cultured in seacages in several regions of the world (Munday et al. 2001, Young et al. 2008, Mitchell and Rodger 2011, Martinsen et al. 2018). The disease was first discovered in Atlantic salmon cultured in Tasmania in the mid-1980s and *Neoparamoeba pemaquidensis*, a free-living marine amoeba, was for some time regarded as the only aetiological agent of AGD as it had been consistently isolated from diseased fish (Kent et al. 1988, Dykova et al. 2000). However, attempts to experimentally transmit AGD using cultured *N. pemaquidensis* failed to cause disease in Atlantic salmon (Morrison et al. 2005). The true agent responsible for AGD was subsequently found to be a new species of amoebae (Young et al. 2007), now known as *Neoparamoeba perurans*. Since that time, *N. perurans* has been confirmed to be the predominant causative agent of AGD in Atlantic salmon, rainbow trout, chinook salmon, coho salmon and turbot from regions as diverse as Tasmania, Ireland, Spain, Norway, North America, Scotland, the Faroe Islands, Korea and New Zealand (Young et al. 2008, Steinum et al. 2008, Kim et al. 2016, Downes et al. 2018, Martinsen et al. 2018). It appears that AGD has become more problematic in salmon farming worldwide in recent years (Murray et al. 2016, Martinsen et al. 2018), this perhaps being associated with global warming trends as high water temperatures are a significant risk factor for the presentation of the disease (Bridle et al. 2010, Oldham et al. 2016, Nowak and Archibald 2018).

Molecular studies have confirmed that *N. perurans* is a free-living amoeba that occurs naturally in the rearing environment around seacages containing cultured salmonids (Bridle et al. 2010, Hellebø et al. 2016). Bermingham and Mulcahy (2007) suggested that other amoebae may also be involved in AGD in addition to *Neoparamoeba* spp., including the genera *Platyamoeba*, *Flabellula* and *Vexillifera* which have all been recorded on the gills of Atlantic salmon with AGD from both Ireland and Tasmania. Although present in New Zealand, AGD is not considered a significant problem because chinook salmon (*Oncorhynchus tshawytscha*) appear to be resistant to this disease, being often infected but rarely experiencing significant mortality in marine seacages (Munday et al. 2001, Tubbs et al. 2010). However, nodular gill disease caused by other genera of freshwater amoebae, including agents that resemble *Cochliopodia* spp., can be associated with disease and mortalities in juvenile chinook salmon held at high densities in freshwater raceways (Tubbs et al. 2010). These freshwater amoebae cannot survive the transfer to seawater (Lom and Dykova 1992), hence they are unlikely to survive the transfer of smolts into seacages. Amoebae can be found on salmon gills at temperatures of around 10°C in both marine (Mitchell and Rodger 2011) and freshwater sites (Tubbs et al. 2010), however in Tasmania clinical disease is most commonly reported in seawater between temperatures of 12 – 20°C and salinities approaching 35 ppt (Munday et al. 2001). Projected increases in global water temperatures are likely to be the main risk factor initiating AGD outbreaks in years to come (Bridle et al. 2010, Oldham et al. 2016, Nowak and Archibald 2018). Seacaged salmon are worst affected during their first year at sea, and in serious AGD outbreaks, up to 80% mortality can occur if there is no treatment (Mitchell and Rodger 2011, Oldham et al. 2016). Affected fish have multifocal gill lesions characterised by hyperplasia, proliferation of mucous cells and necrosis (Kent et al. 1988, Roubal et al. 1989, Munday et al. 1990, 1993, 2001). Control of AGD is usually obtained by exposing fish to baths of freshwater or hydrogen peroxide, which can be stressful to fish unless innovations such as freshwater layers inside snorkel seacage designs are used (Wright et al. 2017a, 2018, Martinsen et al. 2018, Nobel et al. 2018).

6.3.5 Release assessment

Because *N. perurans* is a free-living amoeba, it occurs naturally in the marine environment, including in areas around seacages containing cultured salmon (Bridle et al. 2010, Hellebø et al. 2016). Within seacages the distribution of *N. perurans* appears to mirror the areas where cultured salmon concentrate (Wright et al. 2017b). It appears that these parasites are opportunistic pathogens that cause disease only in salmonids cultured at high density under adverse environmental conditions (Kent and Poppe 1998, Mitchell and Rodger 2011, Nowak and Archibald 2018). Studies of wild fishes near seacage farms containing infected salmon have found that they are not a significant reservoir of infection, and indeed none of 325 wild fish of 12 different species sampled from around seacages in Tasmania were infected by *Neoparamoeba* spp. (see Douglas-Helders et al. 2002). However use of more sensitive molecular diagnostic methods optimised for *N. perurans* found that while biofouling organisms are not reservoirs of infection, some wild fish (saithe and goldsinny wrasse caught in a trap situated 200 meters away from salmon cages) harboured low intensity infections of *N. perurans*, but only when clinically diseased salmon were present in the nearby seacages (Hellebø et al. 2016). Infection is direct via horizontal exposure to amoebae in the water (Munday et al. 2001). Taking into account that these disease agents are known to occur in the New Zealand environment and are sometimes observed in cultured chinook salmon, the likelihood estimation for salmon infected by amoebae occurring in seacages in the Cook Strait north of the Marlborough Sounds is considered to be **High**.

6.3.6 Exposure assessment

Marine teleosts in New Zealand are already at risk of exposure to free living amoebae such as *N. perurans*, which occurs naturally in the environment. It appears that these parasites are mainly opportunistic pathogens that cause disease only in salmonids cultured at high density under adverse environmental conditions (Kent and Poppe 1998, Mitchell and Rodger 2011). Wild fish are therefore unlikely to be susceptible to infection unless they are also exposed to high numbers of amoebae under adverse environmental conditions at high stocking densities. For example, 8 of 23 (34.7% prevalence) wild fish captured in a trap situated 200 meters away from a salmon cage experiencing an outbreak of AGD harboured low intensity infections of *N. perurans* without any clinical signs of AGD (Hellebø et al. 2016). However one ballan wrasse (*Labrus bergylta*) which was stocked into seacages as a cleanerfish (to remove sea lice) appeared to harbour a clinical AGD infection (Hellebø et al. 2016), and on two occasions cleaner fish in salmon cages were found to be PCR positive for *N. perurans* when the salmon were PCR negative (Hellebø et al. 2016), suggesting that cleanerfish could act as reservoirs for

N. perurans and vectors for AGD transmission. Susceptible fish can become infected with amoebae via horizontal transmission through the water. Salmon with clinical AGD can be infected by high numbers of amoebae, and amoebae can survive and multiply on the gills of dead fish up to at least 30 h post-mortem (Douglas-Helders et al. 2000). However, chinook salmon appear resistant to AGD (Munday et al. 2001), and thus AGD outbreaks seldom cause mortality in seacages in New Zealand (Tubbs et al. 2010), while routine husbandry practices such as early identification and removal of runts and dead fish from seacages limits proliferation of the amoebae and the chances of them spreading to wild fish. Nevertheless, given that there is a direct pathway for amoebae from seacaged salmon to re-enter the marine environment and infect wild fishes that may be attracted to the vicinity of seacages (Dempster et al. 2009, Uglem et al. 2009), and acknowledging that susceptible hosts may occur in the wild, the risk of exposure and establishment is non-negligible, and the likelihood of additional backspill exposure of wild fish populations to amoebae from seacages in the Cook Strait north of the Marlborough Sounds is considered to be **Low.**

6.3.7 Consequence assessment

Although *N. perurans* is present in New Zealand, AGD is not considered a significant problem because chinook salmon are resistant to infection. Wild fishes are not a significant reservoir of infection, and indeed they do not seem to become clinically diseased even in areas around seacages that contain clinically diseased salmon (Douglas-Helders et al. 2002, Hellebø et al. 2016). Given that free living amoebae are already present in the New Zealand marine environment, they do not cause disease in wild fish, and their presence does not adversely impact national or international trade, the consequences of introduction of amoebae into the environment of the Cook Strait north of the Marlborough Sounds with live salmon cultured in seacages are likely to be **Very Low**.

6.3.8 Risk estimation

The unrestricted risk associated with amoebic gill disease is determined by combining the likelihood of release and exposure (from Table 5) with the consequences of establishment (Tables 6, 7). The unrestricted risk estimate for amoebic gill disease does not exceed the ALOP, suggesting that no additional risk management for this disease agent is required at this time.

Risk estimate for amoebic gill disease (AGD)

Commodity type	**Sea caged salmon**
Combined likelihood of release and exposure	Low
Consequences of establishment and spread	Very Low
Risk estimation	Negligible Risk

6.4 Sea lice

6.4.1 Aetiologic agent: Ectoparasitic crustaceans within the Family Caligidae.

6.4.2 OIE List: No **Reportable disease in New Zealand:** No

6.4.3 New Zealand's status: Several different species of the genera *Lepeophtheirus* and *Caligus* (Family Caligidae) occur on a wide variety of wild fishes throughout New Zealand (Hewitt 1963, Jones 1988, Hine et al. 2000).

6.4.4 Epidemiology

Ectoparasitic copepods are parasitic crustaceans that live on the body surfaces, gills and fins of marine and freshwater fishes. Their lifecycles are direct with fish being infected by planktonic larval stages that hatch from eggs deposited by adult copepods (Kabata 1984). In New Zealand, a large number of marine fishes harbour copepod ectoparasites from the Family Caligidae (sea lice) (see Hewitt 1963, Jones 1988, Hine et al. 2000). These copepods encounter their host as copepodid larvae then attach to the host fish via the specialized chalimus larvae (Kabata 1984), which is sedentary until such time as the copepod moults to the pre adult and adult stages, which are mobile and can be found attached to gills, skin or fins (MacKenzie et al. 1998). Chalimus larvae can cause localized pathological changes at their attachment sites (Roubal 1994, MacKenzie et al. 1998), while high numbers of mobile pre-adult and adult caligids (particularly members of the genera *Lepeophtheirus* and *Caligus*) on cultured fish damage the skin of the fish as they feed on host mucus and blood, resulting in morbidity and in some cases, death (Grimnes and Jakobsen 1996, Kent and Poppe 1998). The numbers of sea lice that can be tolerated by the host fish varies with host size, with 1 motile *Lepeophtheirus salmonis* per 0.75–1.6 g body weight being tolerated (Grimnes and Jakobsen 1996, Krkosek et al. 2005). This means that small fish such as juvenile coho and pink salmon around 40 mm long may only be able to tolerate 1 adult sea louse, or less (Krkosek et al. 2005). Sea lice have been responsible for disease and significant mortalities in the culture of salmonids in several overseas countries (Pike and Wadsworth 1999). In cases where cultured fish become heavily infected, they become stressed, and death commonly occurs, ultimately due to osmoregulatory failure or secondary bacterial infection (Grimnes and Jakobsen 1996, MacKenzie et al. 1998, Pike and Wadsworth 1999).

In regions of the world where salmonids are native fishes that occur naturally in the wild, there is some evidence indicating that in areas where large scale intensive salmon farming occurs in seacages, farmed salmon can act as reservoirs of sea lice (mainly *Lepeophtheirus salmonis*, but also other species including *Caligus elongatus*) which can result in increased infection of wild salmonids that must swim past seacage sites during their migrations (Krkosek et al. 2005, Costello 2006, 2009, Todd 2007). Even though wild salmonids and other marine fish are also reservoirs for sea lice (Brooks 2009, Gottesfeld et al. 2009, Penston et al. 2011), the additional infection pressure exerted by salmon farms may increase sea lice burdens on wild fish, possibly resulting in increased morbidity or even mortality in juveniles leaving salmon rivers (Krkosek et al. 2005, Costello 2009) or early river entry in adult fish returning to rivers to spawn (Wells et al. 2007, Todd 2007). Experimental treatment of wild salmon to remove sea lice increased salmon survival by odds ratios of 1.14 – 1.17 in Irish and Norwegian studies, respectively, although meta-analyses by other authors conclude sea lice treatments improve wild salmon survival even more (Jones et al. 2015). The ongoing scientific debate regarding the quantitative effect of sea lice infection on wild salmonids emphasises the challenges associated with attempting to quantify the incremental impact of these parasites within wild fish populations already experiencing >95% natural mortality (Jones et al. 2015).

6.4.5 Release assessment

Parasitic copepods occur on a range of marine and freshwater fishes throughout New Zealand (Hine et al. 2000). Different species of copepods exist on various hosts in different parts of the country, and the identity and distribution of many species is probably not known at this time. *Caligus elongatus* is a host generalist which has been problematic in salmonid aquaculture in the northern hemisphere, and could threaten a wide range of hosts in sea cage culture (Todd 2007) as it has been found on over 80 different hosts (Kabata 1979, Todd 2007, Oines and Heuch 2007). *Caligus elongatus* has been found in the South Island of NZ in the Heathcote Estuary, Christchurch on flounder *Rhombosolea* spp. (Jones 1988, Hine et al. 2000), but has not been reported on cultured salmon in New Zealand to date. *Caligus longicaudatus* was found on sockeye salmon (*O. nerka*) reared in seacages in New Zealand (Jones 1988), but chinook salmon in nearby seacages were not affected (Boustead 1989). Indeed, chinook salmon are relatively resistant to sea lice (*Lepeophtheirus salmonis*) infection compared to Atlantic salmon, but are not as resistant as coho salmon (Johnson and Albright 1992a). Host resistance to sea lice infection is due to both innate genetic factors as well as immunological competence (Johnson and Albright 1992b, MacKinnon 1998, Glover et al. 2001). Another notable species of *Caligus* that is present in New Zealand is *Caligus epidemicus*, which has been recorded on yellowbelly flounder (*Rhombosolea leporina*) in northern New Zealand (Hine et al. 2000). *Caligus epidemicus* has caused mortality in wild fishes (Hewitt 1971), and is an important disease agent in aquaculture of several fish species. For example, one yellowfin bream (*Acanthopagrus australis*) held in experimental seacages was infected by over 6000 *C. epidemicus* (see Roubal 1994). Similarly, a single surgeonfish in the Philippines was recorded to have been infected by 5000 *C. epidemicus* (see Ho et al. 2004), while in Taiwan, heavy infections by *C. epidemicus* resulted in mass mortalities of cultured Tilapia (Lin et al. 1996). *Caligus epidemicus* is known to infect a broad range of hosts (see Hewitt 1971, Byrnes 1987, Roubal 1994, Hallett and Roubal 1995, Venmathi Maran et al. 2009), but to date it has not been recorded from the South Island of New Zealand (Hine et al. 2000).

The lack of evidence of sea lice infection in chinook salmon in New Zealand after many years of culturing these fish at high densities demonstrates that chinook salmon are resistant to infection by endemic species of sea lice. However, two species of sea lice that have been recorded in flatfish in New Zealand, namely *C. elongatus* and *C. epidemicus*, are known to have low host specificity, and this may mean that chinook salmon could be susceptible to infection by these parasites in the future at some stage if they were to become exposed to them and host switching occurred. The water temperatures in the Marlborough Sounds region (annual range 10 – 19°C) may be too cold for *C. epidemicus* at this time, as this species is usually found in tropical and warm temperate regions. On the other hand, *Caligus elongatus* has already been recorded from the South Island (Jones 1988). However, it appears that this parasite has not been problematic in culture of chinook salmon elsewhere (Jackson et al. 2000), and it is not generally found on wild chinook salmon in the northern hemisphere either (Gottesfeld et al. 2009), which reinforces the empirical evidence that chinook salmon in New Zealand do not appear susceptible to *C. elongatus* at this time. Host switching by caligids onto new hosts is known to occur (Molinet et al. 2011), and one possible mechanism that could encourage this process is increased use of artificial lighting to delay onset of maturation of seacaged salmon (Unwin et al. 2005). The copepodid infective stage of caligid copepods is photopositive (Heuch et al. 1995, Genna et al. 2005), hence use of artificial lighting tends to attract them and increase the number of encounters between copepodids and caged salmon (Hevroy et al. 2003), potentially increasing the risk of host switching. On the other hand, given that the known hosts for potentially problematic sea lice in New Zealand (*C. elongatus* and *C. epidemicus*) are both bottom dwelling flatfish (flounder *Rhombosolea* spp. and yellowbelly flounder *Rhombosolea leporina*), and water depths at the proposed farming site in Cook Strait are c. 70–100 meters, the proposed new location would greatly reduce the chances of cultured salmon being in close proximity to known sea lice vectors compared to the existing status quo in the Marlborough Sounds.

Taking into account that sea lice have not been problematic in cultured chinook salmon in New Zealand at this time, but acknowledging that sea lice species known to be problematic in seacage aquaculture elsewhere are known to occur on flatfish in marine waters of the South Island, and increased intensity of sea cage salmon farming in the Marlborough Sounds or in Cook Strait adjacent to the Marlborough Sounds could trigger host switching due to increased host density (Krkosek 2010) and/or increased use of artificial lighting, the likelihood estimation for salmon becoming infected by sea lice in seacages in the Cook Strait north of the Marlborough Sounds is non-negligible, and is considered to be **Very Low**.

6.4.6 Exposure assessment

Marine teleosts throughout New Zealand are already at risk of exposure to endemic caligid parasites. They naturally infect wild fishes and a few species of copepods cause disease, usually in circumstances where environmental conditions are favourable for their multiplication on the host. Infection and establishment in wild fish would occur only if sufficient quantities of infective copepodid stages (i.e. an infective dose) were introduced into an area where susceptible hosts were present. However, copepod infections can become established if susceptible hosts are exposed even to only one viable copepodid larvae (Diggles 2018), although in the natural environment several factors will influence infectivity (Brooker et al. 2018). For example, the infectivity of copepodids of *C. epidemicus* increased with increasing copepodid density and varied with the age of the copepodid, peaking after 3 or 4 days post hatching at 26 or 19°C, respectively, then declining over time (Hallett and Roubal 1995). Further, some fish appeared refractory to infection, while other individuals of the same host species were extremely susceptible to infection, resulting in an overdispersed distribution typical of that seen in many parasite/host relationships (Hallett and Roubal 1995).

Both empirical measurements and models have been used to estimate the additional infection pressure potentially exerted by marine farms containing salmon infected with sea-lice (mainly *L. salmonis* and *C. elongatus*). As the lifespan of the planktonic nauplii and infective copepodid stages of sea lice can be as long as 14 days at 10°C (Johnson and Albright 1991), significant transport and dispersion with surface currents is possible (Amundrud and Murray 2009, Brooks 2009, Asplin et al. 2014, Kragesteen et al. 2016, Skarðhamar et al. 2018). Some models suggest that sea lice infection pressure near infected marine farms can be 2 to 4 orders of magnitude higher than ambient background levels, and may exceed background levels at least 30 km from infected farms (Krkosek et al. 2005), and possibly up to 80 km (Kragesteen et al. 2016) or more (Asplin et al. 2014, Skarðhamar et al. 2018).

However, there are variations in results generated by different models, resulting in significant scientific debate. For example the model by Krkosek et al. (2005) had several errors which meant that it was likely to be unreliable (Brooks 2005). A particle tracking model used by Brooks (2005) predicted that most sea lice nauplii would be transported by currents 7.3–10.0 km downcurrent (out of the archipelago) before they become infective, and that they may be transported up to 40 km from an infected farm before becoming infective. Dispersal distances of larvae of other marine species in relation to the range of typical coastal ocean current conditions suggested that sea lice larvae may disperse an average of 27 km (11–45 km range) over 5–15 days, depending on current velocity (Costello 2006). Based on data from Johnson and Albright (1991), copepodids suffer mortality at an average rate of 1.0 - 2.9% per hour in seawater, depending on temperature and salinity (Stein et al. 2005, Bricknell et al. 2006), so while some infective stages can survive for long periods under optimal conditions, infection pressure still decreases rather rapidly with increasing distance from an infected marine farm (Amundrud and Murray 2009, Brooker et al. 2018).

If chinook salmon in seacages did become infected with sea lice via host switching, there is a direct pathway for sea lice infective stages originating from infected salmon to enter the marine environment and infect wild fishes close to salmon farms, but also possibly up to 45 km away, depending on currents at the farm and a myriad of other factors (Krkosek et al. 2005, Amundrud and Murray 2009, Brooks 2009, Johnsen et al. 2016, Diggles 2018). Acknowledging the empirical evidence demonstrating that sea lice infections have not occurred in cultured chinook salmon in New Zealand at this time, but noting that some sea lice species are able to infect a broad range of susceptible hosts, and that host switching due to increased host density (Krkosek 2010) may be facilitated by activities such as artificial lighting and/or if the intensity of sea cage salmon farming in the Marlborough Sounds or Cook Strait is increased in the future, the risk of exposure and establishment is non-negligible, and the likelihood of exposure of wild fish populations to sea lice is considered to be **Moderate**.

6.4.7 Consequence assessment

Many species of sea lice are already present in New Zealand's marine environment. All size classes of juvenile and adult fish can become infected with caligid copepods, and infections of some species with low host specificity, such as *C. epidemicus*, can have negative impacts on the health of individual fish and their populations in the wild, but only under extraordinary circumstances (Hewitt 1971). However, *C. epidemicus* does not occur in the South Island, and at this time water temperatures are likely to be too cold for it to become established there, though water temperatures may increase in the future consistent with global trends, and this needs to be taken into account. The potential for host switching to occur if a threshold intensity of fish farming is reached (Krkosek 2010) also needs to be considered. There is evidence that chinook salmon have established self sustaining populations in the Clarence and Wairou Rivers (N. Boustead, personal communication), which may indicate that establishment of sea lice infections on cultured chinook salmon could result in interactions with migrations of wild salmon through the Marlborough Sounds region, although the extent of these potential interactions would be difficult to quantify. Because sea lice that infect seacaged salmonids only tend to occur at subclinical levels in wild non-salmonids (Jones et al. 2006a, 2006b), localized increases in prevalence and/or intensity of sea lice infections in wild marine fish near affected salmon farms are unlikely to have significant impacts on wild native fish populations. No copepod parasites are listed by the OIE or in New Zealand's national reportable disease list, hence their presence is unlikely to have adverse impacts on trade. Considering all of these factors, establishment of sea lice in sea caged salmon would have mild biological consequences for wild fishes, and/or may cause some environmental effects, which would not be serious or irreversible. It is therefore estimated that the environmental consequences of introduction of sea lice via salmon in seacages in the Cook Strait north of the Marlborough Sounds would be **Low**.

6.4.8 Risk estimation

The unrestricted risk associated with sea lice infections is determined by combining the likelihood of release and exposure (from Table 5) with the consequences of establishment (Tables 6, 7). The unrestricted risk estimate for sea lice does not exceed the ALOP, suggesting that additional risk management for these disease agents is not required at this time.

Risk estimate for sea lice

Commodity type	**Seacaged salmon**
Combined likelihood of release and exposure	Very Low
Consequences of establishment and spread	Low
Risk estimation	Negligible Risk

6.5 Whirling Disease

6.5.1 Aetiologic agent: *Myxobolus cerebralis*, a myxosporean parasite of salmonid fishes.

6.5.2 OIE List: No **Reportable disease in New Zealand:** Yes

6.5.3 New Zealand's status: *Myxobolus cerebralis* has been reported from several species of salmonids in the South Island (Boustead 1993, 1996), but does not appear to have been recorded from the North Island (Anderson 1996, Diggles et al. 2002).

6.5.4 Epidemiology

Myxosporeans are economically important histozoic and coelozoic endoparasites which have adversely affected the culture of freshwater and marine fishes worldwide (Alvarez-Pellitero and Sitja-Bobadilla 1993, Moran et al. 1999a). The higher taxonomy of the group has been controversial in the past but the link between myxosporeans and cnidarians within basal metazoa has now been confirmed (Smothers et al. 1994, Holland et al. 2010, Nesnidal et al. 2013), and it appears that myxosporeans are highly specialised parasitic cnidarians. The myxosporean parasite *Myxobolus cerebralis* infects cartilage of the skeletal system, including the cranium, affecting the auditory and nervous systems resulting in neurological changes and tail chasing behaviour in clinically diseased fish (particularly rainbow trout *Oncorhynchus mykiss*), resulting in what is termed whirling disease (Bartholomew and Reno 2002).

First reported in Germany in rainbow trout (*O. mykiss*) and brook trout (*Salvelinus fontinalis*) in 1893 (Höfer 1903), *M. cerebralis* has since been documented in temperate freshwater ecosystems around most of the world (Bartholomew and Reno 2002). The parasite primarily infected the cartilage of the cranium, affecting the auditory and nervous systems resulting in neurological changes and tail chasing (whirling behaviour, or Drehkrankheit) in clinically diseased fish, particularly juvenile rainbow trout which appeared highly susceptible to infection if they were exposed to *M. cerebralis* infective stages before their cartilaginous skeletons had hardened (Bartholomew and Reno 2002). In contrast, infections of the European brown trout (*Salmo trutta*) by the same parasite were apparently benign, with infected fish being sub-clinical carriers of *M. cerebralis*, suggesting that the parasite is likely to have evolved as an endemic parasite of brown trout in Europe (see Schäperclaus 1931, Bartholomew and Reno 2002). In contrast, wild and cultured salmonids in North America have suffered significant disease outbreaks since the parasite was first documented in the United States in Pennsylvania in 1956 (Bartholomew and Reno 2002). *Myxobolus cerebralis* is thought to have been transported to North America in the 1950s in either live brown trout imported into hatcheries as broodstock, or in frozen trout products imported from Europe and introduced into local waterways as bait or fishfeed (Nickum 1999, Bartholomew and Reno 2002) and possibly also through translocation of its invertebrate intermediate hosts (Lowers and Bartholomew 2003, Hallett et al. 2005, 2006). Since the original introduction, *M. cerebralis* has since spread through much of the United States through stocking of infected fingerlings into uninfected waterways (Bartholomew and Reno 2002), and angler activities (Budy et al. 2003, Gates et al. 2008, 2009). How and when *M. cerebralis* was introduced into New Zealand is not clear, however it was first detected in New Zealand at a trout hatchery near Dunedin in 1971 (Hewitt and Little 1972), and was thought to have been present many years before that, perhaps as early as 1952 (Hewitt and Little 1972, Boustead 1993, Bartholomew and Reno 2002). Since then *M. cerebralis* has been found in wild and cultured salmonids at several locations in the South Island in both clinically diseased rainbow trout as well as clinically healthy salmonids that were sampled for research or export certification (Hewitt 1972, Knowles 1992, Boustead 1993, 1996, Anderson 1993, 1995, 1996, 1997). It appears that *M. cerebralis* has not been recorded in the North Island (Anderson 1996, Diggles et al. 2002).

The lifecycle of *M. cerebralis* is indirect and requires tubificid oligochaetes as an intermediate host (Markiw and Wolf 1983, Wolf and Markiw 1984). Once the myxospores liberated from a dead infected fish are consumed by these worms, the spores release their infective sporoplasm which migrates into the lining of the intestine where it multiplies and replicates to form triactinomyxon (TAM) infective stages (Hedrick and El‐Matbouli 2002), which are then shed by the worms into the water to reinfect susceptible salmonids (Markiw and Wolf 1983, Wolf and Markiw 1984, Hedrick and El‐Matbouli 2002). Different strains of *T. tubifex* have different susceptibility to infection with *M. cerebralis*, a factor which can influence the severity of clinical disease in local rainbow trout populations (Baxa et al. 2008, Beauchamp et al. 2005, Hallett et al. 2009). Myxosporean triactinomyxon infective stages can be disseminated via translocation of oligochaete worms (Lowers and Bartholomew 2003, Hallett et al. 2006), and in regions where *M. cerebralis* has been introduced, sites with highest angler activity tend to have the highest prevalences of the parasite (Budy et al. 2003). Indeed, transfer of spores or other infective stages of the parasite via soil or other material lodged in fishing boots, waders or other angling equipment is a likely source of unexpected spread of the parasite through angler activity (Gates et al. 2008, 2009). *Myxobolus cerebralis* spores can tolerate freezing at -20°C for a week (Arsan and Bartholomew 2008), to 3 months (El-Matbouli and Hoffmann 1991), while the triactinomyxon infective stages can be spread via translocation of oligochaetes (Hallett et al. 2006), hence imported salmon products, tubificids imported as ornamental fish food, and translocation of spores on angling equipment such as waders could all have been potential mechanisms by which the disease agent was introduced into New Zealand (Bartholomew and Reno 2002). *Myxobolus cerebralis* infects salmonids only and has not been known to infect any other groups of fishes (Anderson 1993).

6.5.5 Release assessment

Myxobolus cerebralis has been introduced and has become established in New Zealand. The parasite has been found in a range of salmonid species, including rainbow trout (*O. mykiss*), brown trout (*S. trutta*), brook trout (*S. fontinalis*), chinook salmon (*O. tshawytscha*) and sockeye salmon (*O. nerka*) (see Boustead 1993). The tubificid oligochaetes that are suitable intermediate hosts for the parasite are ubiquitous in the aquatic freshwater environment, and because of this the disease agent occurs naturally in freshwater aquatic environments in several places in the South Island (Boustead 1993, Anderson 1996). As salmonids age their susceptibility to infection by *M. cerebralis* reduces markedly due to several factors, particularly the degree of ossification of cranial cartilage (Markiw 1992, Anderson 1993). Use of bore water and concrete raceways can significantly reduce the chances of exposure of young salmon to the disease agent (Knowles 1992, Anderson 1997). However, juvenile chinook salmon reared in freshwater in concrete raceways can still be exposed to infective stages of the parasite via their water supply and have become infected at very low prevalences and intensities in New Zealand (Boustead 1993, 1996), although clinical whirling disease has never been recorded in this species in

New Zealand (Boustead 1993, 1996, Anderson 1996, 1997). Taking into account that *M. cerebralis* is rarely detected in cultured chinook salmon fingerlings, the likelihood estimation for salmon infected by *M. cerebralis* occurring in seacages in the Cook Strait north of the Marlborough Sounds is considered to be **Low**.

6.5.6 Exposure assessment

Salmonids in freshwaters throughout the South Island of New Zealand are already at risk of exposure to *M. cerebralis* through natural pathways. However marine fishes are not susceptible to this disease agent, nor are the freshwater tubificid intermediate hosts required to complete the lifecycle likely to be present in the marine environment under salmon farms. However, it is possible that chinook salmon infected with *M. cerebralis* could escape from seacages, survive and re-enter freshwater, potentially allowing the opportunity for the lifecycle to be completed. There is evidence that chinook salmon have established self sustaining populations in the Clarence and Wairou Rivers, and some of these fish may have originated as escapees from seacages (N. Boustead, personal communication). Because of this, even though the prevalence and intensity of *M. cerebralis* infections in chinook salmon smolt is very low (Boustead 1993, 1996), the risk of exposure and establishment of *M. cerebralis* in the environment of the Marlborough Sounds via introduction of live salmon cultured in seacages is non-negligible, and the likelihood of exposure and establishment of wild fish populations to *M. cerebralis* in freshwater rivers adjacent to Cook Strait is considered to be **Extremely Low**.

6.5.7 Consequence assessment

Myxobolus cerebralis is already present in several locations in the South Island of New Zealand. This disease agent only infects salmonids and has caused clinical disease in New Zealand only on rare occasions in rainbow trout cultured in earth or gravel ponds (Anderson 1997). It is possible that some of the chinook salmon in the Clarence and Wairou Rivers may have originated from salmon farms (N. Boustead, personal communication), which indicates that a potential pathway exists which could allow completion of the lifecycle of *M. cerebralis* if infected fish were released into seacages and subsequently escaped. However the likelihood of this pathway being successfully completed would appear remote, and needs to be measured against the significant risks of transfer of spores or other infective stages of the parasite via angling activity (Gates et al. 2008, 2009). This parasite is not listed by the OIE, though it remains a reportable disease in New Zealand (Table 2). Considering all of these factors, transfer of *M. cerebralis* into the marine environment with sea caged salmon would have mild biological consequences for wild salmonids, and/or may cause minor environmental effects, which would not be serious or irreversible. It is therefore estimated that the environmental consequences of introduction of *M. cerebralis* via salmon in sea cages in the Marlborough Sounds would be **Very Low**.

6.5.8 Risk estimation

The unrestricted risk associated with whirling disease is determined by combining the likelihood of release and exposure (from Table 5) with the consequences of establishment (Tables 6, 7). The unrestricted risk estimate for whirling disease does not exceed the ALOP, suggesting that additional risk management for this disease agent is not required at this time.

Risk estimate for whirling disease

Commodity type	Seacaged salmon
Combined likelihood of release and exposure	Extremely Low
Consequences of establishment and spread	Very Low
Risk estimation	Negligible Risk

7.0 Recommendations for disease risk mitigation

7.1 Mitigating risks posed by infection with *Piscirickettsia*-like bacteria

This qualitative risk analysis has determined that the only disease of concern in cultured salmon that requires additional risk mitigation at this time is infection with *Piscirickettsia*-like bacteria (NZ-RLO) when it occurs in clinically diseased salmon. The emergence of this disease in farmed salmon in New Zealand in recent years confirms observations from overseas that new diseases tend to originate from wild fish populations, but emergence is generally only observed first in farmed fish populations (Jones et al. 2015). Because of this, maintenance of a high health status in farmed fish reduces both their susceptibility to putative pathogens carried by wild fish populations, and also reduces the risk of possible subsequent back spill of the same disease agents into wild fish populations (Jones et al. 2015, Jackson et al. 2018).

Given that this analysis suggests the environmental risks only exceed the ALOP if populations of clinically diseased salmon are held in seacages, mitigation of the risk of disease outbreaks due to *Piscirickettsia*-like bacteria is important. As for other bacterial diseases, vaccination is likely to be the most effective way of controlling *Piscirickettsia* disease outbreaks (Fryer and Hedrick 2003), however there are several technical challenges that need to be addressed before long lasting protection against *Piscirickettsia* agents is achieved (Evensen 2016, Maisey et al. 2017). Neverttheless, development of a vaccine for the local strains of NZ-RLO is highly recommended if the disease becomes more problematic. Use of best practice husbandry methods to control known risk factors can also reduce the likelihood of *Piscirickettsia* disease outbreaks. Perhaps the most important risk factor is water quality, which needs to be optimized via site selection and farm management to maximize the immune competence of the fish, which is especially important as NZ-RLO infected fish may not become clinically diseased if they are not stressed or infected with other pathogens (DAFF 2013, Fischer and Appleby 2017, Brosnahan et al. 2018). In the case of salmonids, this means maintaining dissolved oxygen levels above 6 mg/L (preferably above 6.5 mg/L), reducing temperature and salinity fluctuations and avoiding temperature extremes (>16°C) and exposure to sediment and pollutants (Ellard 2015). It would be reasonably expected that all these water quality objectives would more likely be achievable at offshore farm sites in Cook Strait.

Other best practice risk reduction methods which should be employed to mitigate risks posed by *Piscirickettsia*-like bacteria include using broodstock that have never been exposed to seawater, rearing fish at optimal stocking densities, allowing farms in a given region to fallow at regular intervals, controlling ectoparasites that may act as vectors, and avoiding horizontal transmission between year classes by holding single year classes of fish at any given site (Fryer and Hedrick 2003). Of these best practices, regular rotational fallowing and single year class farming within each farm management area are not explicitly addressed by the NZKS biosecurity management plan (NZ King Salmon 2016, Fischer and Appleby 2017). Broodstock management which prevents use of broodstock fish originating from seawater was also not explicitly addressed in the current biosecurity management plan, although this policy is reportedly in place (Colin Johnston, personal communication 25 May 2016).

Obviously, this analysis has necessarily been based on those diseases that occur in New Zealand salmon at this point in time. New disease agents (e.g. microsporidians) may emerge, while some of the known disease agents of concern which presently do not occur in the South Island of New Zealand (e.g. sea lice *Caligus epidemicus*) may extend their range into the Marlborough Sounds in the future if current global warming trends continue as projected. The risk of host switching of other sea lice (e.g. *C. elongatus*) or emergence of other endemic diseases (e.g. *Kudoa* spp.) vectored by native marine fishes if a threshold intensity of chinook salmon farming is reached (Krkosek 2010) also needs to be considered when planning for this industry. Furthermore, there have been many instances of disease emergence in finfish aquaculture around the world that have occurred due to lapses in biosecurity. Although New Zealand's biosecurity arrangements are amongst the best in the world, there have been several biosecurity leaks in recent years that have allowed exotic pests and diseases to establish in New Zealand waters (Smith et al. 2003, Stuart 2004, Kilroy et al. 2009, Lane et al. 2016). These examples demonstrate that a risk remains and exotic diseases could be introduced, and/or new endemic diseases could emerge in salmon aquaculture in New Zealand at some time in the future. Because of this, it is important to ensure that biosecurity planning is integral to management of the salmon farming industry in order to firstly avoid disease problems, and in a worse case scenario, to be able to effectively manage any new problems that may emerge (Munro et al. 2003, Murray and Peeler 2005, Gustafson et al. 2005, 2007, Kibenge et al. 2009, Mardones et al. 2009). As detailed above, the biosecurity protocols listed in the NZKS biosecurity management plan (NZ King Salmon 2016) effectively mitigate most, but not all, of the risks related to management of diseases such as the NZ-RLO. Site selection is extremely important for biosecurity management and the proposed establishment of an offshore farm area in Cook Strait has several advantages in this regard, particularly in relation to improved water quality and reduced vessel traffic (see Section 2.0), large buffer zones between the site and other salmon farming zones (see Section 7.3), and increased water depth which reduces proximity to bottom dwelling fishes which can act as vectors for birnaviruses (see Section 6.1.6) and sea lice (see Section 6.4.5). Effective disease surveillance is also an important activity that can help reduce the risks of establishment of new diseases, and the risks to the industry can be further mitigated through implementation of worlds best practice biosecurity management arrangements for finfish seacage farming. Some of the best practice management arrangements used in salmon farming to minimise disease risks are discussed in more detail in the sections below.

7.2 Year class farming and site fallowing

Year class farming and site fallowing are methods of farm management used to control some of the risk factors associated with disease emergence and persistence in seacage aquaculture (Stewart 1998). The presence of multiple year classes of fish on any given site can allow disease agents to persist for long periods on site because holdover fish provide an avenue for transfer of pathogens between year classes (Gustafson et al. 2007, Sitjá-Bobadilla and Oidtmann 2017). Management arrangements that allow only one year class of fish to be held in any given individual farm management area significantly reduce the risk of persistence and spread of disease agents (Gustafson et al. 2007, Brooks 2009). Because of this, year class farming is generally acknowledged to be worlds best practice for salmon farming. Furthermore, fallowing of seacage sites is often useful to reduce or eliminate residual infection pressure for disease agents such as viruses and parasites by removing their hosts (Gustafson et al. 2007, Penston et al. 2011). There is also evidence that fallowing can assist with mitigation of bacterial diseases (Stewart 1998) including piscirickettsiosis (Price et al. 2017) and indeed, fallowing can reduce the risk of emergence of new diseases which otherwise could adapt (switch) to new hosts if they are allowed to co-exist with them for long uninterrupted periods (Snow 2011). Synchronised fallowing within farm management areas has become compulsory in some salmon farming areas for these very reasons (Chang et al. 2007, Jones et al. 2015, Murray and Gubbins 2016).

The proposed location of the new offshore salmon farming area in the Cook Strait is likely to provide more suitable water quality for salmon farming than the other existing inshore locations within the Marlborough Sounds. The proposed offshore area would also be additional to the existing 2 zones outlined in the Controlled Area Notice (Queen Charlotte Sound Management Area and Pelorus Sound Management Area). The fact that chinook salmon reach market size within 18 months to 2 years after introduction into seacages theoretically suggests that this arrangement could eventually allow the option to move towards world's best practice biosecurity arrangements using 3 epidemiologically independent farm management areas with regular synchronised site fallowing within each management area and only one year class of fish in each independent farm management area at any given time. However, because both the Queen Charlotte Sound Management Area and Pelorus Sound Management Area do not have sufficient farm sites to accommodate an entire years worth of production in each area, hence the proposed changes alone are still not sufficient to allow migration to worlds best practice (entailing complete year class farming within each area followed by fallowing) at this time. While the proposed situation is a significant improvement over existing arrangements, in view of current global warming trends which are likely to increase disease risks to the industry over time, the ideal situation of 3 sufficiently large independent farm management areas with regular synchronised fallowing of each area should still be considered the ultimate goal for future planning arrangements for the industry in the Marlborough Sounds region.

7.3 Buffer zones and location of seacages

Site selection is critical to maintenance of high health status in seacage cultured fish. The restricted distribution of disease associated with the NZ-RLO (which historically has mainly been problematic at low flow sites within the Marlborough Sounds), suggests that environmental conditions at those sites are marginal and more permissive for disease to emerge than at other sites, especially during summer when salmon may be stressed by high water temperatures >16°C. The proposed addition of a new offshore salmon farming area in the Cook Strait would provide better water quality which would minimise risks of emergence of infectious diseases such as piscirickettsiosis as well as non-infectious diseases, and thus would better allow the salmon farming industry to minimize risks to itself and the environment posed by diseases of salmon. The proposed location also provides an ideal buffer zone (>16 km) between each of the other two salmon farming management areas in Queen Charlotte Sound and Pelorus Sound (Section 2.0). The following sections (reproduced from Diggles 2018) provide more detail on the size of ideal buffer zones for each of the major groups of salmon disease agents.

7.3.1 Viruses

Empirical evidence based on surveys of wild marine fish showed that the risk of infection with IPNV in coastal waters of Scotland was increased slightly above background levels (from 0.15% prevalence to 0.58% prevalence) in wild fishes within 5 km of salmon farms that contained fish clinically diseased with IPN (Wallace et al. 2008). An epidemiological study of Scottish salmon farms in coastal areas found that increased risk of IPNV infection no longer occurred at a distance of 8-10 km from an infected farm (Murray et al. 2004). A similar increased risk distance for IPNV was modelled by Murray and Gubbins (2016) for Atlantic salmon (*Salmo salar*) farms in lochs in Scotland. In farms rearing *S. salar* in Chile, however, Mardones et al. (2016) found that having one other marine salmon farm within a 15 km radius increased the risk of clinical outbreaks due to IPNV between 22 to 34%. A more recent epidemiological study from Chile suggested that increased infection pressure for IPNV in *S. salar* may extend as far as 10 km from a source farm in instances of high farm /fish stock intensity (Escobar – Dodero et al. 2018).

For ISAV, earlier studies in Norwegian fjords showed that infection risk for farmed *S. salar* increases significantly when non-infected salmon farms are less than 5 km from a processing facility or infected salmon farm (Jarp and Karlsen 1997, Scheel et al. 2007). McLure et al. (2005) found risk of infection with ISAV in Canadian (New Brunswick) bays was increased within 0.5 km of cages with clinically diseased *S. salar*, however in Chile Mardones et al. (2009) found that in some cases salmon farms within a 15 km radius of an ISA index case had up to 12 times increased risk of infection.

7.3.2 Bacteria

For bacteria, an epidemiological study in Chile found that the infection pressure for the pathogen *Piscirickettsia salmonis* in farmed *S. salar*, rainbow trout *Oncorhynchus mykiss*, and Coho salmon (*Oncorhynchus kisutch*) was elevated above background levels within a distance of 7.5–10-km of an infected source farm (Rees et al. 2014). Indeed, they found that the probability that a farm will report disease due to *P. salmonis* was directly associated with whether their neighbouring farms within 10 km had the disease.

7.3.3 Monogeneans

For monogeneans a study by Chambers and Ernst (2005) examined infections of the capsalid monogenean *Benedenia seriolae* on kingfish (*Seriola lalandi*) cultured in Spencer Gulf, South Australia. Their data was based on empirical results from sentinel fish held in experimental cages at varying distances from a farm holding a population of *B. seriolae* infected kingfish. They found that infection pressure was highest nearest the infected farm, reducing logarithmically with distance from the farm. Kingfish within an 8 km radius of the farm still had increased levels of infection (3.7% of that at the source), but infection pressure had returned to background levels (0.7% of that at the source) by 18 km down current. Monogeneans have a simple direct lifecycle and it was presumed that the current was the main factor responsible for transport of the non-infective eggs as well as the short-lived (24 hours) oncomiricidium infective larval stage (Chambers and Ernst 2005). Entrapment of eggs on cage infrastructure was likely to be a major factor responsible for high infection pressure at the farm site. Unfortunately no current data was presented in their paper (except observations that the "strong" current from the 2.4 m spring tides had dragged one sentinel cage from 16 km to 18 km in 24 hours), so it is difficult to compare these results to those from other metazoan parasites such as sea lice.

7.3.4 Sea lice

Several studies have shown that peak sea lice (*Lepeophtheirus salmonis*, *Caligus* spp.) infection pressure for wild fish is likely to be located away from salmon farms under any residual current scenarios, because the newly hatched sea lice nauplii are not infective. Indeed, sea lice larval stages only become infective after several days in the plankton (up to 2 weeks at 10°C, see Johnson and Albright 1991) after they moult into the infective copepodid stage (Brooks 2005, Murray and Gillibrand 2006, Amundrud and Murray 2009, Molinet et al. 2011). Asplin et al. (2004) used a numerical model to estimate that *L. salmonis* infective stages could spread as far as 100 km from salmon (*S. salar*) farms in Norwegian fjords. However, they assumed the salmon lice infective stages were immortal, which likely resulted in overestimation of the dispersal capabilities of viable infective stages (Brooker et al. 2018). Similarly, an early model for the Pacific coast of Canada suggested that sea lice infection pressure near infected marine farms can be 2 to 4 orders of magnitude higher than ambient background levels, and can exceed background levels at least 30 km from infected farms (Krkosek et al. 2005). However the model by Krkosek et al. (2005) had several errors which meant that it was likely to be unreliable (Brooks 2005). A particle tracking model used by Brooks (2005) instead predicted that most sea lice nauplii would be transported by currents 7.3–10.0 km downcurrent (out of the archipelago) before they become infective, and that they may be transported up to 40 km from an infected farm before becoming infective.

Based on data from Johnson and Albright (1991), copepodids suffer mortality at an average rate of 1.0 - 2.9% per hour in seawater, depending on temperature and salinity (Stein et al. 2005, Bricknell et al. 2006), so while some infective stages can survive for long periods under optimal conditions, infection pressure still decreases rather rapidly with increasing distance from an infected marine farm (Amundrud and Murray 2009). Dispersion distance depends greatly on prevailing currents, and thus also varies with many other hydrodynamic and geographic variables (Johnsen et al. 2016). When these are taken into consideration (usually using complex modelling, but sometimes using empirical data from plankton samples or caged sentinel fish), the risk of sea lice infection tends to be increased above background levels at least 8 to 18 km from lice infected salmon farms (Brooks 2009, Penston et al. 2011), and the maximum distance where increased infection pressure has been observed empirically or modelled is around 30-45 km (Amundrud and Murray 2009, Penston et al. 2011, Johnsen et al. 2016, Table 1), with individual particles (not all of which are likely to be viable) being modelled up to 90-100 km away in some of the larger Norwegian fjords (Asplin et al. 2004, 2014, Skarohamar et al. 2018) and the high current environment of the Faroe Islands (Kragesteen et al. 2018). However in smaller systems, such as Scottish lochs, sea lice tend to travel shorter distances, with the highest accumulation of infective stages tending to occur between 6 km (Amundrud and Murray 2009) and up to 12 km away from individual source seafarms (Gillibrand and Willis 2007, Gillibrand and Amundrud 2007).

To summarize, modelling has indicated that the maximum individual sea lice infective stages can be transported is up to 100 km in long, Norwegian fjords, and 10–40 km in Pacific Canada, whereas in smaller systems such as Scottish lochs, lice tend to travel shorter distances usually less than 10 km (Amundrud and Murray 2009, Salama et al. 2013). A large number of recent modelling studies have not changed these conclusions, however the empirical measurements from sentinel fish or plankton tows tend to provide results reflecting shorter real world transport distances than predicted by the modelling. These data together suggest that in typical salmon farming environments, most sea lice infection pressure tends to act within 15-20 km of infected farms, with transmission success reducing significantly at extreme distances beyond 40 km (Diggles 2018). This suggests that the width of an ideal on-water buffer zone ("as the fish swims", not "as the crow flies") to ensure true independence of salmon farming management areas in the presence of sea lice would be between 18 and 45 km from the nearest farm in one farm management area to the nearest farm in an adjacent farm management area.

7.3.5 Buffer zone discussion

In Sections 7.3.1 to 7.3.4, two different components of disease agent spread are recognised. Dispersal distance is the maximum distance recorded (or modelled) for movement of an infective stage (e.g. of a sea lice copepodid stage) whether it is viable or not, while transmission distance is the maximum distance at which successful infection via viable infective stages has been confirmed to occur. The difference between the two metrics is important for all disease agents, but especially for sea lice.

The markedly reduced infection pressure with distance associated with the viruses and bacteria is likely because they require a minimum infectious dose before they are successfully transmitted. In contrast, monogeneans have an intermediate transmission distance due to the robust non infective egg stage that can be transported away from the farm before it hatches, but the resulting oncomiricidium larvae is relatively fragile and short lived. Sea lice are the most persistent because they have a non-infective nauplius stage which moults after a week or two (depending on water temperature) into a reasonably robust infective copepodid, and theoretically a single copepodid is sufficient to cause reinfection.

This review of the scientific literature suggests that the width of an ideal on-water buffer zone ("as the fish swims", not "as the crow flies") to ensure true independence of salmon farming management areas under the existing disease situation in New Zealand (in the absence of sea lice but presence of bacteria and viruses) would be somewhere between 10-15 km. However, if sea lice outbreaks became problematic in New Zealand in the future, consideration could be made to increase the ideal buffer zone into a range of between 18 and 45 km, with the actual minimum distance depending on detailed modelling (MAF Biosecurity 2011a, Diggles 2018).

7.4 Harvesting

Harvesting is another process that presents an increased risk of disease transmission. Indeed, the spread of ISA in Scotland, and Norway (Murray et al. 2002, Munro et al. 2003, Thorud and Hastein 2003) and also Canada (Gustafson et al. 2005) was associated with spread of effluent from well boats used for harvesting, and/or from processing plants. A brief summary of the best practice arrangements used for both of these activities is included below.

7.4.1 Harvesting method

There have been instances of spread of viral disease agents such as ISA during the harvesting process when live fish are transported from farming areas to centralised processing facilities in well boats (Murray et al. 2002). Munro et al. (2003) evaluated the relative risks of spread of ISA associated with various different harvesting methods commonly used in Scotland. The highest risks of transmission to neighbouring farms was likely to occur when live fish in seacages were towed to centralised processing plants (Munro et al. 2003). Any harvesting methods that could allow escape of live fish were also considered to be higher risk. In contrast, the harvesting methods currently used by NZKS (rested slaughter at the cage site using anaesthetic followed by bleeding into an ice slurry in a harvest tub and transport of fully sealed harvest tubs (MPI 2016) by barge to the wharf for road transport to land based processing plants) were considered to represent a moderate risk of spread of disease to neighbouring farms, but the lowest risk of spread of disease en-route to the processing plant (Munro et al. 2003).

The harvesting methods used by NZKS are therefore compatible with the process of establishment of independent farm management areas, provided that there is no movement of harvest barges from one farm management area to another. This would be accommodated by ensuring in the biosecurity management plan that all fish harvested from the Queen Charlotte Sound Management Area are landed only in Picton, and that separate barges and equipment are used to service the Pelorus Sound Management Area and that salmon from there are only landed at Havelock, as is required by the current CAN (MPI 2016). Such an arrangement would be consistent with worlds best practice management for this activity from both minimisation of disease risk and maximisation of product quality and animal welfare (Gregory 2008, Tuckey et al. 2009, 2010). The location of landing of harvest barges from the offshore farming site would need to be different to Picton or Havelock, if world's best practice was to be maintained in this regard.

7.4.2 Processing premises

Spread of viral diseases such as ISA has been documented where several companies within a salmon farming area utilise a central processing premise (Munro et al. 2003). The increased risk of disease transmission under these circumstances is associated with sharing of contaminated harvesting and processing equipment such as well boats, harvest barges, grading equipment and harvesting tubs, as well as activities such as transport of live fish to the vicinity of the processing plant (Munro et al. 2003). The highest risks were associated with holding live fish in cages adjacent to processing plants, and discharge of untreated effluent from processing plants (Munro et al. 2003).

NZKS is a vertically integrated company that utilises its own land based processing plants with no discharge of effluent back into the sea. NZKS also does not share harvesting barges, tubs, and other transport equipment with other salmon farming companies and is required to transport live or dead fish to processing plants in fully sealed containers (MPI 2016). Because of this, NZKS is in a good position to minimise risk of cross contamination of equipment during harvest, transport and processing provided they ensure equipment from different management areas remains separated and/or is completely decontaminated after each use.

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8.0 Conclusions

This risk analysis found that in the context of the proposed new salmon farming zone in Cook Strait, infection with *Piscirickettsia salmonis* -like bacteria (NZ-RLO) in clinically diseased chinook salmon held in seacages represents the only disease of concern in cultured salmon that requires additional risk mitigation measures at this time. The emergence of this disease in salmon farmed at low flow sites in the Marlborough Sounds demonstrates the increased risk of disease emergence at farm sites where environmental conditions are suboptimal. Thus, the proposed planning changes to locate salmon farms in the Cook Strait north of the Marlborough Sounds is a step in the right direction as the increased water depth and flows at the new site is likely to reduce risks to NZKS and the environment that presently exist due to infection with *Piscirickettsia*-like bacteria (NZ-RLO) in clinically diseased salmon.

However, this assessment by necessity was based on the diseases of salmon presently known to occur in New Zealand at this point in time. Given that new diseases can emerge and biosecurity leaks can occur, we cannot assume that the disease status of chinook salmon in New Zealand will not change at some stage in the future. Because of this, it is notable that the proposed addition of a third "Offshore Management Area" to the existing management areas in Pelorus Sound and Queen Charlotte Sound would better allow the salmon farming industry to minimize risks to the environment and industry development posed by diseases of salmon. The proposed changes, if approved, would allow the industry to mitigate several disease risk factors that contribute to emergence of infectious diseases, and provide an option to establish 3 epidemiologically independent farm management areas separated by ideal buffer zones. These arrangements would allow the salmon farming industry to enhance its existing biosecurity controls, implement integrated pest management strategies if required and potentially allow eventual migration to worlds best practice (entailing year class farming within each area followed by regular synchronised fallowing) in the near future if the number of farm sites within the Queen Charlotte Sound and Pelorus Sound Management Areas were increased to accommodate an entire years worth of production in each area. In view of current global warming trends which are likely to increase disease risks to the industry over time, the ideal situation of 3 sufficiently large independent farm management areas with regular synchronised fallowing should be considered the ultimate goal for future planning arrangements for the industry in the Marlborough Sounds region.

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Appendix 1 – Risk Assessment Methodology

Release assessment

The likelihood that a hazard would be translocated into the environment is determined through the release assessment stage of the process. The only hosts considered in the risk analysis component of this document are chinook salmon (*Oncorhynchus tshawytscha*) cultured in seacages. The release pathway for spread of disease from the host into the New Zealand marine environment is direct via faeces, urine, blood, mucus and other fluids shed by cultured salmon into the water. The risk assessment for a particular hazard was concluded if the release assessment determined that the likelihood of release of that hazard was negligible.

Table 4. Nomenclature for the qualitative likelihood estimations used in this RA.

Likelihood	Definition
High	The event would be very likely to occur
Moderate	The event would occur with an even probability
Low	The event would be unlikely to occur
Very Low	The event would be very unlikely to occur
Extremely low	The event would be extremely unlikely to occur
Negligible	The event would almost certainly not occur

Exposure assessment

The exposure assessment examines the likelihood of wild aquatic animals in an uninfected jurisdiction being exposed to the hazards via infected seacaged salmon and determines the likelihood of the establishment of the hazard. The likelihood of exposure will depend on several factors relating to the capacity of the disease agent to survive in the environment in an infective form, the availability of susceptible hosts, the ease of infection of susceptible hosts, and the likelihood of subsequent transmission of infection to others within a population. In determining the likelihood of exposure of susceptible hosts to disease agents carried by salmon, the following key factors were considered relevant:

1. *Route of Infection (Oral/Contact):* Viable infective stages must be ingested by a susceptible host or otherwise come into contact with susceptible fish or invertebrate species. Infection may occur via the digestive tract, or through direct contact with contaminated water via the skin and gills or integument.

2. *Infective Dose:* There must be sufficient quantities of viable infective stages to induce an infection following ingestion or contact via the skin and gills or integument.

Once a hazard is released into the environment, the likelihood of whether the disease agent would survive, infect susceptible hosts, and become established within a population was expressed qualitatively using the likelihood estimations in Table 4, based on information available in the scientific (and other) literature, unpublished data, as well as the professional judgment of the analyst. The likelihoods for the release and exposure assessments were combined using the matrix of 'rules' for combining descriptive likelihoods, as shown in Table 5.

Table 5. Matrix of rules for combining descriptive likelihoods for the release and exposure assessments.

Likelihood of exposure

Likelihood of release	**High**	**Moderate**	**Low**	**Very Low**	**Extremely low**	**Negligible**
High	High	Moderate	Low	Very Low	Extremely low	Negligible
Moderate		Low	Low	Very Low	Extremely low	Negligible
Low			Very Low	Very Low	Extremely low	Negligible
Very Low				Extremely low	Extremely low	Negligible
Extremely low					Negligible	Negligible
Negligible						Negligible

The risk assessment for a particular hazard was concluded if the exposure assessment determined that the probability of establishment was negligible.

Consequence assessment

The consequence assessment estimates the likely magnitude of the consequences of establishment and/or spread of a disease agent into the environment and the possible effects of the disease agent on aquatic animals, the environment, industry and the economy. The qualitative terms used to describe the consequences of establishment of an unwanted disease agent in this RA are defined in Table 6. These descriptions are based on information available in other RAs, the scientific literature, unpublished data, as well as the professional judgment of the analyst. For each disease of concern, the consequence assessment determined the likelihood of occurrence and the associated impact for each of two main outbreak scenarios. Either:

1. The disease agent becomes established and spreads throughout populations of susceptible species in the Cook Strait north of the Marlborough Sounds and beyond. This scenario assumes that if a disease agent were to establish in a local population it would eventually spread to its natural geographical limits, or;

2. An index case occurs and infection may even spread to co-habiting animals, but the agent does not persist in the environment.

Only the first scenario was considered to represent establishment of the disease agent, because the second scenario would go undetected.

Table 6. Definition of terms used to describe consequences of establishment of disease agents.

Consequence	Definition
Extreme	Establishment of disease would cause substantial biological and economic harm at a regional or national level, and/or cause serious and irreversible environmental harm.
High	Establishment of disease would have serious biological consequences (high mortality or morbidity) and would not be amenable to control or eradication. Such diseases would significantly harm economic performance at a regional level and/or cause serious environmental harm which is most likely irreversible.
Moderate	Establishment of disease would cause significant biological consequences (significant mortality or morbidity) and may not be amenable to control or eradication. Such diseases could harm economic performance at a regional level on an ongoing basis and/or may cause significant environmental effects, which may or may not be irreversible.
Low	Establishment of disease would have moderate biological consequences and would normally be amenable to control or eradication. Such diseases may harm economic performance at a local level for some period and/or may cause some environmental effects, which would not be serious or irreversible.
Very Low	Establishment of disease would have mild biological consequences and would be amenable to control or eradication. Such diseases may harm economic performance at a local level for a short period and/or may cause some minor environmental effects, which would not be serious or irreversible.
Negligible	Establishment of disease would have no significant biological consequences and would require no management. The disease would not affect economic performance at any level and would not cause any detectable environmental effects.

The risk assessment for a particular hazard was concluded if the consequence assessment determined that the consequences of introduction were negligible.

Risk estimation

Risk estimation is the final step involved with each assessment and would be used to determine whether the extent of the unrestricted risk presented by each disease agent to the environment and aquatic animals of New Zealand was sufficient to require risk management. 'Unrestricted risk' means the estimated risk if the current industry practices remain unchanged. Risk was assessed using the risk estimation matrix in Table 7 which uses a combination of the qualitative answers given for the combined likelihoods of release and exposure (= probability of establishment and spread) and the significance of the consequences of establishment of a disease agent to provide an estimate of the risk involved, ranging from 'negligible' through to 'extreme'. The appropriate level of protection (ALOP) for the environment adopted in this RA is expressed in qualitative terms. The ALOP is expressed as providing a high level of sanitary or phytosanitary protection whereby risk is reduced to a **very low** level, but not to zero. This definition of ALOP, and its illustration by way of a risk estimation matrix is shown below in Table 7.

Table 7. Risk estimation matrix showing the ALOP utilized for this RA (white squares = very low risk). Any diseases which fall to the right of the ALOP during the RA will require additional risk management (red font).

Combined likelihood of release and exposure	Negligible	Very Low	Low	Moderate	High	Extreme
High	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Moderate	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Low	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk	High risk
Very low	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk
Ext. Low	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk
Negligible	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk

Consequences of establishment and spread

If either the likelihood of establishment and spread, or the significance of the consequences of establishment and spread were considered to be negligible, it was considered the unrestricted risk posed by the disease agent was negligible (rising to very low for extreme consequences of establishment), and there would be no need to implement any additional risk management steps (Table 7). If the consequences of establishment and spread were considered to be very low, even a high probability of establishment and spread was tolerable without the need for risk management. If the likelihood of establishment and spread were considered to be very low, even high consequences of establishment and spread were tolerated without the need for risk management, but extreme consequences of establishment and spread were considered to exceed the ALOP, and risk management would be required (Table 7). Alternatively, if the likelihood of establishment and spread was high, even if the consequences of establishment and spread were considered to be low, this scenario would exceeded the ALOP and require risk management (Table 7).

Risk mitigation

If the unrestricted risk estimation for any disease agent is determined to be unacceptable (that is above very low), the threats posed by the disease agent will be ranked (high, medium, low) based on the likelihood that it would pose a disease risk when introduced into the Cook Strait north of the Marlborough Sounds with cultured salmon. The ranking process will take into account not only the types of disease agents harboured by cultured salmon, but also the quantity of the salmon being cultured. For any diseases with risk estimation rankings that exceed the ALOP, risk mitigation measures may be necessary to reduce the risk estimate back to within the ALOP. The risk mitigation processes examined as part of this RA process will relate only to option evaluation.

Option evaluation

The RA will identify the options available for mitigating any risks that may exceed the ALOP.