Appendix Q Wild fish report

Statement of Experience
Paul Robert Taylor
4/11/22

1. My full name is Paul Robert Taylor. I am a self-employed consultant biologist working in the field of finfish biology and ecology. I hold an MSc(Hons) in Zoology and Sensory Physiology, an MPhil in Applied Statistics and a BSc in Biological Sciences and Statistics, all from the University of Waikato. I have a current membership with The Royal Society of New Zealand which I have maintained since the late 1980s and I am a past president of the Waikato Branch. I have previously been a member of both the New Zealand Marine Sciences Society and the New Zealand Statistical Association.

2. I have been an independent consultant since founding Statfishtics Ltd. in July 2011. Statfishtics provides services related to fish research and science, including environmental effects assessments, data analyses and the writing and presentation of technical reports. Through Statfishtics I have been contracted to The National Institute of Water and Atmospheric Research (NIWA), Department of Conservation (DOC), and various aquaculture companies including New Zealand King Salmon Ltd (NZKS) and Ngāi Tahu Seafood Resources (NTSR). My most recent contribution other than the Hananui project, was to NZKS's Blue Endeavour application.

3. My areas of expertise include the biology, ecology, and fisheries of pelagic finfish species, applied statistical modelling using multivariate methods, and the visual physiology of crustaceans and finfish species. Since 2011 I have contributed technical support for a number of aquaculture projects in the context of aquatic farm licence renewals and plan change applications through the provision of fish biological and ecological information and advice to the EPA and District Councils.

4. Before founding Statfishtics I was employed from 1987 to 2011 as a pelagic fisheries biologist by The Ministry of Agriculture and Fisheries (MAF) and The National Institute of Water Atmospheric Research (NIWA). During this time my main responsibilities included involvement in research investigating aspects of:

   - Pelagic fisheries biology, ecology, and stock assessments;
   - Development of quantitative methods for stock assessments;
   - Use of aerial sightings data for estimating relative abundance indices of schooling pelagic species;
   - Development of aerial survey for monitoring and producing stock indices of inshore pelagic schooling species; and
   - Developing tools for assessing marine habitats and environments.

5. During this employment I was project leader for 36 fisheries research projects contracted by the Ministries of Fish and of Primary Industries. I participated at sea on 27 research voyages with operational responsibility for 6 of these. I have also worked on two separate occasions as an observer at sea on Japanese bluefin tuna longliners, recording data on pelagic fish species taken in that fishery in New Zealand waters.

6. My current research is with DOC and involves the development of methods relating the distribution of pelagic fish species to environmental features using aerial sightings of schooling pelagic fish to provide information on the current status of seabird prey species.

7. Since my initial employment in pelagic fisheries research in 1987 my publication list has mainly been of reports to working groups and private companies with some contributions to primary journals. In total I have produced or been involved in the writing of 39 refereed documents, 5 of these to the primary literature; and 30 other working documents for internal reporting and as background documents for both local and international working group meetings.

A discussion on the effects of salmon farming on the wild fish fauna of an area in Foveaux Strait and management options for avoiding, remedying, and mitigating any adverse effects including proposed methods for monitoring and investigating the impact of deploying a sea pen salmon farm in the area

Paul Taylor[1]
Tim Dempster[2]

August 2021

[1]**Statfishtics**
PO Box 12067
Hamilton
New Zealand 3248

[2]**Melbourne University**
Dept of Zoology
Victoria 3010
Australia

EXECUTIVE SUMMARY

A discussion on the effects of salmon farming on the wild fish fauna of an area in Foveaux Strait, with management options for avoiding, remedying, and mitigating adverse effects including proposed methods for monitoring and investigating the impact of deploying a sea-pen salmon farm in the area. Taylor, P.R.; Dempster, T. 87 pp.

This report was contracted by Ngāi Tahu Seafood Resources (NTSR) to provide information on wild fish species in the vicinity of a proposed farm site (Hananui) off north-eastern Stewart Island/Rakiura 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.

The following is a summary of the main points from the report.

Marine environment

1. Several early studies provide information on the water circulation and hydrology of Foveaux Strait, describing the west to east flow of the Southland Current and its formation to the west of the strait from subtropical and subantarctic components, as well as the inflow to the northwest within the southeastern entrance in the vicinity of the proposed site.

2. Tidal flows in Foveaux Strait set to the east on a rising tide, to the west on a falling tide, and may reach 120 cm s^{-1}. Current records show a net inflow in the southeastern entrance of 6.8 cm s^{-1} to the northwest, a net inflow in the western entrance of 6.8 cm s^{-1} to the east, and a net outflow of 14.2 cm s^{-1} to the east in the northeastern entrance, resulting in a water residence time within the strait of 5–6 days

3. Two studies in 1991 and 1992 discuss the variable productivity of the pelagic habitat in Foveaux Strait, demonstrating high variability in nutrient influx as a result of irregular and variable contribution of the subantarctic component to the Southland Current.

4. Recent studies under the current project report high current velocities (38 to 44 cm sec^{-1}) in the area of the proposed site as well as bottom substrates mostly of sand (about 77% of the area), with bushy bryozoans thickets (5%) and areas of bryozoan-sponge reefs (17%).

Finfish species

5. An inventory of finfish species for the Foveaux Strait area was compiled from five sources, augmented with observations from existing salmon and mussel farms in the Marlborough Sounds and Golden Bay. The final inventory contains a total of 125 finfish species: 21 pelagic, 52 reef/rocky-bottom species, 20 reef/rocky-bottom triplefin species, 28 benthic/demersal species, and 4 elasmobranchs other than sharks.

6. The highest probability of potential colonisers comes as empirical data from the commercial and recreational fisheries data. A total of 12/2 pelagic, 12/6 reef and rocky bottom species, 18/6 benthic or demersal species and 3/2 elasmobranchs other than sharks were represented in commercial/recreational catches.

7. There is no intention to provide a definitive list of finfish that will inhabit the pelagic and benthic zones near the proposed farm, only to suggest the starting point of an inventory to be defined as work at the site proceeds. Reef/rocky bottom species are split from the general benthic group and further divided to separate out triplefin species to ease accessibility because of numbers.

8. 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 empirical information on species that would be attracted to the proposed farm if shown to be present in the Foveaux Strait area. However, there are inconsistencies in the appearance of a number of these and other species in the lists compiled for Foveaux Strait.

9. It is suggested here that the inconsistencies may be the result of temporal variations in the presence of these species due to the high spatiotemporal variability in productivity identified for Foveaux Strait in the 1991 and 1992 studies mentioned above in #2.

10. The most common families observed in farm aggregations in Mediterranean studies were Clupeidae, Sparidae, Mugilidae, and Carangidae, which included several pelagic planktivorous fish species. Sprat (*Sprattus antipodum*) is the only clupeid apparently present in Foveaux Strait; snapper is the only sparid, with an occasional appearance in the commercial catch; there is no evidence for mugilid species in Foveaux Strait; and Carangidae are the best represented from this group by the jack mackerels and trevally, with large catches of jack mackerel (species unrecorded) reported from the commercial catch and trevally reported less than occasionally.

Effects on wild finfish and their habitat

11. Farm discharge comprises the components of waste feed as well as faecal and other organic waste material from the fish themselves. These components can impact finfish in three ways: (1) by making accessible artificial feed, (2) by impacting the benthos with farm derived organic material, and (3) by communicating the presence of the farm through suspension/resuspension as fine particles within the water column. Each of these represents a mode of action by which the farm impacts the finfish population.

12. In addition to the three above are modes of action independent of farm discharge: (4) the FAD effect (the tendency of certain fish species to be attracted to floating/suspended objects and structures and aggregate beneath them) and (5) the structure effect (the tendency of some fish to be attracted and establish a close physical association with parts of an artificial structure); and finally (6) the combination of actions (3) and (4) referred to above, called "FAD + chemical cues". The modes of action differ in the way they affect the three component subpopulations, the benthic, reef dwelling, and pelagic species, and the distance over which they operate.

13. Studies overseas show that fish farms attract large, multi-species assemblages of wild pelagic and bentho-pelagic fish which aggregate in their immediate vicinity. While there is no specific information for the interaction between wild fish and existing salmon farms in New Zealand, this effect appears to be universal given its occurrence in many places globally.

14. Aggregations have been observed as temporally persistent, although specific species within the aggregated assemblage will probably vary with season, reproductive stage and feeding regime. Aggregations typically comprise a high proportion of adult fish, making farms particularly attractive locations for commercial and recreational fishers.

15. 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 characteristics of the farm include *large*, *located in shallow water*, and *close to the coast*. The site proposed by NTSR matches most of the described criteria.

16. The diet of wild fish aggregated at fish farms shifts from a natural diet to a farm-modified diet. They consume more food around fish farms than in natural habitats, and feed largely on feed lost from the farm pens. This diet change leads to marked condition and physiology changes.

17. Heavy metal concentrations are typically elevated in sediments beneath fish farms, and the levels of some heavy metals in wild fish tissues may be increased or reduced, depending on the

wild fish species. Elevated levels of mercury have been detected in the tissues of one long-lived, highly resident, demersal fish species and one mobile, pelagic fish species associated with salmon farms in Norway, but these levels were below health limits set for safe consumption. The high-flow characteristic of the proposed site should lead to a marked reduction in the evidence of this effect in benthic/demersal species.

18. Parasite loads may be elevated in some farm-associated wild fish, while loads of some parasites may be reduced. Similarly, levels of some organohalogenated contaminants may be elevated or reduced in wild fish tissues, depending on the species.

19. The role of wild fish in assimilating nutrient wastes lost from salmon farms appears to be significant in both the pelagic and benthic realms based on overseas studies, but there is no accounting for this process in current models predicting sedimentation and nutrient dispersal around salmon farms. In New Zealand little to nothing is known about the extent and composition of midwater aggregations under farms so currently it cannot be quantified.

20. Consideration of a no-fishing restriction near salmon farms is generally relevant in the New Zealand situation because of the potential benefits from preventing the fishing. These include providing a population source for the aggregated species, providing ecological services through the consumption of waste feed and salmon escapees, containment without harvest of long lived individuals having elevated tissue mercury levels from long associations with salmon farms, and preventing increased fishing pressure on the aggregated species.

21. Without a fishing exclusion zone around farms, customary, 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. If such fishing is allowed to occur, the benefits listed above are prevented.

22. The benefit of preventing increased fishing pressure applies to the recreational fishery only. The customary and commercial fisheries are constrained by catch limits, which precludes any catch exceeding levels set by the Ministry of Primary Industries (MPI). By contrast, uncontrolled recreational fishing on farm aggregations has the potential to increase fishing pressure on wild fish stocks because catch per unit effort on farm aggregations is likely to be high. Nevertheless, applying an exclusion zone to all three fisheries ensures that the all of the potential benefits listed above in paragraph 20 are maximised, including gains from all fishing for not harvesting the adult spawning fraction which tends to be attracted to farms.

23. These issues are currently being discussed by NTSR and various commercial fishing organisations/groups, and will continue between NTSR and the harbour master and relevant fishing groups, with NTSR seeking agreement to a voluntary 200m buffer around the farm to avoid outcomes such as entanglement with the farm structure.

Effects on quota species

24. Greatest representation in the commercial fisheries data from Foveaux Strait are of benthic/demersal species with pelagic far less represented. Therefore, if there is any effect on the commercially fished species, the most likely to be affected by installation of a farm at the proposed site are those from the benthic group, including the bentho-pelagic species. This effect may change over time from establishment of the farm.

25. 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 with indigenous biological diversity of wild fish

26. Three wild fish teleost species were identified as meeting the NZCPS 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 Foveaux Strait.

27. 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.

28. 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. Both are indigenous. Potential interactions between white sharks and the proposed Hananui farm are discussed in detail in the shark reports prepared for Hananui application (Francis 2019; Lyon, 2020). Basking shark is not included in these reports, suggesting an absence of evidence for its likely presence in the area of the proposed site.

Methods for monitoring aspects of a salmon farm's impact on wild finfish

29. Three aspects of a farm's impact on wild fish species require standardised monitoring and investigation: waste feed, midwater aggregations and tissue contamination.
    - A method for quantifying feed waste with an appropriate apparatus is required to produce standardised feed loss reports that would be consistent between farms and operators.
    - Work related to wild fish aggregations would determine the extent wild fish species are affected by farm installation and whether there is any seasonal variation in the response.
    - Tissue samples for monitoring contamination levels can be taken as part of the sampling of fish aggregations.

30. A key summary on the ecological effects of aquaculture by MPI states that "*Aquaculture planning must be supported and underpinned by science-based information on ecological effects"* (Ministry of Primary Industries 2015), but to date there is no method available in New Zealand to provide reliable science-based information for estimating volumes of lost feed, determining species most affected by the farms, or monitoring contamination levels in wild fish.

31. It is therefore recommended that a wild-fish best management practice document (BMP) for salmon farm operators be produced by an appropriate independent agent, such as the Principal Scientist for Aquaculture within the Aquatic Environment Science team at Fisheries NZ. This BMP requires development by the appropriate agent of standard methods and relevant instrumentation/apparatus for quantifying and monitoring waste feed, wild fish aggregations, and contamination levels in wild fish using methods deemed most effective. It should be referred to the appropriate agent with urgency to ensure its availability for use at the earliest possible advent during the establishment of new farming locations, to allow standardised monitoring particularly of evolving midwater aggregations, but also feed loss levels and their variations as new farms develop. A review condition should be attached to the BMP to allow appropriate discussion.

32. Urgency is required because of the protracted time expected for development of the BMP. In any case it is expected that availability of an agreed BMP is unlikely to coincide with the beginning of farm operations. To ensure that feed waste is maintained within minimum levels, a feeding study could be undertaken during the initial period of operation leading up to BMP availability, although such would be outside the bounds of a standardised method. Details could be presented within a wild fish management plan.

Contents

1. SCOPE

This report synthesizes existing background information on the wild fish habitat and fauna of an area in Foveaux Strait adjacent to Stewart Island/Rakiura, proposed by Ngāi Tahu Seafood Resources (NTSR) as a possible salmon farm site and referred to as Hananui. The nature of the wild fish habitat in the area of the site is characterised from published studies of Foveaux Strait, and the extensive international literature on farmed-wild fish population interactions is summarised, both in terms of the effects on wild fish populations and interactions that affect customary, recreational and commercial harvests.

Based on background knowledge of fish farms and wild fish interactions, and knowledge of the pelagic[1] and benthic/demersal habitats and the fish fauna present in Foveaux Strait, predictions are made 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.

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. Incorporated into the report is discussion of how to investigate the impact of farm installation on finfish species inhabiting the region near Hananui. This discussion considers approaches for monitoring feed loss and for monitoring the finfish aggregations that develop within the vicinity of the farm, both with regards the species composition and, from a public health perspective, the condition and contaminant levels in those fish.

2. WILD FISH IN FOVEAUX STRAIT AND THE PROPOSED SITE

2.1 The Existing Wild-Fish Habitat In Foveaux Strait

2.1.1 Background

The wild-fish habitat in Foveaux Strait includes both the pelagic and benthic zones, which are inhabited by three different groups of finfish species: the pelagic and benthic species are native to their respective zones and bentho-pelagics move between the two. The benthic zone has been well documented over time, most often in the context of the commercial dredge oyster fishery for *Ostrea chilensis* or the blue cod (*Parapercis colias*) fishery (e.g., Cranfield et al., 2003; Carbines & Cole, 2009) but also as part of NTSR's current application (Bennett et al, 2019). The pelagic zone is less well known, particularly from a temporal perspective. Although there have been investigations of nutrient sources (Butler et al., 1992) and productivity with regards plankton growth (Bradford et al., 1991) and the causes of variation, which have also been summarised for the current application (Campos et al., 2019), details of any long-term fluctuations and their triggers have yet to be described. Ultimately, these variations also affect the benthic zone.

Note that *benthic* and *demersal* are almost 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.*

Foveaux Strait is the approximately 23–53 km wide by 80 km long body of water separating Stewart Island/Rakiura from the South Island's south coast. The farm site proposed by Ngāi Tahu Seafood is an approximately 2,500 ha area located 2 to 6 km offshore of north-eastern Stewart Island/Rakiura (Figure 1), east of Garden Point and about 13 km northwest of Oban.

---

[1] See Appendix A for definition.

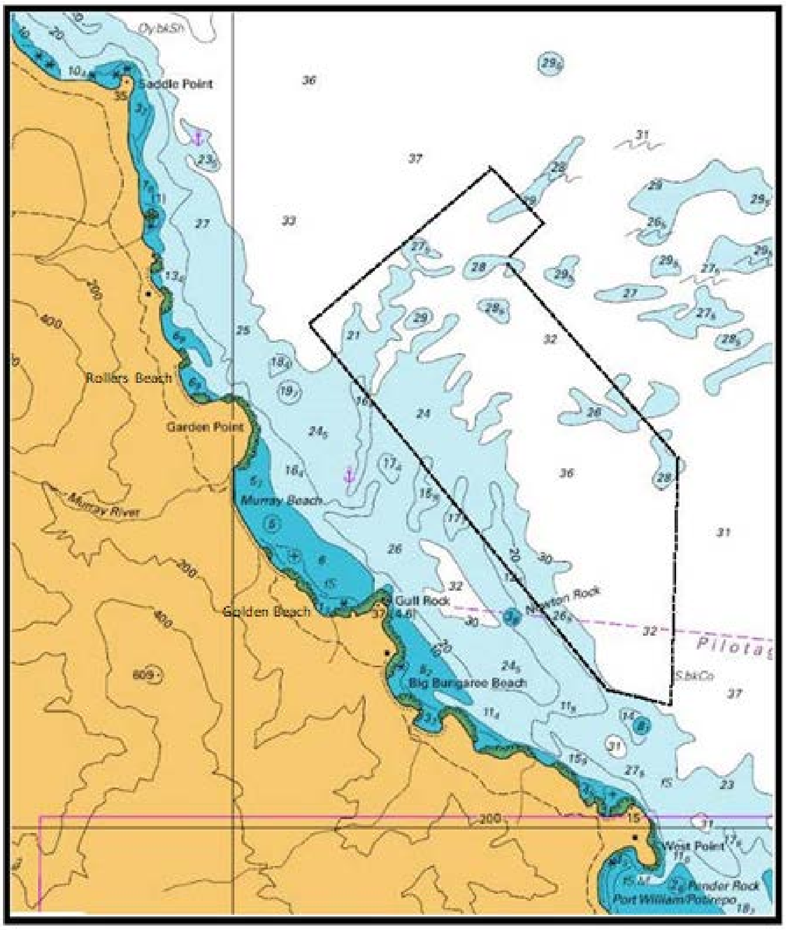


Figure 1: Approximate boundary and position of the proposed site off Rakiura/Stewart Island showing bottom bathymetry and other local features. Source: the polygon was drawn on a tiff version of the LINZ Marine Chart, Approaches to Bluff and Riverton/Aparima, NZ300681, downloaded from https://www.linz.govt.nz/sea/charts/nz-chart-catalogue-list-view?page=1**.**

2.1.2 Summary of published studies

A number of studies have contributed to current knowledge of the circulation and hydrology of Foveaux Strait with early key discoveries by Brodie (1960), Garner (1961), Rurling (1961) and Houtman (1966), as summarised by Heath (1972 & 1975). This summary described the main flow through Foveaux Strait from west to east as the Southland Current, which comprises water of mainly subtropical origin with "some admixture of Australasian Subantarctic water". Vincent et al., (1991) determined the relatively high nitrate/nitrite levels in this subantarctic water in contrast with the subtropical water, although the former is mixed in only infrequently and irregularly to form part of the Southland Current. Heath (1972) referred to the Southland Current as warm, saline water and Heath (1975) compared the surface salinity distribution and the near-surface maximum salinity which showed that the surface water was diluted by coastal runoff, with pronounced dilution occurring off the west coast, and in Foveaux Strait.

Current records show a net inflow in the southeastern entrance of 6.8 cm s^{-1} to the northwest, a net inflow in the western entrance of 6.8 cm s^{-1} to the east, and a net outflow of 14.2 cm s^{-1} to the east in the northeastern entrance resulting in a water residence time in the strait of 5–6 days (Cranfield et al., 2003 & 2005, citing Houtman, 1966). Tidal flows set to the west on the falling tide, to the east on the rising tide, and may reach 120 cm s^{-1}. The depth of Foveaux Strait extends from 50m in the west to 20 m in the east (Cullen, 1967).

Two studies have investigated productivity in the Foveaux Strait region. Bradford et al (1991) referred to the high levels of commercial exploitation of oysters, squid and sooty shearwater in Foveaux Strait relative to other areas of New Zealand to infer high levels of primary and secondary productivity, but suggested that there was evidence from the exploited populations that this high productivity is spatially and temporally variable. These researchers summarised the results of previous studies on the hydrography of Foveaux Strait, to indicate that, according to the work of Houtmann (1966) and Heath (1975), water may be well mixed to the bottom but contended that little was known concerning the vertical distribution of nutrients around southern New Zealand except for "scattered data collected by other nations" and cited Bradford & Taylor (1980) in this context.

This provided background for the work that Bradford et al (1991)., then carried out investigating the production of plankton in the area. Their study was based on samples taken during February in each of the four years from 1977 to 1980 in which they examined the relation between phytoplankton biomass and the hydrography of Foveaux Strait, from Puysegur Bank in the west to Toetoes Bay east of Bluff between the southern coast of the South Island to a line approximately due west from Codfish Island, and approximately due east from the northern extent of Port Adventure. Specifically, they aimed to describe the distributions of surface temperature, salinity, dissolved nitrate-nitrogen (NO3-N) and chlorophyll-*a* during the four summers to gain insight into the range of variability and its possible causes. Those records were augmented with more recent, remotely sensed sea surface temperature data and were used to discuss the origin of each type of water and any physical processes that might influence standing stocks of phytoplankton.

However, results from the Bradford et al., (1991) study were difficult to interpret. Relationships were too unclear for the authors to question whether the "snapshot" approach they had used provided a good indication of conditions prevailing through the summer. They offered several possible explanations for the poor feeding conditions that they suggested were responsible for the poor condition of local oysters (*Ostrea chilensis*) and sooty shearwater (*Puffinus griseus*) in 1986. Their conclusion was that the exact cause of annual variability in oyster condition required investigation of the mechanism that introduces nutrient-rich, saline water into waters around Stewart Island/Rakiura and its timing, as well as the identification of other possible processes that might affect phytoplankton populations and biomass.

A study by Butler et al., (1992) investigated short-term oceanic variability over several days using oceanographic data collected concurrently from two ships in an area including Foveaux Strait in May 1989. Sea surface temperature (SST) data of the area from two National Ocean and Atmospheric Administration (NOAA) satellites were also used in the analysis. The SST images showed the transition from subtropical convergence water at the western end of Foveaux Strait to subantarctic water east of the strait and how this varied using individual images from a five year period.

The images showed winter freshwater discharge to northern Foveaux Strait as pockets of cold water near the coastline reflecting conclusions about dilution documented by Heath (1975). Other results showed this as a period when Foveaux Strait was low in the nutrients nitrate, phosphate, and iodate, compared with "shelf-break" areas where slightly enriched water occurs at about 200 m depth. This also applied to dissolved oxygen when compared with water samples from offshore waters of similar salinity.

Results of samples taken on both boats showed that the concentration of all nutrients, which included ammonia-N, urea-N, nitrate+nitrite-N, nitrite-N, reactive silicate, reactive phosphorus, iodate-I, increased from west to east with the transition from subtropical to subantarctic waters. Nitrite was distributed uniformly through the water column, whereas ammonia and urea were more concentrated in the bottom waters of the strait. A strong linear relationship between nitrate and phosphate was clearly evident from a plot for all waters samples from all depths of the survey, but such was not the case for iodate with either phosphate or nitrate which showed a break point coinciding with the salinity at the southern boundary of the Subtropical Convergence Zone (STCZ).

Data collected with conductivity-temperature-depth profilers showed that surface temperatures were almost uniform at about 13°C west of Foveaux Strait and followed a decreasing trend to less than 9.5°C east of the Southland Front. At all stations within the strait, temperature profiles were isothermal with depth, indicating a water column that is well mixed throughout. The salinity profiles, both with depth and across the west to east continuum reflected those of temperature with the additional feature of apparent freshwater runoff mid-strait that was absent from the temperature records. Likewise the vertical nitrate concentrations followed similar patterns to temperature and salinity within the strait.

Data recorded within Foveaux Strait over three days indicated a cooling effect caused by the horizontal advection of cooler water from its northern edge which reflects information reported by Houtman (1966) regarding the extension of cooler water to the middle of the strait during winter. These effects on temperature did not show correspondence in salinity.

In conclusion, Butler et al. (1992) suggested that the enhanced biological productivity in Foveaux Strait was the result of two possible mechanisms: horizontal advection and uplifting (as opposed to upwelling) of subsurface waters, both coupled with deep mixing events or with influence of the continental slope. They concluded that all of these processes could be irregular and variable, and they reported that they had not observed any sustained process such as upwelling in the area.

2.1.3 The Cawthron Institute Benthic and Water Column Studies

The benthic assessment completed by Cawthron Institute as an investigation into seabed effects at the proposed site (Bennett et al., 2019) describes the proposed area as having water depths 20 to 25m inshore and up to 40m offshore with large sandbanks particularly at the northwestern end. Three main types of seabed habitat were observed and described: 1.) sand (about 77% of the area), sculptured (ripples, waves, banks), with sparse epifaunal assemblages dominated with varying amounts of additional elements (shell hash, whole shell debris, gravel, isolated biogenic clumps) and occasional patches of biogenic structure (mainly bushy bryozoans), all with occasional blue cod (*Parapercis colias*), leather jacket (*Parika scaber*) and one triplefin (species unknown); 2.) bushy bryozoan thickets (about 5% of area) on sandy substrates with shell hash, interspersed with calcareous tubeworms, providing various degrees of cover (5−80%) and high epifaunal diversity, with moderate-abundant fish, including blue cod, leather jacket and tarakihi (*Nemadactylus macropterus*); and 3.) bryozoan-sponge reefs (17% of the area) providing high epifaunal diversity and biodiverse habitats (assemblages of erect and encrusting bryozoans, sponges and tubeworms), ranging from patchy to dominating the substrate, all with moderate-abundant fish (including blue cod, leather jacket and tarakihi).

With regards the depositional footprint of the proposed farm, Bennett et al., (2019) discuss the concept of the Index of Suitable Location (ISL) (proposed by Yokoyama et al., 2004) which provides “a single metric of water depth and flow, giving an indication of the assimilative capacity[2] and the upper limit of fish production at a given location” or “the ability of the an area to maintain a ‘healthy’ environment and ‘accommodate’ wastes” such that “the higher the ISL, the better the site for finfish farming”. Although previously untested for salmon farming, these researchers apply an ISL of 2−3 inshore, to 6−7 further offshore, compare this to other sites currently utilised by the industry in the Marlborough Sounds, and conclude that there is potential for finfish farming throughout the proposed area. According to Bennett et al (2019), placement of farms has been made within the proposed area with the aim of avoiding “significant biogenic habitat and ecologically important taxa” and farm sites have been chosen at a minimum of 200 m from bushy bryozoan thickets and bryozoan sponge reefs.

The Cawthron Institute water column study (Campos 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 currents with mean depth-averaged velocities ranging from 38 to 44 cm/sec that are strongest near the surface (47−59 cm/sec) and weakest near the seabed (39−41 cm/sec); they describe the predominant axis of current flow as northwest/southeast and the mean and maximum significant wave heights at about 1 and 3m as estimated from a 37-year regional wave hindcast model (commissioned from MetOcean Solutions Ltd).

---

[2] The ability of an area to maintain a ‘healthy’ environment and ‘accommodate’ wastes.

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 assessment 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 (see §3.1). 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.

The Cawthron Institute water column study (Campos et al., 2019) also provides information on tides and water column structure that can be directly related to the pelagic environment. These researchers describe strong bi-directional flow and current speeds increasing with distance from the Stewart Island/Rakiura shore. Except for some small seasonal variation at the surface, their data showed little variation in water temperature with depth, although there was a tendency for cooler water in the more eastern sites. Generally, salinity and turbidity were about uniform within the water column of the proposed area, with some small variation in salinity in the upper 10m and towards the north-eastern edge in December and some evidence of increasing turbidity from October to January.

Campos et al., (2019) provided information on nutrient concentrations. Of particular note were nitrate and nitrite species, which followed a seasonal pattern (October-high, January-low) and there was evidence for their replenishment faster than consumption by phytoplankton, suggesting that stock abundance/mortality limits growth, not nitrogen. These workers also investigated chlorophyll-*a* and phytoplankton biomass by sampling concentrations over a three month period and found a typical seasonal pattern for coastal waters (October-lowest; December-highest, typical of spring bloom; January-reducing). They also recommended the continuation of monitoring through the autumn when they predicted a secondary bloom from storm-released nutrients, suggesting this as an important time, particularly for all those species (including finfish) whose larvae rely directly or indirectly on plankton blooms. Phytoplankton composition from the existing samples showed the dominance of common diatom species (most commonly *Skeletonema costatum*, *Chaetoceros* spp. and *Thalassiosira* spp.) with a rare representation of flagellates, especially dinoflagellates.

2.1.4 The Pelagic Habitat related to the Proposed Site – Key Points

- Foveaux Strait water circulation and ocean conditions are largely dictated by the Southland Current in association with the Southland Front, moving from the west through the strait.
- Water entering Foveaux Strait from the west originates from at least two sources: the subantarctic fraction is cool and contains relatively high levels of nitrate/nitrite, but is often absent from the Southland Current; the subtropical fraction is warmer, nutrient-poor, but a constant contributor to the Southland Current.
- Winter freshwater discharge occurs into northern Foveaux Strait as pockets of cold water close to South Island's southern coastline.
- During the study period (May 1989; Butler et al., 1992), the concentration of all nutrients increased from west to east with the transition from subtropical to subantarctic waters.
- Generally the pelagic habitat throughout Foveaux Strait and particularly in the proposed area offshore of Stewart Island/Rakiura is well mixed resulting in uniform temperatures, salinity and turbidity throughout the water column.
- Results of the studies by Bradford et al. (1991) and Butler et al., (1992), showed that Foveaux Strait was characterised by productivity that was highly variable in space and time.
- The proposed site is a high-flow environment which, coupled with probable high farm-discharge level, will produce a wide area of potential attraction to pelagic finfish species.
- Residual tidal flow in the area of the site proposed by NTSR is from southeast to northwest (Figure 2), with westerly mean transport in southern Foveaux Strait becoming progressively weaker towards the west, giving way eventually to easterly mean transport in the western entrance to Foveaux Strait (Cranfield et al., 2003).

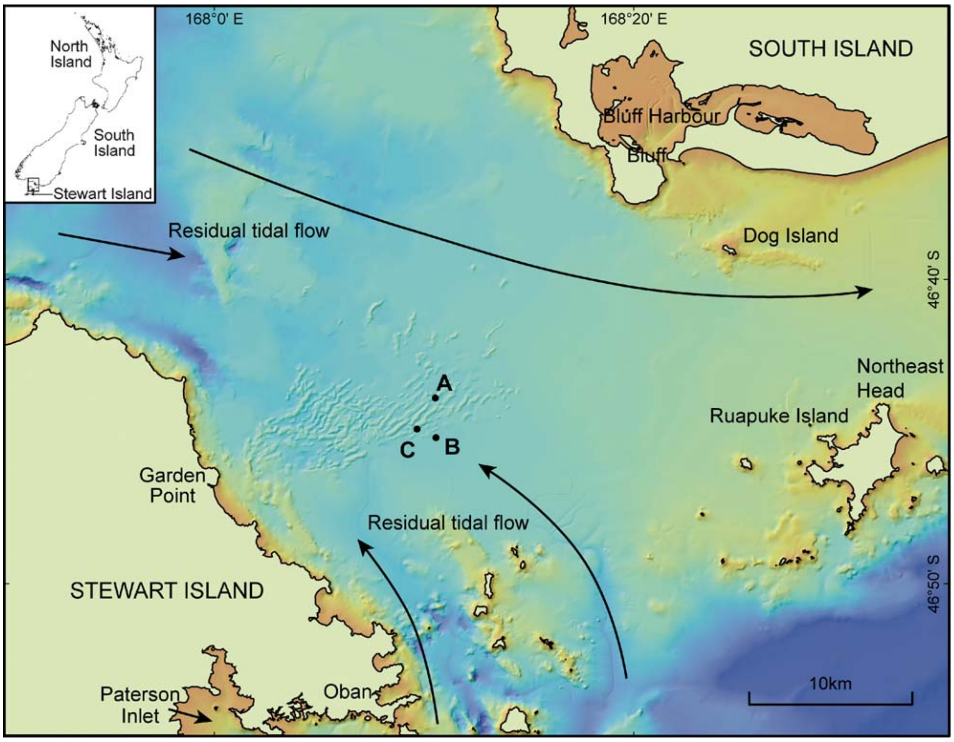


Figure 2: Residual tidal flow in Foveaux Strait (from Cranfield et al., 2003; points at A−C show sites of sediment sampling during their study).

2.2 Finfish Species Inhabiting Foveaux Strait

2.2.1 Introduction

The information presented in this section is summarised from several sources that differ in methodological details including geographical/environmental focus, data collection method, and statistical analysis. It is summarised here as an inventory of species potentially inhabiting Foveaux Strait, thus providing a possible list of finfish species that might be encountered within the vicinity of the site proposed by NTSR. The aim was to cover all fish taxa as well as available information would allow, except sharks, which have been covered in the present context by Francis (2019). There is no intention here to provide a definitive list of finfish that will inhabit the pelagic and benthic zones near the proposed farm, only to suggest a starting point for an inventory that can be defined as work at the site proceeds. Reef/rocky bottom species are split from the general benthic group and further divided to separate out triplefin species to ease accessibility because of numbers.

2.2.2 Species from the National Aquatic Biodiversity Information System

The National Aquatic Biodiversity Information System (NABIS) is an interactive web-based mapping tool originally set up by the then Ministry of Fisheries between 2000 and 2002 (Duckworth 2010); it is currently managed by the Ministry for Primary Industries (MPI)[3]. NABIS contains data on fish, plants, mammals, invertebrates and birds in the NZ environment and users can map and display information about NZ's marine environment, species distributions and fisheries management.

The list contains 318 items on marine finfish. All species are represented by what is referred to as an annual distribution. For some the information is limited to this, but for other species several additional

---

[3] https://mpi.maps.arcgis.com/home/index.html

distributions are also available, which may include the spawning distribution, the annual juvenile distribution, and several seasonal distributions such as the spring distribution. Thus the number of species represented is considerably less than 318.

To build the inventory for the Foveaux Strait area, distributions from the NABIS fish list were examined and species whose distributions included the area of interest were selected and added to the list (Table 1, column A). Distributions in NABIS comprised a number of localities unique to the species that were individually categorised according to the following classes.

- Hotspot— a high frequency area of the species distribution;
- Full Range — within which virtually 100% of the species is found;
- Normal Range — within which virtually 90% of the species is found;
- Known not to exist — the species is known to not be distributed in this area; and
- Unknown — the existence of the species is unknown

Species from the NABIS web page in Table 1 are also included in Appendix B as summaries of annual, juvenile annual and spawning distributions (where available) with relevant distribution classes.

2.2.3 Rocky Reef Species

A study by Smith et al. (2013) provides a useful contribution to the species inventory. They used the statistical modelling method *boosted regression trees* to predict the distribution and relative abundance of 72 rocky reef fish species 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 (including NE Rakiura) over the 18 years from November 1986 to December 2004, as well as 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.

Results from the study include a distribution map for each of the 72 species with the species represented at different localities according to a probability scale that is included as a key. For the Foveaux Strait farm inventory, these maps were examined and species whose distributions included the area of interest were selected and added to the list. Species were included only as a presence; the value of the probability scale was not included in any way except that it was >0.

In total, 35 species were predicted for the area of interest. 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 time during the period from preliminary investigations through to a time when sea pens have been deployed there for several years. This list is included as Column B in Table 1.

2.2.4 Reef and reef-associated fish

An extensive list of 252 reef and reef-associated fish for the NZ region (from Norfolk and Kermadec Islands to Macquarie Island) was available from Francis (1996). Species were listed according to 16 broad-scale areas, the relevant area in the present context being Stewart Island/Rakiura, which is considerably larger geographically than Foveaux Strait and may contain species that exist beyond the influence of the proposed farm. The distribution of recorded observations were from a presence-absence database compiled out of an extensive list of five categories of data sources described by Francis (1996).

This list contributed a large number of species (70) to the inventory being created here (column C, Table 1), particularly rockfish (5), clingfish (4) and triplefins (18) some of which are not available from any other source. They were selected for the inventory simply based on their being present in the Stewart Island/Rakiura area from the original list.

Table 1: A finfish inventory for Foveaux Strait: column A—species selected from fish layers on the National Aquatic Biodiversity Information System (NABIS), B—selected from Smith et al. (2013), C—from Francis (1996), D—from Kettles et al. (2017), E—from Fisheries NZ, F—from Morrisey et al., (2006), G—from Taylor & Dempster (2018); ticks are for species listed by specified author(s); ⁑ indicates Foveaux Strait presence in museum (Te Papa) records—added for *some* key Nabis absences only (see text).

Common name	Species	Family	A	B	C	D	E	F	G
Pelagic finfish									
Ahuru⁑	*Auchenoceros punctatus*	Moridae							
Albacore tuna	*Thunnus alalunga*	Scombridae					2		
Anchovy⁑	*Engraulis australis*	Engraulididae						✓	✓
Barracouta	*Thyristes atun*	Gempylidae	✓			✓	✓	✓	✓
Blue mackerel	*Scomber australasicus*	Scombridae							✓
Garfish/Piper	*Hyporhamphus ihi*	Hemiramphidae	✓					✓	✓
Golden mackerel	*Trachurus novaezelandiae*	Carangidae	✓				*	✓	✓
Horse mackerel	*Trachurus declivis*	Carangidae	✓				*		
John dory	*Zeus faber*	Zeidae	✓				✓	✓	✓
Kahawai	*Arripis trutta*	Arripidae					3	✓	✓
Murphy's mackerel	*Trachurus murphyi*	Carangidae	✓				*		
Pilchard⁑	*Sardinops neopilchardus*	Clupeidae						✓	✓
Redbait	*Emmelichthys nitidus*	Emmelichthyidae					7		
Ray's bream	*Brama brama*	Bramidae	✓						
Silverside	*Argentina elongata*	Argentinidae					4		
Sprat ‡	*Sprattus antipodum*	Clupeidae	✓						
Sunfish	*Mola ramsayi*	Molidae					4		
Trevally†	*Pseudocaranx dentex*	Carangidae			✓		1		✓
Warehou	*Seriolella brama*	Centrolophidae	✓		✓		✓		✓
Yellow-eyed mullet	*Aldrichetta forsteri*	Mugilidae	x	x	✓		8	✓	✓
Yellowtail kingfish	*Seriola lalandi*	Carangidae	✓	✓			✓	✓	✓
Reef/rocky bottom species									
Banded wrasse	*Notolabrus fucicola*	Labridae		✓	✓	✓	✓		
Black goby	*Gobiopsis atrata*	Gobiidae			✓				
Black rockfish	*Acanthoclinus littoreus*	Plesiopidae			✓				
Blue moki	*Latridopsis ciliaris*	Latrididae	✓	✓	✓	✓	✓		
Bluntnose clinid	*Cologrammus flavascens*	Clinidae			✓				
Butterfish	*Odax pullus*	Odacidae	✓	✓	✓	✓	✓		
Butterfly perch	*Caesioperca lepidoptera*	Serranidae		✓	✓	✓	2		
Common roughy	*Paratrachichthys trailli*	Trachichthyidae		✓	✓				
Conger eel	*Conger* spp.	Congridae					✓		
Conger eel	*Conger verreauxi*	Congridae			✓	✓			
Copper moki	*Latridopsis forsteri*	Latrididae			✓	✓	3		
Dwarf scorpionfish	*Scorpaena papillosus*	Scorpaenidae		✓	✓				
Giant clingfish	*Haplocyclix littoreus*	Gobiesocidae			✓				
Girdled wrasse	*Notolabrus cinctus*	Labridae		✓	✓	✓			
Goatfish	*Upeneichthys lineatus*	Mullidae		✓					
Grahams gudgeon	*Grahamichthys radiata*	Eleotrididae			✓				
Hector's clingfish	*Gastroscyphus hectoris*	Gobiesocidae			✓				
Leather jacket	*Parika scaber*	Monacanthidae	✓	✓	✓	✓	✓	✓	✓
Little rockfish	*Acanthoclinus rua*	Plesiopidae			✓				
Longsnout pipefish	*Leptonotus norae*	Syngnathidae			✓				
Lumpfish	*Trachelochismus pinnulatus*	Gobiesocidae			✓				
Māori chief	*Notothenia angustata*	Nototheniidae			✓				
Marblefish	*Aplodactylus arctidens*	Aplodactylidae		✓	✓	✓			
Olive rockfish	*Acanthoclinus fuscus*	Plesiopidae			✓				
Opalfish	*Hemerocoetes monopterygius*	Percophidae			✓				
Orange clingfish	*Diplocrepis puniceus*	Gobiesocidae			✓				
Pipefishes	*Stigmatopora* spp.	Syngnathidae						✓	
Pipefishes	*Lissocampus* spp.	Syngnathidae						✓	
Red moki	*Cheilodactylus spectabilis*	Cheilodactylidae		✓					
Red-banded perch	*Hypoplectrodes huntii*	Serranidae		✓	✓				
Red scorpionfish	*Scorpaena papillosa*	Scorpaenidae					3		
Rock cod	*Lotella rhacinus*	Moridae		✓			1		
Scarlet wrasse	*Pseudolabrus miles*	Labridae		✓	✓	✓	✓		
Sea perch	*Helicolenus percoides*	Sebastidae	✓	✓	✓	✓	✓		

Common name	**Species**	**Family**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Seahorse	*Hippocampus abdominalis*	Syngnathidae			✓	✓		✓	✓
Shortsnout pipefish	*Lissocampus filum*	Syngnathidae			✓				
Slender clingfish	*Gastrocyathus gracilis*	Gobiesocidae			✓				
Smallscale cod	*Notothenia microlepidata*	Nototheniidae			✓				
Smooth pipefish	*Stigmatopora macropterygia*	Syngnathidae			✓				
Southern bastard cod	*Pseudophycis barbata*	Moridae		✓	✓				
Southern pigfish	*Congiopodus leucopaecilus*	Congiopodidae			✓	✓			
Southern splendid perch	*Callanthias allporti*	Callanthidae			✓				
Speckled pipefish	*Leptonotus elevatus*	Syngnathidae			✓				
Splendid rockfish	*Acanthoclinus matti*	Plesiopidae			✓				
Spotty	*Notolabrus celidotus*	Labridae		✓	✓	✓		✓	✓
Stout rockfish	*Acanthoclinus marilynae*	Plesiopidae			✓				
Striped clingfish	*Trachelochismus melobesia*	Gobiesocidae			✓				
Sweep	*Scorpis lineolatus*	Scorpididae							
Telescope fish	*Mendosoma lineatum*	Latrididae		✓	✓	✓			
Thornfish	*Bovichtus variegatus*	Bovichtidae			✓	✓		✓	
Trumpeter	*Latris lineate*	Latrididae	✓	✓	✓	✓	✓		
Urchin clingfish	*Dellichthys morelandi*	Gobiesocidae			✓				
Reef/rocky bottom species — Triplefins									✓
Banded triplefin	*Forsterygion malcolmi*	Tripterygiidae		✓	✓	✓		✓	
Blue dot triplefin	*Notoclinops caerulepunctus*	Tripterygiidae		✓	✓				
Blue-eyed triplefin	*Notoclinops segmentatus*	Tripterygiidae		✓	✓	✓			
Brown topknot	*Notoclinops compressus*	Tripterygiidae		✓	✓				
Common triplefin	*Forsterygion lapillum*	Tripterygiidae		✓	✓	✓		✓	
Cryptic triplefin	*Cryptichthys jojettae*	Tripterygiidae			✓				
Longfinned triplefin	*Ruanoho decemdigitatus*	Tripterygiidae			✓	✓		✓	
Mottled triplefin	*Grahamina capito*	Tripterygiidae			✓				
Mottled twister	*Bellapiscis lesleyae*	Tripterygiidae			✓				
Oblique-swimming triplefin	*Obliquichthys maryannae*	Tripterygiidae		✓	✓	✓			
Robust triplefin	*Grahamina gymnota*	Tripterygiidae		✓				✓	
Scaly-headed triplefin	*Karalepis stewarti*	Tripterygiidae		✓	✓				
Spectacled triplefin	*Ruanoho whero*	Tripterygiidae		✓	✓	✓			
Thripenny	*Gilloblennius tripennis*	Tripterygiidae			✓				
Topknot	*Notoclinops fenestratus*	Tripterygiidae		✓	✓				
Twister	*Bellapiscis medius*	Tripterygiidae			✓				
Variable triplefin	*Forsterygion varium*	Tripterygiidae		✓	✓	✓		✓	
Yaldwyn's triplefin	*Notoclinops yaldwyni*	Tripterygiidae		✓	✓				
Yellow-black triplefin	*Forsterygion flavonigrum*	Tripterygiidae		✓	✓	✓		✓	
Benthic/Demersal species									
(Red) Gurnard	*Chelidonichthys kumu*	Triglidae	✓				✓		✓
Bass	*Polyprion americanus*	Percichthyidae	✓				†		
Black flounder	*Rhombosolea retiarii*	Rhombosoleidae	✓						
Blue cod	*Parapercis colias*	Pinguipedidae	✓	✓	✓	✓	✓	✓	✓
Bluenose	*Hyperoglyphe antartica*	Centrolophidae	✓				1		
Brill	*Colistium guntheri*	Rhombosoleidae	✓						
Deepsea flathead	*Hoplichthys cf. haswelli*	Hoplichthyidae					3		
Electric ray	*Tetronarce fairchildl*	Torpedinidae					4		
Gemfish	*Rexea solandri*	Gempylidae					3		
Giant stargazer	*Kathetostoma giganteum*	Leptoscpidae	✓				✓		
Hapuku	*Polyprion oxygeneios*	Percichthyidae	✓		✓		†		
Javelinfish	*Lepidorhynchus denticulatus*	Macrouridae					5		
Lemon sole	*Pelotretis flavilatus*	Rhombosoleidae	✓						
Ling	*Genypterus blacodes*	Ophidiidae	✓				✓		
NZ sole	*Peltorhamphus novaezeelandiae*	Rhombosoleidae	✓						
Pigfish (southern?)	*Congiopodus leucopaecilus*	Congiopodidae					✓		
Rattails (unspecified)	Unspecified	Macrouridae					7		
Red cod	*Pseudophycis bachus*	Moridae	✓		✓		✓		
Sand flounder	*Rhombosolea plebeia*	Rhombosoleidae	✓						
Sandfish⁑	*Gonorynchus gonorynchus*	Gonorynchidae							
Silver dory	*Cyttus novaezealandiae*	Cyttidae					7		
Scaly gurnard	*Lepidotrigla brachyoptera*	Triglidae					8		
Snapper	*Pagrus auratus*	Sparidae	x				2		✓

Common name	Species	Family	A	B	C	D	E	F	G
Spotted stargazer	*Genyagnus novaezelandiae*	Leptoscpidae	✓				8		
Tarakihi	*Nemadactylus macropterus*	Cheilodactylidae	✓	✓	✓	✓	✓	✓	✓
Turbot	*Colistium nudipinnis*	Rhombosoleidae	✓						
Yellowbelly flounder	*Rhombosolea leporine*	Rhombosoleidae	✓						
Other Elasmobranchs									
Dark or pale ghost shark	Unspecified	Chimaeridae	x						
Elephant fish	*Callorhynchus milii*	Callorhinchidae	✓				✓		
Rough skate	*Raja nasuta*	Rajidae	✓				✓		
Smooth skate	*Dipturus innominatus*	Rajidae	✓				✓		

* On south coast, away from site. ⁑Recorded in museum records (Roberts et al., (2015). ‡*S. muelleri* in the NABIS list is incorrect Whitehead et al., (1985); corrected here to *S. antipodum*. †Commercial catch recorded as hapuka-bass. ∗Commercial catch recorded as single spp *jack mackerel*, individual catches unknown (see text, §2.2.10). Shaded cells column E = recreational caught spp (see Table C2). Numbers in column E refer to no of years of 10 that species recorded in commercial catch but unknown volume taken because only 3 or less permit holders harvesting species (see Table C1).

2.2.5 Subtidal and rockwall species

Kettles et al., (2017) recorded cryptic and reef fishes from 36 sites with the objective of quantitatively describing shallow subtidal reef communities in the Foveaux Strait region. Reef sites were chosen to ensure a full range of exposure settings although sea conditions on sampling day often dictated the sites actually sampled. In this case, fishes are referred to as being cryptic because they are comparatively smaller and are often associated with sessile invertebrates (e.g., sponges and ascidians), requiring a different sampling regime in characterising their relative abundance. Given the locality of the sampling, species were selected for the inventory based on their being listed in the results from this study. These species are shown in column D of Table 1.

2.2.6 Species identified from the commercial fishing database

An application was made to Fisheries New Zealand (FNZ) under the Official Information Act 1982 (OIA) for extracts of commercial fisheries catch data by species for Fisheries Statistical Area (i.e., stat area) 025 (Foveaux Strait) over the 10 years 2011 to 2020. The data were summarised as catches (kg) of those species caught in stat area 025 (Table C1, Appendix C) and each species was added as a presence in Foveaux Strait to Table 1 (column E). For a number of species catch totals were unavailable from the data provided by FNZ because they must withhold such data if the number of contributing permit holders are three or less. These species appear in Table C1 as zeros in the year that a catch was taken. In these cases, they were transferred to column E of Table 1 as a number between 1 and 10 to indicate the number of years they were represented in the catch. If the number of years was less than 3, they were only transferred to Table 1 if there was other supporting information available (see further discussion on details of this in §5.3).

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.

2.2.7 Species taken by Recreational Fishers

Recreational fishing catch data for stat area 025 were also requested as part of the OIA application. The finfish species listed as being harvested include snapper (*Pagrus auratus*) barracouta (*Thyristes atun*), blue cod, sea perch (*Helicolenus percoides*), trumpeter (*Latris lineate*), leather jacket, flatfish, butterfish, blue moki (*Latridopsis ciliaris*), conger eel (spp unspecified), hapuka-bass (mixed recording category for commercial catch of hapuka, *Polyprion oxygeneios* and bass, *Polyprion americanus*), red gurnard (*Chelidonichthys kumu*), red cod (*Pseudophycis bachus*), rough skate (*Raja nasuta*) and smooth skate (*Dipturus innominatus*). This information was tabulated in Table 2 as catch (kg) and added to the Table 1 inventory as part of the commercial catch in column E.

2.2.8 Potential Colonisers of Longline Mussel Farms in the Marlborough Sounds

The results of work by Morrisey et al. (2006) provides perspective as the present inventory is being developed. These researchers identified a group of species "that might associate with marine farms[4] in the geographical area" (i.e., Marlborough Sounds–Golden Bay) 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).

Information from these authors and personal observations were used by Morrisey et al (2006) to construct their list. Species were included either because they or their taxonomic family had been recorded in association with drift algae or sessile invertebrates or they were locally common. And, while their list was aimed at providing information for mussel farms, there is common ground in that both mussel and salmon farms are floating structures with the potential to attract pelagic species acting as fish aggregating devices (FADs) and providing an accessible food source, or influence the distribution of demersal species with the same food source and by altering their habitat.

Species listed by Morrisey et al (2006) are included as Column F in Table 1. This inclusion is a useful standard or checklist against which species known to be from the Foveaux Strait area can be compared for likely attraction to a marine farm structure for the reasons the authors included them originally.

2.2.9 Information from Existing Salmon Farms in the Marlborough Sounds

A second source of perspective is the list of finfish species observed at the existing farms in the Marlborough Sounds (column G). 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), specifically with information from salmon farms. As was discussed by Taylor and Dempster (2016), this information from existing farms is all anecdotal and based only on observations from above the water. Although a method was followed to quantify these observations in the original publication, they are included here simply as a presence at salmon farms. As with the list from Morrisey et al.(2006), this list is included as a checklist.

2.2.10 Discussion on the compiled lists

Species selected from the NABIS resource provide a good basis for an inventory of finfish in Foveaux Strait. Although the species are mainly pelagics and demersals, with only a smattering of rocky reef dwellers, that group is well covered by the next three sources, Smith et al., (2013), Francis (1996), and Kettles et al (2017). While the Francis (1996) list is perhaps more empirical than that of Smith et al., (2013), in that the distributions reported by the latter are based to some extent on statistical prediction, the scale of the distributions by Smith et al., (2013) is spatially finer so that species can be directly assigned to Foveaux Strait. By contrast, the broader-scale "Stewart Island" area for the Francis (1996) species means there is a lower probability that any listed by this author only will be influenced by the proposed farm. Species recorded by Kettles et al., (2017) provide a fine-scale, real-time list, thereby proofing some of the species listed from other sources. The list from FNZ (commercial and recreational data) is also based on species actually taken within Foveaux Strait (i.e., from fisheries stat area 025), therefore providing further proofing for some listed species.

---

[4] Mussel farms

The presence of species in column E (NZF commercial and recreational fisheries data) is perhaps the strongest evidence for their probable interaction with a farm at the proposed site especially where there is a corresponding presence in column G. The most likely active colonisers are those categorised as pelagic species: barracouta, john dory (*Zeus faber*), warehou (*Seriolella brama*) and jack mackerel (unidentified spp). These data also provide a number of additional elasmobranchs from the area which have been added to Table 1 and flagged in column E. Note that the commercial catch records HPB, the code for hapuka-bass, but does not distinguish each species; and records JMA for jack mackerel, but does not distinguish the three species.

The remaining two lists (Morrisey et al., 2006; Taylor & Dempster, 2018) are included to provide an indication of the species that might be expected to be attracted to the farm, based on what has been observed elsewhere. Generally, it is the pelagic and bentho-pelagic species that are attracted to, and form aggregations near, marine farms. Morrisey et al., (2006) discuss anecdotal evidence for several demersal species with a pelagic habit (spotty, *Notolabrus celidotus*; snapper; and leatherjacket) feeding on mussel spat and cite the work of Carbines (1993) who concluded that the spotty probably recruits to macroalgae on reefs near marine farms rather than directly to the farm itself, later migrating to the farm in small numbers. Morrisey et al., (2006) discovered "a small suite of mainly demersal species present on the lines[5] in low abundances throughout the year" that included two triplefin species, spotties and leatherjackets as well as a thornfish. The only pelagic species recorded on the lines was the golden mackerel *Trachurus novaezelandiae*.

The list from Taylor & Dempster (2018) is a record of fish occurring in and around the farm pens as observations by managers of farms in the Marlborough Sounds. Discussion related to these observations showed that the most frequently represented species in pens at times when it was present was yellow-eyed mullet (*Aldrichetta forsteri*, family Muglidae), followed closely by pilchard (*Sardinops neopilchardus*, Clupeidae), anchovy (*Engraulis australis*, Engraulididae), and golden mackerel (Carangidae). The presence of these species was highly seasonal, and they can appear as small juveniles as they are able to swim through the mesh into the pens. Other species, defined as cryptic because they were unobservable visually within the farm vicinity, but could be taken by hook and line, included snapper (Sparidae) and tarakihi (Cheilodactylidae). It was known from recreational fishing records that these two species are widely distributed in the Sounds and could therefore be expected at all sites, but such a comparison was invalid for the more common species recorded near farms, because they are unlikely target species of recreational fishers and distributions from recreational fishing records were therefore inconclusive.

Globally, approximately 160 fish species, belonging to 60 families, have been observed in close proximity to fish farms. The most common families appear to be Clupeidae, Sparidae, Mugilidae, Carangidae, Scombridae and possibly Gadidae, and Lotidae. However, most of these families are absent from the list in Table 1, which is not the same as lists compiled for salmon farms in the Marlborough Sounds. Note that the single member of the Family Sparidae, the well-known snapper species, *Pagrus auratus*, is absent from Table 1, except for information from the recreational fishery.

The lists in Table 1 are particularly interesting in how they differ from lists compiled previously for wildfish species in the vicinity of existing and planned salmon farms in and near the Marlborough Sounds. Conspicuous by their absence in most lists compiled here for the Foveaux Strait area are kahawai (*Arripis trutta)*, anchovy, trevally (*Pseudocaranx dentex*), pilchard, blue mackerel (*Scomber australasicus)*, and yellow-eyed mullet None of these were included in any of the Foveaux Strait lists except for trevally and yellow-eyed mullet in the list from Francis (1996). There is also some uncertainty about pilchard, anchovy and trevally. Museum records (Roberts et al., 2015), show a single record in Foveaux Strait for pilchard and anchovy, and two for trevally, while yellow-eyed mullet is recorded near Puysegur Point; all except yellow-eyed mullet are considerably further south than the next northward record. The lists of Francis (1996) also include museum records, reflecting Roberts et al., (2015). By

---

[5] Of the mussel farm.

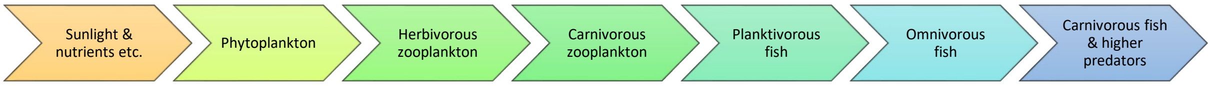
contrast, sprat[6] (*Sprattus antipodum*) is known from Foveaux Strait. A number of them are present in the commercial list recorded by three or less permit holders (column E), which provides useful empirical information, although their presence is often inconsistent (Table C1).

One characteristic that these species have in common is that they are either obligate (pilchard, anchovy, sprat) or facultative (yellow-eyed mullet, blue mackerel, kahawai, trevally) planktivores. A major feature of the pelagic habitat in Foveaux Strait is the highly variable nature of the productivity, both in time and space. The inconsistency in spatial distributions apparent here suggest that there could be some fluctuation in the populations of these finfish species as a result of varying productivity in the waters of Foveaux Strait. This would agree with the discussion on the effect of a highly variable environment from a productivity perspective by Bradford et al., (1991) and Butler et al., (1992). Inconsistencies are also apparent in the records of snapper, red moki (*Cheilodactylus spectabilis*) and, perhaps, yellowtail kingfish (*Seriola lalandi*). This is discussed further in §4.2.

2.3 Ecosystem Productivity and Feeding in Pelagic Finfish Species

As was discussed by Taylor & Dempster (2018), consideration must be given to both the species of interest and the trophic relations between them, as well as their relations with other members of the food web, when the aim is to characterise a pelagic habitat in the context of the finfish species that inhabit it. One can then develop an overall picture, beginning with where the energy originates, how it moves through the system, and incorporate this into the current status of the habitat. Of particular importance to the pelagic habitat is plankton productivity and the capacity of the various components of the plankton community to provide forage for planktivorous/omnivorous fish species, which are central to pelagic trophic dynamics. This includes consideration of the benthic and reef finfish species, many of which enter the pelagic habitat from time to time, particularly in relation to sea pen farming.

The major channel of energy flow in this system is represented simply by a pelagic food chain, which could include several elements in a process 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 other organisms not included here (Taylor & Paul 1998).



Thus, energy captured from sunlight through primary production (phytoplankton) is a key to its function and is passed up to larger and more complex organisms through grazing and predation. Of course, the system also requires some combination of the other elements shown here to exist, so something must consume the phytoplankton/algae to provide a mechanism for converting the plant-based energy into the energy storage represented by animal tissue.

For the finfish species listed in Table 1, several of the smallest (sprat, anchovy and pilchard) are known to be plankton feeders (see review by Paul et al 2001). With regard to anchovy and pilchard, previous uncertainty about which elements (i.e., small/large, phytoplankton/zooplankton) of the plankton they target (Blaxter & Hunter 1982) has more recently been revised. In the Benguela and Humbolt Current systems, van der Lingen et al (2006a & b) and Espinoza et al (2009) have shown (respectively) that the local anchovy species ingests larger particle sizes than the local pilchard/sardine species. Both of these studies have shown that zooplankton are the more important component of the diet for these species, a conclusion that has replaced earlier knowledge that phytoplankton species were the most important component in their diets.

---

[6] *Sprattus antipodum* has been recorded from Foveaux Strait (Whitehead et al., 1985), not *S. muelleri* as is listed on the NABIS website.

Globally, the Benguela and Humbolt Currents are two of several boundary systems where major fisheries have thrived for small pelagic species such as pilchard/sardine and/or anchovy. The biological community structure of these large marine ecosystems is often characterised by large numbers of species at both the upper (i.e., near apex and apex) and lower (e.g., planktonic) trophic levels, but with one to only several species of small plankton-foraging finfish dominating the intermediate trophic levels (see review by Bakun 2012). Trophic dynamic variability in these ecosystems have been shown with modelling studies to usually be the result of changes in the populations of the species inhabiting these intermediate trophic levels (Rice 1995). The wide-narrow-wide structural shape of these communities has led to the intermediate-level species being dubbed "wasp-waist" populations.

Trophic control within ecosystems 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 causing the next lower level to increase). 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".

Discussion of the effects of different environmental conditions on plankton growth by van der Lingen et al (2009) referred to 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, in contrast with more stable, warmer (> 15 °C) conditions, which cause diatom growth to become limited and allow the dominance of small nanoflagellate populations. Consequently, the community structure of zooplankton can be affected, so that large copepods ingest large phytoplankton cells at a higher rate than small cells (Peterson 1989) thus exhibiting 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[7] within Foveaux Strait may 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. Clearly, the highly variable nature of productivity in Foveaux Strait provides the kind of conditions that underlie the discussion summarised above, which, along with the uncertainty regarding the presence/absence of the potential wasp-waist analogues within Foveaux Strait, prompts the need for initial exploration in an investigation with wide ranging implications. In its most simple design this could compare commercial fish catch by species with satellite imagery for subantarctic water influx as was discussed by Vincent et al (1991).

2.4 Benthic Finfish Species

Benthic species are closely associated with the sea floor and, in the current context, this means benthic species of the continental shelf only. Two habitats are of interest, biogenic reefs and sedimentary

---

[7] The small planktivorous species discussed in the penultimate paragraph of §2.2.10.

seabeds. Because of their tendency to colonise biogenic reefs, species often categorised as rocky reef species are important here.

2.4.1 Adult Fish

Bennett et al., (2019) identified and described three main types of seabed habitat or strata (see §2.1.3): sand (about 77% of the area), bushy bryozoan thickets (about 5% of area) and bryozoan-sponge reefs (17% of the area), the latter two generally representing biogenic reefs. However, there is little information available for linking biogenic habitats with particular fish species. While Morrison et al., (2014a), have suggested a general link in this case between habitat and species, in that a range of finfish species are provided with several benefits, including shelter from predation, access to prey species, surfaces for specialised reproductive strategies for some species and indirect benefits from primary production, and that these benefits apply particularly to juvenile life history stages, they point out that work defining specific linkages are in the early stages of investigation in New Zealand.

These researchers also referred to the empirical evidence showing that a number of demersal fish species, (including snapper, trevally, blue cod, tarakihi and leatherjackets), are strongly associated with biogenic habitats during their juvenile life phases. Morrison et al., (2014a) also argued for what they call the logical conclusion that reductions in biogenic habitats are causing reductions in subsequent juvenile recruitment into adult fished populations, albeit with the knowledge that no hard empirical data exist to support this except in the case of observations from Kaipara Harbour.

In their review Morrison et al., (2014a) summarised the associations that had been identified. For coastal locations, the area of interest in the present discussion, the following associations were listed:

- biogenic pits and burrows (Hauraki Gulf) (juvenile snapper);
- kelp forest edges and sponge gardens (Hauraki Gulf) (juvenile snapper);
- bryozoan mounds at Separation Point and Torrent Bay (juvenile tarakihi, leatherjackets, snapper, blue cod and red cod);
- tubeworm mounds and sponges, Port Underwood (Marlborough Sounds) (juvenile and adult blue cod);
- Otago Shelf bryozoans (juvenile blue cod, red cod, and southern pigfish);
- Biogenic assemblages (sponges, tubeworms, horse mussels and others) on the east coast continental shelf, South Island (juvenile tarakihi); and
- Foveaux Strait bryozoans (juvenile and adult blue cod).

Observations of finfish recorded by Bennett et al., (2019) largely reflect these associations, but with specific reference to Foveaux Strait. They refer to the presence of moderate-abundant fish, including blue cod, leather jacket and tarakihi, in both the bushy bryozoan thickets and bryozoan-sponge reefs. Over the largest stratum of sand they observed occasional blue cod and leather jacket, and a single triplefin. Carbines and Cole (2009) found that sponge cover was significantly correlated with the abundance of all three colour phases of blue cod, as well as leatherjacket and scarlet wrasse (*Pseudolabrus miles*). Also significantly correlated with the abundance of adult phase blue cod and leatherjacket was topographic complexity, general epifauna cover, and macro-algae cover. As juveniles up to 25 cm in length, blue cod are rusty brown in length, then becoming iridescent grey or green, and finally changing to deep blue on the back when longer than 35 cm (Carbines and Cole, 2009).

The category of reef/rocky bottom species appearing in Table 1 is a subset of benthic fish species, used there to separate these species for easy identification. A large part of this category are the triplefin species, family Tripterygiidae, with 13 species identified in Foveaux Strait by Smith et al., (2013) and 18 identified in the more extensive "Stewart Island area" (see §2.2.4) by Francis (1996). One interesting observation by Bennett et al., (2019) is the single, unidentified triplefin in the sand stratum.

Some information on local fish habitat is available. Extensive areas of subtidal biogenic patch structures have been documented nearby in Big Glory Bay as serpulid (*Galeolaria hystrix*) reefs, some in excellent condition according to Smith et al., (2005), who describe these structures as providing habitat for a temperate reef community with abundant fish including blue cod, spotted wrasse (*Notolabrus celidotus*), southern pigfish (*Congiopodus leucopaecilus*), red cod, butterfly perch (*Caesioperca lepidoptera*) and triplefin, and rough skate and shark egg cases commonly found attached to the reefs.

The study of fish species on mussel farms in the Golden Bay-Marlborough Sounds area by Morrisey et al., (2006) provides useful empirical information on species observed within the immediate environment of marine farm structures. Although they were investigating longline mussel farm structures, and there are obvious differences in the 'attraction factors' to finfish species when compared with salmon farms, there are similarities also. Three sampling methods were employed (diver counts, ROV[8], destructive/anaesthetic/Aqui-S) "to sample as wide a selection of the fish fauna as possible". Demersal species identified as potential occupants of the structures were dominated by triplefins and spotties, and leatherjackets were usually observed; seahorse and pipefish were present occasionally; one thornfish was observed. These researchers concluded that the composition of the demersal species list depended on the pool of local species, and that this composition and their relative abundances could show temporal variation according to changes in factors like the type and abundances of fouling organisms and the larval supply of the species of interest. It was concluded that pelagic finfish do pass through the farms, but there is no evidence of them making regular use of them.

From the work of Morrisey et al., (2006) and Carbines, (1993) it is clear that different species colonise the structure in different ways. Generally, these workers showed that the abundance of spotties on mussel lines were low compared with nearby reefs and farm anchor blocks They commented on anecdotal evidence of spotties, leatherjackets and snapper feeding on mussel spat.

2.4.2 Juvenile Fish

Of particular interest is whether the area of the proposed site coincides with, or is near to a spawning ground or nursery area of any fish species. According to Beck et al., (2001) whose work is widely cited, "The ecological processes operating in nursery habitats, as compared with other habitats, must support greater contributions to adult recruitment from any combination of four factors: (1) density, (2) growth, (3) survival of juveniles, and (4) movement to adult habitats".

As part of the selection of NABIS data for Table 1, data were also selected for each species on whether Foveaux Strait included the known spawning distribution or juvenile distribution (Table B1/Appendix B). This also included sharks, which were omitted from Table 1. For the adult distributions used as a basis for Table 1, 11 species were categorised as producing a hotspot within Foveaux Strait, 12 were categorised as the area of Foveaux Strait being within their normal range (i.e., the range within which virtually 90% of the species[9] is found), and 23 were categorised as the area of Foveaux Strait being within their full range (i.e., the range within which virtually 100% of the species[7] is found); of those 11 species whose spawning distributions included Foveaux Strait or were nearby, all were categorised as within the full range; and of those 16 species whose annual juvenile distributions included Foveaux Strait or were nearby, 4 were categorised as producing a hotspot within or near Foveaux Strait, 1 was categorised as being within the normal range, and 13 were categorised as being within the full range.

The species with annual adult distributions within Foveaux Strait categorised as a hotspot were: blue cod, brill, butterfish, leatherjacket, NZ sole, red gurnard, rough skate (*Raja nasuta*), sand flounder (*Rhombosolea plebeia*), turbot (*Colistium nudipinnis*), spiny dogfish (*Squalus acanthias*), and elephant fish (*Callorhynchus milii*). The species with juvenile distributions categorised as hotspot were: barracouta, hapuka, red cod and school shark. No species were categorised with a hotspot spawning distribution within Foveaux Strait. From this information it seems that there is no relationship between high density of adults with high density of juveniles. Given the four factors of Beck et al., (2001), it is

---

[8] Remote-operated video.

[9] The species within New Zealand.

reasonable to suggest that, for there to be a nursery for a species in a given area, the requirement of high density compared with other areas should at least be met. Consequently, these data only support the possibility of barracouta, hapuka, red cod and school shark having a nursey area within Foveaux Strait.

However, there are a number of obvious omissions from the NABIS data. Blue cod, brill, leatherjacket, NZ sole, turbot and rough skate all have adult hotspot distributions, but their juvenile distributions are unavailable from the NABIS webpage. So, the probability of their not having a nursery ground within Foveaux Strait is indeterminate, based on this information.

A suggestion made by Morrison et al (2014a) regarding juvenile blue cod (< about 10cm) is that their ecology is poorly known and that they are rarely seen, and that they are mainly observed "at the bottom of reef systems, at the general reef-sediment interface, or in biogenic habitat areas". The suggestion is then made that the possible explanation of their recruitment to the reef is a two-step process with the intermediate phase occurring with recruitment being "'off-reef' or on the reef boundary in deeper water" followed by "an ontogenetic shift onto the reef proper as they grow in size and age". Included is reference to Rapson's (1956) suggestion that juveniles in some areas may migrate from shelf waters to shallow waters inshore, followed by the warning that if these suggestions are the case, "then the loss of biogenic habitats has implications for juvenile blue cod production".

While this remains an important consideration, the point in the current context is the apparent cryptic nature of juvenile blue cod and their link with biogenic habitat areas such as the bryozoan structures identified by Barrett et al., (2019) in the area of the proposed site.

Also discussed by Morrison et al (2014a) are nursery areas of tarakihi. They present observations of juvenile tarakihi at the Snares Islands and Chatham Islands before concluding that tarakihi "may have a number of shallow water nursery areas still waiting for discovery (including deeper areas of southern harbours and coastal embayments)". Although there is no specific reference made to Foveaux Strait, there is older information suggesting the potential for a nursery area there for tarakihi. Vooren (1975) analysed data from a catch sampling programme using Granton trawls and small-meshed cod-end liners to identify nursery areas for tarakihi nation-wide (Figure 3). He found that tarakihi smaller than 20 cm had been taken in the area of interest, but had to conclude that "The existence of nurseries off Castlepoint and in Foveaux Strait suggested by the catch sampling data has yet to be confirmed". It seems that the follow-up work to examine this possibility has never been undertaken.

What is clear from the review by Morrison et al., (2014a), is that juvenile tarakihi are closely associated with biogenic habitats. He refers to Vooren's (1975) conclusion that they were found closely associated with bryozoans in Tasman and Golden Bays. Morrison et al., (2014a) lists a number of observations by various observers of juvenile tarakihi associated with various biogenic habitats.

The following information regarding the distribution of juvenile (0+, <110 mm) blue cod (Figure 4) was recently received from Mark Morrison (NIWA, pers. comm.).

> Extensive sampling as part of the MBIE Research Programme 'Juvenile fish habitat bottlenecks' has found (in order of greatest to lesser densities) the following habitats to be important as juvenile blue cod nurseries: 1) bryozoan fields (*Celleporina agglutinans*), 2) coastal horse mussel beds, 3) biogenic habitat clumps (bryozoans/sponges/horse mussels) on gastropod turret shell plains, 4) dead cockle shell drifts (usually adjacent to rocky reef systems), and 5) biogenic rubble (dead shell etc) adjacent to reefs.
>
> These habitat associations are thought to hold at the national scale also e.g. while not common as too warm, 0+ blue cod has been found associated with (3) in the Hauraki Gulf, and in high abundances with (5) for coastal reef off Patea (South Taranaki).

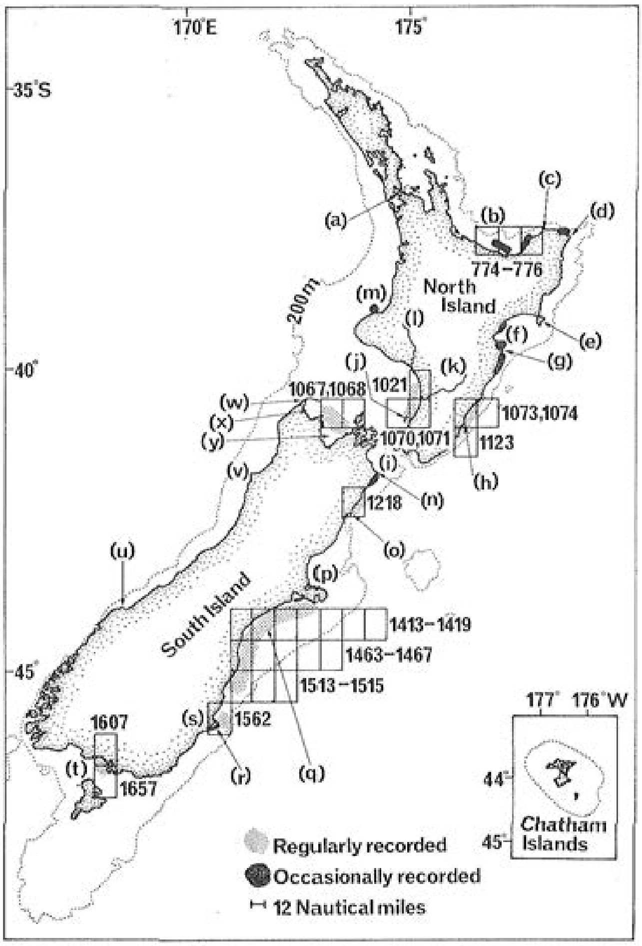


FIG. 1—Main localities mentioned in the text, and numbered grid squares where tarakihi *Cheilodactylus macropterus* (Bloch & Schneider) smaller than 20 cm long were recorded in commercial catches in the Catch Sampling Programme 1967–71 (summed length frequencies for the numbered grid squares are listed in Appendix 1). Catches were not sampled around the Chatham Islands. Localities:

(a) Auckland
(b) Bay of Plenty
(c) Cape Runaway
(d) East Cape
(e) Mahia Peninsula
(f) Hawke Bay
(g) Cape Kidnappers
(h) Castlepoint
(i) Cook Strait
(j) Kapiti Island
(k) Manawatu River
(l) Wanganui River
(m) North Taranaki Bight
(n) Cape Campbell
(o) Kaikoura Peninsula
(p) Pegasus Bay
(q) Canterbury Bight
(r) Otago Peninsula
(s) Otago
(t) Foveaux Strait
(u) Jackson Head
(v) Cape Foulwind
(w) Cape Farewell
(x) Golden Bay
(y) Tasman Bay

Figure 3: Nurseries for tarakihi suggested by Vooren (1975).

Figure 4: Juvenile 0+ blue cod on dog cockle shells, Marlborough Sounds. Photo: Mark Morrison, NIWA.

3. INTERACTIONS OF WILDFISH SPECIES WITH SALMON FARMS

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 inventory of species known from the Foveaux Strait area and 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 salmon farm 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 site, the information and inferences drawn in this section apply equally to all potential sites in locations similar to the Foveaux Strait site.

3.1 Effects and Their Modes of Action

As was discussed by Taylor & Dempster (2018), we know little about certain aspects of the nature and extent of any effect on finfish species caused by the deployment of farm enclosures at sites such as that proposed by NTSR. For example, the distance over which any effect operates is unknown and knowledge about the specific impact of any effect on different species is limited, which is further complicated by differences in the mode of action of an effect as it impacts either highly mobile pelagic species inhabiting the water column from midwater to the surface, or the usually less active benthic species closely associated with the sea floor, or species groupings based on other aspects of their "ecological requirements". Also important is whether the impact will be negative, or the opposing possibility that some aspect of the finfish population is enhanced in some way.

The components contributing to farm discharge include waste feed as well as faecal and other organic waste material produced by the fish themselves, which can impact finfish in at least three ways: (1) by making artificial feed accessible, (2) by impacting the benthos with farm derived organic material, and (3) by broadcasting the farm's presence through suspension/resuspension of discharged material as fine particles within the water column. Each of these effects represents a mode of action by which the farm impacts the finfish population and they differ in the way they might affect the three component subpopulations, the benthic, reef dwelling, and pelagic species. These modes of action also differ in the distance over which they operate.

The mode of action may also operate according to the functional feeding method used by the species and other more subtle requirements. A study by Tuya et al., (2006) aimed at detecting changes in abundance and the composition of wild fish species associated with a sea-pen fish farm before and after farming ceased, by grouping 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. Estimates of aggregation size under the farm was 50x greater than control areas during full operation of the farm, and this fell to <2x when operations ceased and the farm reduced to pen structures only. POM feeders and large Chondrichthyid rays declined under the farm after farming ceased, indicating that the waste feed attracted these groups. Inversely, 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 provided support for the hypothesis that increased physical structure of the sediments as a result of the farming contributes to the aggregating function.

The "FAD[10] attraction" of the farm, otherwise known as the tendency of fish species to be attracted to floating/suspended objects and structures, is also important in this context (see Bakun 2012 for useful discussion). Fish recruit to a wide variety of anthropogenically altered environments, including artificial structures such as docks and jetties (Rilov and Benayahu, 2000), oil platforms (Love et al., 1994), and artificial reefs (Beets, 1989) in addition to the FAD. The effect is well known, although the mode of action does not seem to be clearly understood. What has been shown is that a different group of species take up residence under aquatic farms than under a FAD (Dempster et al., 2002; Boyra et al., 2004). Based on suggestions by both of these authors it is not unreasonable to assume that the mode of action attracting potential residents to a fish farm includes some chemical cue(s) that is/are part of that component of the farm discharge that acts to communicate the presence of the farm over some unknown distance.

While the FAD effect attracts fish to artificial structures that results in formation of an aggregation of mainly pelagic and bentho-pelagic finfish species beneath the structure, there seems to be another mode of action where the fish are attracted to artificial structures as if to a reef. In this case, it is the structure itself that is important, perhaps for its ability to provide protection and/or food and/or reproductive surfaces, rather than the volume of water beneath the structure (see discussion on spotty and snapper on mussel farm lines in §2.2.10). Thus, the FAD effect and the "structure effect" are two additional modes of action by which a farm impacts the finfish population that do not result from the farm discharge, but can work in tandem with them as when the FAD effect operates with chemical cues. The FAD and structure effects are additional to modes of action 1-3 above and referred to below as modes of action 4 and 5 respectively.

A further subtlety regarding the structure effect concerns juvenile fish and the biofouling community that develops on the farm structure. Fernandez-Jover & Sanchez-Jerez (2015) discuss the similarity in the fatty acid profiles of adult and juvenile fish and the contrasting pathways followed in each case: adult wild fish feed directly on the waste pellets, whereas the juveniles of two species (*Liza aurata* and *Oblada melanura*) tested by Fernandez-Jover et al., (2009) develop similar profiles to the adults, but from feeding on zooplankton (mainly copepods and their early stages and, to a lesser extent, amphipods) that inhabit the biofouling and are preyed upon by juvenile fish.

Secondary attraction of predators is discussed by Callier et al., (2018). In this case predators are attracted to the farm by the aggregated wild fish that are "in residence", having been attracted by what is referred

---

[10] fish aggregating device

to here as the "FAD + chemical cues" mode of action. Clearly, the ecological requirements of predators attracted in this way require their own, characteristic resolution, as do those of the juveniles consuming zooplankton and small prey inhabiting the biofouling on the farm structure.

Based on this information, the vulnerability to farm installation at the proposed site of a particular fish can be described 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 of residence for that fish. This can be generalised to a local population of a particular species.

The site proposed by NTSR is high-flow, the coarse sediments are non-cohesive and the coarse sandy sediments found across the proposal area are more readily oxygenated possibly facilitating decomposition of farm wastes (Bennett et al., 2019). This led these authors to suggest that effects usually attributable to the excessive accumulation of organic waste at a lower-flow, muddier site are less likely to be as discernible at this site and that the most appropriate model of farm waste deposition is one that comprises an initial depositional area (the primary footprint) followed by resuspension of the waste material and eventual secondary deposition to create the "total footprint".

Although there is no absolute certainty about the degree of impact that might occur from farm installation at the proposed site, the results of Bennett et al., (2019) with regards farm discharge are important in considering the vulnerability of local benthic finfish. We might expect that, potentially, the benthic species resident within the primary depositional footprint 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 largely sedentary species such as stargazer, or indirect through its ultimate effect on a species' prey.

Following deployment of farm pens, initially only the FAD attraction will impact any pelagic/benthic-pelagic wild fish species. Later, when the pens are populated with farmed fish, the mode of action will become the "FAD + chemical cues" mode of action referred to above, which will also include the suspended/re-suspended farm discharge as fine particles within the water column and operate over a wider area than the benthos impacted by farm-derived organic material estimated by the modelled extent of the deposition footprint. Although the actual distance is unknown, it will affect an extended area of Foveaux Strait, particularly in a downstream, west-to-east direction along the main current axis (see Heath, 1972 & 1975), with some addition to the west by the action of the tides (Figure 2). Ultimately, it will potentially influence all pelagic and bentho-pelagic species over the affected range, although it is unknown which of these will be attracted to the farm. Once any pelagic/bentho-pelagic individuals arrive at the farm, then waste feed potentially becomes available to them as an alternative to their natural diet.

The outcome of this effect and whether it is short or long term, then becomes a function of whether the presence of a particular fish is temporary or they become resident, either intermittently or on a permanent basis. Some researchers overseas (Dempster et al. 2002, 2009, Otterå and Skilbrei 2014, Skilbrei and Otterå 2016) have shown that aggregations are temporally stable, both in relative size and species composition, on a scale of several weeks to months, a result that implies some degree of residency of wild fish at farms. Researchers (Fernandez-Jover et al. 2007, Valle et al. 2006, Arechavala-Lopez et al. 2015a) working in the Spanish Mediterranean have shown large seasonal variations in species composition and biomass of aggregations, although this is inconsistent between locations with strong seasonality absent elsewhere (e.g. Canary Islands; Boyra et al. 2004). Other studies in the Spanish Mediterranean (Ballester-Molto et al. 2015) 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. Overall then, these results imply difficulty in predicting 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 §3.4 regarding the movement of some species between farms suggesting, perhaps, that residence may actually be over an extended distance in some instances.

As an alternative strategy that alleviates spatial conflict, facilitates dispersal or amelioration of farm waste and reduces disease transmission risks, offshore fish farming is increasingly being promoted to resolve problems associated with coastal sea-pen fish farming (Holmer 2010). 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. One major difference compared with coastal farms is the likely predominance of pelagic species around farms. Offshore tuna ranching pens in the Mediterranean Sea attract large pelagic predators such as bluefin tuna (Arechavala-Lopez et al. 2015b).

In New Zealand, analogous offshore wild fish aggregations might include several species of large tuna (Scombridae) and large sharks (Francis, 2019), with such species more likely to have undesirable interactions with farms and stock. However, this will not preclude offshore fish farming in itself. Future offshore fish farms are also likely to be characterised by being larger than coastal farms, which may lead to wild fish aggregations being larger. However, it is unlikely that the nature of interactions between farms and wild fish will be changed otherwise.

The vulnerabilities discussed in this section occur within an ecological perspective, which differs from vulnerabilities occurring from a fishery perspective. An important consideration in the present context is whether the farm's impact removes members of a species from a fishery. Then any assignment of vulnerability must include consideration of whether the species' availability to the fishery is affected. Members of a pelagic species attracted to the farm that take up residence there may become the permanent subject of an ecological trap (see §3.8, para. 4), and therefore effectively be removed from the fishery. An associated outcome is the increased vulnerability to fishing caused by being concentrated at a location known to fishers, particularly where fishing in the vicinity of salmon farms is unrestricted (see §3.8). Without the restriction, fish of a particular species may be removed from one fishery but made more accessible to another, with an overall increase in their vulnerability to fishing.

Outcomes resulting in an opportunity for increased abundance and/or biomass in the finfish population do not appear to add to their vulnerability, but could be viewed as a mechanism for offsetting losses that occur elsewhere. However, an individual's fitness may be compromised through a reduction in food quality, for example, caused by their replacing their natural diet with one dominated by artificial feed. These issues are discussed below in §3.2.2.

3.2 Consequences of Fish Farm Effects on Wild Fish

3.2.1 The Aggregating Effect of the Farm

The aggregating effect of the farm comprises two modes of operation: the FAD effect and the broadcasting effect of the farm's presence through suspension/resuspension of discharged material as fine particles within the water column. The combined operation of these two components attracts mainly pelagic and bentho-pelagic species to form an aggregation in midwater beneath the farm structure, as has been observed in extensive studies completed overseas (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. 2013, 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 5) in a concentrated area may affect local fisheries in several ways.

Such aggregations can be large, with some 250 tonnes of saithe (*Pollachius virens*) estimated beneath a farm in western Norway (Gudmundsen et al. 2012 cited in Otterå and Skilbrei 2014) although other estimates are considerably less: combined farm-aggregated biomass of the dominant species averaged 10.2 t per farm throughout the latitudinal extent of Norway (Dempster et al., 2009), and aggregations of up to 40 tons have been recorded from the Mediterranean (Dempster et al., 2002, 2004, 2005; Fernandez-Jover et al., 2008).

Figure 5. Wild sparids and carangids massed beneath a sea-pen fish farm in the Mediterranean Sea. The bottom of the pen structure can be seen as the dark area at the top of the frame.

The most common families observed in these Mediterranean studies were Clupeidae, Sparidae, Mugilidae, and Carangidae which included several pelagic planktivorous fish species (*Boops boops*, *Oblada melanura*, *Trachurus mediterraneus*, *Trachinotus ovatus*, *Sardinella aurita*) and several species belonging to the family Mugilidae that were numerically dominant in the assemblages. This dominance varied with both the farm and season (Fernandez-Jover et al., 2008). Larger predators (*Seriola dumerili* and *Pomatomus saltatrix*) have also been observed at many of the farms in large schools and 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).

In a Mediterranean study by Dempster et al., (2002), where pelagic species were dominant at farms and few benthic wild fish occurred, results showed that 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. Also of interest in the present context were the results of Bacher et al., (2015), who found that fish aggregations at a Spanish sea bream farm were larger where rocky reef was present.

Within the Norwegian coastal ecosystem, the bentho-pelagic Atlantic cod, *Gadus morhua* (family Gadidae) were significantly more abundant beneath salmon farms on rocky bottoms than on plain sand or mud bottoms (Dempster et al. 2009). Abundance of this was negatively correlated with water depth, indicating that more of this species is aggregated at farms in shallower areas. Consideration of all results indicated that fish farms are most attractive to wild fishes when they are:

- large in size;
- located in shallow waters;
- close to the coast; and
- placed over a rocky substrate.

However, there are certain species that will likely be attracted regardless of these features.

Although information on the role of fish farms as settlement habitat for juvenile fish is apparently scarce (Taylor & Dempster, 2018), some details have been examined and reported, with recent work by Fernandez-Jover & Sanchez-Jerez (2015) citing previous discussion on whether this is a consequence of shelter availability and prey abundance (Fernandez-Jover et al., 2009) or chemical and acoustic cues (Simpson et al., 2010). They add the further possibility, that the "offshore structures may offer the unique option of providing habitat with a sufficient level of complexity in environments of extensive sand and mud bottoms, which is the case of the sampled locations in the present study".

Dempster and Taquet, (2004) suggest that spawning periods regulate the appearance of juvenile species around artificial structures because the majority of small juvenile fish that associate with artificial habitats only do so for a specific period of their life history. Fernandez-Jover and Sanchez-Jerez (2015) reported juvenile carangids, clupeids, atherinids, sparids and mugilids present on sea-pens at comparable densities to natural shallow rocky habitats, extending the work of Fernandez-Jover et al. (2009) who found that 20 juvenile fish species settle at farms throughout the year, mainly belonging to the families Sparidae, Mugilidae, and Atherinidae and that the abundance of postlarvae and juveniles around a single pen of 12 m diameter may include tens of individuals of *Diplodus* spp. to thousands of individuals of *Atherina* spp. and *Mugil* spp. A study by Oakes and Pondella (2009), found that juvenile fish populations were less dense on sea-pen structures than natural reefs, while the opposite occurred for adult fish.

Fernandez-Jover & Sanchez-Jerez (2015) reported that changes in growth rates of farm-associated juvenile fish were indicated by analysis of otolith morphology and suggest that "otolith shape descriptors could be an interesting tool for monitoring fish farming influence on wild-fish populations". These authors conclude that "coastal fish farms may provide similar habitat complexity and diverse food availability, including both benthic and pelagic prey, as natural settlement environments for many species" and that "mortality of juvenile fish by predation does not seem to be high, due to the abundance of food in the form of pellets available for the aggregated piscivorous fish (Fernandez-Jover et al., 2007) or because an appropriate habitat complexity protects juveniles against predation".

Lights are frequently used in salmonid farming to control maturation. 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, Campos et al., 2019).

3.2.2 Access to Artificial Feed

Consumption of waste feed by wild fish species represents a major change from their natural diet, which affects their physiology, body condition and alters their parasite loads. This section discusses these factors with reference to the action of particular components of the farm-feed (i.e., *aquafeed*, Autin, 1997) including fatty acids, organohalogenated contaminants and heavy metals.

Physiological Consequences

Because of the different composition of farm-feed compared with natural resources and its easy availability, the consumption of food pellets by aggregated fish results in changes to their biological condition. The ingredients of aquafeeds include fish meal, fish oil and vegetable-based components (Autin, 1997). According to this author, a high quality fishmeal should comprise a highly digestible protein content (40–70%), with low measures of lipids, ash, salts, total volatile nitrogen, biogenic amines, and 0% of the carcinogen dimethylnitrosamine.

Although the change in biological condition resulting from consuming waste feed can be a positive effect, with enhancement indicating elevated spawning potential, negative changes can result from inferior commercial feeds, particularly when fat content and fatty acid composition differ appreciably from typical natural diets. In one study (Fernandez-Jover et al., 2007), the variation in fat content of feed pellets has been shown to range from 17% to 24%. Terrestrially-derived vegetable oils are also used, to substitute for fish oil when sourcing is difficult or prices too high, which can introduce high concentrations of ingredients such as oleic acid (18:1ω9), linoleic acid (18:2ω6), and α-linolenic acid (18:3ω3). This food source modifies the fatty acid composition of the diet and may elevate the fat content levels of wild fish feeding on the wate feed pellets.

Several studies (Arechavala-Lopez et al. 2015d; Skog et al., 2003; Fernandez-Jover et al., 2011) have demonstrated this for saithe (*Pollachius virens*) and Atlantic cod (*Gadus morhua*) (Fernandez-Jover et al., 2011) inhabiting areas close to salmon farms along the Norwegian coastline. These fish 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 inhabiting waters distant from farms. In addition, the ω3:ω6 ratio was clearly different between control and farm-associated fish.

Physiological changes can occur rapidly after switching to a farm feed diet (2-8 weeks: Gonzalez-Silvera et al. 2017). Captive feeding trials suggest that a diet high in farm feed causes reduced egg quality in some species (e.g. Salze et al. 2005); and a captive spawning trial using Atlantic cod taken from areas of high and low salmon farming density produced evidence for reduced fitness in the offspring of the farm-associated Atlantic cod (Barrett et al. 2018b). However, some work (e.g. Laurel et al. 2010) on the biosynthesis of essential fatty acids in marine fish and invertebrates indicates that some farm-associated organisms are probably resilient to changes in dietary fatty acids.

Changes in Body Condition

As a result of their diet being dominated by farm-feed, farm-associated wild fish tend to display a significantly higher Fulton's condition index and/or hepatosomatic index and/or tissue-fat content than control individuals e.g., saithe, Atlantic cod, jack mackerel spp., and the 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). Norwegian coastal salmon farms modified wild fish diets, both in quality and quantity, and consequently providing farm-associated wild fish with a strong trophic subsidy. This translated to greater body condition index (saithe: 1.06–1.12 times; Atlantic cod: 1.06–1.11 times) and liver condition index (saithe: 1.4–1.8 times; Atlantic cod: 2.0–2.8 times) than control fish caught distant from farms (Dempster et al., 2011) (Figure 6).

Diets of farm-associated saithe and Atlantic cod were dominated by waste feed, but a difference in the composition of other dietary items suggested a difference in their availability between farm and non-farm locations. Modified meio- and macro-fauna communities (Kutti et al. 2007) and modified fish assemblages (Dempster et al. 2009) were characteristic of the sea floor beneath the salmon farms in these studies compared to control locations, and wild fish associated with farms clearly also prey upon these fauna.

The trophic subsidy from the waste feed is the likely cause of the increased body and liver condition observed in farm-associated saithe and Atlantic cod. The main lipid store in gadoids and therefore their principal energy store is the liver (Lambert & Dutil 1997). A measure of total lipid energy is provided by the liver index, and a high value is a direct indicator of egg production in gadoid fish (Marshall et al. 1999), with a measure of lipid energy reserves 3 to 4 months before spawning the best proxy for fecundity (Skjæraasen et al. 2006). For saithe and Atlantic cod, which spawn in early spring, being associated with fish farms throughout summer and autumn could increase their fecundity even if they leave the farm months before spawning.

However, despite the increased fecundity, egg quality of these fish may be affected. The composition of stored lipids in these farm-associated Atlantic cod and saithe may differ from the stored lipids of

Figure 6. 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.

those not associated with a farm and consume a natural diet (Fernandez-Jover et al. 2011). The key to fertilization rates and egg quality is highly unsaturated fatty acids (HUFAs) and arachidonic acids (Salze et al. 2005) and farm-feeds contain low proportions of these elements. If the liver fatty acid composition of saithe and Atlantic cod feeding on waste-feed has a negative effect upon egg quality during vitellogenesis, the apparent advantage from increased condition may not translate to a similar advantage in spawning success. The hypothesis regarding egg quality requires experimental manipulations of the diets of wild fish species such as saithe and Atlantic cod with varied proportions of waste feed for various durations to examine the effect this has on egg and larval quality to determine the extent of this potentially negative effect.

Changes in Parasite and Pathogen Loads

For farm-associated wild fish, their parasite and pathogen loads are modified when compared with control fish, but this effect is bi-directional (Fernandez-Jover et al. 2010, Dempster et al. 2011) and Fernandez-Jover et al. 2010 concluded that wild fish parasitic communities were not severely affected by the influence of coastal sea-pen aquaculture. 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, and that the internal parasite *Anisakis simplex* was significantly less abundant in the livers of farm-associated saithe compared with those of wild saithe. These modified parasite loads appeared to have little detrimental effect upon wild fish condition, so that Dempster et al. (2011) concluded that, although the abundances of parasites were altered, the strong effect of the trophic subsidy represented by the diet of waste feed seemed to override any effects of altered loads upon wild fish condition. Little is known about viral and bacterial transmission between farmed and wild fish, an issue beyond the scope of the work documented here, which is covered in the NTSR Salmon Disease Risk Assessment Report (DigsFish, 2019) and Biosecurity Management Plan – Stewart Island Salmon Farm (Ngai Tahu Seafood, 2019).

Whether the parasite levels of wild fish that will likely reside around the proposed farming site in Foveaux Strait 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.

Organohalogenated Contaminants

Organohalogenated contaminants (OHCs) are a wide range of chlorinated, brominated and fluorinated pollutants commonly found in marine ecosystems. They include: organochlorines (OCs; PCB, and OC-pesticides), brominated flame retardants (BFRs), polybrominated diphenyl ethers (PBDE), hexabromocyclododecane (HBCD) and perfluorooctanesulfonate (PFOS). Many of these compounds are prevalent in marine fish and biomagnify[11], both as a result of long-range transport and local sources. OHCs include well-studied legacy compounds (i.e. polychlorinated biphenyls (PCBs) and OC-pesticides), as well as 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 comprise approximately 25% of the Skretting salmon feed used in some salmon farms in NZ) is produced mostly from fish meal and oil from lipid-rich oceanic fishes. It contains 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 concentrations of these compounds for which documentation is available in the Skretting feeds are lower than both current Australian and European Union standards, according to information from Skretting Australia's Residue Monitoring Reports published online up to and including 2019[12]. Within the period 2006-2019 (inclusive) concentrations of dioxins (PCDD / PCDF) have varied between 0.038-0.158 ng/kg (EU limit = 2.25 ng/kg), and the sum of Dioxins & Dioxin-like PCBs (WHO-PCDD/F+PCB) varied between 0.16-0.65 ng/kg (EU limit = 7 ng/kg) (Table D1, Appendix D).

There has been no consistent evidence to suggest that farmed salmon worldwide have elevated concentrations of OHCs compared with wild salmon (Hites et al. 2004a, b, Shaw et al. 2006, 2008, Cole et al. 2009). Detected concentrations are below those considered safe for human consumption by EU or US standards[13]. The diet of wild fish occurring near salmon farms is different to diets of farmed salmon and includes a mixture of both the waste feed and other invertebrate and fish prey (Dempster et al. 2011). Therefore, levels of OHCs in farmed salmon cannot be used to infer likely levels in the wild fish occurring near salmon farms.

Norwegian coastal salmon farms provide an additional source of lipid-soluble OHCs, causing a species-dependent 20-50% increase of these compounds in wild fish captured in their vicinity (Bustnes et al. 2010). This species-dependent variation in OHC levels seems to be the result of variations in life-history and habitat use in the different fish species.

In an interesting contrast to the relationship for lipid soluble OHCs, control fish had 67% higher PFOS levels than farm-associated wild fish. This suggests that the natural food content of this compound is higher than the commercial feed used in salmon farms (Bustnes et al. 2010). Therefore, salmon farms drove a lowering of the level of this group of OHC contaminants in wild fish.

Elevated levels of lipid-soluble OHCs in farm-associated wild fish detected by Bustnes et al. (2010) were lower than European safe consumption standards. To date, there have been no studies demonstrating negative consequences of OHCs to the wild fish themselves at the levels detected. Some OHCs are known to act as endocrine disruptors, leading Bustnes et al. (2010) to suggest the need for

---

[11] Biomagnification is any concentration of a toxin in the tissues of tolerant organisms at successively higher levels in a food chain.

[12] https://www.skretting.com/en-AU/quality--safety/reports--brochures/

[13] NZ Food Standard Code is coupled with the Australian Govt Federal Register of Legislation; maximum levels of contaminants are included in Schedule 19 (https://www.legislation.gov.au/Details/F2017C00333), but there is little reference to organohalogenated contaminants except polychlorinated biphenyls (PCBs); EU and US standards are more extensive, although there are complexities related to variations on a global scale that require consideration for a comprehensive overview of the subject (see Hites et al., 2004a).

further work to determine whether OHCs negatively affect reproductive processes of the wild fish associated with salmon farms.

A number of long-lived benthic/benthopelagic fish species of commercial, recreational and customary fishing interest are present within Foveaux Strait (e.g. blue cod, tarakihi, blue moki; Table 1) and may be attracted to an established farm. Existing evidence suggests that the levels of any OHC contaminants within their tissues occurring from extended periods of residence and feeding on benthic invertebrates beneath salmon farms are likely to remain below those that would affect the fish themselves and below those considered safe for human consumption. In addition, it is possible that certain lipid soluble OHCs, such as PFOS, may be reduced in their tissues as a result of their consuming waste feed, as was determined by Bustnes et al. (2010) for saithe.

Because the Bustnes et al. (2010) study was performed 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 any farm established at the proposed site in Foveaux Strait. There has been no study conducted at farming sites that have been operating over multi-decadal time scales, so reliable inference cannot be made regarding longer term effects.

Heavy Metal Contamination

Trace concentrations of heavy metals can be contained within aquafeeds, including mercury (Hg), 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). The monitoring of heavy metal concentrations in feed is crucial, because of their likely accumulation in both sediments and cultured fish (e.g. Liang et al., 2016; Maurya & Malik, 2019; Meng & Feagin, 2019).

For elements in the Skretting feeds that have been measured the concentrations are lower than current Australian and European Union standards, according to information from Skretting Australia's Residue Monitoring Reports published online up to and including 2019[14]. Within the period 2006-2019 (inc.), concentrations of arsenic varied between 0.15-1.6 mg/kg (EU limit = 10 mg/kg), lead varied between 0.05-0.33 mg/kg (EU limit = 5 mg/kg), cadmium varied between 0.18-0.33 mg/kg (EU limit = 1 mg/kg) and mercury varied between 0.01 – 0.03 mg/kg (EU limit = 0.1 mg/kg) (Table D2, Appendix D).

The most detailed existing information on heavy metal concentrations in the tissues of wild fish near salmon farms is from work carried out in Norway (e.g. Bustnes et al. 2011). Comparison of the future levels in NTSR salmon diets with levels in diets used in the Norwegian salmon industry will enable comparison of the two. 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, 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 in Skretting feeds.

There is no consistent evidence to date suggesting 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). The diets of wild fish occurring near salmon farms are different and the wild fish are subject to different processes than the farmed salmon, so possible heavy metal levels in wild fish occurring in the vicinity of salmon farms cannot be inferred from levels in farmed salmon.

Although it is only trace concentrations of heavy metals that are present in salmon feeds, the volume of feed introduced to the limited area of a salmon farm on a multi-year time scale could result in bio-accumulation of certain elements in sediments below farms. The antifouling treatments, such as Zn or Cu are also likely to contribute to metal accumulation in sediments (e.g. Nikolaou et al. 2014), where they are used. Sediments below salmon pens have been shown to contain elevated concentrations of some elements such as Zn, Cu Cd and Fe (e.g. Dean et al. 2007; Naylor et al. 1999). Because the

---

[14] https://www.skretting.com/en-AU/quality--safety/reports--brochures/

abundance and biomass of benthic invertebrates also is typically higher in farm-influenced locations (e.g. Kutti et al. 2007), and wild fish in aggregations near salmon farms consume benthic invertebrates as well as the salmon feed (e.g. Dempster et al. 2011), studies have sought to determine if heavy metals in wild fish around salmon farms are elevated.

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 Atlantic cod caught near salmon farms and control Atlantic cod caught at distant sites. Only three elements (U-238, Aluminium (Al) and Ba) were higher in farm-associated Atlantic 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 Atlantic cod compared to farm-associated Atlantic 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 Foveaux Strait, some evidence suggests that several long-lived demersal fish species (e.g. blue cod, tarakihi, red cod; see Table 1) will reside in the vicinity of salmon farms. Blue cod and tarakihi, in particular, are targets for commercial, recreational and customary 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.

3.2.3 Impact on the Benthos of Farm-derived Organic Material

While waste feed dominated diets of farm-associated saithe and Atlantic 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 with control locations, and wild fish associated with farms clearly also prey upon these fauna.

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.

These studies provide useful background information in the context of the Hananui site. Although there was no reference made to current strength in publications for these studies, it is most likely that these researchers were working with low flow sites. For example, the study by Russell et al., (2011) took sediment samples in the vicinity of farms established in sea lochs or voes, where they describe "restricted exchange between the waters of the sea lochs/voes and coastal waters" which "may in turn lead to higher sedimentation rates than in the more dispersive coastal water bodies". By contrast, the Hananui site is a high flow site where we would expect lower accumulation of waste feed and fish waste and correspondingly lower levels of accumulated OHCs, in keeping with the deposition footprint described by Bennett et al., (2019).

Localised far-field enrichment effects are also discussed by Bennett et al., (2019). This effect is the result of resuspension processes and, although the expectation of its impact is for minimal ecological change (Keeley & Taylor, 2011; Bannister et al., 2016), Bennett et al., (2019) discuss the possible deposition of a significant portion of particulate organic matter in deposition-prone areas such as "nearby low-flow areas, seafloor depressions and areas with greater rugosity such as reefs or bivalve beds", suggesting that with sufficiently elevated depositional inputs, the possible result in areas outside of the immediate depositional footprint could be for localised enrichment, increased availability of organic particulates and dissolved nutrients as well as increased turbidity. The potential effect on finfish species would be to enhance their abundances by providing increased abundance of prey species over a greater area and within habitats not immediately adjacent to the proposed farm.

This also suggests some accumulation of OHCs associated with the localised far-field enrichment effects. However, the outcome of deposition over an extensive area is that the concentration of these contaminants would be considerably lower than those reported in the overseas studies, particularly that of Russell et al., (2011) and therefore well within the Scottish EAC or considerably lower than polluted marine sediments worldwide. Nevertheless, it must be kept in mind that feed loss is a major contributor to contaminant accumulation and good management in this area is important in minimising farm-generated contaminant levels.

3.3 Monitoring Rates of Feed Loss

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 should be considered a key issue in determining the effects of salmon farming on wild fish species.

The rate of feed loss from sea-pen aquaculture is likely to vary considerably with location, environmental conditions (e.g. current strengths) and the feed-monitoring technologies in use. The 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 nine Norwegian salmon farms put feed loss at a minimum of 1.4% in the summer months (Dempster et al. 2009).

To determine the extent to which this is likely to drive wild fish aggregations at the proposed farming sites, and to avoid any future debate on possible bias in the estimates, independent verification of feed loss rates from NTSR farms is required. A brief plan is included in §6.

3.4 Movements of Farm-Associated Fish

Possible movements of wild fish among farms and also to other areas of ecological and commercial interest may affect the local fish population and, implicitly, the fisheries in several ways. For example, 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 transfer parasites and pathogens from one to another.

Acoustic telemetry has been used to study the movement patterns of several species of farm-associated wild finfish (Uglem et al., 2009; Arechavala et al. 2010; Otterå and Skilbrei 2014, Skilbrei and Otterå 2016). Saithe were studied in Norway and mullet (*Liza aurata* and *Chelon labrosus*) in Spain were shown to move rapidly and repeatedly between fish farms located several kilometres apart. Farm associated Atlantic cod were also shown to move repeatedly from and between fish farms (Uglem et al., 2008). These movement patterns make these species possible vectors for transmitting diseases and parasites both to and from farms and into wild fish populations (Uglem et al. 2014). Risks and their management related to wild fish interactions with the proposed Hananui farm are discussed in the Draft Biosecurity Management Plan (Ngai Tahu Seafood, 2019).

Any hypothesis that wild fish spread diseases or parasites occurring on cultured fish assumes that wild fish share pathogens with the farmed fish and that, under natural conditions, these pathogens can be transferred between the wild and farmed species. Fernandez-Jover et al. (2010) found that macroparasites were not shared between reared sea bass and sea bream, and farm-associated wild fish (bogue and Mediterranean horse mackerel). They also found that there was no effect of farms on the total parasite community when farm-associated wild bogue and horse mackerel were compared with wild bogue and horse mackerel not associated with a farm.

In contrast to this potentially negative effect is the potential effect resulting from consumption of greater amounts of food by fish resident near fish farms. This implies an increased biomass of wild fish, so that movements of fish from farms to other areas may lead to an export of "added biomass" to local fisheries. Little is known however, about the extent of such biomass exports, 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 Atlantic cod fishing areas (Bjørn et al., 2007). As was discussed above (§3.2.2, Changes in Body Condition), farm-associated fish might also leave the fish farms during their reproductive period to spawn, a possibility that has previously received little attention. If and how this might affect the reproductive ability of wild fish is unclear, but acoustically tagged, farm-associated Atlantic cod may move between a fish farm and local spawning grounds during the natural spawning season (Uglem et al., 2008).

3.5 Feed Waste Amelioration By Wild Fish

The role of wild fish in assimilating nutrient wastes lost from salmon farms appears to be significant in both the pelagic and benthic realms. Saithe is the main species populating farm-associated aggregations within coastal areas in Norway and more than 70% of their diet when in the vicinity of farms is waste feed. Several other species, including *Gadus morhua*, *Melanogrammus aeglefinus* and *Scomber scombrus* also consume lost pellets around farms (Dempster et al. 2011). These researchers also found that the stomachs of farm-associated saithe sampled during summer contained an average of 14.2 g of waste pellets. Based on an aggregation size of 10 000 saithe, an estimate within the range observed at many farms (Dempster et al. 2009), this suggests 142 kg of pellets consumed by this species each day during summer, totalling 12.8 t of waste food consumed over a 3 month period.

With regards the feed lost from a farm with 1000 t of salmon feeding at a rate of 1% of biomass (or 10 t) per day, a minimum feed loss of 1.4% produces 142 kg of waste feed per day. This estimate illustrates the capacity of wild saithe aggregations to provide an 'ecosystem service' to fish farmers by reducing particulate sedimentation in the vicinity of salmon farms. Estimates for wild fish aggregated around fish farms elsewhere have given similar results. In Australia, the result of excluding wild fish from the water column beneath salmonid sea-pens was a doubling of the waste accumulating under the pen (Felsing et al. 2005). In the Mediterranean Sea, two studies found similar or higher levels of amelioration (Vita et al. 2004; Sanz-Lázaro et al. 2011), and a more recent experimental study in the Mediterranean Sea, estimated wild fish consumption of particulate waste as 18 % (Ballester-Molto et al. 2017).

There is no accounting for this process in current models predicting sedimentation and nutrient dispersal around salmon farms. The overestimation of food pellets at farms by widely used models such as DEPOMOD may be tens of tons per year. Incorporating the effects of wild fish into models would 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. However, it is also true that little is known of the numbers of fish attracted to farms in New Zealand. While European studies report large aggregations under farms, the same may not be so here, and any such addition to models in the local context would be hypothetical at best. What we require are data to quantify aspects of the wild fish aggregations that develop under farm pens here.

3.6 Interactions of Salmon Farms with Wild Salmonid Populations

In northern Europe and North America, where farmed and wild salmon co-occur in coastal waters, two major 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 cultured fish held in coastal areas in large numbers may increase parasite loads of their wild counterparts (Bjorn et al. 2001, Morton et al. 2004, 2008, Krkošek et al. 2005; Ford & Myers 2008). These concerns arise from the possibility that escapees inter-breeding and competitively interacting with wild salmon within rivers will detrimentally impact wild populations, and that high parasite loads on seaward-migrating salmon smolts have been implicated as a potential cause of high mortality at sea and the reduced return of adults to rivers (Bjorn et al. 2001; Krkosek et al. 2013). In Ireland, Jackson et al. (2013) found no evidence for the distribution of aquaculture affecting wild salmon stocks; rather, changes in the quality of freshwater habitat was implicated.

Because salmonids are non-native to New Zealand's waters, it could be argued that these two concerns of how salmon aquaculture interacts with native wild salmonid populations are of limited relevance in the present context. However, although they are introduced, three salmon species occupying an important place in the New Zealand sport-fishers world are established in the rivers and lakes of the South Island: Atlantic salmon (*Salmo salar*), quinnat[15] salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*). Nevertheless, there is no convincing evidence for an established wild salmon population on Stewart Island/Rakiura. A comprehensive, island-wide freshwater fauna sampling regime employed by Chadderton (1990) on Stewart Island/Rakiura between August 1987 and December 1989 recorded a single quinnat salmon and a single salmon fry.

3.7 The Quality of Farm-Associated Wild Fish for Human Consumption

In many cases the wild fish species occurring in salmon farming areas are the targets of important local fisheries. In Norway, interaction between wild fish and salmon farms has resulted in conflict between farmers and local fishers. Many local fishers believe that the flesh quality is inferior of wild saithe that have resided around farms and consumed food intended for salmon. Consequently, local fishermen in Norway avoid fishing in salmon farming areas where they claim that the flesh quality of farm-associated fish is inferior to saithe that do not interact with salmon farms (Bjørn et al., 2009).

---

[15] Commonly called chinook salmon in North America

However, this assumed negative relationship between fish associated with farms and inferior flesh quality is poorly supported by scientific studies (Skog et al., 2003; Bjørn et al., 2009; Otterå et al., 2009). Although differences in 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), a sensory panel under controlled experimental conditions could not distinguish the taste of saithe fed typical wild diets from saithe fed an exclusively salmon feed diet for 8 months (Otterå et al., 2009). However, a difference in tissue 'dullness' and chewing resistance was detected. It is possible that these attributes could both 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.

More recently, a 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 considered 'gentler' in flavour and softer in texture than control samples, perhaps as a result of higher fat and lower water content (Bogdanović et al. 2012). These results indicate that aspects of the culinary quality of farm-associated fish are not necessarily negative.

3.8 Ecosystem-Based Management of Fish Farming and Local Fisheries

It is known from overseas studies that the large aggregations of fish species associated with fish farms are often targets of recreational and commercial fisheries, and therefore have the potential to generate substantial interactions between aquaculture and fishing at a local scale (Dempster & Sanchez-Jerez 2008). In areas where coastal waters support concentrations of fish farms, it is likely that these effects are amplified and will interact with fisheries at a regional scale. It is expedient that sea-pen aquaculture is accounted for in fisheries management because of its potential to affect the spatial distribution and demographic processes of a range of important fisheries species.

Farm managers in the Mediterranean Sea have observed an increase in commercial and recreational fishing pressure near fish farms (Valle et al. 2006) which is evident from studies assessing the extent of catches made near fish farms (Akyol & Ertosluk 2010). Fisheries targeting wild fish aggregated at salmon farms occurs in the Norwegian coastal ecosystem, although the extent of this interaction has not been quantified (Maurstad et al. 2007). Targeting of farm aggregations of wild fish has been with deployment of gillnets and purse seines close to farms, which capture large quantities of wild fish when they leave the farm or migrate seasonally.

The distinct farm-modified fatty acid profiles of farm-associated fish have been identified from sampling at local fish markets (Fernandez-Jover et al., 2007; Arechavala-Lopez et al., 2010, 2011) and local fishermen along the Norwegian coast have reported salmon pellets in the stomachs of relatively high numbers of saithe that are caught in fjords with intensive fish farming. Generally, farm-associated saithe have much larger livers and are significantly fatter than non-associated fish (Skog et al., 2003, Fernandez-Jover et al. 2011). Previous tag and release studies have shown that farm-associated saithe have later occurred in the catches of commercial fishermen (Bjordal and Skar, 1992).

It has been suggested that the potential of coastal fish farms to act either as ecological traps (Hale and Swearer 2016) or population sources for wild fish populations depends on how the interaction of fishing with fish farms is managed (Dempster et al. 2006, 2009, 2011). An ecological trap occurs when an artificial structure added to natural habitats causes a mismatch between the habitat preference of fish and the value of their fitness consequence (Hallier and Gaertner 2008). Extensive fishing on wild fish populations when they are farm-aggregated and vulnerable result in increased mortality rates that may drive a local decline in fish populations. Farms will continue to attract wild fish into their vicinity where they can be fished, which could drive populations down. Alternatively, if fishing is prohibited from the immediate surrounds of farms and farm-associated diet is of sufficient quantity and nutritional quality for reproductive provisioning, the enhanced condition that wild fish exhibit due to their association with fish farms could translate into enhanced spawning success, a potential that is further augmented by the tendency for farms to attract mainly adult fish i.e. the spawning fraction of the population (Dempster et al. 2002, 2006). Providing spatial protection from fishing may allow fish farms to act as population sources for certain fish stocks.

Fishing restrictions may not need to be extensive spatially to be effective in protecting farm-associated wild fish, because wild fish are typically very tightly aggregated to the underwater farming structures (Dempster et al. 2002, 2010). Several Mediterranean countries prohibit fishing within the farm leasehold area (typically defined by corner marker buoys positioned 50 – 100 m from pens) and, in Norway, fishing is prohibited within 100 m of fish farming structures. This relatively restricted spatial exclusion to fishing has the added advantage of reducing interactions of fishing gear with fish farming gear, which greatly reduces events causing gear damage that may also result in the escape of farmed fish.

Another advantage of restricting fishing in the immediate vicinity of fish farms is that wild fish are able to provide their 'ecosystem service' of consuming waste feed, thereby reducing the severity of any benthic impacts (e.g. Vita et al. 2004). Moreover, recent evidence suggests a further useful ecosystem service whereby the abundant large wild fish predators that aggregate around farms consume a significant proportion of the escapees, thus reducing their potential negative interactions with more remote wild populations (Dempster et al. 2016; Glover et al. 2017).

Spatial protection from fishing will also reduce the probability of harvesting any long lived benthic fish species that may acquire elevated loads of mercury in the vicinity of fish farms from their long association with farm-impacted sediments (e.g. deBruyn et al. 2006). Pelagic wild fish are likely to aggregate at fish farms for shorter periods than the more sedentary benthic species (Uglem et al. 2008, 2009) and, consequently, will not become "locked away" from the regional fishery for extended periods. However, the protection afforded by spatial protection in the immediate surrounds of fish farms is only temporary and would apply only while they were aggregated and more vulnerable at fish farms. Once the wild fish move away from farms, they are once again subject to the standard local fishing pressure.

Because of the various potential benefits referred to in this section, consideration of a no-fishing restriction around farms is generally relevant in the New Zealand situation. Without a fishing exclusion zone, customary, 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. If such fishing is allowed to occur, the benefits discussed above are prevented from occurring.

However, it should be noted that in the case of preventing increased fishing pressure, a benefit is possible for the recreational fishery only. The customary and commercial fisheries are constrained by catch limits, which precludes any catch exceeding levels set by the Ministry of Primary Industries (MPI). By contrast, uncontrolled recreational fishing on farm aggregations has the potential to increase fishing pressure on wild fish stocks because catch per unit effort on farm aggregations is likely to be high. Nevertheless, applying an exclusion zone to all three fisheries ensures that the all potential benefits are maximised, including gains from all fishing for not harvesting the adult spawning fraction which tends to be attracted to farms, as is mentioned above in the context of enhanced spawning success.

Realising these benefits requires the proactive setting of no-fishing zones. Given the relatively shallow water depth of 25–36m across the proposed farm site (Bennett et al., 2019), the mooring lines will be anchored relatively close laterally to the farm pens, so that any benefit of a "natural" restriction area for fishing methods such as trawling would not be great. Also, other netting and line gear could be deployed up to some point within the mooring lines. Of course, it is unknown whether potential risk outweighs possible benefit and limits such operations in cases where restrictions are not set. To some extent the risk is increased by the absence of available information on aggregations in the New Zealand context.

These issues are currently being discussed by NTSR and various commercial fishing organisations/groups and will continue between NTSR and the harbour master and relevant fishing groups, with NTSR seeking agreement to a voluntary 200m buffer around the farm to avoid outcomes such as entanglement with the farm structure.

3.9 Fish Farms and Predatory Fish

Because of the high concentrations of wild and reared fish associated with them, fish farms attract numerous predatory fish species. Sharks are a common cause of pen 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 pens.

The assemblages of small wild fish that become concentrated around fish farms in large numbers 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 pens and may kill or harm large numbers of farmed fish which is a serious problem for farmers in terms of the economic loss and added technical difficulties in the production process. Farms appear to be used as a new and productive feeding habitat by the bluefish. This may be response to reduced trophic resources for these predators from overfishing of stocks of their normal pelagic fish prey. Bluefish are widely distributed, so further development of marine net pen farms in coastal and offshore areas will most likely result in increased levels of interaction between fish farms and bluefish populations.

Although such attention is given to the interaction of predators with aquaculture, there seems to be little evidence of positive or negative interactions of aggregations of predatory fish with local fishermen. The result of higher concentrations of predatory fish, such as bluefish, in coastal waters where fisheries operate could be economic distress for fishers (Bearzi, 2002). However, there have been few studies where coastal aquaculture has developed that have addressed conflict between fishers and predators.

4. 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 E) in terms of five questions. Policy 11 deals with indigenous biological diversity. The five questions refer to the Foveaux Strait area with the aim of providing a summary for the north eastern Stewart Island/Rakiura farm site proposed by Ngai Tahu Seafood Ltd. The questions are as follows:

1. Are there any indigenous[16] 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 indigenous species are being considered, so the criteria for inclusion in any list is that species are naturally occurring and distributed within Foveaux Strait where the proposed site is situated.

---

[16] Naturally occurring, not necessarily endemic.

4.1 Indigenous fish species listed as threatened or at risk[17]

4.1.1 Background

A working list of relevant New Zealand fish species was compiled using selections from the threatened and at risk lists and the IUCN red list. Included in this compilation were marine finfish species and diadromous[18] species from the freshwater lists.

At the time of writing this text (October 2020), the threatened and at risk lists for both chondrichthyans and freshwater fish had been recently updated by Duffy et al., (2018) and Dunn et al., (2018) respectively, but marine fish had not been updated since 2005 and no document was currently available. 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 E. 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 replaced mostly by a single new category, 'Declining'.
- 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. Both are indigenous so are included in the final list.

Three species in the current NZTCS freshwater fish threatened and at risk lists met the criteria of endemic, diadromous, and (probably) distributed within Foveaux Strait. These were shortjaw kokopu (*Galaxias postvectis*) in the Threatened-Nationally vulnerable list, and longfin eel (*Anguilla dieffenbachii*) and giant kokopu (*Galaxias argenteus*) in the At risk-Declining list.

There is a little uncertainty about the Gollum galaxias (*Galaxias gollumoides*) in that Roberts et al., (2015), describe its life cycle as unknown, therefore leaving its status with regards being diadromous as indeterminate. However, these authors also describe this species as non-migratory, which suggests they are non-diadromous, so it is not included in the final list.

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 Foveaux Strait as well as other areas, such as around Fiordland and Stewart Island/Rakiura, the Marlborough Sounds 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". NABIS distributions indicate a hotspot for the annual distribution of rough skate in

---

[17] Common and scientific names used here are consistent with those used by IUCN and Roberts et al (2015).

[18] 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).

Foveaux Strait and elephant fish in Te WaeWae Bay on the northern edge of Foveaux Strait; Te WaeWae Bay is marked as a spawning ground for elephant fish, but there is no information on the spawning of rough skate.

4.1.2 List of marine and diadromous species meeting the Policy 11 criteria for the Foveaux Strait Area

The five species included in this section meet the NZTCS Policy 11 criteria for protection under clauses (a)(i) and (a)(ii) (see Appendix E). They are all endemic and diadromous, and, according to the best available information, are found within the area of Foveaux Strait.

Basking shark (*Cetorhinus maximus*)
An indigenous species, the only member of Family Cetorhinidae, and the world's second largest fish after the whale shark. Occurs throughout the waters of New Zealand; most common between 39°S and 51°S (Roberts et al., 2015). This includes Foveaux Strait, and although no museum specimens have been taken there, including the verified observation category, this species has recently been re-assessed with a worse conservation status based on catch and effort data and an absence of reported surface aggregations in coastal hotspots since the 1990s (Duffy et al., 2018).

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. Evidence of its presence in the Foveaux Strait area is from two museum voucher collections from Stewart Island/Rakiura and one east of Waipapa Pt. (Roberts et al., 2015). 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. This species spawns in autumn or early winter; "when the young hatch they must be washed out to sea" (McDowall 1978).

Great white shark/white pointer (*Carcharodon carcharias*)
In New Zealand this species occurs from the Kermadec Islands to Campbell Island/Motu Ihupuku; it is well known from Foveaux Strait with a local population there. This species has been fully protected from New Zealand vessels fishing on the High Seas and from all fishing in New Zealand waters since 2007. Its recent heightened conservation status is based on new information on population structure and estimated population size (Duffy et al., 2018, citing: Blower et al. 2012; Duffy et al. 2012; Bruce et al. 2018; Hillary et al. 2018).

Longfin eel (*Anguilla dieffenbachii*)
An endemic, diadromous (catadromous) species widespread throughout New Zealand in freshwater, except above swift rapids and waterfalls. Evidence of its presence in the Foveaux Strait area is from two museum voucher collections from Stewart Island/Rakiura (Roberts et al., 2015) (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. 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.

Shortjaw kokopu (*Galaxias postvectis*)
An endemic, diadromous (anadromous) species distributed throughout the North and South Islands. Evidence of its presence in the Foveaux Strait area is from one museum non-voucher record from western Te Waewae Bay (Roberts et al., 2015). 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"..

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 five species fit the criteria of indigenous to New Zealand and distributed within the Foveaux Strait area. This includes three species normally referred to as being freshwater.

All three of these freshwater species spend their larval stages in the marine environment, although the longfin eel differs from the others in that it is catadromous so that adults first migrate to a marine spawning ground before spawning and dying. The marine phase of the galaxiid species is poorly known. Generally, these species appear to return to freshwater at roughly the same time, the earliest being the longfin eel in August and the latest the giant kokopu towards the end of the whitebait run in spring–late spring.

The two shark species included here are indigenous, but follow much more extensive distributions beyond New Zealand. Apparent reductions in numbers and sightings have led to their both being reassessed with a heightened conservation status in 2018.

4.1.3 Implications

Freshwater species
The three freshwater species of interest are diadromous with the larval stage of each occurring within the marine environment, but little information is available for their marine phases, except for the longfin eel. Both the shortjawed and giant kokopu are whitebait species (McDowall, 1978). The evidence for these species distribution within the Foveaux Strait area is quite specifically localised according to the distributions from museum records, so it is not clear how widespread within the freshwater bodies of the area these species are distributed. This section assumes that the three species will inhabit the three rivers and streams local to the proposed site that are described below, although the catchment of this area appears quite limited compared with other parts of Stewart Island/Rakiura.

Migrations during the marine phases of these species comprise an outward migration, from freshwater into the sea and beyond, and a returning migration, from the sea into freshwater. Although it is unknown how far the migrations of the two larval galaxiidae take them, it is assumed that it is well beyond the coast given the inter-continental scale gene flow shown for the closely related, *Galaxias maculatus* (Waters et al., 2000). For the longfin eel, it is well known that this species undertakes the entire, extended journey to the breeding ground (see discussion in McDowall, 1978), 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 galaxiidae could be vulnerable because of their size and distribution within the water column.

The inward migrations of these species begins in August with the arrival of longfin eel glass eels. Metamorphosis from leptocephalus to the glass eel occurs with the depth change when the larvae reach the continental shelf, followed by continued migration until the glass eel enters the freshwater habitat, mainly at night, and moves up rivers and streams (McDowall, 1978; Jellyman 1987). Pigmentation occurs as the glass eel enters freshwater.

In considering the possible vulnerability of glass eels to a salmon farm at the proposed site, it would seem that any type of schooling behaviour close to the farm site might increase vulnerability by concentrating the glass eels. Glass eels have been known to migrate up rivers and streams in large numbers and mixed in shoals with whitebait (Graham 1956), but it seems that they do not form schools of any sort before invading a stream or river. Jellyman (1977) offers the following:

> 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.

Because of the reference to Deelder (1958), who worked 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 and through areas similar to the proposed site, their distribution is as singular individuals. This suggests a vulnerability to any pens installed at the proposed site would be relatively low.

Finfish schooling behaviour has been known for some time particularly in the context of foraging and as an anti-predator strategy (e.g., Pitcher 1993, Magguran 1990). Recent renewed interest in the energetic benefits that fish gain from swimming in schools (e.g., Hemelrijk et al 2015, Killen et al 2011) may provide a useful explanation in the present context. The clear change in behaviour 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 returning galaxiid juveniles is almost non-existent, apart from their size of about 45–55 mm at this time. Schooling behaviour is a well-known characteristic of the Five galaxiid species that contribute to the whitebait fishery (Charteris & Ritchie 2002). Although there does not appear to be a published description of the transition from marine to freshwater habitat as there is for the eel life history stages, 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 to some degree supported by the well-known fact that the whitebait fishery occurs within freshwater, not saltwater, where 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 of returning juvenile giant kokopu and shortjaw kokopu to any pens installed at the proposed site is low, for the same reason as that given for the returning glass eel.

Several streams and rivers drain into Foveaux Strait within the vicinity of the Hananui site. Although not exhaustive, this includes (from north to south) Mt Anglem Tarn River (drains a little north of Christmas Village Bay), Christmas Village River (drains into Christmas Village Bay about midway Saddle Point and Garden Point), Murray River (drains to Murray Beach, immediately south of the Garden Point headland) and Maori River (drains to Little Bungaree Beach). These named water bodies were included in an island-wide study of freshwater community ecology on Stewart Island/Rakiura by Chadderton (1990).

In his sampling, Chadderton (1990) used an *abundant* > *common* > *occasional* > *rare* scale, where *rare* = 1-2 fish/100 m, *occasional* = 3-5 fish/100 m, *common* = 6-10 fish/100 m, and *abundant* = 11+ fish/100 m. His results showed that, of the water bodies listed above, longfin eel was present in the Mt Anglem Tarn, Murray and Maori Rivers, at a rate of *occasional*; giant kokopu was present in Maori River only, at a rate of *occasional*. By contrast, giant kokopu was *abundant* in the Rakeahua River, which drains into the Southwest Arm of Paterson Inlet from the mid-western region of the island, and *rare* or *occasional* in the other two water bodies it inhabited, thus totalling 4; longfin eel was measured as *occasional* in the 7 water bodies it inhabited, including the Rakeahua River.

Shark species

Although its local distribution is believed to be New Zealand wide, there appears to be no evidence of basking shark species occurring in the vicinity of Hananui site; neither of the shark reports prepared for Hananui application (Francis 2019; Lyon, 2020) include this species in their discussions with regards potential interactions between sharks and the proposed Hananui farm.

Great white sharks and their potential interaction with the proposed farm are discussed in detail within the shark reports (Francis 2019; Lyon, 2020); the reader is directed to them for further information.

4.1.4 Conclusions

Available information suggests that, of the galaxiid species of interest only the giant kokopu is present in streams and rivers in the vicinity of the Hananui site and only from the waters of Maori River. The early life history stages of galaxiid species are mostly characterised by a dispersed distribution during their marine phase. Little is known of their behaviour during their marine phase, such as whether they are adapted to moving in the same direction as local currents, although, given their size, it is a reasonable conclusion to make. Considering that residual tidal flow in the area of the proposed site is from southeast to northwest (see Figure 2) and the fact that the Maori River drains into Foveaux Strait at the southern extreme of the Hananui site (Figure 7), it seems possible that fish entering the marine phase may be transported towards the Hananui pens by the residual flow under a falling tide, although the probable dispersed nature of the migration suggests that their vulnerability to the proposed farm pens is likely to be low. It is also seems that, because of the swimming strength of outgoing adult eels and the probable dispersed nature of returning glass eels that the vulnerability of both to the pens is likely to be low.

4.2 Habitats for species at the limit of their range

An interesting feature of the species listed in Table 1 is the inconsistencies in presence/absence discussed in §2.2.10. In addition to the species discussed there are snapper, red moki and yellowtail kingfish, which, according to Andrew Stewart (Museum of NZ, Te Papa, pers. comm.) are at the limit of their range in Foveaux Strait because they prefer warmer temperatures further north. Consequently their presence has usually been noted at the height of summer and has been ephemeral because they have not established permanent populations, but this appears to be changing, with their ‘season of occupation’ becoming extended with increasing temperatures under climate change conditions. Whether they become established in Foveaux Strait will be interesting to observe.

4.3 Nationally significant fish communities

A community is a group of species that are identifiable by both their taxonomic characterisation and their ecological role, which is defined by the resources they utilise and the habitat they occupy. With regards finfish communities in the Foveaux Strait 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.

One aim of the work presented here has been to construct an inventory of fish species that might interact with the NTSR farm at the proposed site. There has been little published information available on which to base this work. Essentially, the approach has been limited to accessing several sources that can contribute to this inventory and, 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.

No information additional to that summarised in §2 of this report has been identified for the pelagic and demersal (including rocky reef) fish communities in the area of interest.

4.4 Habitats of importance during vulnerable life history stages

According to the NABIS data, elephant fish and rough skate have hot spot annual distributions in the Foveaux Strait area, although for elephant fish this is mainly within Te Waewae Bay, with some

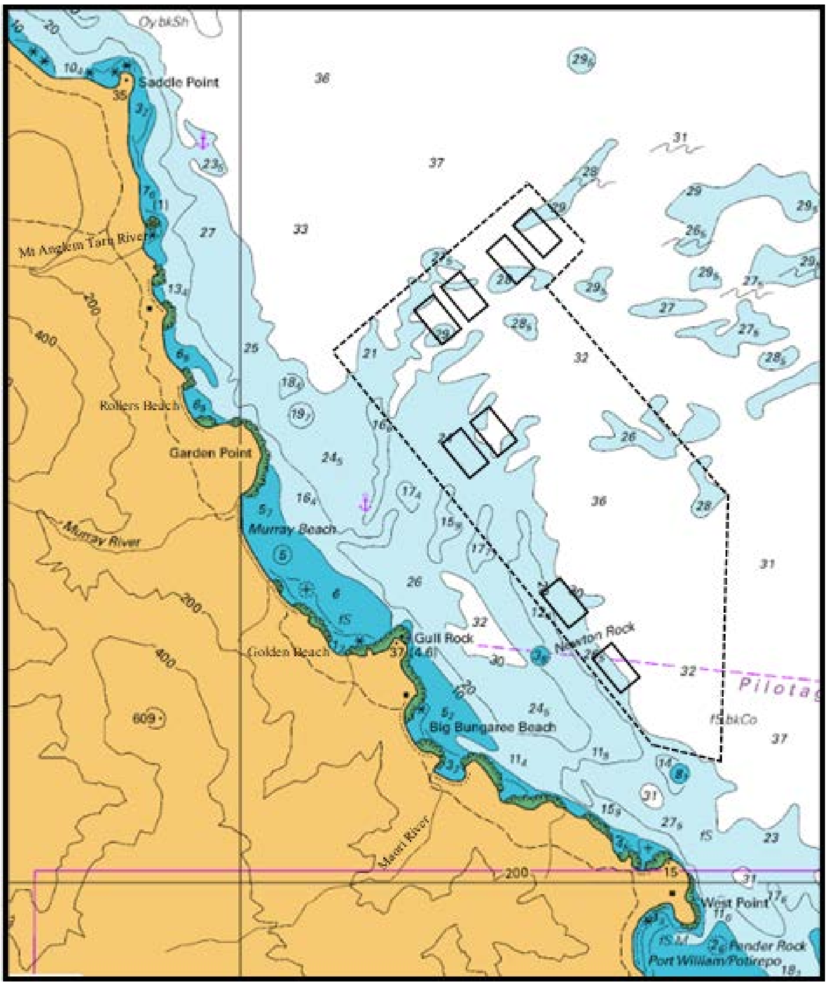


Figure 7: Approximate positions and sizes of proposed 8 block layout (solid black rectangles; each to contain 10 pens) at the proposed Hananui farm site (dotted black outline), relative to local rivers and streams. Source: the polygon was drawn on a tiff version of the LINZ Marine Chart, Approaches to Bluff and Riverton/Aparima, NZ300681, from https://www.linz.govt.nz/sea/charts/nz-chart-catalogue-list-view?page=1**.**

extension into the strait. The hotspot for rough skate is part of extensive area stretching down the east coast from Port Robinson north of Banks Peninsula, throughout Foveaux Strait and further south.

Lyon et al., (2011) refer to three spawning areas for elephant fish: “Their major coastal spawning sites in New Zealand include Pegasus Bay, Canterbury Bight and Te Waewae Bay in the South Island” although the NABIS dataset extends the area to Bluff. There is no record of spawning grounds in NABIS for rough skate and Roberts et al., (2015) warn that the species is poorly studied and that, because distinction from smooth skate (*Dipturus innominatus)* was not appreciated at the time, many earlier accounts of rough skate are unreliable.

These species 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 roughskate (*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.

Consequently the area in Te Waewae Bay and probably through to Bluff is a habitat of importance for elephant fish, which is well beyond the influence of the proposed farm. Whether a similar area exists anywhere within the Foveaux Strait area for either rough or smooth skate is unknown, but the hotspot for the annual adult distribution prompts the need for investigation.

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

4.5.1 Overview

Puth & Wilson (2001) review 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". Patches represent concentrations of energy and materials within a broader matrix that are seldom homogeneously distributed across a landscape. The authors stress that the traditional definition should be recognised as a special case of the more general concept that focuses on movement rather than form.

These authors treat ecological boundaries similarly, referring to the historical approach of recognising them "more for their structural distinction on the landscape than for their role in landscape function" and defining boundary "as an area of sharp gradients in ecological flows that slows or redirects flows of organisms, matter, or energy between patches". They assert 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) consider boundaries and corridors to be entities linked by their strong influence on ecological flows, not separate landscape components as they have usually been considered. Instead they denote the opposite ends of a sequence of flow regulation, each affecting rates and direction of flow differently. Boundaries can alter direction of flow by reflecting, stopping, or "shuttling[19]"; with corridors allowing unlimited movement across boundaries and potentially increasing flow rates.

Because the terrestrial environment is the main source of human experience, we mostly adopt the concepts known from this experience when considering processes within the aquatic environment, which is not necessarily the best approach. Bakun (2012), for example, observed that the most important dynamic constraint in the lives of terrestrial organisms is gravity, which affects all active movements and provides a certain system of dominance/refuge in predator/prey relationships. Thus, prey avoids predators by climbing away, and some predators, such as birds of prey, can maintain a dominant position above prey. A second constraint is caused by structural requirements, such that, with increasing structural mass weight increases, which generally results in reduced speed and agility. While this model represents behaviours within the terrestrial environment it does not effectively represent the aquatic environment. This is particularly true of marine habitats where Bakun (2012) describes organisms as most often being almost neutrally buoyant, resulting in the law of gravity being replaced by those of hydrodynamics in effecting constraints on behaviour: frictional drag takes over from gravitational pull as the main force opposing active movement.

Instead, marine organisms adopt strategies that reduce this frictional drag to achieve a positive energy balance and some take advantage of the benefits offered by large size. 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", and cites Lighthill (1977) and Wardle & Reid (1977), whose

---

[19] 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).

work on the swimming mechanics of fishes, has shown that a high degree of tuning is evident in the effective reduction of the energy required for swimming. He also refers to the available information on fish migration routes and work on the pink salmon (*Oncorhynchus gorbuscha*) by Royce et al (1968), skipjack tuna (*Katsuwonas pelamis*) by Seckel (1972), and plaice and Atlantic cod by Harden Jones (1977), concluding that ocean currents are utilised rather than opposed by migrating fish, even when the fishes' velocity is considerably higher than that of the current.

Bakun (2012) further summarised the study by Harden Jones (1977), describing how these finfish species can adjust their depth relative to the tidal cycle, to access oscillating tidal currents and achieve a positive energy balance during migratory swimming. The study highlights the complexity of the aquatic environment in a structural sense, and how the adjustment of depth to gain advantage is a strategy commonly utilised by several different life history stages. In this case, adult Atlantic cod and plaice utilise depth adjustment to access environmental corridors represented by tidal currents.

Bakun (2012) also discusses depth adjustment by larval fish, in which they maintain their position within a boundary-delineated zone related to a shelf-sea front. He cites Iles and Sinclair (1982) whose work describes herring larvae within such a zone that maintain their position where water movement is on-shore either near the ocean surface or near the bottom, (contrasted with midwater depths that are characterised by flow in the opposite direction). Using this strategy they avoid being carried offshore and could take advantage of the high concentration of preferred forage items such as crustacean nauplii in the pycnocline[20] region associated with the front. Bakun (2012) further supports this suggestion, referencing the results of Buckley & Lough (1987), who describe such a region of the Georges Bank where haddock larvae are more numerous and faster growing compared with other zones of that shelf complex.

Perhaps the most obvious areas where ecological boundaries operate are zones that exist at the surface thus providing a system that inhibits oceanic flow. For example, Bakun (2012) discusses aspects of the Southern Californian Bight where eggs and larvae are probably retained by the gyral geostrophic circulation pattern dominant there for most of the year. Because the area is from local strong coastal winds, a very low level of turbulent mixing occurs that produces a layer of concentrated food particles (Lasker 1978), and the productivity is sustained at 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) refers to the work of Parrish et al (1981) and their descriptions of the probable long-distance spawning migrations into this area of species such as the Pacific sardine (*Sardinops sagax*), hake (*Merluccius productus*), and blue mackerel (*Scomber japonicus*).

From these various publications it is clear that the corridor-boundary continuum of Puth & Wilson (2001) is applicable to marine finfish species. But, it is not necessarily immediately clear what constitutes a boundary or corridor. For example, Brill and Lutcavage (2001) discuss the effects of the physical environment on the behaviour of highly migratory tunas (family Scombridae) and billfishes (families Istiophoridae and Xiphiidae), observing 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 inhabit, suggesting that sea surface temperature gradients are not alone in influencing their horizontal movements or aggregation patterns. These authors point out that empirical information from observations of the behaviours of tuna and billfish are required, using acoustic telemetry or electronic data-recording tags. Models of the relationship between behaviour and physical environment can then be based on this empirical data, used in combination with information on the fishes' physiological tolerances to environmental extremes, distributions of forage abundance, and relevant oceanographic data.

Clearly, fish movements are not only related to spawning migrations. A distinction was made by Green et al (2015) between the following three types of movement by adult and juvenile coral reef and coastal pelagic fish species: home ranges, spawning migrations and ontogenetic shifts in habitat. Though

---

[20] A zone where water density increases with depth.

broadly similar in their function, these movements will not necessarily be displayed in the same way by all individuals of a species' population at a given time. For example, Afonso et al (2009) followed 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 their daily movements differed: where those 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 just the summits of the reefs.

Afonso et al (2009) also used passive telemetry to show that the 'offshore' trevally will relinquish this seasonal attachment to the reef and replace it with periods of migratory behaviour, when, in relatively short periods of only hours to just a few days, they can move between areas and habitat types separated by tens of kilometres. These results show that the home ranges of trevally in this environment varied substantially, and that this occurred not only as a within-season difference between individuals from the two groups (coastal and offshore) within the population, but also for individuals from a particular group between seasons during the course of a year.

The issue of fish movements and how they relate to the boundary-corridor structure is complex, obscure, and varies both within and between species in a variety of ways, although there are certain aspects that are generally observable in most species. However, the summary presented here is only a very restricted glimpse, not only of what actually exists in the wild, but also of what is known.

4.5.2 Relevance

The relevance of this information to the Foveaux Strait situation can be seen if we consider certain aspects of the pelagic habitat with reference to finfish species of interest described in §4.1.3 under "*The inward migration of these species*". This discussion of the shortfin eel along with the giant and shortjaw kokopu, provide examples of how the corridor-barrier continuum might apply to the larvae of three fish species. The question is whether installation of farm structures is likely to interfere negatively with the natural form of the continuum and interrupt the passage of these species.

What we do not have is any knowledge of what is actually happening with the fish in the area of interest. We can use information from elsewhere to speculate about their behaviour, 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 §4.1, it seems unlikely that the nett effect on the finfish fauna of farms at sites similar to that proposed in northeastern Stewart Island/Rakiura through impacts on movement corridors and other components of the corridor-barrier continuum could be anything but low.

However, this conclusion is more an hypothesis that requires testing. It is in the best interests of our environment and marine finfish resource that such ecological issues related to wild finfish species are investigated. Non-commercial, marine fish species-related issues are almost always overlooked in the allocation of research funding, irrespective of their ecological importance. For example, the importance of pilchard[21] and other small pelagic species that have been shown globally to occupy key positions in energy flow through inshore food webs (see §2.3) are ignored. A method designed to examine the impact of farms on the species influenced by salmon farms is briefly described in §6.

5. IMPLICATIONS FOR A FISH FARM IN FOVEAUX STRAIT

This section is a brief discussion of the implications for the proposed Hananui farm of the various categories of information presented in the sections above.

---

[21] 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.

5.1 The Pelagic Habitat

Information from several studies provides us with some insight into the wild fish habitat at the proposed site. Nutrient advection into Foveaux Strait is highly variable, both spatially and temporally, resulting in a common conclusion of high variability in productivity by researchers. Currents along the main northwest-southeast axis are strong, as is the net north-westerly inflow into the south-eastern entrance in the vicinity of the proposed site, indicating the probable development of an extensive farm footprint and therefore the operation of a relatively wide-ranging finfish attraction throughout the strait.

5.2 Finfish Distributions in the Area

A comparison of data from the various sources in Table 1 suggests some contradictions in the presence of certain finfish species, the cause of which is unknown, but it is suggested here that it may be the result of the high spatio-temporal variation in productivity within Foveaux Strait. 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. The observational data from existing farms provides a list of known colonisers and, although these are from farms within the Sounds, it is reasonable to expect that, where those species inhabit Foveaux Strait, they will be attracted to pens at the proposed site. In other cases, species with similar ecological requirements might be expected as colonisers, either in addition to those resident in Foveaux Strait, or in replacement for those identified in the Sounds but absent from Foveaux Strait.

Data from existing farms in the Marlborough Sounds indicate very high observations of seasonally moderated numbers of the baitfish species, yellow-eyed mullet, pilchard, anchovy, and jack mackerel. Although observed in much lower numbers, the larger, predatory yellowtail kingfish was also described as a frequent visitor to existing farms in Marlborough Sounds. Information summarised in Table 1 above suggests the absence of pilchard and anchovy from Foveaux Strait and the presence of yellow-eyed mullet, jack mackerel and yellowtail kingfish, particularly from commercial catch data in all cases, although there is no separation of jack mackerel into the three species inhabiting NZ waters. The NABIS data also indicates the presence of sprat and garfish/piper in Foveaux Strait, which can be considered analogues of the pilchard and anchovy.

As was discussed in §3.2.1, the most common families observed in Mediterranean studies were Clupeidae, Sparidae, Mugilidae, and Carangidae, which included several pelagic planktivorous fish species. Pilchard and sprat are the clupeids in Table 1 and pilchard is absent from Foveaux Strait; snapper is the only sparid, with an occasional appearance in the commercial catch; Mugilidae are absent from Table 1; and Carangidae are the best represented from this group by the jack mackerels and trevally, with large catches of jack mackerel reported from the commercial catch (Table C1) and trevally reported less than occasionally.

Based on this information we would expect the presence of yellow-eyed mullet and yellowtail kingfish at the Hananui farm. Although apparently present in Foveaux Strait in large numbers, jack mackerel is somewhat uncertain because there is no specification of species, either from the Marlborough Sounds observations or the Foveaux Strait commercial data. However, its Carangidae designation suggests the likelihood of any of the three component species appearing in farm aggregations, although making such a link is considerably more tenuous. The same applies to the carangid trevally and to snapper because of its Sparidae designation, although the link is stronger in this case because snapper was considered a cryptic species in the Marlborough Sounds observations (Taylor & Dempster, 2018). As analogues of pilchard/anchovy, the presence of sprat and garfish/piper at the Hananui farm is also possible.

5.3 Implications for Customary, Recreational, and Commercial fisheries

Ten years (2011−20) of commercial catch and recreational data were received from Fisheries NZ for stat area 025, Foveaux Strait (Figure 8). The commercial data can effectively be considered two grades:

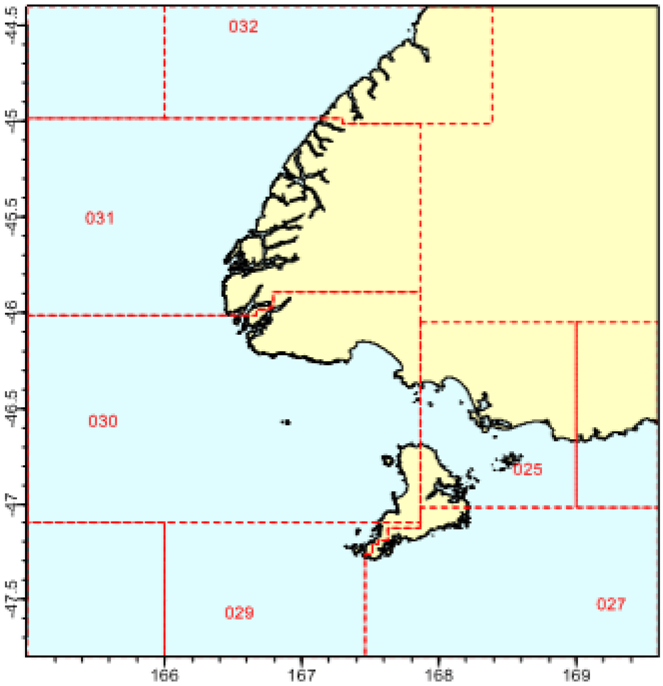


Figure 8: Statistical areas in southern New Zealand.

grade 1 is the data with accompanying catch weights; grade 2 is the data where 3 or less permit holders have recorded the catch of certain species. This latter category does not include catch weights and often persists for only a few years, suggesting that, for at least some records, their reliability may not be high. Because there is no accompanying catch weight, the extent of the data cannot be examined. For this reason, species within this category for which there were less than three years of data were not transferred from Appendix C to Table 1, unless there was other supporting information.

An examination of commercial fisheries catches over the 10 year period 2011 to 2020 (inclusive) in the area of the proposed site (Table 1, column E) showed that the majority of catch is of benthic species, which probably is mostly a reflection of the particular fishing method used in the area of interest. In the "grade 1" data only 5 pelagic species were apparent in catches — barracouta, jack mackerel (unspecified species), john dory, common warehou and kingfish (the latter supposedly being yellowtail kingfish because the alternative possibility, southern kingfish/*Rexea solandri*, is usually referred to as gemfish in commercial fishing records). This number is raised to 12 if "grade 2" data are included, but some of these records are for <5 years; 2 are for <3.

It would seem then, that 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. For the "grade 1" data, a total of 8 reef/rocky bottom species (banded wrasse *Notolabrus fucicola*; blue moki, butterfish, conger eel, leather jacket, scarlet wrasse, *Pseudolabrus miles*; sea perch and trumpeter), 8 benthic species (gurnard, hapuka-bass, blue cod, giant stargazer, *Kathetostoma giganteum*; ling, *Genypterus blacodes*; red cod; tarakihi) and 3 non-shark elasmobranchs (elephant fish, rough skate, smooth skate,) were represented in commercial catches totalling 19 species in all; a further 13 species are added as the "grade 2" data.

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. The only bentho-pelagic species recorded in the commercial data is blue warehou.

Greatest representation in the recreational catches are also of benthic species. No pelagic species were recorded. A total of 4 reef/rocky bottom species (blue moki, butterfish, sea perch, and trumpeter) and 4 benthic species (hapuka-bass, blue cod and bluenose *Hyperoglyphe antartica*) were recorded in the data. Consequently, the situation is similar to the commercially fished species, that species most likely to be affected are those from the benthic group which exist mainly on a diet of benthic organisms.

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 for which most species are the same.

5.4 Effects of Farms

It is clear from the information compiled here that interactions occur between wild pelagic finfish species and New Zealand salmon farms. Such species are undoubtedly attracted to farms, frequently in such numbers that higher densities occur there than in unfarmed areas. Attraction is caused by a number of factors, including light, sound, at least two sources of food (i.e., other fish and feed pellets), and protection from predators provided by the farm structure.

Discussion here of international research results indicates that the potential for farms to act as ecological traps on wild finfish species is of concern. This action relies on the continued attraction of the farm for fish that select the farm for its easily accessible benefits, but instead of being provided the resources they require to maximise their biological fitness, the feed composition is of lower quality than their natural diet so that increased body condition from consuming feed pellets actually reduces their reproductive fitness. At present, no direct evidence suggests that this is the case.

The alternative outcome occurs when artificial feed is of equal or higher quality than the natural diet. In this case condition is added that increases the reproductive fitness of wild fish, and evidence from numerous overseas studies suggests that there is a significant increase in the condition of wild fish resident around farms. Nevertheless, an ecological trap may continue to operate. If the harvest rate of fish from around the farm exceeds the maximum mortality in areas where there is no artificial aggregation and the farm continues to attract fish, local depletions could result if harvesting continues over a medium to long time frame.

As is discussed above (§3.8), the alternative to the ecological trap is the population source. In this case, any reproductive benefit gained from being resident close to a farm increases the reproductive success of the fish. This result is often what is expected from marine protected areas: the uninterrupted reproduction beyond any anthropogenic activity is aimed at increasing reproductive success. Greater access to feed for fish residents near a fish farm provides additional benefit in the form of increased reproductive fitness. With prevention of harvesting there is an addition to the overall biomass for the species that are present resulting from these reproductive gains.

However, increased condition is not the only possible outcome of consuming artificial feed. As is discussed above, an important second effect concerns the various contaminants of wild fish with the implication of possible impacts on human health. A number of potentially dangerous chemical species are introduced to the pelagic food web through this contamination, and the danger often does not become visible until the level is high enough to threaten human health. Although some organohalogenated contaminants and mercury have been detected as slightly elevated in the tissues of wild fish residing near salmon farms in comparison with other fish, they have never exceeded the levels considered safe for human consumption.

As was stated above, such levels are also an unlikely result for farms in the Foveaux Strait area under present conditions, but the long term effects through the function of bioaccumulation are seldom considered. To ensure there is no development of such effects, monitoring of key contaminants should be standard practice in the interest of public health, particularly in long-lived, bentho-pelagic and pelagic fish species that are of recreational, commercial or customary fishing interest residing in the near vicinity of salmon farms. Such monitoring depends first upon such species being identified as occurring in the near vicinity of the salmon farms, and frequency of monitoring would be determined based on the status of the benthic conditions beneath farms, as biological availability of certain heavy metals increases in anoxic sediments. Monitoring should include comparisons to relevant control locations.

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. Summaries from the international literature describe feed wastage from the pens in the order of 1 to 5%. Determining the effects of farms on wild fish in New Zealand cannot be reached without independent data on measurement of feed fallout from local 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. We also recommend development of a standardised method to carry out this monitoring (see §6.2).

6. DEVELOPING METHODS FOR MONITORING ASPECTS OF THE IMPACT OF FARM DEPLOYMENT ON WILD FISH SPECIES

6.1 Background

This section is included to provide information on the sampling required to monitor the effect of farm installation on local wild fish species. It is widely agreed that organic discharge from an established farm, particularly lost feed, has the greatest impact on wild fish species. Development of methods that provide reliable data for monitoring this impact is fundamental for minimising its effect, with regards outcomes related to environmental wellbeing, public health, and operational costs of the farm itself.

As has been discussed above, the coastal sea-pens can impact wild fish in at least two ways: highly mobile pelagic species will be attracted to the structures as they are to most floating objects, with apparent reinforcement from other factors such as the continual dispensing of artificial food and chemical attraction from farmed fish, whereas the impact on benthic species is perhaps a little more direct with the potential effect being more from farm discharge as it is deposited on the seafloor and alters the composition of the local sediments.

A key summary on the ecological effects of aquaculture by MPI states that "*Aquaculture planning must be supported and underpinned by science-based information on ecological effects*" (Ministry of Primary Industries 2015), but to date there is no method available in New Zealand to provide reliable science-based information for estimating volumes of lost feed, monitoring contamination levels in wild fish, or determining species most affected by the farms. To ensure consistency between farms and aquacultural companies there is the need to develop standard methods to perform these tasks. Development of the methodology and apparatus should be undertaken and formalised within a wild fish best management practice document (BMP) for salmon farm operators by an appropriate independent agent, such as the Principal Scientist for Aquaculture within the Aquatic Environment Science team at Fisheries NZ.

6.2 Waste Feed

Discussion in §3 above indicates that overseas estimates of feed loss from salmon farms ranges from 1% to 5%. Alver et al., (2016) estimated that feed represents about 50% of the total production cost of Atlantic salmon in Norway, based on data from the Norwegian Directorate of Fisheries, and feed is also the primary driver of fish growth. Therefore minimising the amount of wasted feed while maximising the feed intake of the farmed fish is one of the key challenges in the Norwegian salmon industry. Such undoubtedly also applies to salmon pen farming in New Zealand and minimising feed loss has the obvious additional effect of reducing the farm effect on the local wild fish population.

The most common method of minimising wasted feed, is to use underwater cameras to visually monitor the fish and feed (Alver et al., 2016). Feed pellet release can be controlled by slowing and/or stopping flow according to either behavioural clues from the fish that indicate reduced appetite or the appearance of uneaten pellets sinking towards the bottom of the pen, with efficiency relying on the operator's ability to interpret these signs and respond as required. However, the use of automated feeding machines can lead to excessive or insufficient feeding (Li et al., 2020). In a review of the advantages/disadvantages under experimental conditions of methods used over the last 30 years, Li et al., (2020) discuss the relative benefits of automated methods using computer vision technology and acoustic-based behaviour recognition in land-based farming applications with reference to the image in Figure 9, which is presented here as a general illustration of applications that can also be utilised in the marine environment. As these researchers conclude, computer vision methods are in real-time, non-invasive and economical, but are currently still limited by surface reflection and low image quality, an issue somewhat addressed by replacing standard lighting with near-infrared imaging; acoustic based methods are unaffected by light intensity and turbidity, but it is relatively expensive and is still of low accuracy.

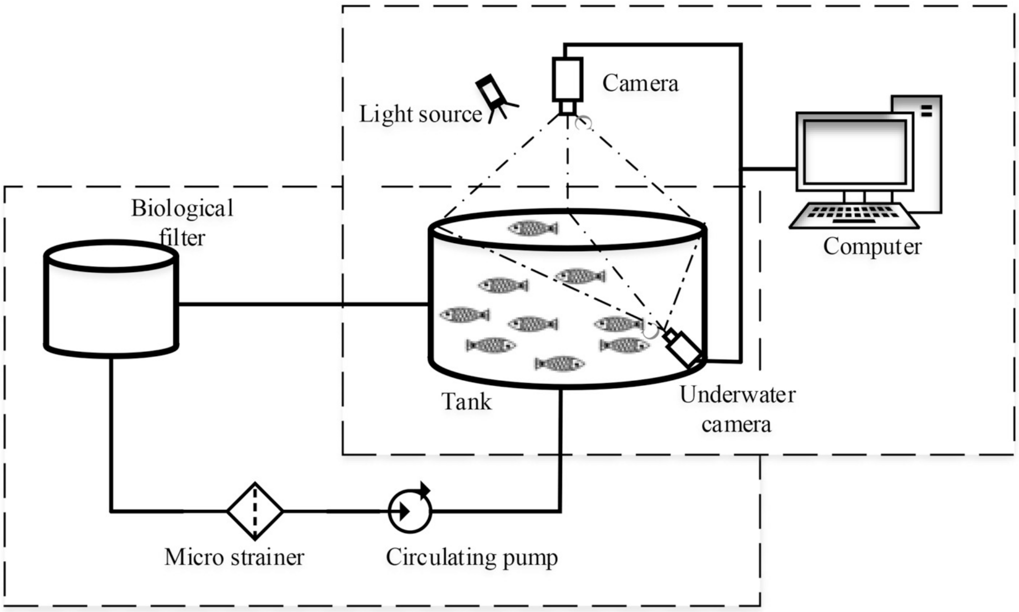


Figure 9: Fish feeding behaviour computer vision recognition system for a land-based tank system. Source: Li et al., (2020).

Clearly these methods have design issues to resolve, although an Australian company has developed a system that is now operational. According to an online article published by Sustainability Matters[22], Huon Aquaculture have "achieved a system that uses artificial intelligence and machine learning to automatically respond to fish behaviour, and can 'learn on the job' ". It is claimed that the pellet detection system is capable of recognising a minimum of two uneaten feed pellets in the water column below the fish, which then allows the dispensing of feed to be automatically slowed or shut off.

However, this system is company-specific and there does not seem to be any immediate intention to make it commercially available. Because of the range of approaches to feeding used in the industry and the uncertainty related to the control of waste feed levels, a monitoring method is needed now in New Zealand to quantify feed loss in a standardised manner within the salmon farm industry. To achieve this there needs to be development of a method and an apparatus with the following features.

---

[22] https://www.sustainabilitymatters.net.au/content/wastewater/article/ai-breakthrough-in-tassie-salmon-farming-1176096463

- Is portable and can be deployed at different farms.
- Is used independently of the farm feed operator.
- Can provide data from sampling over extended periods of up to two weeks.
- Can be used under different conditions e.g., during different seasons.

Such could then be used to produce standardised feed loss reports that would be consistent between farms and operators. It is therefore recommended that development of such a method and apparatus be referred to the appropriate agent with urgency to ensure its availability for use at the earliest possible advent during the establishment of new farming locations to allow standardised monitoring of feed loss levels and their variations as these new farms develop. This recommendation extends also to the development of the methods discussed below for determining and monitoring impacts on wild fish. All would be contained within the BMP referred to above (§6.1).

Urgency is required because of the protracted time expected for development of the BMP. It is expected that availability of an agreed BMP is unlikely to coincide with the beginning of farm operations. To ensure that feed waste is maintained within minimum levels, a feeding study could be undertaken during the initial period of operation leading up to BMP availability, although such would not be within the bounds of a standardised method. Details could be presented within a wild fish management plan.

6.3 Impact on Wild Fish

Deployment of farm pens followed by populating with salmon stock provides an opportunity to collect data on the effect of the farm on wild fish species. An understanding of how the finfish population responds to the farm installation can form 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 an impact study when seeking to establish farms elsewhere in the future.

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 are related in that they utilise approaches with similar underlying designs, and they 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. One example is the transect approach that was modified by Dempster et al. (2005) from that used in previous studies, who then used “stationary timed counts” for investigating vertical variability of wild fish assemblages around sea-pen fish farms.

The main objective of the type of study suggested here would be development of a methodology for carrying out an ecological impact study based on overseas studies and well-documented, well-established sampling and statistical procedures published elsewhere (e.g., Green, 1979; Steel & Torrie, 1981; Hurlbert, 1984; Kingsford & Battershill, 1998). The impact study itself would aim to determine whether the deployment of sea pens at farm sites similar to that proposed by NTSR has an effect on wild finfish, which species are affected, and whether this effect is influenced seasonally. Monitoring of tissue contamination levels could also be incorporated into the methodology.

6.3.1 Abundance, Biomass and Species Composition

Because of the clear difference in impact on the benthic and pelagic components of the wild fish population, any method designed to examine the impact of farm installation requires an approach that collects data from both of these groups. A key difference between the two is that the impact of farm installation on the benthic group will be as a population existing within the farm site at the time of pen deployment. Contrast this with the expected impact on the pelagic population: it will increase from a low, possibly undetectable level, 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 populations" of these components, although the eventual local pelagic population is drawn from a wide geographical range.

Hypotheses

The first step in achieving the objective is formulation of specific hypotheses. The first hypothesis to be tested for the species 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 and species composition will undergo greater increases at the farm operational site than at control locations and that this effect will occur after the farm pens are installed.

A second hypothesis applies to each of the two groups independently. Specifically, the hypothesis to be tested for each is that abundance and biomass, as well as species composition and fish sizes of aggregations will vary on a seasonal basis.

Data collection

A number of data collection methods are available including fish traps and baited and unbaited cameras, but there are uncertainties and biases associated with a number of them (Appendix F, Table F1). Moreover, collecting fish lengths and weights requires taking fish, certainly in the preliminary stages if lengths are to be collected later using camera-based methods. Therefore, based on successful work overseas (§6.3) particular methods could be considered. For the benthic species either a transect approach could be employed, with counts of fish by species along the transect made either by divers, a camera mounted on a remote operated vehicle (ROV) or, possibly, a drift underwater video (DUV) (Carbines & Cole, 2009), although there may be difficulties negotiating mooring lines on the sea pens, especially under high flow conditions, that would preclude this approach. A second possibility is to use the revolving camera method of Dempster et al. (2010) for sampling the benthic group.

Two methods are available for the pelagic group. The first is divers using rapid visual counts (RVCs) while remaining at a defined position and rotating through 360°; the second is using the video-based stationary timed counts recording method (Dempster et al., 2009, 2010). For the second a camera is contained within a half-spherical housing that records footage while slowly revolving through 360°. In both cases, the spatial range for each sample is a cylindrical volume defined during preliminary work (Dempster 2010 used an approximate 700 m^3 volume of 4 m height x 7.5 m radius from the camera) which is applied according to a predetermined series of depths and distances from the pens.

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. The RVC method requires that divers can identify the species they encounter as a basis for recording the count data. Video-based stationary counts provides a permanent record that can be viewed later

Essentially, these methods were 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 in the present context. 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.

The DUV method of sampling is described by Carbines and Cole (2009) who examined dredge impacts on demersal fishes and benthic habitat complexity in Foveaux Strait. It is a transect-based method with a camera attached to a mounting platform that included a bulb keel and tail fin. This was suspended on a rope and cable with scaling lasers and lights attached. A medium sized vessel was used for deployment and operation of the apparatus was while following a randomly placed virtual transect and drifting down-current over the area of interest. The scaling lasers were used to "back-calculate the size and variations of transect width". Fish count data were transposed from the video footage.

Fish capture

Fish need to be caught to allow calibration of the method 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 associated publications (e.g., Fisheries New Zealand, 2018). Preliminary work needs to minimise difficulties related to farm structure while providing representative samples from the population.

Sampling design

Sampling should be based on the premise that *every level of sampling should be replicated* (Kingsford & Battershill, 1998). To achieve this, sampling would be carried out on several days within each season with several sampling units/sets of fish counts taken for each sub-population (i.e., benthic and pelagic). Preliminary work would determine the method of recording each set of fish counts.

To maintain this approach and avoid any pseudoreplication (Hurlbert, 1984), multiple control sites should be utilised, with several fish count events of the same number taken in each and at the farm operational site. Control sites should be selected with similar characteristics (e.g., substrate and bottom depth) as the farm operational site. Preliminary work would determine details of the sampling design.

Data analysis

Preliminary work would be required to determine some aspects of the data analysis although much is to be gained from previous studies. Analysis of the relationship between farm sites and control sites has normally used analysis of variance (ANOVA). This has included data collected using RVCs (e.g., Dempster, 2002) as well as from 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). In the case of the first three studies, Cochran's test for heterogeneity of variances was used prior to ANOVA. The fourth study calculated Pearson correlation coefficients between number of fish and measures of benthic habitat features (e.g., topographic complexity, epifauna cover, tunicates).

ANOVA was also the method used by Fernandez-Jover et al., (2008) for investigating seasonal variation, although the analysis included data from several farms, thus incorporating an extra level of complexity than would be required at a site such as that in Foveaux Strait. This approach could be useful for comparing multiple sites in the future. The analysis included four factors: season (Spring, Summer, Autumn, Winter), year (2004, 2005), farm (3 farms), and day (three different days per season), with six RVC censuses performed each sampling day. Season and Year were modelled as fixed and orthogonal factors, Farm and Day as 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).

6.3.2 Levels of Tissue Contamination

As was discussed previously, the monitoring of key contaminants should become standard practice in the interest of public health, particularly in long-lived, bentho-pelagic and pelagic fish species that are of recreational, commercial or customary fishing interest and that reside in the near vicinity of salmon farms. Such monitoring should depend first upon such species being identified as occurring in the near vicinity of the salmon farms, and 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. This monitoring should include comparisons to relevant control locations.

As suggested here, not all fish need to be sampled, only those that are longer-lived and might carry a raised level of contaminants. However, standing levels should be determined early so that a baseline is available for comparison. Sampling of fish for tissue samples could easily be part of ongoing sampling for investigating farm effects on wild fish. Development of an appropriate methodology needs to take into account sources of bias such as the movement of fish between farms as is discussed in §3.4.

7. ACKNOWLEDGEMENTS

The authors thank Mark Morrison (NIWA), for discussion on recently published and current work on links between benthic finfish and habitat types, Andrew Stewart (Museum NZ), for discussion on aspects of the Te Papa finfish collections and Clinton Duffy (DOC) for discussion on NZTCS lists. Thanks also to several members of the NTSR team for comments on an earlier version of this manuscript.

8. REFERENCES

Abaad M, Tuset VM, Montero D, et al (2016) Phenotypic plasticity in wild marine fishes associated with fish-cage aquaculture. *Hydrobiologia* 765:343–358.

Afonso, P.; Fontes, J.; Holland, K.N.; Santos, R.S., 2009. Multi-scale patterns of habitat use in a highly mobile reef fish, the white trevally *Pseudocaranx dentex*, and their implications for marine reserve design.*Marine Ecology Progress Series*, *381*, pp.273-286.

Akyol O, Ertosluk O (2010) Fishing near sea-cage farms along the coast of the Turkish Aegean Sea. *Journal of Applied Ichthyology* 26: 11–15.

Alver, M.O., Skøien, K.R., Føre, M., Aas, T.S., Oehme, M. and Alfredsen, J.A., 2016. Modelling of surface and 3D pellet distribution in Atlantic salmon (Salmo salar L.) cages. *Aquacultural engineering*, *72*, pp.20-29.

Arechavala-Lopez, P., P. Sanchez-Jerez, J. Bayle-Sempere, D. Fernandez-Jover, L. Martinez-Rubio, J.A. Lopez- Jimenez, and F.J., Martinez-Lopez. 2010. Coastal fish-farms influence the captures of local fisheries: An example with *Boops boops* on SW Mediterranean sea. *Aquaculture Research* 42: no. doi: 10.1111/j.1365-2109.2010.02683.x.

Arechavala-Lopez P, Sanchez-Jerez P, Bayle-Sempere J, et al (2011) Direct interaction between wild fish aggregations at fish farms and fisheries activity at fishing grounds: a case study with Boops boops. Aquac Res 42:996–1010.

Arechavala-Lopez P, Izquierdo-Gomez D, Uglem I, Sanchez-Jerez P (2015a) Aggregations of bluefish *Pomatomus saltatrix* (L.) at Mediterranean coastal fish farms: seasonal presence, daily patterns and influence of farming activity. Environ Biol Fishes 98:499–510.

Arechavala-Lopez P, Borg JA, Segvic-Bubic T, et al (2015b) Aggregations of wild Atlantic Bluefin Tuna (*Thunnus thynnus* L.) at Mediterranean offshore fish farm sites: Environmental and management considerations. Fish Res 164 :178–184.

Arechavala-Lopez P, Sæther B-S, Marhuenda-Egea F, Sanchez-Jerez P, Uglem I (2015c) Assessing the influence of salmon farming through total lipids, fatty acids, and trace elements in the liver and muscle of wild saithe *Pollachinus virens*. *Marine and Coastal Fisheries* 7: 59-67

Autin, M. 1997. Commercial aquafeed manufacturer and production. *CIHEAM—Options Mediterraneennes* 22: 79–104.

Bacher K, Gordoa A, Sague O (2012) Spatial and temporal extension of wild fish aggregations at Sparus aurata and Thunnus thynnus farms in the north-western Mediterranean. Aquac Environ Interact 2:239–252.

Bacher K, Gordoa A, Sagué O (2015) Feeding activity strongly affects the variability of wild fish aggregations within fish farms: a sea bream farm as a case study. Aquac Res 46:552–564.

Bagdonas K, Humborstad O-B, Løkkeborg S (2012) Capture of wild saithe (Pollachius virens) and cod (Gadus morhua) in the vicinity of salmon farms: Three pot types compared. Fish Res 134-136:1–5. doi: 10.1016/j.fishres.2012.06.020.

Baker, A.N. (1972). Reproduction, early life history, and age-growth relationships of the New Zealand pilchard, *Sardinops neopilchardus* (Steindachner). *Fisheries Research Division (N.Z.), Fisheries Research Bulletin No. 5*. 64 p.

Bakun, A. 2012. *Patterns in the ocean: ocean processes and marine population dynamics*. California Sea Grant, in cooperation with Centro de Investigaciones Biologicas del Noroeste, La Paz, Mexico. (Originally 1996, University of California Press, La Jolla, CA). 323pp.

Ballester-Molto M, Sanchez-Jerez P, Garcia-Garcia B, Aguado-Gimenez F (2015) Husbandry and environmental conditions explain temporal variability of wild fish assemblages aggregated around a Mediterranean fish farm. Aquac Environ Interact 7:193–203.

Ballester-Moltó M, Sanchez-Jerez P & Aguado-Giménez F (2017) Consumption of particulate wastes derived from cage fish farming by aggregated wild fish. An experimental approach. Mar Environ Res 130:166–173.

Balmelli,M.,and Wickens,P.A. (1994).Estimates of daily ration for the south-African (Cape) fur-seal. *South Afr .J. Marine Sci. Suid Afrikaanse Tydskrif Vir Seewetenskap* 14,151–157. doi:10.2989/02577619478428 7111.

Bannister RJ, Johnsen IA, Hansen PK, Kutti T, Asplin L 2016. Near- and far-field dispersal modelling of organic waste from Atlantic salmon aquaculture in fjord systems. ICES Journal of Marine Science 73(9): 2408-2419.

Barrett LT, Swearer SE, Dempster T (2018a) Impacts of marine and freshwater aquaculture on wildlife: a global meta-analysis. Rev Aquac. doi:10.1111/raq.12277

Barrett, LT, Swearer SE, Harboe T, Karlsen Ø, Meier S, Dempster T (2018b) Limited evidence for differential reproductive fitness of wild Atlantic cod in areas of high and low salmon farming density. Aquacult Environ Interact 10:369–383.

Barton, M; Bond, C.E. 2007. *Bond's biology of fishes*. Thomson.

Batchelor,A.L.,andRoss,G.J.B.(1984).The diet and implications of dietary change of Cape gannets on Bird Island, Algoa Bay. *Ostrich* 55,45–63. doi: 10.1080/00306525.1984.9634757.

Beardmore, B., Hunt, L.M., Haider, W., Dorow, M. and Arlinghaus, R., 2014. Effectively managing angler satisfaction in recreational fisheries requires understanding the fish species and the anglers. *Canadian Journal of Fisheries and Aquatic Sciences*, *72*(4), pp.500-513.

Bearzi, G. 2002. Interactions between cetacean and fisheries in the Mediterranean Sea. In G. Notarbartolo diSciara (Ed.), Cetaceans of the Mediterranean and Black Seas: State of Knowledge and Conservation Strategies. A report to the ACCOBAMS Secretariat, Monaco, February 2002. Section 9, 20 pp.

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J. and Orth, R.J., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *Bioscience*, *51*(8), pp.633-641.

Beets, J. 1989. Experimental evaluation of fish recruitment to combinations of fish aggregating devices and benthic artificial reefs. *Bulletin of Marine Science*, 44(2): 973–983.

Bell, J.D. 2001. Results from the Marlborough Sounds recreational fishing survey 1998. Final Research Report for the Ministry of Fisheries Project REC9807. 73 p. (Unpublished report held by Ministry of Fisheries, Wellington-Project REC9807).

Bennett H, Smeaton M, McGrath E, Newcombe E 2019. Assessment of seabed effects associated with farming salmon offshore of northern Stewart Island/Rakiura. Prepared for Ngāi Tahu Seafood Resources. Cawthron Report No. 3315. 80 p. plus appendices.

Bergh, Ø. 2007. The dual myths of the healthy wild fish and the unhealthy farmed fish. *Diseases of Aquatic Organisms 75*: 159–164.

Berntssen, M. H. G., Julshamn, K., Lundebye, A.-K. 2010. Chemical contaminants in aquafeed and Atlantic salmon (*Salmo salar*) following the use of traditional- versus alternative feed ingredients. *Chemosphere 78*, 637–646.

Bjordal, A. and A.B. Skar. 1992. Tagging of Saithe (*Pollachius virens* L.) at a Norwegian Fish Farm: Preliminary Results on Migration. ICES Council Meeting Papers, 1992/G:35.

Bjørn PA, Finstad B, Kristoffersen, R. 2001. Salmon lice infection of wild sea trout and Arctic char in marine and freshwaters: the effects of salmon farms. *Aquaculture Research* 32: 947–962

Bjørn, P.A., Uglem, I., Kerwath, S., Sæther, B.S. and Nilsen, R., 2009. Spatiotemporal distribution of Atlantic cod (Gadus morhua L.) with intact and blocked olfactory sense during the spawning season in a Norwegian fjord with intensive salmon farming. *Aquaculture*, *286*(1-2), pp.36-44.

Blaxter, J.H.S.; Hunter, J.R. 1982. The biology of the clupeoid fishes. *Advances in Marine Biology 20*: 1–223. Academic Press, London.

Blower, D.C.; Pandolfi, J.M.; Bruce, B.D.; Gomez-Cabrera, M. del C.; Ovenden, J.R. 2012: Population genetics of Australian white sharks reveals fine-scale spatial structure, transoceanic dispersal events and low effective population sizes. Marine Ecology Progress Series 455: 229–244.

Bogdanovic T, Simat V, Frka-Roic A, Markovic K (2012) Development and Application of Quality Index Method Scheme in a Shelf-Life Study of Wild and Fish Farm Affected Bogue (Boops boops, L.). J Food Sci 77:S99–S106.

Boyra A, P. Sanchez-Jerez, F. Tuya, F. Espino, and R. Haroun. 2004. Attraction of wild coastal fishes to Atlantic subtropical cage fish farms, Gran Canaria, Canary Islands. *Environmental Biology of Fishes* 70: 393–401.

Bradford, J.M., Cranfield, H.J. and Michael, K.P., 1991. Phytoplankton biornass in relation to the surface hydrography of southern New Zealand and possible effects on the food chain. *New Zealand journal of marine and freshwater research*, *25*(2), pp.133-144.

Bradford, J. M.; Taylor, F. J. 1980: New Zealand region, reactive phosphorus; October-April, surface. New Zealand Oceanographic Institute chart, miscellaneous series 46.

Brill, R.W.; Lutcavage, M.E., 2001, Understanding environmental influences on movements and depth distributions of tunas and billfishes can significantly improve population assessments. In *American Fisheries Society Symposium* (pp. 179-198). American Fisheries Society.

Brodie, J. W. 1960: Coastal surface currents around New Zealand. *New Zealand journal of geology and geophysics 3:* 235-252.

Bruce, B.; Bradford, R; Bravington, M.; Feutry, P.; Grewe, P.; Gunasekera, R.; Harasti, D.; Hillary, R.; Patterson, T. 2018: A national assessment of the status of white sharks. National Environmental Science Programme, Marine Biodiversity Hub, CSIRO, Hobart, Tasmania. 41 p. B

Buckley, L.J.; Lough, R.G., 1987. Recent growth, biochemical composition and prey field of larval haddock (Melanogrammus aeglefinus) and Atlantic cod (Gadus morhua) on Georges Bank. *Canadian Journal of Fisheries and Aquatic Sciences*, *44*(1), pp.14-25.

Bustnes J.O., Herske D., Dempster T., Bjørn P.A., Nygård T., Lie E., Uglem I. 2010. Salmon farms as a source of organohalogenated contaminants in wild fish. *Environmental Science and Technology* 44*:* 8736-8743.

Bustnes J.O., Nygård T., Dempster T., Ciesielski T., Jensse B.M., Bjørn P.A. and Uglem I. 2011. Do salmon farms increase the concentrations of mercury and other elements in wild fish? *Journal of Environmental Monitoring* 13: 1687-1694.

Butler, E.C.V., Butt, J.A., Lindstrom, E.J., Teldesley, P.C., Pickmere, S. and Vincent, W.F., 1992. Oceanography of the subtropical convergence zone around southern New Zealand. *New Zealand Journal of Marine and Freshwater Research*, *26*(2), pp.131-154.

Callier MD, Byron CJ, Bengtson DA, Cranford PJ, Cross SF, Focken U, Jansen HM, Kamermans P, Kiessling A, Landry T, O'Beirn F, Petersson E, Rheault RB, Strand Ø, Sundell K, Svåsand T, Wikfors GH, McKindsey CW (2018) Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: a review. Rev Aquacult. doi:10.1111/raq.12208

Campos C, Smeaton M, Bennett H, Mackenzie L, Scheel M, Vennell R, Newcombe E, Knight B 2019. Assessment of water column effects associated with farming salmon offshore of northern Stewart Island /Rakiura. Prepared for Ngāi Tahu Seafood Resources. Cawthron Report No. 3326. 99 p. plus appendices.

Carbines, G.D., 1993. The ecology and early life history of *Notolabrus celidotus* (Pisces: Labridae) around mussel farms in the Marlborough Sounds. Unpublished MSc thesis, Department of Zoology, University of Canterbury. Christchurch, New Zealand.

Carbines, G. and Cole, R.G., 2009. Using a remote drift underwater video (DUV) to examine dredge impacts on demersal fishes and benthic habitat complexity in Foveaux Strait, Southern New Zealand. *Fisheries Research*, *96*(2-3), pp.230-237.

Carss, D.N. 1990. Concentrations of wild and escaped fishes immediately adjacent to fish farm cages. *Aquaculture* 90: 29–40.

Charteris, S.C.; Ritchie, P.A. 2002. Identification of galaxiid nests, emigrating larvae and whitebait, using mitochondrial DNA control region sequences. *New Zealand Journal of Marine and Freshwater Research*, *36*(4), pp.789-795.

Choat, J.H.; Ayling, A.M. 1987. The relationship between habitat structure and fish faunas on New Zealand reefs. *J. Exp. Mar. Biol. Ecol. 110*, 257–284.

Choi M.H. and J.J. Chec. 1998. Unexpectedly high mercury level in pelleted commercial fish feed. *Environmental Toxicology and Chemistry* 17: 1979-1981.

Cloern, J. E. 1991a: Tidal stirring and phytoplankton bloom dynamics in an estuary. *Journal of Marine Research* 49: 203–221.

Cole D.W., Cole R., Gaydos S.J., Gray J., Hyland G., Jacques M.L., Powell-Dunford N., Sawhney C., Au W.W. 2009. Aquaculture: Environmental, toxicological, and health issues. *Int. J. Hyg. Environ. Health* 212: 369–377.

Cranfield, H.J., Manighetti, B., Michael, K.P. and Hill, A., 2003. Effects of oyster dredging on the distribution of bryozoan biogenic reefs and associated sediments in Foveaux Strait, southern New Zealand. *Continental Shelf Research*, *23*(14-15), pp.1337-1357.

Cranfield, H.J., Dunn, A., Doonan, I.J. and Michael, K.P., 2005. Bonamia exitiosa epizootic in Ostrea chilensis from Foveaux Strait, southern New Zealand between 1986 and 1992. *ICES Journal of Marine Science*, *62*(1), pp.3-13.

Cullen, D.J., 1967. The submarine geology of Foveaux Strait. New Zealand Department of Scientific and Industrial Research. *New Zealand Oceanographic Institute Memoir Vol 33*. 184 pp.

Davidson, R.J. 2001. Changes in population parameters and behaviour of blue cod (*Parapercis colias*: Pinguipidae) in Long Island-Kokomohua Marine Reserve, Marlborough Sounds, New Zealand. *Aquatic Conservation: Marine and Freshwater Ecosystems* 11: 417–435.

Dean, R. J.; Shimmield, T. M.; Black, K. D. (2007). Copper, zinc and cadmium in marine cage fish farm sediments: an extensive survey. *Environmental Pollution, 145*(1), 84-95.

deBruyn, A.M.H., Trudel, M., Eyding, N., Harding, J. and others. 2006. Ecosystemic effects of salmon farming increase mercury contamination in wild fish. *Environmental Science and Technology* 40:3489–3493.

Deelder, C.L. 1958. On the behaviour of elvers *{Anguilla vulgaris* Turt.) migrating; from the sea into fresh water. *Journal du Conseil Permanent International pour l'Exploration de la Mer 24 (1)*: 135-46.

Dempster, T., D. Fernandez-Jover, P. Sanchez-Jerez, F. Tuya, J. Bayle-Sempere, A. Boyra, and R.J. Haroun. 2005. Vertical variability of wild fish assemblages around sea-cage fish farms: Implications for management. *Marine Ecology Progress Series* 304: 15–29.

Dempster, T., H. Moe, A. Fredheim, and P. Sanchez-Jerez. 2007. Escapes of marine fish from sea-cage aquaculture in the Mediterranean Sea: Status and prevention. *CIESM Workshop Monograph* 32: 55–60 (www.ciesm.org/online/monographs/Lisboa.html).

Dempster T, Sanchez-Jerez P (2008) Coastal aquaculture and marine space planning in Europe: an ecological perspective. pp 87-116. In: *Aquaculture in the Ecosystem*. Eds Holmer M, Black K, Duarte C, Marba N, Karakassis I. Elsevier, 325 pp (http://www.springerlink.com/content/q1x4814g05600853)

Dempster T., P. Sanchez-Jerez, J.-T. Bayle-Sempere, F. Giménez-Casalduero, and C. Valle. 2002. Attraction of wild fish to seacage fish farms in the south-western Mediterranean Sea: Spatial and short-term temporal variability. *Marine Ecology Progress Series* 242: 237–252.

Dempster, T., P. Sanchez-Jerez, J. Bayle-Sempere, and M.J., Kingsford. 2004. Extensive aggregations of wild fish at coastal sea-cage fish farms. *Hydrobiologia* 525(1–3): 245–248.

Dempster T, Sanchez-Jerez P, Fernandez-Jover D, Bayle-Sempere, Nilsen R, Bjørn PA, Uglem I. 2011. Proxy measures of fitness suggest coastal fish farms can act as population sources and not ecological traps for wild fish. *PLoS One* 6(1): e15646

Dempster, T., P. Sanchez-Jerez, F. Tuya, D. Fernandez-Jover, J. Bayle-Sempere, A. Boyra, and R. Haroun. 2006. Coastal aquaculture and conservation can work together. *Marine Ecology Progress Series* 314: 309–310.

Dempster, T., P. Sanchez-Jerez, I. Uglem, and P. Bjørn. 2010. Species-specific aggregations of wild fish around fish farms. *Estuarine, Coastal and Shelf Science Estuarine, Coastal and Shelf Science* 86: 271-275.

Dempster, T., Taquet, M. 2004. Fish aggregation device (FAD) research; gaps in current knowledge and future directions for ecological studies. *Reviews in Fish Biology and Fisheries* 14: 21-42.

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

Dempster T, Arechavala-Lopez P, Barrett LT, Fleming IA, Sanchez-Jerez P, Uglem I (2016) Recapturing escaped fish from marine aquaculture is largely unsuccessful: alternatives to reduce the number of escapees in the wild. Reviews in Aquaculture 10: doi: 10.1111/raq.12153

Duffy (1992). Shallow rocky reef habitats in Hawkes Bay. Unpublished DOC report.

Duffy, C., M.F., Dunn, M., Finucci, B., Ford, R., Hitchmough, R. and Rolfe, J., 2018. Conservation status of New Zealand chondrichthyans (chimaeras, sharks and rays).

Duffy, C.A.J.; Francis, M.P.; Manning, M.J.; Bonfil, R. 2012: Regional population connectivity, oceanic habitat, and return migration revealed by satellite tagging of white sharks, Carcharodon carcharias, at New Zealand aggregation sites. Pp. 301–318 in Domeier M.L. (Ed.): Global perspectives on the biology and the life history of the white shark. CRC Press, Boca Raton.

Dunn, N.R., Allibone, R.M., Closs, G., Crow, S., David, B.O., Goodman, J., Griffiths, M.H., Jack, D., Ling, N., Waters, J.M. and Rolfe, J.R., 2018. *Conservation status of New Zealand freshwater fishes, 2017*. Publishing Team, Department of Conversation.

Espinoza, P.; Bertrand, A.; van der Lingen, C.D.; Garrido, de Mendiola, S.B.R. 2009. Diet of sardine (*Sardinops sagax)* in the northern Humbolt Current system and comparison with diets of clupeoids in this and other eastern boundary upwelling systems. *Progress in Oceanography* 83: 242–250

Felsing, M. Glencross, B. Telfer, T. 2005. Preliminary study on the effects of exclusion of wild fauna from aquaculture cages in a shallow marine environment. *Aquaculture* 243: 159-174.

Fernandez-Jover D, Sanchez-Jerez P (2015) Comparison of diet and otolith growth of juvenile wild fish communities at fish farms and natural habitats. Ices J Mar Sci 72:916–929.

Fernandez-Jover, D., E. Faliex, P. Sanchez-Jerez, P. Sasal, and J. Bayle-Sempere. 2010. Coastal fish farming does not affect the total parasite communities of wild fish in SW Mediterranean. *Aquaculture* 300: 10–16.

Fernandez-Jover, D.; Jimenez, J.A.L.; Sanchez-Jerez, P.; Bayle-Sempere, J.; Casalduero, F.G.; Lopez, F.J.M.; Dempster, T. (2007) Changes in body condition and fatty acid composition of wild Mediterranean horse mackerel (*Trachurus mediterraneus*, Steindachner, 1868) associated to sea cage fish farms. *Marine Environmental Research* 63: 1-18

Fernandez-Jover D, Martinez L, Sanchez-Jerez P, Bjørn PA, Uglem I, Dempster T. 2011. Waste feed from coastal fish farms: a trophic subsidy with compositional side-effects for wild gadoids. *Estuarine, Coastal and Shelf Science* 91: 559-568. DOI: 10.1016/j.ecss.2010.12.009

Fernandez-Jover, D., P. Sanchez-Jerez, J.T. Bayle-Sempere, P. Arechavala-Lopez, L. Martinez-Rubio, J.A. Lopez Jimenez, and F.J. Martinez Lopez. 2009. Coastal fish farms are settlement sites for juvenile fish. *Marine Environmental Research* 68: 89–96.

Fernandez Jover, D., P. Sanchez-Jerez, J. Bayle-Sempere, C. Valle, and T. Dempster. 2008. Seasonal patterns and diets of wild fish assemblages associated with Mediterranean coastal fish farms. *ICES Journal of Marine Science* 65: 1153–1160.

Fisheries New Zealand (2018). Fisheries Assessment Plenary, May 2018: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 1674p.

Foran J. A., R. A. Hites, D. O. Carpenter, M. C. Hamilton, A. Mathews-Amos and S. J. Schwager. 2004. A survey of metals in tissues of farmed Atlantic and wild Pacific salmon. *Environmental Toxicology and Chemistry* 23: 2108-2110.

Ford, J.S. and R.A. Myers. 2008. A global assessment of salmon aquaculture impacts on wild salmonids. *PLoS Biology* 6: 411–417.

Forman, R. T. T., and P. N. Moore. 1992. Theoretical foundations for understanding boundaries in landscape mosaics. Pages 236–258 in A. J. Hansen and F. di Castri, editors. Landscape boundaries: consequences for biotic diversity and ecological flows. Ecological studies. Volume 92. Springer-Verlag, New York.

Francis, M.P. (1996) Geographic distribution of marine reef fishes in the New Zealand region, New Zealand Journal of Marine and Freshwater Research, 30:1, 35-55, DOI: 10.1080/00288330.1996.9516695

Francis, M. 1997. A summary of biology and commercial landings and a stock assessment of rough and smooth skates (*Raja nasuta* and *R. innominata*). New Zealand Fisheries Assessment Research Document 97/15. 27 p.

Francis, Malcolm. 2019. Potential interactions between sharks and a proposed fish farm off northern Stewart Island/Rakiura. Prepared for Ngāi Tahu Seafood Resources Limited. *NIWA Client Report* 2019311WN.

Froehlich, H. E., Smith, A., Gentry, R. R., & Halpern, B. S. (2017). Offshore aquaculture: I know it when I see it. Frontiers in Marine Science. doi:10.3389/fmars.2017.00154

Garner, D. M. 1961. Hydrology of New Zealand coastal waters, 1955. *NZ. oceanogr. Inst. 8. (Bull. N.Z. Dep. scient. ind. Res. 138)*.

Garner, D. M. 1959. The subtropical convergence in New Zealand coastal waters. *New Zealand journal of geology and geophysics 2:* 315-337.

Glover KA, Solberg MF, McGinnity P, Hindar K, Verspoor E, Coulson MW, Hansen MM, Araki H, Skaala Ø, Svåsand T (2017) Half a century of genetic interaction between farmed and wild Atlantic salmon: status of knowledge and unanswered questions. Fish Fish. doi: 10.1111/faf.12214

Gonzalez-Silvera D, Guardiola FA, Cordero H, Cuesta A, Esteban MA, Martínez-López FJ, López-Jiménez JA (2017) The short-term effects of farmed fish food consumed by wild fish congregating outside the farms. Mar Pollut Bull 114:689–698.

Goodbrand L, Abrahams M V, Rose GA (2013) Sea cage aquaculture affects distribution of wild fish at large spatial scales. Can J Fish Aquat Sci 70:1289–1295.

Graham, D.H. 1953. A Treasury of New Zealand Fishes. A.H. & A.W. Reed, Wellington.

Green, A.L.; Maypa, A.P.; Almany, G.R.; Rhodes, K.L.; Weeks, R.; Abesamis, R.A.; Gleason, M.G.; Mumby, P.J.; White, A.T. 2015. Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews*, *90*(4), pp.1215-1247.

Green, R.H. 1979. *Sampling design and statistical methods for environmental biologists*. John Wiley & Sons.

Gudmundsen, O., Lisæther, L. M., and A˚rseth, L. M. 2012. Ryfylkeprosjektet. Project report—in Norwegian. 18 pp.

Haddad, N. M. 1999. Corridor use predicted from behaviors at habitat boundaries. The American Naturalist **153:** 215–227.

Hale, R., & Swearer, S. E. (2016). Ecological traps: current evidence and future directions. Proceedings of the Royal Society B: Biological Sciences, 283(1824), 494–499.

Hallier, J.-P., & Gaertner, D. (2008). Drifting fish aggregation devices could act as an ecological trap for tropical tuna species. Marine Ecology Progress Series, 353, 255–264.

Harden Jones, F.R. 1977. Performance and Behaviour on Migration. In: J.H. Steele (ed.) Fisheries mathematics, pp.131-144. Academic Press, London, New York, San Francisco. 198 pp.

Heath, R.A., 1972. The southland current. *New Zealand journal of marine and freshwater research*, *6*(4), pp.497-533.

Heath, R.A., 1975. *Oceanic circulation off the east coast of New Zealand*. New Zealand Oceanographic Institute Memoir Vol 55. 80 p.

Heath, R.A., 1975. *Oceanic circulation and hydrology off the southern half of South Island, New Zealand*. Wellington: New Zealand Oceanographic Institute Memoir Vol 72. 36 p.

Hellou, J. Haya, K., Steller, S., Burridge, L. 2005. Presence and distribution of PAHs, PCBs and DDE in feed and sediments under salmon aquaculture cages in the Bay of Fundy, New Brunswick, Canada. *Aquatic Conservation: Marine and Freshwater Ecosystems 15*: 349–365.

Hemelrijk, C.K.; Reid, D.A.P.; Hildenbrandt, H.; Padding, J.T. 2015. The increased efficiency of fish swimming in a school. *Fish and Fisheries*, *16*(3), pp.511-521.

Hebert, C.E., Weseloh, D.C., Idrissi, A., Arts, M.T., O'Gorman, R., Gorman, O.T., Locke, B., Madenjian, C.P. and Roseman, E.F., 2008. Restoring piscivorous fish populations in the Laurentian Great Lakes causes seabird dietary change. *Ecology*, *89*(4), pp.891-897.

Hickford, M.J.H.; Schiel, D.R. 2003. Comparative dispersal of larvae from demersal versus pelagic spawning fish. *Mar. Ecol., Prog. Ser. 252*, 255– 271.

Hillary, R.M.; Bravington, M.V.; Patterson, T.A.; Grewe, P.; Bradford, R.; Feutry, P.; Gunasekera, R.; Peddemors, V.; Werry, J.; Francis, M.P.; Duffy, C.A.J.; Bruce, B.D. 2018: Genetic relatedness reveals total population size of white sharks in eastern Australia and New Zealand. Scientific Reports 8: 2661. DOI:10.1038/s41598-018-20593-w

Hites R.A., Foran J.A., Carpenter D.O., Hamilton M.C., Knuth B.A., Schwager S.J. 2004a. Global assessment of organic contaminants in farmed salmon. *Science* 303 226–229.

Hites, R. A., Foran, J. A., Schwager, S. J., Knuth, B. A., Hamilton, M. C., Carpenter, D. O. 2004b. Global assessment of polybrominated diphenyl ethers in farmed and wild salmon. *Environ. Sci. Technol.* 38 4945–4949.

Holmer M (2010) Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs. Aquac Environ Interact 1:57–70.

Houtmann, Th. J. 1966: A note on the hydrological regime in Foveaux Strait. *New Zealand journal of science 9:* 472-483.

Hurlbert, S.H., 1984. Pseudoreplication and the design of ecological field experiments. *Ecological monographs*, *54*(2), pp.187-211.

Iles, T.D.; Sinclair, M., 1982. Atlantic herring: stock discreteness and abundance. *Science*, *215*(4533), pp.627-633.

Jackson D, McDermott T, Kane F. (2013) Evaluation of the impacts of aquaculture and freshwater habitat on the status of Atlantic salmon stocks in Ireland. Agric Sci 4:62–67.

Jackson,S. (1990). Seabird Digestive Physiology in Relation to Foraging Ecology. PhD. University of Cape Town.

Jacobs, M N., Covaci, A., Schepens, P. 2002. Investigation of selected persistent organic pollutants in farmed Atlantic salmon (*Salmo salar*), salmon aquaculture feed, and fish oil components of the feed. *Environmental Science and Technology 36*: 2797–2805.

Jacomb, C., Walter, R. and Jennings, C., 2010. Review of the archaeology of Foveaux Strait, New Zealand. *The Journal of the Polynesian Society*, pp.25-59.

Jardine L. B., M.D.B. Burt, P.A. Arp and A.W. Diamond. 2009. Mercury comparisons between farmed and wild Atlantic salmon (*Salmo salar* L.) and Atlantic cod (*Gadus morhua* L.) *Aquaculture Research* 40: 1148-1159.

Jellyman, D.J. 1977. Invasion of a New Zealand freshwater stream by glass-eels of two Anguilla spp. *NZ J Mar Freshwater Res 11*:193–209.

Jellyman, D.J. 1987. Review of the marine life history of Australasian temperate species of Anguilla. *Am Fish Soc Symp 1*:286–297.

Jellyman, D.J.; Chisnall, B.L.; Sykes, J.R.E.; Bonnett, M,L, 2002. Variability in spatial and temporal abundance of glass eels (*Anguilla* spp.) in New Zealand. *NZ J Mar Freshwater Res 36*:511–517

Jellyman, D.; Tsukamoto, K. 2005. Swimming depths of offshore migrating longfin eels Anguilla dieffenbachii. *Marine Ecology Progress Series*, *286*, pp.261-267.

Jiang W, Carbines G. 2002. Diet of blue cod, Parapercis colias, living on undisturbed biogenic reefs and on seabed modified by oyster dredging in Foveaux Strait, New Zealand. Aquatic Conservation: Marine and Freshwater Ecosystems 12:257–272. DOI: 10.1002/aqc.495.

Jones, G.P. 1988. Ecology of rocky reef fish of north-eastern New Zealand: a review. *New Zealand Journal of Marine and Freshwater Research 22*: 445–462.

Kalantzi I, Papageorgiou N, Sevastou K, et al (2014) Metals in benthic macrofauna and biogeochemical factors affecting their trophic transfer to wild fish around fish farm cages. Sci Total Environ 470 :742–753.

Karakassis, I. and E. Hatziyanni. 2000. Benthic disturbance due to fish farming analyzed under different levels of taxonomic resolution. *Marine Ecology Progress Series* 203: 247–253.

Katz, T., B. Herut, A. Genin, and D.L. Angel. 2002. Gray mullets ameliorate organically enriched sediments below a fish farm in the oligotrophic Gulf of Aqaba (Red sea). *Marine Ecology Progress Series* 234: 205–214.

Keeley N, Taylor D 2011. The New Zealand King Salmon Company Limited: Assessment of Environmental Effects - Benthic. Prepared for New Zealand The New Zealand King Salmon Company Ltd. Cawthron Report No. 1983. 74 p. plus appendices.

Kelly, B. C., Fernandez, M. P., Ikonomou, M. G., Knapp, W. 2008a. Persistent organic pollutants in aquafeed and Pacific salmon smolts from fish hatcheries in British Columbia, Canada. *Aquaculture 285*, 224–233.

Kelly B.C., Ikonomou M.G., Higgs D.A., Oakes J., Dubetz C. 2008b. Mercury and other trace elements in farmed and wild salmon from British Columbia, Canada. *Environmental Toxicology and Chemistry* 27: 1361–1370.

Kettles H, Smith F, Shears N 2017. Subtidal reef and rockwall communities of the greater Foveaux Strait region, Southland, New Zealand. Science for Conservation 329. Department of Conservation, Wellington. 91 p.

Killen, S.S.; Marras, S.; Steffensen, J.F.; McKenzie, D.J. 2011. Aerobic capacity influences the spatial position of individuals within fish schools.*Proceedings of the Royal Society of London B: Biological Sciences*, p.rspb20111006.

Kingsford, M.J., 1988. The early life history of fish in coastal waters of northern New Zealand: a review. *New Zealand Journal of Marine and Freshwater Research,* 22, 463– 479.

Kingsford, M.J. 1993. Biotic and abiotic structure in the pelagic environment: importance to small fishes. *Bulletin of Marine Science, 53*: 393–415.

Kingsford, M.J., 1992. Drift algae and small fish in coastal waters of northeastern New Zealand. *Mar. Ecol., Prog. Ser. 80*, 41– 55.

Kingsford, M.J., 1993. Biotic and abiotic structure in the pelagic environment: importance to small fishes. *Bull. Mar. Sci. 53*, 393– 415.

Kingsford, M.J.; Choat, J.H. 1985. The fauna associated with drift algae captured with a plankton-mesh purse-seine net. *Limnology and Oceanography: Methods, 30*: 618–630.

Kingsford, M.J., Choat, J.H., 1989. Horizontal distribution patterns of presettlement reef fish: are they influenced by the proximity of reefs? *Mar. Biol. 101*, 285– 297.

Kingsford, M.J.; Milicich, M.J. 1987. Presettlement phase of *Parika scaber* (Pisces: Monacanthidae): a temperate reef fish. *Mar. Ecol., Prog. Ser. 36*, 65– 79.

Kingsford, M.J. and Battershill, C.N., 1998. Procedures for establishing a study. In: Kingsford, M.J. and Battershill, C.N., Eds, *Studying temperate marine environments — A handbook for ecologists. Canterbury University Press, Christchurch*, pp. 29-48.

Krkosek, M., J.S. Ford, and A. Morton. 2007. Declining wild salmon populations in relation to parasites from farm salmon. *Science* 318: 1772–1775.

Krkošek M, Revie CW, Gargan PG, Skilbrei OT, Finstad B, Todd CD (2013) Impact of parasites on salmon recruitment in the Northeast Atlantic Ocean. Proc R Soc London B 280. doi: 10.1098/rspb.2012.2359

Kutti, T., Hansen, P.K., Ervik, A., Høisæter, T., Johannessen, P. 2007. Effects of organic effluents from a salmon farm on a fjord system. II. Temporal and spatial patterns in infauna community composition. *Aquaculture* 262(2–4): 355–366.

Lambert, Y., Dutil, J.–D .1997. Can simple condition indices be used to monitor and quantify seasonal changes in the energy reserves of Atlantic cod (*Gadus morhua*)? *Canadian Journal of Fisheries and Aquatic Science* 54(Suppl. 1): 104–112.

Lasker, R., 1978. The relations between oceanographic conditions and larval anchovy food in the California Current: identification of factors contributing to recruitment failure. *Rapports et Proces-Verbaux des Reunions (Denmark)*.

Laurel BJ, Copeman LA, Hurst TP, Parrish CC (2010) The ecological significance of lipid/fatty acid synthesis in developing eggs and newly hatched larvae of Pacific cod (*Gadus macrocephalus*). Mar Biol 157:1713–1724.

Li, D., Wang, Z., Wu, S., Miao, Z., Du, L. and Duan, Y., 2020. Automatic recognition methods of fish feeding behavior in aquaculture: A review. *Aquaculture*, p.735508.

Liang P, Wu SC, Zhang J, Cao Y, Yu S, Wong MH (2016) The effects of mariculture on heavy metal distribution in sediments and cultured fish around the Pearl River Delta region, south China. Chemosphere 148:171–177.

Lighthill, M.J. 1977. Mathematical theories of fish swimming. In: J.H. Steele (ed.) Fisheries mathematics, pp.131-144. Academic Press, London, New York, San Francisco. 198 pp.

Lorentzen M. and A. Maage, 1999. Trace element status of juvenile Atlantic salmon *Salmo salar* L. fed a fish-meal based diet with or without supplementation of zinc, iron, manganese and copper from first feeding. *Aquaculture Nutrition* 5: 163-171.

Lorentzen M., A. Maage and K. Julshamn, 1998. Supplementing copper to a fish meal based diet fed to Atlantic salmon parr affects liver copper and selenium concentrations. *Aquaculture Nutrition* 4: 67-72.

Love, M., J. Hyland, A. Ebeling, T. Herrlinger, A. Brooks, and E. Imamura. 1994. A pilot study of the distribution and abundances of rockfishes in relation to natural environmental-factors and an offshore oil and gas-production platform off the coast of southern California. *Bulletin Marine Science* 55: 1062–1085.

Lowe, M. (2013). Factors affecting the habitat usage of estuarine juvenile fish in northern New Zealand. Unpubl. PhD thesis, University of Auckland. 282 p.

Lyon, W.S. (2020) Potential interactions between sharks and a proposed fish farm off northern Stewart Island/Rakiura: Response to Questions. *NIWA Client Report* 2020169WN: 14.

Lyon, W.S., Francis, R.I.C.C. and Francis, M.P., 2011. Calculating incubation times and hatching dates for embryonic elephantfish (Callorhinchus milii). *New Zealand Journal of Marine and Freshwater Research*, *45*(1), pp.59-72.

McConnell A, Routledge R, Connors BM (2010) Effect of artificial light on marine invertebrate and fish abundance in an area of salmon farming. Mar Ecol Prog Ser 419:147-156.

McDowall, R.M., 1978. New Zealand freshwater fishes: a guide and natural history. Heinemann Educational Books (NZ) Ltd, Auckland.

McDowall, R.M., 1991. *Conservation and management of the whitebait fishery*. Science and Research Series No. 38, Head Office, Department of Conservation. 22 pp.

McDowall, R.M., 2000. Biogeography of the New Zealand torrentfish, *Cheimarrichthys fosteri* (Teleostei: Pinguipedidae): a distribution driven mostly by ecology and behaviour. *Environmental Biology of Fishes, 58*(2), pp.119-131.

Magurran, A.E., 1990, January. The adaptive significance of schooling as an anti-predator defence in fish. In *Annales Zoologici Fennici* (pp. 51-66). Finnish Zoological Publishing Board, formed by the Finnish Academy of Sciences, Societas Scientiarum Fennica, Societas Biologica Fennica Vanamo and Societas pro Fauna et Flora Fennica.

Marshall, C.T., Yaragina, N.A., Lambert, Y., Kjesbu, O.S. 1999. Total lipid energy as a proxy for total egg production by fish stocks. Nature 402: 288–290.

Maurstad, A.; Dale, T.; Bjørn, P.A. 2007. You wouldn't spawn in a septic tank, would you? *Human Ecology* 35(5): 601–610.

Maurya, P.K. and Malik, D.S., 2019. Bioaccumulation of heavy metals in tissues of selected fish species from Ganga river, India, and risk assessment for human health. *Human and Ecological Risk Assessment: An International Journal*, *25*(4), pp.905-923.

Meng, W. and Feagin, R.A., 2019. Mariculture is a double-edged sword in China. *Estuarine, Coastal and Shelf Science*, *222*, pp.147-150.

Michell-Innes, B.A.; Pitcher, G.C. 1992. Hydrographic parameters as indicators of the suitability of phytoplankton populations as food for herbivorous copepods. In: Payne, A.I.L; Mann, K.H.; Hilborn, R. (eds) Benguela Trophic Functioning. *South African Journal of Marine Science* 12: 355–365.

Middleton, D. A. J. (03 March 2020). Fisheries and fish populations in statistical area 025 (Foveaux Strait) in relation to a proposed finfish farm, 30 pages. Report for Sanford Ltd.

Ministry for Primary Industries. 2015. Fisheries Assessment Plenary, May 2015: stock assessments and stock status. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1477 p.

Morrisey, D.J.; Cole, R.G.; Davey, N.K.; Handley, S.J.; Bradley, A.; Brown, S.N.; Madarasz, A. 2006. Abundance and diversity of fish on mussel farms in New Zealand. *Aquaculture 252*: 277–288.

Morrison, M.; Jones, E.G.; Consalvey, M.; Berkenbusch, K. 2014a. *Linking marine fisheries species to biogenic habitats in New Zealand: a review and synthesis of knowledge*. Ministry for Primary Industries, New Zealand Aquatic Environment and Biodiversity Report No. 130. 156 pp.

Morrison, M., Jones, E.G., Parsons, D.M. and Grant, C.M., 2014b. *Habitats and areas of particular significance for coastal finfish fisheries management in New Zealand: A review of concepts and life history knowledge, and suggestions for future research*. Ministry for Primary Industries.

Morton, A.; Routledge, R.; Krkosek, M. 2008. Sea louse infestation in wild juvenile salmon and Pacific herring associated with fish farms off the east-central coast of Vancouver Island, British Columbia. North Am J Fish Manag 28:523–532.

Morton, A.; Routledge, R.;, Peet, C.; Ladwig, A. 2004. Sea lice (*Lepeophtheirus salmonis*) infection rates on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in the nearshore marine environment of British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 147–157

Naiman, R. J., H. Décamps, J. Pastor, and C. A. Johnston. 1988. The potential importance of boundaries to fluvial ecosystems. Journal of the North American Benthological Society **7:** 289–306.

Naylor S. J., R. D. Moccia and G. M. Durant. 1999. The Chemical Composition of Settleable Solid Fish Waste (Manure) from Commercial Rainbow Trout Farms in Ontario, Canada. *North American Journal of Aquaculture* 61: 21-26.

Ngai Tahu Seafood (2019). Biosecurity Management Plan – Stewart Island Salmon Farm. Draft Management Plan, Ngai Tahu Seafood. www.ngaitahuseafood.com. 41 p.

Nikolaou, M., Neofitou, N., Skordas, K., Castritsi-Catharios, I., & Tziantziou, L. (2014). Fish Farming and Antifouling Paints: A Potential Source of Cu and Zn in Farmed Fish. *Aquaculture Environment Interactions*, *5*, 163-171.

Oakes, C.T. and D.J. Pondella. 2009. The value of a net-cage as a fish aggregating device in southern California. *Journal of the World Aquaculture Society* 40: 1–21.

Otterå, H., O. Karlsen, E. Slinde, and R.E. Olsen. 2009. Quality of wild-captured saithe (*Pollachius virens* L.) fed formulated diets for 8 months. *Aquaculture Research* 40: 1310–1319.

Otterå H, Skilbrei OT (2014) Possible influence of salmon farming on long-term resident behaviour of wild saithe (*Pollachius virens* L.). ICES J Mar Sci 71:2484–2493. doi: 10.1093/icesjms/fsu096

Ozgul A, Angel D (2013) Wild fish aggregations around fish farms in the Gulf of Aqaba, Red Sea: implications for fisheries management and conservation. Aquac Environ Interact 4:135–145.

Parrish, R.H.; Bakun, A.; Husby, D.M.; Nelson, C.S., 1983. Comparative climatology of selected environmental processes in relation to eastern boundary current pelagic fish reproduction. *FAO Fisheries Report (FAO)*.

Parrish, R.H.; Nelson, C.S.; Bakun, A. 1981. Transport mechanisms and reproductive success of fishes in the California Current. *Biological Oceanography*, *1*(2), pp.175-203.

Paul, L.J. 2000. New Zealand Fishes: Identification, History and Fisheries, Revised Edition. Reed Publishing, Auckland.

Paul, L.J.; Taylor, P.R.; Parkinson D.M. 2001. Pilchard (*Sardinops neopilchardus*) biology and fisheries in New Zealand, and a review of pilchard (*Sardinops, Sardina*) biology, fisheries, and research in the main world fisheries. *New Zealand Fisheries Assessment Report 2001/37*. 44 p.

Peterson, W.T. 1989. Zooplankton feeding and egg production in comparison to primary production along the west coast of South Africa. In *Proceedings of the Plankton Dynamics Mini-Symposium, May 1989* ed. Anon. *Bengeula Ecology Programme Report 17*: 5pp

Pitcher, T.J. (Ed.). 1993. Behaviour of Teleost Fishes, Second Edition. Fish and Fisheries Series 7. Chapman & Hall.

Prosch, R.M. (1986). The Biology, Distribution and Ecology of *Lampanyctodes hectoris and Maurolicus Muelleri* along the South-African Coast. M.Sc., University of Cape Town.

Puth, L.M.; Wilson, K.A., 2001. Review: Boundaries and Corridors as a Continuum of Ecological Flow Control: Lessons from Rivers and Streams.*Conservation biology*, pp.21-30.

Rapson, A.M. (1956). Biology of the blue cod (*Parapercis colias forsteri*) of New Zealand. Doctor of Science thesis, Victoria University, Wellington. 53 p.

Rice, J. C. 1995. Food web theory, marine food webs, and what climate change may do to northern marine fish populations. *In* Climate Change and Northern Fish Populations, pp. 516–568. Ed. by R. J. Beamish. *Canadian Special Publication Fisheries and Aquatic Science, 121.*

Rilov, G.;, Benayahu, Y. 2000. Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. *Marine Biology* 136: 931-942.

Roberts, C.D.; Stewart, A.L.; Struthers, C.D. eds. 2015. The fishes of New Zealand. In 4 volumes. Te Papa Press, Wellington. 2008 p. [Vol. 1: S1-S256; vol. 2: 1-576; vol. 3: 577-1152; vol. 4: 1153-1748].

Royce, W.F.; Smith, L.S.; Hartt, A.C., 1968. Models of oceanic migrations of Pacific salmon and comments on guidance mechanisms. *Fishery Bulletin US 66*: 441-462.

Rurling. 1961. Referenced in Heath, 1975, but citation not listed.

Russell M., Robinson C.D., Walsham P., Webster L., Moffat C.F. 2011. Persistent organic pollutants and trace metals in sediments close to Scottish marine fish farm. Aquaculture 319: 262–271.

Salze, G., Tocher, D.R., Roy, W.J., Robertson, D.A. 2005. Egg quality determinants in cod (*Gadus morhua* L.): egg performance and lipids in eggs from farmed and wild broodstock. *Aquaculture Research*, 36: 1488-1499.

Sanchez-Jerez, P., D. Fernandez-Jover, J. Bayle-Sempere, C. Valle, T. Dempster, F. Tuya, and F. Juanes. 2008. Interactions between bluefish *Pomatomus saltatrix* (L.) and coastal sea-cage farms in the Mediterranean Sea. *Aquaculture* 282: 61–67.

Sanz-Lázaro C, Belando MD, Navarrete-Mier F, Marín A (2011) Effects of wild fish and motile epibenthic invertebrates on the benthos below an open water fish farm. Estuar Coast Shelf Sci 91:216–223. doi: 10.1016/j.ecss.2010.10.023

Sather P.J., Ikonomou M.G., Haya K. 2006. Occurrence of persistent organic pollutants in sediments collected near fish farm sites. Aquaculture 254: 234-247

Seckel, G.R., 1972. Hawaiian-caught skipjack tuna and their physical environment. *Fishery Bulletin*, *70*, pp.763-787.

Segvic-Bubic T, Grubisic L, Ticina V, Katavic I (2011) Temporal and spatial variability of pelagic wild fish assemblages around Atlantic bluefin tuna *Thunnus thynnus* farms in the eastern Adriatic Sea. J Fish Biol 78:78–97.

Shaw S.D., Brenner D., Berger M.L., Carpenter D.O., Hong C.-S., Kannan K. 2006. PCBs, PCDD/Fs, and organochlorine pesticides in farmed Atlantic salmon from Maine, eastern Canada, and Norway, and wild salmon from Alaska. *Environ. Sci. Technol*. 40: 5347–5354.

Shaw S.D., Berger M.L., Brenner D., Carpenter D.O., Tao L., Hong C.-S., Kannan K. 2008. Polybrominated diphenyl ethers (PBDEs) in farmed and wild salmon marketed in northeastern United States. *Chemosphere* 71: 1422–1431.

Simpson, S.D., Meekan, M. G., Larsen, N. J., McCauley,D., and Jeffs, A. 2010. Behavioral plasticity in larval reef fish: orientation is influenced by recent acoustic experiences. Behavioral Ecology, 21: 1098–1105.

Skjæraasen, J.E., Nilsen, T., Kjesbu, O.S. 2006. Timing and determination of potential fecundity in Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Science* 63: 310–320.

Skilbrei OT, Otterå H (2016) Vertical distribution of saithe (Pollachius virens) aggregating around fish farms. ICES J Mar Sci J du Cons 73:1186–1195. doi: 10.1093/icesjms/fsv261

Skog T.E., K. Hylland, B.E. Torstensen, and M.H.G. Berntssen. 2003. Salmon farming affects the fatty acid composition and taste of wild saithe *Pollachius virens* L. *Aquaculture Research* 34(12): 999–1007.

Smith, A.N.H.; Duffy, C.A.J.; Leathwick, J.R. 2013. Predicting the distribution and relative abundance of fishes on shallow subtidal reefs around New Zealand. *Science for Conservation 323*. Department of Conservation, Wellington. 25 p. + 2 supplements.

Smith C, Machias A, Giannoulaki M, Somarakis S, Papadopoulou KN, Karakassis I (2003). Diversity study of wild fish fauna aggregating around fish farm cages by means of remotely operated vehicle (ROV). Abstract, 7th Hel Symposium on Oceanography & Fish, 227 pp.

Stanton, B. R. 1971. Hydrology of Karamea Bight, New Zealand. *New Zealand journal of marine and freshwater research 5:* 141-163.

Stanton, B. R. 1976. Circulation and hydrology off the west coast of the South Island, New Zealand. *New Zealand journal of marine and freshwater research 19:* 445-467.

Steel, R.G.D.; Torrie, J.H. 1981. Principles and procedures of statistics. *Principles and procedures of statistics, 2nd Edition*. McGraw-Hill.

Syms, C., 1995. Multi-scale analysis of habitat associations in a guild of blennioid fishes. Mar. Ecol., Prog. Ser. 125, 31– 43.

Taylor, P.R.; Dempster, T. 2016. Effects of salmon farming on the pelagic habitat and fish fauna of the Marlborough Sounds and management options for avoiding, remedying, and mitigating adverse effects. Client Report Prepared for The New Zealand King Salmon Co. Limited. 68 p.

Taylor, P.R.; Dempster, T. 2018. 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. Client Report Prepared for The New Zealand King Salmon Co. Limited. 97 p.

Taylor, P.R.; Paul, L.J. 1998. A summary of the biology, recreational and commercial landings, and stock assessment of yellow-eyed mullet, *Aldrichetta forsteri* (Cuvier and Valenciennes, 1836) (Mugiloidei: Mugilidae). *New Zealand Fisheries Assessment Research Document 98/17*. 34 p. (Unpublished report held in the NIWA library, Wellington.)

Thetmeyer H., Pavlidis A., Cromey C. 2003 Development of monitoring guidelines and modeling tools for environmental effects from Mediterranean aquaculture. Newsletter 3: Interactions between wild and farmed fish, p 7. Available at: www.meramed.com

Tricklebank, K.A.; Jacoby, C.A.; Montgomery, J.C. 1992. Composition, distribution and abundance of neustonic ichthyoplankton off northeastern New Zealand. *Estuar. Coast. Shelf Sci. 34*, 263– 275.

Tuya, F., P. Sanchez-Jerez, T. Dempster, A. Boyra, and R. Haroun. 2006. Changes in demersal wild fish aggregations beneath a sea-cage fish farm after the cessation of farming. *Journal of Fish Biology* 69: 682–697.

Tuya, F., Boyra, A., Sanchez-Jerez, P. and Haroun, R.J., 2005. Multivariate analysis of the bentho-demersal ichthyofauna along soft bottoms of the Eastern Atlantic: comparison between unvegetated substrates, seagrass meadows and sandy bottoms beneath sea-cage fish farms. *Marine Biology*, *147*(5), pp.1229-1237.

Uglem, I., P.A. Bjørn, T. Dale, S. Kerwath, F. Økland, R. Nilsen, K. Aas, I. Fleming, and R.S. McKinley. 2008. Movements and spatiotemporal distribution of escaped famed and local wild Atlantic cod (*Gadus morhua* L.) in a Norwegian fjord. *Aquaculture Research* 39: 158–170.

Uglem, I., T. Dempster, P.A. Bjørn, and P. Sanchez-Jerez. 2009. High connectivity of salmon farms revealed by aggregation, residence and repeated migrations of saithe (*Pollachius virens*) among farms. *Marine Ecology Progress Series* 384: 251–260.

Uglem I, Karlsen Ø, Sanchez-Jerez P, Sæther B (2014) Impacts of wild fishes attracted to open-cage salmonid farms in Norway. Aquac Environ Interact 6: 91–103.

Uglem I, Ulvan EM, Toledo-Guedes K, Hegstad E, Blakstad S, Buserud B, Sæther BS (2017) Does a diet including pellets from salmon cage farms affect the taste of wild saithe (*Pollachius virens* Linnaeus, 1758)? J Appl Ichthyol 33: 374–376.

Underwood, A.J., 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of experimental marine biology and ecology*, *161*(2), pp.145-178.

Underwood, A. J. 1997. *Experiments in Ecology. Their Logical Design and Interpretation Using Analysis of Variance*. Cambridge University Press, Cambridge, UK. 504 pp.

Valle, C., J. Bayle, T. Dempster, P. Sanchez-Jerez, and F. Gimenez-Casalduero. 2006. Temporal variability of wild fish assemblages associated with a sea-cage fish farm in the south-western Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 72: 299–307.

van der Lingen, C.D., Bertrand, A., Bode, A., Brodeur, R., Cubillos, L., Espinoza, P., Friedland, K., Garrido, S., Irigoien, X., Miller, T., Möllmann, C., Rodriguez-Sanchez, R., Tanaka, H., Temming, A. 2009. Trophic dynamics. In: Checkley Jr., D.M., Alheit, J., Oozeki, Y., Roy, C. (Eds.), Climate Change and Small Pelagic Fish. Cambridge University Press, pp. 112–157 (Chapter 7).

van der Lingen, C.D., Hutchings, L., Field, J.G. 2006a. Comparative trophodynamics of anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax* in the southern Benguela: are species alternations between small pelagic fish trophodynamically mediated? *African Journal of Marine Science* 28: 465–477.

van der Lingen, C.D., Shannon, L.J., Cury, P., Kreiner, A., Moloney, C.L., Roux, J.-P. and F.,Vaz-Velho. 2006b. Resource and ecosystem variability, including regime shifts in the Benguela Current system. In Benguela: Predicting a Large Marine Ecosystem, ed. V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C. Moloney and J. Woods. Large Marine Ecosystems 14, Elsevier, Amsterdam, pp. 147–185.

Vincent, W.F., Howard-Williams, C., Tildesley, P. and Butler, E., 1991. Distribution and biological properties of oceanic water masses around the South Island, New Zealand. *New Zealand journal of marine and freshwater research*, *25*(1), pp.21-42.

Vita, R., A. Marin, J.A. Madrid, B. Jimenez-Brinquis, A. Cesar, and A.L. Marin-Guirao. 2004. Effects of wild fishes on waste exportation from a Mediterranean fish farm. *Marine Ecology Progress Series* 277: 253–261.

Vooren, C. M. 1975. Nursery grounds of Tarakihi (Teleostei: Cheilodactylidae) around New Zealand, New Zealand Journal of Marine and Freshwater Research, 9:2, 121-158,
DOI: 10.1080/00288330.1975.9515555

Walker, D.R. and W.T. Peterson. 1991. Relationships between hydrography, phytoplankton production, biomass, cell size and species composition, and copepod production in the southern Benguela upwelling system in April 1988. *South African Journal of Marine Science 11*: 289–305.

Waters, J.M., Dijkstra, L.H. and Wallis, G.P., 2000. Biogeography of a southern hemisphere freshwater fish: how important is marine dispersal?. *Molecular Ecology*, *9*(11), pp.1815-1821.

Wardle, C.S.; Reid, A., 1977. The application of large amplitude elongated body theory to measure swimming power in fish. In: J.H. Steele (ed.) Fisheries mathematics, pp.131-144. Academic Press, London, New York, San Francisco. 198 pp.

Whitehead, P. J. P. , P. J. Smith & D. A. Robertson (1985) The two species of sprat in New Zealand waters *(Spratus antipodum* and S. *muelleri)*, New Zealand Journal of Marine and Freshwater Research, 19:2, 261-271, DOI: 10.1080/00288330.1985.9516093

Würtz, M. 2010. Mediterranean Pelagic Habitat: Oceanographic and Biological Processes, An Overview. Gland, Switzerland and Malaga, Spain: IUCN.

Yokoyama H, Inoue M, Abo K 2004. Estimation of the assimilative capacity of fish-farm environments based on the current velocity measured by plaster balls. Aquaculture 240: 233-247.

Zhulay I, Reiss K, Reiss H. 2015. Effects of aquaculture fallowing on the recovery of macrofauna communities. Marine Pollution Bulletin 97:381–390. DOI: 10.1016/j.marpolbul.2015.05.064.

9. APPENDICES

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: Species selected from National Aquatic Biodiversity Information System (NABIS)

Table B1: Species selected from the NABIS for Table 1, repeated here to show additionally the presence of spawning and juvenile life history stage . Source: Ministry of Primary Industries[23].

Common/‡Maori names	Specific name	Range		
		Annual	**Spawning**	**Juvenile**
Barracouta/maka	*Thysites atun*	Normal	Nearby	HS-Normal
Bass/moeone	*Polyprion americanus*	Full	No	No
Black flounder/mohoao	*Rhombosolea retiaria*	Normal†	Not shown	Not shown
Blue cod/rawaru	*Parapercis colias*	Hot spot	Not shown	Not shown
Blue mackerel/tawatawa	*Scomber australasicus*	Normal	No	Full
Blue moki/moki	*Latridopsis ciliaris*	Full	Not shown	Full
Blue warehou/ warehou	*Seriolella brama*	Normal	Nearby	No
Bluenose/matiri	*Hyperoglyphe antarctica*	Full	Not shown	Not shown
Brill/patikinui	*Colistium guntheri*	Hot spot	Not shown	Not shown
Butterfish/mararii	*Odax pullus*	Normal-Hotspot†	Full†	Full†
Garfish/takeke	*Hyporhamphus ihi*	Normal**	Not shown	Not shown
Giant stargazer/NA	*Kathetostoma giganteum*	Full	Full	Full
Golden mackerel/ hauture	*Trachurus novaezelandiae*	Full	No	Full
Hapuka/haapuka	*Polyprion oxygeneios*	Full	No	Hot spot
Horse mackerel/hauture	*Trachurus declivis*	Normal	Full	Full
John dory/kuparu	*Zeus faber*	Full	No	No
Kingfish/warehenga	*Seriola lalandi*	Full	Not shown	Not shown
Leatherjacket/Kokiri	*Meuschenia scaber*	Hotspot	Not shown	Not shown
Lemon sole/Paatiki	*Pelotretis flavilatus*	Normal	Not shown	Not shown
Ling/hokarari	*Genypterus blacodes*	Full	No	No
Murphyi's mackerel/NA	*Trachurus murphyi*	Full	Full	No
NZ Sole/patiki rori	*Peltorhamphus novaezeelandiae*	Hot spot	Not shown	Not shown
Pilchard/mohimohi	*Sardinops sagax*	Not known		
Ray's bream/NA	*Brama brama*	Full	Not shown	Not shown
Red cod/hoka	*Pseudophycis bachus*	Full	Full	Full (HS nearby)
Red gurnard/kumukumu	*Chelidonichthys kumu*	Hotspot	Full	Full
Red moki/nanua	*Cheilodactylus spectabilis*	Full	Not shown	Not shown
Rough skate/pakaurua	*Zearaja nasuta*	Hotspot	Not shown	
Sand flounder/paatiki	*Rhombosolea plebeia*	Full-Hotspot*	Not shown	Full††
Sea perch/pohuiakaroa	*Helicolenus percoides*	Full	No	Full
Smooth skate/pakaurua	*Dipturus innominatus*	Full	Not shown	Not shown
Snapper/taamure	*Pagrus auratus*	Not known		
Spotted stargazer/ngu	*Genyagnus monopterygius*	Full	Not shown	Not shown
Sprat/kupe	*Sprattus muelleri*	Normal†	Full†	Not shown
Tarakihi/tarakihi	*Nemadactylus macropterus*	Full	No	Full
Trevally/arara	*Pseudocaranx georgianus*	Full	No	No
Trumpeter/kohikohi	*Latris lineata*	Full/No†	Not shown	Not shown
Turbot/patiki	*Colistium nudipinnis*	Full/hotspot*	Not shown	Not shown
Yellow belly flounder/ paatiki tootara	*Rhombosolea leporina*	Full	Full	Full††
Yellow-eyed mullet/aua	*Aldrichetta forsteri*	Not known, full†	Not shown	Full†

---

[23] https://mpi.maps.arcgis.com/home/index.html

Table B1 — *continued*				
Common/‡Maori names	**Specific name**	**Range**		
		Annual	**Spawning**	**Juvenile**
Elasmobranchs				
Sharks				
Basking shark/reremai	*Cetorhinus maximus*	Normal	Not shown	Not shown
Blue shark/Mangoo-pounamu	*Prionace glauca*	Full	Unknown	Unknown
Bronze whaler/horopekapeka	*Carcharhinus brachyurus*	Unknown	Not shown	Not shown
Hammerhead shark/kakere	*Sphyrna zygaena*	Unknown	Not shown	Not shown
Mako/mako	*Isurus oxyrinchus*	Full	Not shown	No
Porbeagle/NA	*Lamna nasus*	Full	Full	Full
School/tupere	*Galeorhinus galeus*	Normal	Not shown	Hot spot
Spiny dogfish/huarau	*Squalus acanthias*	Hot spot	Not shown	Full
Thresher/mango ripi	*Alopias vulpinus*	Normal		
Other elasmobranchs				
Dark ghost shark/NA	*Hydrolagus novaezealandiae*	Unknown	Unknown	Not shown
Elephant fish/makarepe	*Callorhinchus milii*	Normal/hot spot‡‡	Full♠♠	Full
Pale ghost shark/NA	*Hydrolagus bemisi*	No	Not shown	No
Rough skate/pakaurua	*Zearaja nasuta*	Hot spot	Not shown	Not shown
Smooth skate/pakaurua	*Dipturus innominatus*	Normal♠	Not shown	Not shown

‡Frequently chosen for this list from several Maori names.*Te Waewae Bay only – otherwise Full range. †South Island south coast only – not on north coast Rakiura. **Inshore & estuarine, most common in sheltered bays & harbours. ††Patterson Inlet, not Foveaux Strait. ‡‡ Te Waewae Bay only. ♠Hotspots west and east of Foveaux Strait.
NA — Maori name required. ♠♠ Te Waewae Bay to Bluff

Key
Distribution class

- Hotspot — a high frequency area of the species distribution;
- Full Range — within which virtually 100% of the species is found;
- Normal Range — within which virtually 90% of the species is found;
- Known not to exist — the species is known to not be distributed in this area; and
- Unknown — the existence of the species is unknown;
- Not shown — distribution not included on NABIS page;
- No — NABIS distribution appears not include Foveaux Strait but the keyed options difficult to decipher in this case (author created); and
- Nearby — distribution just outside Foveaux Strait (author created).

APPENDIX C: Summaries of Data from Fisheries New Zealand Commercial and Recreational Databases

Table C1: Commercial finfish catches from fisheries statistical area 025 (Foveaux Strait); kilogram totals by species and calendar year. Blank cells indicate zero catch, 0 indicates data withheld by NZF because number of permit holders harvesting that species <3. Source: Fisheries New Zealand.

Species	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Totals
Albacore tuna	0			0							
Banded wrasse						0	0	0	1 131	2 029	3 160
Barracouta	552 724	889 599	370 980	520 374	726 972	959 626	417 811	496 490	223 329	274 322	5 432 227
Bellowsfish			0								
Black cod									0	0	
Blue cod	553 503	522 683	612 074	510 007	413 251	591 452	495 236	408 244	326 072	307 278	4 739 800
Blue moki	3 860	1 825	3 079	1 985	3 422	2560	2 968	3 469	1 944	809	25 920
Blue shark	0				0			0			
Blue fish			0								
Bluenose						0					
Broadnose sevengill shark	0	0	0	0	0	475	390	884	1 101	827	3 677
Butterfish	18 500	0	0	7 070	24 112	0	0	0	19 349	10 924	79 955
Butterfly perch				0			0				
Capro dory	0								0		
Carpet shark	8 317	8 557	2 074	7 980	8 944	8 415	3 602	12 857	6 113	7 992	74 851
Cod (unspecified)				0							
Common warehou	658 818	243 620	474 301	266 721	452 791	609 555	108 034	176 460	150 619	89 552	3 230 471
Conger eel	4 338	3 814	3 248	2 983	2 730	3 385	5 807	5 406	7 139	4 988	43 838
Copper moki			0			0			0		
Dark toadfish								0			
Deepsea flathead							0	0	0		
Deepwater eel (unspecified)								0			
Eagle ray	0										

Table C1: continued											
Electric ray	0							0	0	0	
Elephant fish	48 863	49 635	53 027	61 368	59 017	47 111	44 078	52 100	60 133	42 873	518 205
Flatfish	59 584	132 608	174 776	142 385	201 690	229 025	171 152	184 125	128 160	68 209	1 491 714
Flounder (Unspecified)	0	0	431	521	1 387	357	0	222	0		2 918
Frostfish	0										
Gemfish					0		0			0	
Ghost shark	0										
Giant stargazer	76 196	57 872	82 648	69 464	93 747	108 849	60 331	86 185	67 385	60 596	763 273
Grass carp				0							
Gurnard	95 688	76 125	111 411	89 661	183 317	221 525	159 023	167 985	195 517	127 647	1 427 899
Hapuku & Bass	28 078	11 705	11 240	17 508	18 747	30 163	16 570	14 021	12 964	6 641	167 637
Hoki	0		0								
Jack mackerel	20 975	35 111	19 410	16 478	24 832	29 624	40 537	89 743	19 447	41 797	337 954
Javelinfish						0	0	0	0	0	
John dory			0				0	11	10		21
Kahawai			0					0		0	
Kingfish	0			0	0	35		0	0	231	266
Leatherjacket	55 227	39 534	28 583	34 757	30 560	19 399	4 730	8 883	12 438	6 012	240 123
Ling	1 709	391	651	1 791	2 032	1 206	2 202	7 599	2 296	1 011	20 887
Lookdown dory	0		0								
Mako shark			0					0	0		
Opalfish										0	
Pale ghost shark					0			0			
Parore					0						
Pigfish				0			0	102	0	355	457
Porbeagle shark					0						
Rattails	0	0				0	0	0	0	0	
Red cod	25 478	38 035	55 432	59 373	45 721	43 568	45 160	27 344	15 382	10 865	366 358

Table C1: continued											
Red perch				0							
Red scorpion fish							0	0	0		
Redbait	0		0	0		0	0		0	0	
Rig	35 152	47 652	46 227	57 521	34 618	60 558	60 749	59 522	48 144	9 419	459 562
Rock cod			0								
Rough skate	17 826	22 780	27 870	29 296	30 071	30 613	23 544	26 454	26 269	15 658	250 380
Scaly gurnard	0	0	0		0		0	0	0	0	
Scarlet wrasse							24	521	889	820	2 254
School shark	73 182	57 884	73 762	55 873	55 992	58 318	22 204	63 459	50 702	48 239	559 615
Sea perch	2 703	0	0	0	83	58	324	359	117	72	3 716
Sharks & dogfish*									0		
Silver dory	0	0				0	0	0	0	0	
Silver warehou	4 258	0	0	0	0	0		0	0		4 258
Silverside							0	0	0	0	
Slender smooth hound								0			
Slender tuna								0		0	
Smooth skate	1 213	1 244	536	820	0	0	1 684	0	0	135	5 631
Smooth skin dogfish									0		
Snapper					0				0		
Southern Bastard cod								0			
Spiny dogfish	281 451	245 787	177 336	176 489	170 016	68 459	60 515	37 890	29 110	43 822	1 290 875
Spotted stargazer			0	0	0	0	0	0	0	0	
Stokells smelt					0						
Sunfish	0			0	0	0					
Swollenheaded conger	0							0			
Tarakihi	46 992	17 444	4 415	24 740	54 372	68 861	37 830	34 973	32 202	27 465	349 294
Telescope fish				0					0		
Thresher shark										0	

Table C1: continued											
Toadfish								0			
Trevally				0							
Trumpeter	2 097	1 184	1 038	408	1 904	585	1 054	1 108	1 023	541	10 942
Whiptail ray					0						
White warehou									0		
Witch	0	1 493	1 955	684	0	1 940	1 513	4 159	1 175	1 670	14 589
Wrasses	1 073	724	1 654	996	504	2 019	992	2 600	1 527	2 222	14 311
Yellow-eyed mullet			0	0	0	0	0	0	0	0	
Yellowfin tuna				0							

*Not otherwise specified in Sch3, Part2 Reporting Regs 2001.

Table C2: Recreational finfish catches from fisheries statistical area 025 (Foveaux Strait); kilogram totals by species and calendar year. Source: Fisheries New Zealand.

Species	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Totals
Octopus	0	5	55	18	0	0	0	3	0	0	81
Barracouta	61	66	127	74	70	78	94	0	0	8	578
Blue Cod	4 589	7 789	14 690	13 477	11 453	19 084	15 339	8 592	7 983	2 697	105 693
Butterfish	0	0	0	0	0	35	20	2	20	3	80
Blue shark	0	0	0	40	0	0	0	0	0	0	40
Conger eel	0	0	10	0	0	10	0	0	0	0	20
Gurnard	0	0	5	3	6	4	56	0	0	0	74
Hapuku	8	4	4	21	0	0	0	0	0	0	37
Hapuku & Bass	0	833	30	0	0	0	0	0	0	0	863
Leatherjacket	0	0	0	0	3	0	0	0	0	6	9

Table C2: continued

Blue moki	0	6	0	1	0	21	5	12	5	0	50
Red Cod	0	0	1	0	10	0	0	27	0	0	38
Rough skate	0	0	33	2	0	0	0	0	0	0	35
School shark	46	95	111	61	47	52	54	0	0	0	466
Snapper	0	0	0	0	0	0	0	0	17	0	17
Spiny dogfish	0	0	2	0	0	0	0	0	0	0	2
Sea perch	9	196	42	15	13	24	22	6	0	0	327
Smooth skate	0	10	0	0	0	0	0	0	0	0	10
Kina	0	0	5	0	10	110	15	0	0	10	150
Tarakihi	3	13	6	62	20	39	34	9	0	0	186
Trevally	0	8	14	3	2	1	3	0	1	0	32
Tripod fish	0	1	0	0	0	0	0	0	0	0	1
Trumpeter	191	580	673	418	141	168	172	55	20	39	2 457
Whiptail ray	0	0	5	22	0	0	0	0	0	0	27
Wrasses	14	0	0	8	0	0	0	0	0	0	22

APPENDIX D: Dioxin, Dioxin-like Compounds, and Heavy Metal Contaminants in Salmon Feed Pellets Produced by Skretting Australia

Table D1: Annual estimates of dioxins and the sum of dioxins and dioxin-like PCB compounds in Aqua Feed produced by Skretting Australia; European Union limits for the two species are 2.25 and 7 ng/kg respectively, as quoted by Skretting Australia. Source: Skretting Australia Annual Residue Monitoring Reports

Year	Dioxins (PCDD/PCDF) ng/kg	Sum of Dioxins & Dioxin-like PCBS (WHO-PCDD/F+PCB) ng/kg		Year	Dioxins (PCDD/PCDF) ng/kg	Sum of Dioxins & Dioxin-like PCBS (WHO-PCDD/F+PCB) ng/kg
2007	0.038	0.65		2014	0.158	0.30
2008	0.062	0.24		2015	0.158	0.28
2009	0.065	0.27		2016*		
2010	0.059	0.18		2017	≈ 0.082	≈ 030
2011	0.048	0.16		2018	> 0.082	< 0.048
2012	0.074	0.23		2019	> 0.158	< 0.048
2013	0.082	0.23				

*2016: estimates of both contaminants reported as below detection limits, <0.240 ng/kg & <0.679 ng/kg respectively.

NB: Before 2016 estimates were reported as both graphed and specific values, but after 2016 estimates were not reported as specific values, but provided as graphed values only; consequently, they are included here compared with values from previous years with similar graphed levels.

Table D2: Annual estimates of heavy metals in Aqua Feed produced by Skretting Australia; European Union limits for the four species are 10, 1, 5 and 0.2 mg/kg respectively, as quoted by Skretting Australia. Source: Skretting Australia Annual Residue Monitoring Reports

Year	Arsenic mg/kg	Cadmium mg/kg	Lead mg/kg	Mercury mg/kg
2007	1.6	0.27	0.10	0.01
2008	1.6	0.33	0.18	0.02
2009	1.10	0.18	0.05	0.03
2010	1.40	0.19	0.10	0.01
2011	0.95	0.27	0.21	0.02
2012	0.95	0.25	0.10	0.02
2013	1.00	0.20	0.33	0.01
2014	1.35	0.32	0.26	0.02
2015	1.28	0.31	0.24	0.02
2016	≈ 0.95	< 0.20	≈ 0.24	≈ 0.02
2017	< 1.28	≈ 0.25	> 0.10	≈ 0.02
2018	< 1.28	≈ 0.20	> 0.10	≈ 0.03
2019	≈ 1.00	≈ 0.20	> 0.10	≈ 0.02

NB: Before 2016 estimates were reported as both graphed and specific values; after 2016 estimates were reported as graphed values only without specific values included; consequently, estimates after 2016 are approximations from comparing the height of the graphed value with values from previous years with graphed levels of similar heights.

APPENDIX E: 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 F: Assessment of the functional performance of possible monitoring methods

Table F1: Practical issues associated with various sampling methods for monitoring finfish species within the farm locality

Method	**Target**	***Stealth**	**‡Data reliability**	**Other issues**
Drop video (DV••)	Demersal/benthic	†High	Good	Possibly deployment difficult near pens
Echosounder	Pelagics, particularly schools	High	Ok but not spp specific•	Spp ID requires 2° sampling
Static camera, unbaited	Position dependent	High	Uncertain	Most useful in combination(?)
Static camera, baited	Pelagic predators	High	OK but species limited	Effective for short time only without rebaiting
Diver census	All species	Low	Probably biased	Bias may be quantifiable during development
ROV	All species	Low	Probably biased	Bias may be quantifiable during development
Fish traps/pots	Position dependent	ΔEffects uncertain	Confirmed poor by DV••	May be worth considering during development
Seine net	Pelagic	Deployment effects	Ok but ▲species limited	Deployment difficult near pens
Set net	Position dependent	High	Probably good	Potential bycatch problems
Trawl net	♦Gear/position dependent	Medium	Extensively used in SA**	Deployment obstructed by presence of pens

*Level/degree method is undetectable by target. †Particularly when deployed during transects from drifting vessel. ‡As basis for species id and quantification ΔSpecies variable? ▲Probably limited to schooling species with some bycatch. ♦Bottom trawl for demersal spp, mid-water trawl for pelagics. • Species id requires specialist development. **SA – stock assessment. ••DV – Drop video.